Feasibility of Refuse Derived Fuel production from fresh and legacy waste in Indian Cities: Enabling business viability through Circular Economy

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By

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I, Mijanur Haque hereby declare that this thesis titled **"Feasibility of Refuse Derived Fuel Production from fresh and legacy waste in Indian Cities: Enabling business viability through Circular Economy"** is submitted for the partial fulfilment of the continuous assessment of Master of Engineering in Civil Engineering, Jadavpur university, Kolkata- 700032 is a record of original work done by me under the guidance of Prof. Amit Dutta.

I declare that the work described in this thesis is entirely my own. No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute. Any help or source information which has been awarded in the thesis, has been duly acknowledged.

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"Feasibility of Refuse Derived Fuel(RDF) production from fresh and legacy waste in Indian Cities: Enabling business viability through circular economy"** is prepared and submitted by **Mijanur Haque** (University Roll Number: 002110402003, Registration Number: 160027 of 2021-2022) under my supervision and guidance for partial fulfilment of the requirement of Master of Civil Engineering with the specialization of Environmental Engineering from Jadavpur university, during the academic session 2022-2023. This thesis or any part of this thesis has not been submitted for any degree or any other academic award anywhere before.

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LIST OF ABBREVIATIONS

AFR	Alternative Fuels and Raw Materials
APC	Air Pollution Control
ASTM	American Society for testing and material
CAPEX	Capital Expenditure
C&D	Construction and Demolition
CPHEEO	Central public health and environmental engineering organization
CP	Cement plant
CPCB	Central pollution control board
CV	Calorific value
EPA	Environmental Protection Agency
EURITS	European Association of Waste Thermal Treatment Companies forSpecialized Waste
GHG	Green House Gas
HCl	Hydrochloric acid gas
HHV	Higher Heating Value
ISWM	Integrated Solid Waste Management
LHV	Lower Heating Value
MBT	Mechanical Biological Treatment
MOHUA	Ministry of housing and urban affair
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NAMA	Nationally appropriate mitigation action
NCV	Net calorific value
O&M	Operating and Maintenance
OC	Overall cost
RDF	Refuse Derived Fuel
SWM	Solid waste management

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ABSTRACT

Refuse-derived fuel is a type of fuel created from renewable energy sources that helps to reduce greenhouse gas emissions and address environmental and health concerns. Using RDF as a secondary fuel can decrease our dependence on fossil fuels and promote the use of renewable energy. The compositional data of urban MSW from 18 Indian cities revealed that the average plastic content in RDF is 39.93% in the southern zone, 24.58% in the northern zone, 25.05% in the central zone, 30.63% in the western zone, and 35.97% in the eastern zone. The average amount of paper and cardboard material in the RDF sample was 27.12% in the southern zone, 14.86% in the northern zone, 17.25% in the central zone, 19.51% in the western zone, and 16.27% in the eastern zone. The average amount of textile material in the RDF sample was 32.25% in the southern zone, 21.01% in the northern zone, 40.55% in the central zone, 36.56% in the western zone, and 32.33% in the eastern zone. The average amount of other combustible material (wood, coconut shell, dry leaves) in the RDF sample was 35.07% in the southern zone, 54.69% in the northern zone, 25.73% in the central zone, 38.22% in the western zone, and 23.14% in the eastern zone.

Based on the study, the average RDF processing rate in India is approximately 12.32 weight percent of total fresh MSW generation, with an average NCV of 4,741.68 kcal/kg. Based on the daily amount of MSW, which is 48501 tonnes, approximately 5975.1 tonnes of RDF are produced each day in India.

This study reveals that fresh RDF in India can be produced with varying heating values depending on the region. The southern zone has an average heating value of 5151.8 kcal/kg, while the northern zone has 4844.6 kcal/kg, the central zone has 4785kcal/kg, the western zone has 4080.38 kcal/kg, and the eastern zone has 4640.7kcal/kg. Additionally, the moisture content differs by region, with an average of 9.7% in the southern zone, 9.6% in the northern zone, 7.4% in the central zone, 9.4% in the western zone, and 10.7% in the eastern zone.

An exemplary examination of the combustible waste percentage in Vellore found that the combustible waste percentage meets the recommended limit values for critical parameters such as chlorine, sulfur (0.24%), and nitrogen (0.35%). This suggests that the NCV of the MSW may be enhanced more easily by size screening. On average, the chlorine and sulfur contents were found to be 0.6% and 0.3%, respectively.

In the case of RDF from recovered aged MSW fractions, the availability of RDF will be around 16 to 18% (with the removal of 20 to 22% moisture). The principal components of the prospective RDF were found to be plastic (~61.02%), Textiles and rags (~11.08%), rubber (~3.19%), paper (~6.79%), Cardboard (~12.97%), wood (~0.42%), thermal (~1.08%), and coconut shell (~3.45%). The average moisture content in the existing RDF is about 18%. During the summer, the calorific value of the existing RDF is about 3536.5 kcal/kg, while during the winter it is 3127 kcal/kg. In contrast, during the monsoon season, its calorific value drops to 1870 kcal/kg.

The viability of the business model depends on several factors, such as the quality and quantity of RDF produced, CAPEX, OPEX, RDF transport costs, and the Government's willingness to invest in CAPEX. The profitability rate will also increase by Selling RDF in the form of pellets as compared to selling it in fluffy or loose form. An exemplary observation for the city of Jaipur, it was found that the profitability rate for RDF pellets increased by 72.64% of the total revenue than fluffy or loose RDF.

To ensure the viability of the business model, transportation costs are a crucial factor. In an exemplary study in Kolkata, it was found that transport costs for 100 TPD RDF that bears ULB are exceedingly high at around Rs. 181640.00 due to the 578km distance. As a result, most of the business models are unfeasible for Kolkata. For Kolkata, the production of RDF pellets can only be feasible if the government invests in CAPEX. This would lead to a profit of 15.98% of the total revenue. ULB can supply fluffy or loose fresh RDF up to 400km without government investments in CAPEX, even if there is minimal profit (8% of the total revenue). For legacy RDF, they can deliver RDF up to 100km with a minimum profit of 13.6%

CHAPTER 1.
INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Inconceivable population expansion, alterations in lifestyles, demographic transfers, rapid urbanization, and industrialization have all contributed to several environmental problems including solid waste management and the energy crisis. Because of growing health and environmental concerns, particularly in most developing countries, solid waste management has emerged as the most pressing issue. The handling, processing, treatment, and disposal of waste play a crucial role in the development of effective solid waste management (SWM) systems [1]. According to the planning commission report, India generated 62 million metric tonnes of MSW annually in urban areas in 2013, and it is estimated to be 165 million metric tonnes by 2031 and 436 million metric tonnes by 2050 [2]. Improper disposal of MSW takes up too much space and is terrible for the environment and human health. Landfills, incineration, and biological treatment are the traditional methods for treating and disposing of solid waste, but each of these approaches has drawbacks [1,3]. As a result, treating and properly disposing of MSW has become a difficult task all over the world [4]. By finding an effective solution to waste management issues constructively, proper waste management can minimize damages [5]. The discarded waste can be useful resources that just need to be reclaimed through reuse or recycling and turned into valuable products [6]. The latest waste management technique has been developed, and it may be used effectively to produce fuel. In addition, due to the high emissions of greenhouse gases, the conversion of solid waste to fuel has emerged as one of the most suitable ways out. In both developed and developing countries, technologies for converting waste to energy have been utilized. This technology has only been used very unwisely in India [7]. One of the most convenient ways to safely dispose of MSW has been recognized as refuse-derived fuel (RDF) [8].

RDF is a fuel made from various types of waste, including municipal solid waste (MSW), industrial waste, and commercial waste. RDF is primarily comprised of combustible components of such waste, such as non-recyclable plastics (not including PVC), paper, cardboard, labels, and other corrugated materials. Utilizing RDF has various benefits, including reducing CO2 emissions and ash residue, generating more homogenous fuel, having a better calorific value, and maintaining a lower moisture content. It is reported that for a net carbon offset through the replacement of coal with RDF, the water content must be less than 15%, and in this case, a net reduction in emissions is obtained as 0.4 t CO_2/tonne coal [9]. RDF is widely produced and utilized in most advanced economies, such as Germany, Italy, Japan, China, Ireland, the USA, etc. Interest in energy recovery from MSW as refuse-derived fuel has also been extended to some developing countries such as India, Indonesia, Thailand, Mozambique, and Namibia. Production of RDF offers an attractive opportunity to both reduce the waste volumes and substitute fossil fuels, in various industries in India.

In this study, we analyze energy-efficient RDF from the solid waste generated in various major cities across the country. This research aims to propose a suitable solution for the disposal of solid waste in various major cities across the country in a safe and reusable manner in the form of RDF. A condensed analysis is also used to evaluate the potential options that are economically viable for utilizing MSW-derived RDF as co-fuel in energy-intensive industries.

1.2 SOURCES OF RDF

RDF can be made from Bio mined and Fresh Municipal Solid Waste, Industrial waste, and Commercial waste (it includes biodegradable material as well as plastics). RDF is mainly composed of combustible components such as non-recyclable plastics (excluding PVC), paper cardboard, labels, and other corrugated materials.

According to the guidelines set by CPCB, the following waste should not be used for co-processing

(i) Biomedical waste

(ii) Asbestos-containing waste.

(iii) Electronic scrap.

(iv) Entire batteries.

(v) Explosives.

(vi) Corrosives.

(vii) Mineral acid wastes.

(viii) Radioactive Wastes.

(ix) Unsorted municipal garbage

1.3 RDF REUSE IN FRESH AND LEGACY WASTE MANAGEMENT

The study examines various major cities as study regions, specifically those that generate a substantial volume of solid waste and have a significant proportion of combustible fractions categorized by zone. In India, the major fraction of waste ultimately ends up untreated in landfills and burned openly [9], which results in resource loss and unsustainable waste disposal in an energy-constrained community. This is because of poor MSW segregation and collection, a lack of waste treatment infrastructure, and poor MSW collection and segregation practices. The new SWM 2016 rules put a strong emphasis on the segregation of MSW into dry and wet fractions right from the source collection stage and prohibit direct dumping of MSW into landfills as well as direct mass incineration of waste, i.e., due to low calorific value and variable waste compositions. The MSW Rules 2016 stipulate that mass incineration must have a calorific value of at least 1500 kcal/kg. The new regulations establish the foundation for effective planning and technical solutions, which are urgently needed to deal with this massive waste. Generally, the organic fraction of MSW (biowaste) is digested as compost while the combustible residual of the pre-sorting operation is turned into RDF through further processing. The production of RDF from fresh waste through additional processing offers an alluring opportunity to reduce waste volumes and replace fossil fuels for energy in a variety of Indian sectors. This study looks at several cities that produce a lot of fresh waste. Non-recyclable, combustible fractions of such solid waste are turned into RDF, which can be used as an energy resource in various industries. [10] has stated that the resource recovery from waste is not only limited to recyclable materials such as glass, paper, wood, metal cans, etc. it as well involves the recovery of residual waste. RDF recovered from MSW is an energy-rich waste that should not be disposed of in landfills to preserve the air volume, facilitate resource recovery, extend economic viability, and contribute to the circular economy. Based on research findings, the standard processing rate of RDF from fresh MSW stands at approximately 12.32% by weight, with an average NCV of 4,741.68 kcal/kg.

In India, there is potential to utilize Refuse Derived Fuel (RDF) from waste that was dumped in landfills many years ago. Based on physical composition, soil-like material, and plastic (waste plastic bags and foils) are the major components of the aged waste recovered from landfills. In India, proper management of plastic waste is the most pressing issue. Due to the presence of significant levels of inert contaminants, plastic recovered through the biomining of legacy waste is not so recyclable. As a result, the coprocessing of such plastic waste recovered from old waste will contribute to enhancing the waste management system's economy. Not only economically viable but will also help eradicate infectious diseases that spread through contaminated air and water. Reclamation of the waste material from these landfills increases the life of the landfill and reduces the usage of non-renewable energy sources in energy production. The most appropriate valorization route for the combustible fraction of legacy waste is to utilize it as RDF in a waste-to-energy plant. This study focused solely on the Dhapa landfill site in Kolkata as the study area. The Dhapa dumpsite contains about 20 to 24 percent combustible materials in its legacy waste. This suggests that there are around 718 metric tonnes of combustible materials are recovered through bio-mining of 3000MT legacy waste, which are dumped from the different locations of Kolkata. These combustible components (typically referred to as segregated combustible fraction or SCF) are excavated as an end-product of the legacy waste dumpsite remediation process. SCF are often highly contaminated with inert material and have a high moisture content (more than 30 percent), making them not so desirable for cement factories. Because of this, many urban local bodies are struggling to find economically viable options for the disposal of recovered material, including combustibles. Currently, the only available option is co-processing in the cement industry. Co-processing is the process of using waste products with a high calorific value as alternative fuels or raw materials (AFR) to extract material and energy from them. Cement kilns can properly dispose of various types of waste without emitting harmful gases due to their high temperatures.

CHAPTER 2.
LITERATURE REVIEW

2.1 INTEGRATED SWM HIERARCHY

In developing nations, especially in municipal areas, the growing amount of MSW has become a serious issue that requires efficient management. Lack of management capabilities, financial resources, knowledge, and expertise are just a few of the factors that prevent effective MSWM. MSWM has an impact on the local, regional, and global environments. The main issue is the release of pollutants, including acid and greenhouse gases [11].

Comprehensive integrated MSWM strategies base on the four-tier solid waste management hierarchy which includes source reduction and reuse, recycling/composting, burning with energy recovery and landfilling [12,13,14]. For managing solid waste, source reduction and reuse are preferred over recycling/composting because they can efficiently reduce waste quantity and resource consumption. However, after waste is reduced, reused, and recycled, it is still left over and needs to be managed further. In this case, combustion with energy recovery is used. Combustion may save landfill space by reducing the amount of waste that is dumped there by 90%.

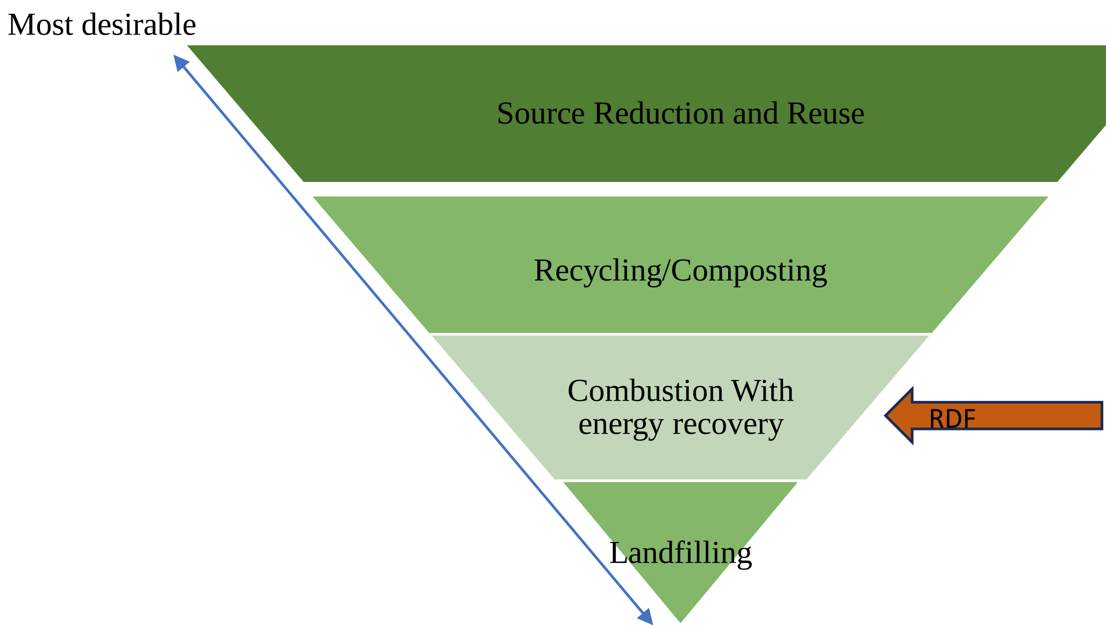


Fig. 2.1: Integrated SWM hierarchy

In this context, RDF is a type of energy recovery from waste. Therefore, it is in the third tired of the integrated MSWM hierarchy. More details about RDF will be explained in Section 2.2.

2.2 BASIC KNOWLEDGE ABOUT RDF

This section covers all the fundamental information about RDF, including its definition, classification, standards, production method, and applications.

2.2.1 Definition of RDF

The SWM Rules 2016 in India defines RDF as "fuel derived from combustible waste fraction of solid waste like plastic, wood, pulp or organic waste, other than chlorinated materials, in the form of pellets or fluff produced by drying, shredding, dehydrating and compacting of solid waste". According to the ASTM standard (2006), another definition is as follows: RDF, which has a particle size of 95% weight and can pass through a 2-in square mesh screen, is shredded fuel made from MSW after metal, glass, and other inorganic materials have been removed.

The composition of MSW varies depending on the source, season, and living habits. Raw MSW has a wide variety of particle sizes, a high ash content, a low calorific value, and a high moisture content. These factors make it challenging and undesirable to use raw MSW as fuel. In comparison to raw MSW, RDF offers several benefits as a fuel. According to [15], the main advantages include a higher calorific value, which also remains fairly constant, more uniformity of physical and chemical composition; ease of storage, handling, and transportation, lower pollutant emissions, and reduction of excess air requirements during combustion.

2.2.2 Classification of RDF

According to American Society for Testing and Materials (ASTM) standards E856-83 (2006), RDF can be classified into 7 categories as follows;

RDF TYPES	SPECIFICATIONS
RDF 1	Raw waste without processing or with minimal processing.
RDF 2 (Coarse RDF or C-RDF)	Waste is processed into coarse particles without separation of metals in such a way that 95% of weight passes through 6-inch square mesh sieve.
RDF 3 (Fluff RDF)	The fuel is processed from waste by separating the metals, glass, and other inorganic materials. The material passes through a 2-inch square mesh.
RDF 4 (Powder RDF or dust RDF)	Combustible waste components in the form of powder and 95% of weight passes through 0.035-inch square mesh sieve.
RDF 5 (Densified RDF or d-RDF)	Flammable wastes were compressed in the form of pellets, cubes, briquettes, and similar forms. The advantages of portability, storage, and the ability to co-ordinate with a variety of combustion systems are developed.
RDF 6	The combustible waste is processed to give rise liquid fuel.
RDF 7	The combustible waste is processed to give rise to gas fuel.

2.2.3 RDF Standards

The characteristics (composition, physical, and chemical properties) of the MSW stream differ across cities in India. Although MSW-based RDF plants have some control over the quality of RDF produced, producing high-quality RDF With high NCV, low moisture, and low Cl content, this may not be possible due to cost considerations (expensive equipment) or the nature of Indian MSW. In a guideline published by the Central Public Health and Environmental Engineering Organisation, the quality standards (Table 1) for RDF when utilised in the cement industry (pre-calciner/kiln) have been specified.

Table 1. Quality requirements (mean) for RDF utilised in the cement industry (pre-calciner/kiln) [16].

Key parameters	RDF Desirable Values	Unit	Boundary (End-uses)
NCV	> 3000	Kcal/kg	Coal Co combustion (cement kiln)
Moisture	< 20	%	
Cl	< 0,7	%	
S	< 2	%	
Particle Size	< 120 - < 70	mm	

More recently, the national Ministry of Housing and Urban Affairs (Mohua) appointed an expert committee to develop classification guidelines and specification requirements (Table 2) for the cement industry sector. The Cement Manufacturing Association subsequently confirmed these guidelines, and other stakeholders reportedly support their use of both SCF and RDF in waste-to-energy plants.

Table 2. Classification criteria and limit values (mean) for waste fuels utilised in cement kilns proposed (2018) in India by the Expert Committee appointed by the national Ministry of Housing and Urban Affairs (MOHUA) [16].

Key Parameters	SCF Limit Value	RDF Grade III Limit Value	RDF Grade II Limit Value	RDF Grade I Limit Value	Unit	Boundary (End Uses)
NCV	>1500	>3000	>3750	>4500	kcal/kg	Coal co-combustion (cement kiln)
Ash	<20	<15	<10	<10	%	
Moisture	<35	<20	<15	<10	%	
Cl	<1.0	<1.0	<0,7	<0,5	%	
Particle size	<1,5	<50, if ILC plant (a)			mm	
		<20, if SLC plants (b)				
(a) ILC: In Line Calciner (b) SLC: Separate Line Calciner						

The guideline highlights the cement industry as the most suited sector to use RDF as a substitute fuel, as compared to its usage as a supplemental fuel in thermal power plants and incineration plants. However, due to many limitations that could have a detrimental effect on the manufacturing process, product quality, and the environment, RDF is viewed as an unsuitable fuel for the thermal, iron, and steel industries, as well as brick kilns. The CPCB has set another standard regarding emissions during the co-processing of RDF in cement plants.

According to Central Pollution Control Board (CPCB) rules a waste type (such as RDF) that has been tested and approved in one cement plant may be used for regular co-processing in another cement plant, and state pollution control boards (SPCBs) may provide approval based on the CPCB recommendations. The SPCB will ensure that emissions are monitored and reported by cement plants in accordance with the regulations. Emissions limits proposed for India and their comparison with limits in other countries are presented in Table 3 below:

Table 3: Emission limits for cement kilns co-processing in India [17]

Parameter [a]	EU limit	US (Load Based)	South Africa	India [b]
Total Dust	30	0.005 kg/t of clinker [c]	30	50 (or 0.125 kg/t of clinker)
HCI	10		10	10
HF	1		1	1
NOx for existing plants	800	0.75kg/t of clinker	800	800
NOx for new plants	500			600
Cd + Tl	0.05		0.05	0.05
Hg	0.05		0.05	0.05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V	0.5		0.5	0.5
Dioxins and furans (ng I-TEQ/Nm3)	0.1 [d]		0.1 [d]	0.1
SO2	50 [e]	0.2kg/t of clinker	50 [e]	100 [f]
TOC	10 [e]		10 [e]	
CO	National values			

[a]Daily average values for continuous measurements (mg/Nm3)

[b]Limits proposed to come into force from 01.08.2015 (the index of industrial pollution, 2014); Emissions limits of EU, US and South Africa taken from [18]

[c] Emissions on a 30-operating day rolling average

[d] Dioxins and furans must be measured at least twice a year, and at least every 3 months for the first 12 months of a plant's operation

[e] Exceptions may be authorized by competent authority if TOC and SO2 do result from the incineration of waste

[f] Relax able up to 400 by SPCBs in special cases, CPCB proposed 100 (for <0.5% Sulphur in raw materials), 1000 (for >0.5% Sulphur in raw materials).

2.3 RDF PROCESSING

The combustible and non-combustible portions of solid waste are mechanically separated to produce RDF. Thus, RDF can be produced from municipal solid waste (MSW) using several processes, including separation at the source, sorting or mechanical separation, size reduction (shredding, chipping, and milling), separation and screening, blending, drying, pelletizing, packaging, and storage [18,19].

Densified RDF (d-RDF) and coarse RDF (c-RDF) (high calorific fraction) are the two fundamental RDF processes, each producing a distinct product [20]. Depending on market demands, d-RDF is produced in the form of pellets or as loose fill with a fluffy consistency. Before transport or pelletization, d-RDF is desiccated, which increases its stability and transportability. Also, storage and handling are like other solid fuels. It can be burned either alone or in combination with coal or other solid fuels. d-RDF requires considerable processing, including drying and pelletizing, and has a relatively high processing energy requirement.

As a result, there has recently been interest in the alternative c-RDF (high calorific fraction). This is available as a coarsely shredded product. Although c-RDF requires less processing, it cannot be stored for long if it has not been dried. Due to microbiological activity, there is a risk that anaerobic conversion processes that produce methane will take place during interim storage. It generates explosive mixes or dangerous atmospheres with a volume percentage of 4.4 volumes (%) in the air (lower explosion limit) and 16.5 volumes (%) in the air (maximum explosion limit) [21]. The basic RDF process can be divided into five stages, i.e., waste receiving and storage, waste liberation and screening, fuel refining, fuel preparation, and fuel storage and quality management [22,23,24].

As a first stage, collection vehicles deliver mixed MSW onto a tipping floor, where any desired bulk components are removed. This initial short-term storage stage acts as a buffer, providing a steady feedstock level for the RDF manufacturing process [24]. **Secondly**, the waste is transported via a conveyor belt to be shredded, e.g., in two-roller shredders, crushers, or mills, and then screened, e.g., with a rotary drum screen or a ballistic bar sizer. It performs three functions- completes the bag emptying process, removes the undersize (fines, 60 mm) fractions, and separates the oversize materials from the fuel fraction [23,24]. The fines fraction contains organic and putrescible components that are rich in moisture, as well as ash, dust, sand, shattered glass, and other inert components. Wet organic materials (nearly 4–60 wt.%) can then undergo further treatment, such as composting or anaerobic digestion, and can be used as a soil conditioner for landfill restoration work or be landfilled. In some cases, the putrescible fraction is kept in place to enable the mass of material to be dried through biological treatment (the process of 'dry stabilisation"). The oversize portion is typically landfilled with other leftovers and consists primarily of huge pieces of paper, board, and plastic film. Despite the fact that it still contains metals and other non-combustible materials, the remaining fraction from this stage is usable as a high-calorie fraction [23,24]. **Thirdly**, size reduction, classification, and magnetic separation refine the medium fraction. Size reduction using a shredder or hammer mill aids in the separation of light and dense fractions. The density separation (classification) stage is required to separate the heavy fraction (metals, dense plastics) from the combustible light fraction (paper, plastic film), from which the densified RDF product is formed. Air classification and ballistic separation are the two main strategies utilised to accomplish this [25]. Overband magnets are typically used for the recovery of ferrous metals (Fe), while eddy current separation (2–3% by weight) is used for the recovery of non-ferrous metals (nFe), particularly aluminium. The light fraction, together with the remains of the magnetically sorted heavy fraction, can be used as a more refined form of coarse RDF [14,24]. **Fourthly**, the fuel preparation stage involves converting the fuel-rich fraction into a dry, dense pellet form by re-shredding, drying, and pelletizing. Secondary shredding is required to lower the particle size of the fuel fraction to the size required for pelletizing, and drying reduces the moisture content from approximately 30 wt. percent to around 12 wt. percent [23]. The dryers in use are simple pneumatic conveying systems that run on hot combustion gas from natural gas burners. Once the combustible fraction is dried, organic, and inert residues can be easily screened out, lowering the product's ash content. Most of the chlorine, heavy metals, and silicates in the product are contained within this inert residue. After this stage of densification, RDF can be produced with a final ash content of 10 wt.% by weight and chlorine levels of 0.5 wt.% [23,22]. In the absence of inert contaminants such as silicates, the calorific value of the material increases significantly. Densified RDF can either take the form of pellets or briquettes, though most plants use a pellet mill to densify the product.

2.4 RDF PRODUCTION IN SEVERAL COUNTRY

Indonesia

Indonesia is one of the countries in the world with highest population growth. Projection by World Bank estimates 271 million people with 179 million of them live in urban area by 2025. With the growth, MSW generation would amount 151,921 ton/day by 2025 [26].

Some cities are considering increasing the production and use of RDF in cement industry. The research on Cilacap city suggests RDF production can be considered when the city locates close to cement plant. The landfill in Cilacap city would reach its maximum capacity in 2018 if no other different treatment and disposal methods would come up [27]. Therefore, their urgent needs to come up with alternative waste management solution pushes RDF production forward in the city. Based on the willingness-to-pay in study [27], RDF in Cilacap city is financially viable option as it is cheaper than price of willingness-to-pay by cement industry in the study and also a price of fossil oil. Other study on usage of RDF in Gresik City suggests the cement company use RDF and substitute 30% of total coal utilization with RDF as part of their Corporate Social Responsibility (CSR) program. The company tagged with the municipality to reduce MSW by RDF production [28]. Their government has made efforts to manage municipal solid waste with high expectations for the conversion of this waste into refuse-derived fuel as a replacement for coal.

Thailand

Total waste generation of Thailand as of 2016, is approximately 27 million tons. And 43 % is still under non-proper waste management. And 23 municipalities have no MSW management. To tackle the situation in the country, Pollution Control Department (PCD) of Ministry of Natural Resource and Environment (MONRE) has prepared the Road Map for Implementing a Management of Solid Waste and Hazardous Waste and was approved by national government in August 2014. Under the road map, appropriate MSW management and energy utilization from waste was promoted by introducing the integrated waste management centre and appropriate treatment and disposal technology. MBT technology was also seen as one of the technologies to reduce MSW that goes to final disposal site. As of 2016, there are 15 municipalities in 13 provinces which uses RDF production as part of the MSW management system. The total amount of MSW sent for RDF production is about 1,100ton/day

To promote the production and utilization of RDF in Thailand, PCD aims to prepare a code of separation facility for solid waste fuel utilization/production. This guideline will set the standard criteria for both RDF products and production facilities. They are now referring to the existing RDF related standards such as EN 15359 published by CEN European Committee for Standardization (CEN) standard on Solid Recovered Fuels. This guideline attempts to control the quality of RDF products and production process standard for market players. However, there has not been much discussion on the environmentally appropriateness of MSW in Thailand as to produce RDF out of it, or, environmental assurance of the plants which uses RDF as fuel.

As for the energy policy side, Thai government has endorsed Thailand Integrated Energy Blueprint as part of their energy policy. One of the five major policy pillars are an Alternative Energy Development Plan which was endorsed in 2015. Overall target of this plan is to achieve 30% of renewable energy use in total energy consumption by 2036. Current renewable energy share in total energy consumption is 14.47% in October 2017 [29].

Japan

Japan relies mostly on thermal treatment of MSW (incineration and gasification, 81% of the almost 43 million tonnes MSW generated in 2015) [30]. RDFs produced in Japan from the so called "general waste" includes household and commercial wastes, according to the national legislation on waste. This RDF is dried by adding chemicals and is pelletized which complies with requirements set in a dedicated national standard (NCV >12,500 kJ/kg, moisture content <10% or ash content < 20%) [31]. RDF produced in Japan is essentially intended to be used in urban Waste to Energy WTE facilities, e.g., mainly power generation plants to satisfy the local demand for electricity but other end-users include cement and pulp and paper industries, and district heating facilities.

A further secondary fuel named RPF (Refuse derived Paper and Plastics Densified Fuel), is also produced in Japan. RPF is a pelletized waste fuel produced from dry and non-hazardous paper and plastic waste from industrial origin (residual wood, textile and rubber waste streams are admitted too as long as the standardized fuel quality requirements are met). The national standards, well recognized and applied by all the operators, regulate RPF matter, of which the JIS Z7311:2010 classifies it in four qualitative “classes”. One of them is the so-called RPF-coke which is defined by a high quality RPF with a calorific value >33 MJ/kg (i.e., lower values for moisture and ash content; higher calorific values).

Germany

In contrast, Germany's experience with waste incineration, energy recovery, and RDF utilization reaches back to the 1970s. In 2014, approx. 47.5 million tons of waste were being treated thermally, of which 46% were treated within 66 waste incineration/waste to energy plants and 28% used as fuel substitute in combustion process (e.g., RDF plant, coal power plants, co-combustion in cement kilns or steelmills) [32,33]. Out of the 66 thermal plants covering 1.53% of the annual German primary energy demand in 2017, 60 plants are equipped with a CHP, while six plants are only generating power [33,34]. 32 power plants using only RDF have a total national capacity of 6.3 Mio. tons per year [33]. Apart from waste/RDF to energy plants, 34 cement kilns and two lime plants are approved for RDF co-processing [33]. Also, 25 coal power plants had an approval to co-process waste in 2016,treating approx. 1.5 million tons of waste per year [35]. Out of 3.2 Mio. tons of waste derived fuels used in 34 cement kilns in 2015 [33,35] 10% was segregated combustible MSW as well 21%plastic fractions and 2.9% paper fractions of industrial and commercial waste [36].
The thermal substitution rate of German cement kilns with alternative fuels amounted 64.6% in 2015 [37]. In addition, 16 coal-fired power plants co-incinerated waste amounting to around 1.5 million tons. The types of waste usedrange from secondary fuels (eight coal-fired power plants) to paper and fibre sludge,sewage sludge, plastics and foils, spit, animal meal, hazardous waste, and organic liquids [35].

Poland

The cement industry in Poland is now substituting thermal energy at a rate of more than 60%. With some cement factories employing up to 85% alternative fuels, 70–80% of which are created from MSW (the remainder of the alternative fuels are made from tyres and sewage sludge). This rate is much higher than the average RDF usage rate for the world and the EU [38,39].

In Poland, the cement sector consumes the most processed waste as fuel, using nearly 1.5 million tonnes a year; this figure is anticipated to rise to 2 million tonnes in the future. One-third of Poland's anticipated future capacity for RDF processing is likely to be absorbed by the cement sector [39]. In order to further reduce the cost of RDF preparation and increase the usage of less-prepared waste, Polish cement manufacturers are investing in new technology and creative methods [40]. RDF reportedly replaced 1 million tonnes of coal in Poland's cement production in 2016, resulting in a 2.5 million tonne CO2 reduction annually [39].

Austria

Austria reported [41] a production of about 2.8 Mt of RDF of which about 1.0 Mt were only from MSW in 2015 and a production of 0.18 Mt of SRF/RDF (fuel product) in 2016. 53 industrial power plants were under operation in the country in 2015, with a total capacity of about 1.0 Mt of waste treated, which includes waste wood (about 0.4 Mt), residues from the pulp and paper industry (about 0.4 Mt), plastic waste (about 0.1 Mt), and, to a lesser extent, textiles, sewage sludge, and other wastes. The 8 cement kilns under operation during 2015 and 2016 consumed 0.5 Mt/y of substitutive fuels, with plastic wastes being the main component of the mix of substitutive fuels, contributing 0.30 Mt in both years, followed by sewage sludge, waste wood, animal meal agricultural residues, used tyres, paper fibres from used tyres, and waste oil (all more or less >0.1 Mt). No details are provided by the data source about the consumption of SRF/RDF. Other sources of information [42] quantify a whole national RDF consumption of about 1.3 Mt in 2015, of which 0.27 Mt were incinerated, 0.71 Mt were used in incineration/co-incineration in dedicated industrial facilities, and 0.33 Mt were in cement kilns. In Austria an average substitution rate of 75% is reported [43].

2.5 RDF OR ARF FROM EXCAVATED LANDFILLED WASTE

The composition of the aged waste, and its physical and chemical properties are influenced by the age of the waste and the degradation of the waste over time. A recent case study [44] has shown that despite these complications, the production of a high-quality RDF from excavated waste streams is feasible. An organic fraction is no longer present in the aged waste samples and has most likely degraded into the fines fraction (‘soil type waste’) of the aged sample. It might seem surprising that the paper/cardboard fraction has not degraded further over such a long period of time. This is due to the fact that most landfills are fundamentally anaerobic because they are compacted so tightly, and thus do not let much air in [45]. Any biodegradation that does take place, does so very slowly. In another study [46], it is reported that only 5–10% of cellulose is degraded in nature under anaerobic conditions. The plastics and paper/cardboard fractions in the aged waste display higher ash fractions than their fresh counterparts. The large fraction of fines present in the excavated waste is partially explained by the thermal degradation of the waste over time. These fines also display a high ash content (around 20%). These two factors combined, provide an explanation for the high ash content (approximately 22%) found in the RDF processed from aged waste. According to a European report, the ash content in RDF processed from fresh waste (ranging from municipal waste to demolition waste) varies from 7% to 20% [47]. Pyrolysis studies available in the literature [48,49] have investigated RDF materials with an ash content from 10% up to 15%.

Recent research activities in Austria have focused on the characterisation of excavated material regarding its elementary composition. The samples were drilled from two different landfill sites in Austria. Samples were taken from material that had been landfilled 1979–1984, 1985–1988 and 1990–2000 and a sieve analysis was conducted. A large amount of fine fraction n (<40 mm), between 68 and 84 wt%, was found. The fractions plastics, wood, leather, rubber, paper, cardboard and textiles summed up to 24.7–36.5 wt%. In total, a metal content between 2.3 and 4.7 wt% was determined. The excavated material landfilled between 1990 and 2000 was shown to have relatively high heating values between 10,750 and 10,900 kJ/kg. Samples from older material contained a comparably high amount of heavy metals, prohibiting direct incineration in Austrian facilities [50].

Large-scale experiments on thermal treatment of excavated fractions from landfilled waste were carried out in Japan by Nippon Steel & Sumikin Engineering Co. Ltd. A pilot scale gasification facility with a throughput of ca. 20 tons/day was used. Input material was excavated municipal solid waste that had been classified to a particle size <200 mm – without any other further treatment. During the experiments, a mixture of normal municipal solid waste and excavated material was used in the facility. The amount of excavated material in the mixture was about 10 wt%. No negative influence on fly ash and slag could be detected. More detailed information about the excavated material or the experiences during thermal treatment has not been published [51].

The most detailed and comprehensive experiences on thermal treatment of excavated landfill material were gathered in the United States between 1991 and 1996 [52,53]. Waste from the Frey Farm Landfill in Lancaster County, Pennsylvania, was incinerated in a nearby waste-to-energy plant, to obtain additional landfill space and to fully load the WtE plant. The excavated waste, with an age between one and five years, was sieved in a drum screen with a mesh size of 1” (2.54 cm).

The underflow (predominantly soil) was applied as a cover material on the landfill again, the overflow material was used as fuel in the waste-to-energy plant. As a result of the relatively low heating value of 7.2 MJ/kg, the material had to be enriched with fractions of higher calorific value (tire and wood chips) and was subsequently mixed with fresh municipal solid waste in a ratio of 1:4. The amount of ash was about 5–7% higher compared to normal waste. Test trials with 20 years old landfilled waste indicated much lower calorific values and even higher contents of ash. The emission limits (CO, Cr-VI, NOx, SOx) of the incineration plant could be met during the entire period, but gradually a significant increase of HCl concentration in the off gas could be observed. Further impacts regarding the plant operation were the necessity of a more intensive fuel mixing in the bunker to ensure homogeneous fuel properties, and increased rates of abrasion, wear and clogging of the equipment, due to the higher ash content. The combustion of the material was stopped in 1996, when the waste-to-energy plant did not need additional fuel anymore [53].

2.6 MAJOR DRAWBACKS IN INDIAN INDUSTRIES

2.6.1 Cement Industry

Refuse-derived fuel (RDF), which is produced by processing the MSW's combustible portion, and the cement industry can play a significant role in utilizing RDF as an alternative fuel in cement kilns. The current thermal substitution rate (TSR) of fossil fuels by alternative fuels, such as industrial waste, biomass, and municipal waste, is only 3.0 percent, which is a significant decrement from the double-digit rates attained in developed nations. The MSW-based SCF/RDF used in cement kilns contribute only 0.6% of thermal substitution. Alternative fuels and raw materials (AFR) utilization is encouraged by the Cement Manufacturing Association (CMA) and the Cement Sustainability Initiative (CS), and over the past ten years, the rate of AFR replacement has increased from less than 1% in 2010 to more than 3% in 2016. The industry has been co-processing sorted MSW at its plants in Gujarat, MP, Karnataka, and Andhra Pradesh with the goal of achieving 25% of TSR by 2025 in the same model across all its cement kilns in India. However, the bottlenecks regarding assured quality and the quantity of the sorted combustible fraction of MSW remain the major bottlenecks in investing in related infrastructure.

The cement clinker may suffer if RDF with a high chlorine level is burned. However, the formation of these kiln bypasses can control volatile alkali chlorides. The composition of the ash, the viscosity of the slag, the SiO_2/Al_2O_3 ratio, and the acid/base ratio are the primary causes of slag and fouling. Therefore, the size of the RDF employed becomes a crucial factor, since large glass particles may provide nuclei that promote slag-forming processes. Since RDF will have a different proportion of non-combustible particles than coal, it will affect fouling and slagging in a different way. When RDF is used in the boiler, corrosion of metal surfaces is another issue. This is a result of the high-temperature liquid corrosion caused by alkali sulphate; a reducing environment within the boiler may result in the partial combustion of corrosive agents like CO and H_2S. The Ministry of Environment, Forest, and Climate Change notified the emission standards for the co-processing of waste/RDF in cement plants in May 2015. The same copy is included in Annexure II. Co-processing in a cement kiln effectively uses the material and energy value present in the waste, preserving natural resources by using less virgin material. The advantages of using RDF as a substitute fuel in the cement industry are demonstrated below.

2.6.1.1 RDF Requirements

It is not a technological issue to shred RDF to a size of less than 50 mm, as required by cement plants. In an oxygen-rich environment, such as that found in a cement kiln, particles smaller than 50 mm typically dissolve completely in 4-5 seconds.

2.6.1.2 RDF Ingestion

With the installation of an alternative fuel feeding system, RDF may easily be fed into the cement kiln. Cement factories typically construct a separate entry point for AFR, which can include pharmaceutical waste, FMCG waste, packaging waste, lubricants, etc. RDF can be fed using the same feeding mechanism.

2.6.1.3 Effect on the Product

RDF is completely burned without affecting productivity at extremely high temperatures of approximately 1400°C and a residence time of 4-5 seconds in an oxygen-rich atmosphere. The fuel has a calorific value of 3000 kcal, which can produce enough thermal energy required in the processes in these plants, reducing the usage of non-renewable fossil fuels like coal.

2.6.1.4 Effect on the Environment

Utilizing RDF causes emissions by substituting materials that would have gone to landfills for fossil fuels. Leachate would have been able to enter groundwater and become a significant source of pollution if landfilling had been done improperly. Furthermore, using equipment for check stack missions may lead to fewer dioxin and furan emissions into the atmosphere.

2.6.1.5 Residual Elimination

The alkaline raw material in the cement kiln neutralized the acidic gases produced during the combustion process and incorporated them into the cement clinker. The interaction of the raw material and the flue gases in the clinker ensures that the non-combustible part of the residue is held back in the process and is incorporated into the clinker in an almost irreversible manner. No additional waste is generated in the process.

2.6.2 Thermal Power Plant

Using RDF as a fuel in thermal power plants has some drawbacks, including

2.6.2.1 Calorific value

The highly variable nature of size, density, and calorific value across regions and seasons of the RDF produced can never ensure that the RDF will be of the same calorific value. The heat release rate of RDF is not consistent compared to that of coal, and hence a study on the combustion behaviour of RDF while co-firing with different blend rations needs to be done.

2.6.2.2 Size

RDF, being in fluffy or loose form, cannot be mixed with coal directly as the existing milling system is not designed to pulverize RDF. Separate milling systems, conveying systems, and modifications to the combustion system shall be required.

2.6.2.3 Quality of output

(i) The presence of silica with alkalis creates agglomeration and fouling on heating surfaces.

(ii) Silica in fly ash causes erosion of heating surfaces.

(iii) Chloride compounds in RDF cause corrosion of heating surfaces.

(iv) RDF combustion products contain SO2/SO3 that cause acid dew point corrosion. The presence of such corrosive non-metals in the RDF will, over a period, reduce the productivity of the boiler and hence the productivity of the turbine as well.

2.6.2.4 Creation of Slag

Combustion temperatures above ash fusion temperatures lead to ash fusion and clinker formation on the grate over a period. This reduces the productivity of the boiler through deposits and increases the cost of maintenance.

2.6.2.5 Policy and finance

(i) Absence of a policy on financials, incentives, technology choice, capacity building, and other regulatory issues.

(ii) Absence of long-term power purchase agreements with favourable tariff structures Boiler Metallurgy.

The present boiler metallurgy of the PC-fired plant is not suitable for the highly corrosive atmosphere generated by the burning of high plastics, PVC, and alkaline elements in RDF. This would result in frequent shutdowns of the boiler on account of tube leakages and corrosion-related failures.

2.6.3 Iron and Steel Industry

The use of RDF as a fuel source has very little experience in the Indian steel industry. This is generally due to concerns related to possible negative impacts on the production process or product quality. The expert members of SAIL have determined that MSW-derived RDF cannot be used in the iron and steel industry as the process is autogenous. The use of RDF as fuel in processes like sinter making or reheating furnaces was also investigated, and it was concluded that since the present mode of energy supply to sinter and reheating furnaces is gaseous, solid RDF would not be the appropriate material for those applications.

2.6.4 Brick Kilns

In the case of brick kilns, biomass and MSW-derived fuel have not been taken into consideration because the furnace's temperature is often lower than 700°C–1100°C and the combustion of RDF at such temperatures will produce harmful pollutants such as dioxins and furans [54].

2.7 KEY INFERENCE FROM THE LITERATURE REVIEW

Developed countries have successfully utilized RDF in various energy-intensive sectors, achieving thermal substitution rates of up to 60-70% by producing standard quality RDF through proper waste segregation and management facilities. In India, RDF has immense potential for utilization. However, due to inadequate waste management facilities and a lack of waste segregation, most cities do not prioritize the recovery of RDF from MSW. India has only achieved 3-5% thermal substitution rates, with few industries achieving 10-15% TSR. Therefore, we take a look to know the potential of RDF for various cities throughout the country.

In India, there are opportunities to use RDF in cement and waste-to-energy plants. However, due to a lack of standards and viable business models, widespread implementation is not yet feasible. Recovering refuse-derived fuel (RDF) from aged waste is a major challenge due to the presence of inert contaminants. However, the lack of physio-chemical standards makes many industries hesitant to use RDF in their boilers. To address these issues, our study aims to investigate the quality standards of fresh as well as legacy RDF and identify the most viable business models that meet the needs of industry stakeholders.

The cost of producing and transporting RDF in India is much higher than the price cement plants are willing to pay. Transport is a major contributor to this financing gap, therefore, depending on the distance between the cement plants or others industry and the RDF plants (that could be from 100 km to 1000 km) the financing needs will vary. As a result, we are examining the proximity of different industries (such as cement, thermal power, and iron-steel plants) to the RDF production sites to determine the feasibility of different business models.

It is a fact that developed countries utilize RDF in their industrial boilers to a greater extent than developing countries. The main use of RDF in India is in cement plants due to limitations on boiler specifications in other industries, which restricts its extensive use. Hence, it is crucial to understand the boiler specifications of each industry to address this issue.

CHAPTER 3.
OBJECTIVE AND SCOPE OF THE STUDY

3.1 OBJECTIVES OF THE RESEARCH

1. To investigate the physicochemical characterization of MSW and assess the possible RDF compositions thereafter using as secondary resources.

2. To determine the economic feasibility of RDF from fresh and legacy waste management for the ULBs and emphasizing on utilization in cement, steel-iron, and thermal power plant industries.

3.2 SCOPE OF THE RESEARCH

1. Primary and secondary data collection.
2. Composition analysis of fresh MSW from 18 Indian cities.
3. Physicochemical analysis of fresh and legacy RDF.
4. Business model development considering CAPEX, OPEX, and RDF transport costs.
5. Profitability analysis in different case studies.
6. Major challenges and findings for RDF utilization in different industries.
7. Understanding potential RDF user needs.
8. Understanding the economic feasibility of fresh and legacy RDF by considering CAPEX, OPEX, and RDF transport costs for the various industries.

CHAPTER 4.
METHODOLOGY

In this research, we thoroughly analysis of data from 18 prominent cities in different regions of the country. These cities were categorized into five distinct regions, namely North, South, Central, Eastern, and Western. Dhapa landfill site is also considered a study area of legacy RDF.

4.1 REFUSE DERIVED FUEL COMPOSITION AND CHARACTERISTICS

The current generation of municipal solid waste for the numerous cities within the region has been collected from relevant literature and current sources. The percentage of combustible fractions of municipal solid waste (MSW) such as plastic, paper, cardboard, textiles, and miscellaneous fractions (such as wood, dry leaves, coconut shell, etc.) are considered for the study. The moisture content of the combustible components of unprocessed MSW is extracted using an analytical procedure reported earlier [13]. The combustible components of municipal solid waste are then recycled at an appropriate rate. In the Indian case study, 10–15% of waste is recycled at the source and in landfills [55]. To make a total of 12% recycling, the percentage of recycled material for the combustible fraction is adjusted to get a total recycling amount of 12%, or 12 MT out of 100 MT. The non-recyclable combustible components of municipal solid waste are computed as RDF for a few cities.

The proximate (moisture, ash, volatile matter, fixed carbon, etc.) and ultimate analysis (carbon, hydrogen, nitrogen, oxygen, sulfur, etc.) of such RDF fractions are computed theoretically based on [13]**.** The modified Dulong formula is then used to determine the heating value of RDF, as illustrated below:

$$MJ/kg=337C + 1419(H2 - 0.125O2) + 93S + 23N \quad \text{…. } \textbf{Equation 3.1}$$

where the percentages of C, H2, O2, S, and N are given in weight.

For the few cities, the physical composition (plastic, paper, plastic, textile, and other combustible fractions), components of proximate analysis (moisture, ash, volatile matter, fixed carbon, etc.), and components of ultimate analysis (carbon, hydrogen, nitrogen, oxygen, sulfur, heating value, etc.) of fresh RDF were directly taken from the previous study.

4.2 BUSINESS MODEL

Several business models are assessed by taking into account the costs associated with the production of RDF (CAPEX and OPEX) and transportation based on the physio-chemical parameters of RDF that have been analyzed for different cities. Costs associated with RDF production and transportation are estimated using the most recent guidelines provided by the Central Public Health Environmental Engineering Organisation [56].

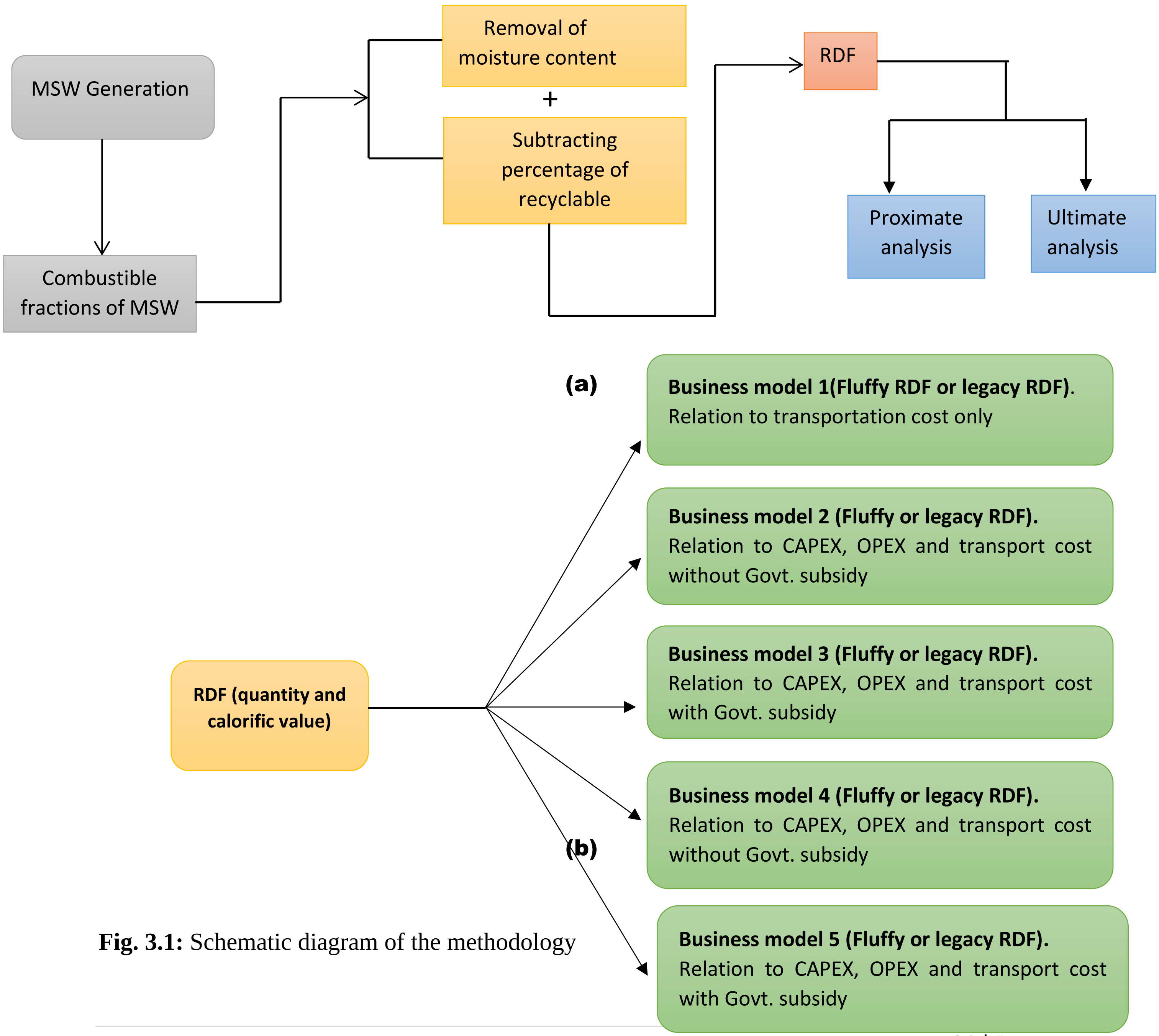


Fig. 3.1: Schematic diagram of the methodology

CHAPTER 5.
PRESENT STATUS OF RDF GENERATION FROM MSW

5.1 LOCAL AND REGIONAL PERSPECTIVE IN 18 INDIAN CITIES

Daily waste generation of the following cities is shown in Fig. 5.1. To produce RDF, the combustible fractions of such waste, which contain plastic, paper and cardboard, textiles, and other combustible fractions (wood, dry leaves, coconut shell, etc.) are considered. To produce RDF of an acceptable grade, 2% moisture content from plastic, 6% from paper and cardboard, 10% from textiles, and 20% from the other combustible fractions (wood, dry leaves, coconut shell, etc.) of MSW are removed [13]. In this study, the leftover fractions after removing the moisture content and subtracting the percentage of recyclable fraction from the combustible components of MSW are referred to as RDF. The daily RDF production for various cities is depicted in Figure 5.1.1.

For the Indian case study, a total of 10–15% recycling is done at the source and landfill [55]. To make a total of 12% recycling, the percentage of recycled material is adjusted to get a total recycling amount of 12%, or 12 MT out of 100 MT. In this study, recycling of plastic materials is taken into account at a rate of 60%, paper, and cardboard recycling at a rate of 70%, textile recycling at a rate of 10%, and other combustible fractions (wood, dry leaves, garden debris) at a rate of 10%. The calculation of the quantity of RDF from MSW for the 18 Indian cities is shown in Annexure I (Table A1.).

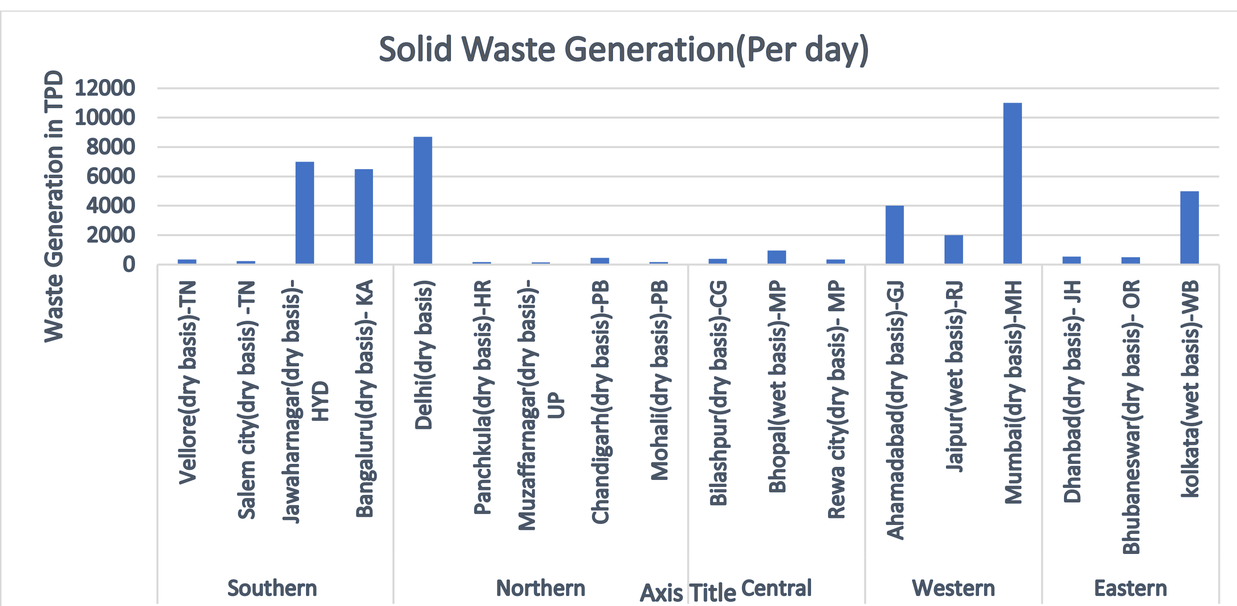


Fig. 5.1: waste generation of the various Indian cities

5.1.1 Southern Region

Vellore

Vellore produces 350 TPD of solid waste per day. The combustible fractions of such waste, which contain 7% plastic, 6.5% paper and cardboard, and 5% textiles are considered to produce RDF [57]. The recyclable portion of MSW's combustible fractions (dry basis) accounts for a total of 30.95 TPD, while the rest of the quantity is estimated to be RDF. According to calculations for the city of Vellore, the non-recyclable combustible portions of RDF is around 30.2 TPD.

Salem City

Salem City generates 230 TPD of municipal solid waste every day. The combustible components of such waste, which contain 12% plastic and 6% paper and cardboard, are used to make RDF [58]. Approximately 25.31 TPD of the dry basis combustible components of MSW are recyclable, while the remaining quantity is estimated to be RDF at around 14.7 TPD. Due to lower amounts of solid waste generation with a higher proportion of non-combustible components, the RDF production rate in this city is relatively low.

Jawahar Nagar

Jawahar Nagar City produces a significant amount of municipal solid waste each day, roughly 7000 TPD. Since there is a substantial amount of MSW generation, the combustible materials in MSW are higher which leads to a higher rate of RDF production in this city. The combustible parts of such waste, which contain 8% plastic, 7% paper and cardboard, 8.5% textiles, and 9% other combustible fractions (wood, coconut, dry leaves, etc.), are utilized to produce RDF [59]. The dry-base combustible MSW component recycling rate is about 705.25 TPD. For the city of Jawahar Nagar, it is estimated that the non-recyclable combustible portion of RDF is 1293.25 TPD.

Bengaluru

In Bengaluru City, the daily production of MSW is about 6500 TPD. The enormous quantity of MSW has a higher percentage of combustible components, which causes a higher rate of RDF production in this city. The combustible parts of such MSW, which contain 6.23% plastic, 11.6% paper and cardboard, and 1.01% textiles, are used to produce RDF [57]. About 740.18 TPD of the dry-basis combustible components of MSW are recycled, with the remaining portion being turned into RDF. For the city of Bengaluru, the estimated RDF production is 424.56 TPD.

5.1.2 Northern Region

Delhi

MSW production in Delhi is 8700 TPD. MSW with 6% plastic, 5.6% paper and cardboard, and 10% other combustible fractions (wood, dry leaves, coconut shell, etc.) are used to make RDF [60]. Approximately 697,11 TPD is recyclable, and the leftover portion of the residue is converted to RDF. MSW contains significant flammable components, which generate large quantities of RDF. For the city of Delhi, the estimated quantity of RDF is around 968.41 TPD.

Panchkula

Each day, Panchkula City generates 180 TPD of municipal solid waste. The combustible components of MSW are composed of 7.06% plastic, 5.43% paper and cardboard, 1.19% textile, and 13.38% other combustible fractions (wood, dry leaves, coconut shell, etc.) [61]. It is worth mentioning that around 15.83 TPD of the dry basis combustible components of MSW can be recycled, while the remaining amount is expected to be RDF. Therefore, the quantity of RDF estimated for the city of Panchkula is approximately 26.81 TPD.

Muzaffar Nagar

Every day, the city of Muzaffar Nagar produces 160 TPD of solid waste, which includes 7% plastic, 6.08% paper and cardboard, and 6.36% textile [62]. About 13.9 TPD of the combustible waste can be recycled, while the remaining 15.4 TPD is processed into RDF.

Chandigarh

Chandigarh City produces 456 TPD of municipal solid waste every day. This waste includes 7.30% plastic, 6% paper and cardboard, 1.70% textile, and 4.1% other combustible materials such as wood, dry leaves, and coconut shells [61]. Out of this combustible waste, 39.77 TPD is recycled, while 40.5 TPD is converted into RDF (refuse-derived fuel) in the city of Chandigarh.

Mohali

The daily MSW generation for the city of Mohali is 180 TPD. MSW with 6.6% plastic, 5.3% paper and cardboard, 1.2% textile, and 9% other combustible fractions (wood, dry leaves, coconut shell, etc.) are used to make RDF [61]. The estimated RDF production rate for the city of Mohali is 20.76 TPD, while the amount of recyclable material is approximately 14.75 TPD.

5.1.3 Central Region

Bilaspur

There are 400 TPD of MSW produced in Bilaspur City. The three main components of MSW that are taken as RDF components with plastic (3%), paper and cardboard (5%), and textiles (5%) for the city of Bilaspur [63]. The estimated recyclable components are around 22.02 TPD, while the production rate of RDF is 26.54 TPD for the city of Bilaspur.

Bhopal

Bhopal City generates 950 TPD of municipal solid waste, which consists of 2% plastic, 10% paper and cardboard, 7% textiles, and 10% other fractions (wood, dry leaves, coconut shell, etc.) that are considered combustible fractions [54]. Out of this component, the recycled portion is about 87.27 TPD, and the RDF production rate is around 156.50 TPD.

Rewa City

Every day, Rewa City produces a certain amount of municipal solid waste, represented by 350 TPD. This waste contains various components, including 18.7% plastic, 6.6% paper and cardboard, 4.5% textile, and 1.5% wood [64]. After the moisture is eliminated, approximately 55.52 tons per day (TPD) of dry combustible materials can be reused, while the remaining amount turns into refuse-derived fuel (RDF). The city of Rewa is expected to generate 48.70 TPD of non-recyclable and combustible waste.

5.1.4 Western Region

Ahmadabad

In Ahmadabad city, the daily production of MSW is about 4000 TPD. Due to the substantial amount of MSW, MSW consists of a higher percentage of flammable components, which leads to a higher rate of RDF production. The combustible parts of such MSW, which consist of 6.7% plastic, 5.7% paper and cardboard, and 3% other combustible fractions (wood, dry leaves, coconut shell, etc.) are used to produce RDF [65]. The estimated recyclable portions of such components are approximately 317.2 TPD, and the RDF production rate is 255.8 TPD for the city of Ahmadabad.

Jaipur

The municipal solid waste (MSW) generation in Jaipur City is 2,000 TPD. The combustible components of such waste, which contain 7% plastic, 6.5% paper and cardboard, and 5% textile are used to make RDF [57]. Around 176.86 TPD of the dry basis combustible components of MSW are recyclable, while leftover residue (that is known as RDF) is about 172.54 TPD for the city of Jaipur.

Mumbai

Mumbai has the highest rate of municipal solid waste production in the country, which is approximately 11,000 TPD. The combustible parts of such MSW consist of 9% plastic, 8% paper and cardboard, 6% textile, and 11% other combustible fractions (wood, dry leaves, coconut shell, etc.) [65]. The most notable rate of solid waste generation with a higher proportion of combustible components occurs in Mumbai, where the production rate of RDF is also rather high. The estimated rate of RDF production for the city of Mumbai is around 2042.04 TPD, and the expected rate of recycling for such combustible fractions is approximately 1317.36 TPD.

5.1.5 Eastern Region

Dhanbad

Dhanbad City produces 545 TPD of municipal solid waste, which contains 13% plastic, 0.6% paper and cardboard, 2.4% textiles, and 5% of miscellaneous fractions (wood, dry leaves, coconut shell, etc.) that are deemed combustible fractions in this analysis [66]. For the city of Dhanbad, the rate of RDF production is 58.91 TPD, whereas the dry-base combustible components of MSW are recyclable at a rate of about 47.17 TPD.

Bhubaneswar

Bhubaneswar City generates 500 TPD of municipal solid waste, which consists of 10% plastic, 9.2% paper and cardboard, and 5% textiles that are used to make RDF [67]. For the city of Bhubaneswar, the recycling rate for such waste is 61.9 TPD, whereas the rate for non-recyclable combustible fractions (also known as RDF) is approximately 52.8 TPD.

Kolkata

5000 TPD of municipal solid waste produced by Kolkata City, there are 3.2% of plastic, 4.6% of paper and cardboard, 4% of textiles, 1.2% of other combustible fractions (such as wood, dry leaves, coconut shells, etc.), and 4% of textiles used to produce RDF [68]. The dry-base combustible municipal solid waste components for the city of Kolkata have a recycling rate of around 268.22 TPD, which is lower than the production rate of RDF (332.78 TPD).

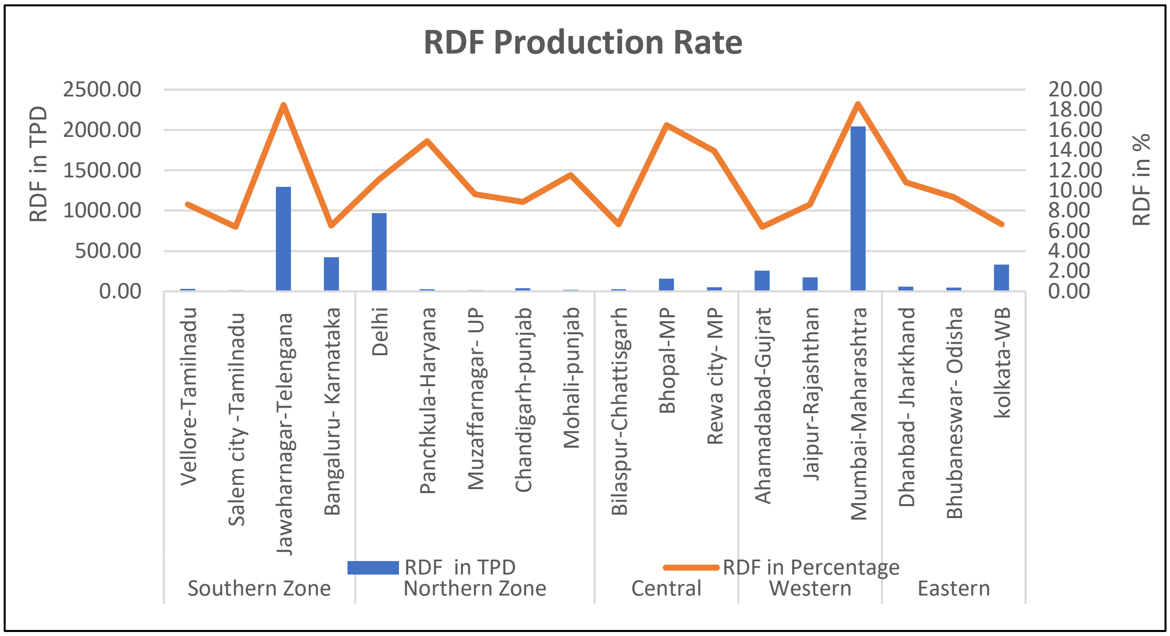


Fig. 5.1.1: RDF production rate from fresh municipal solid waste

5.2 PHYSICAL COMPOSITION OF FRESH RDF

Plastic, paper and cardboard, textiles, and other combustible fractions like wood, dry leaves, etc. are components taken into consideration for the RDF sample. In the southern zone, plastic material constitutes 39.93% of the total RDF quantity, while it is 24.58% in the northern zone, 25.05% in the central zone, 30.63% in the western zone, and 35.97% in the eastern zone. The RDF sample in the southern zone contains 27.12% paper and cardboard material (as depicted in Fig. 5.2), while it is 14.86% in the northern zone, 17.25% in the central zone, 19.51% in the western zone, and 16.27% in the eastern zone. Textile material constitutes 32.25% of the RDF sample in the southern zone, 21.01% in the northern zone, 40.55% in the central zone, 36.56% in the western zone, and 32.33% in the eastern zone. In addition, the RDF sample contains other combustible materials such as wood, coconut shell, and dry leaves, which constitute 35.07% in the southern zone, 54.69% in the northern zone, 25.73% in the central zone, 38.22% in the western zone, and 23.14% in the eastern zone.

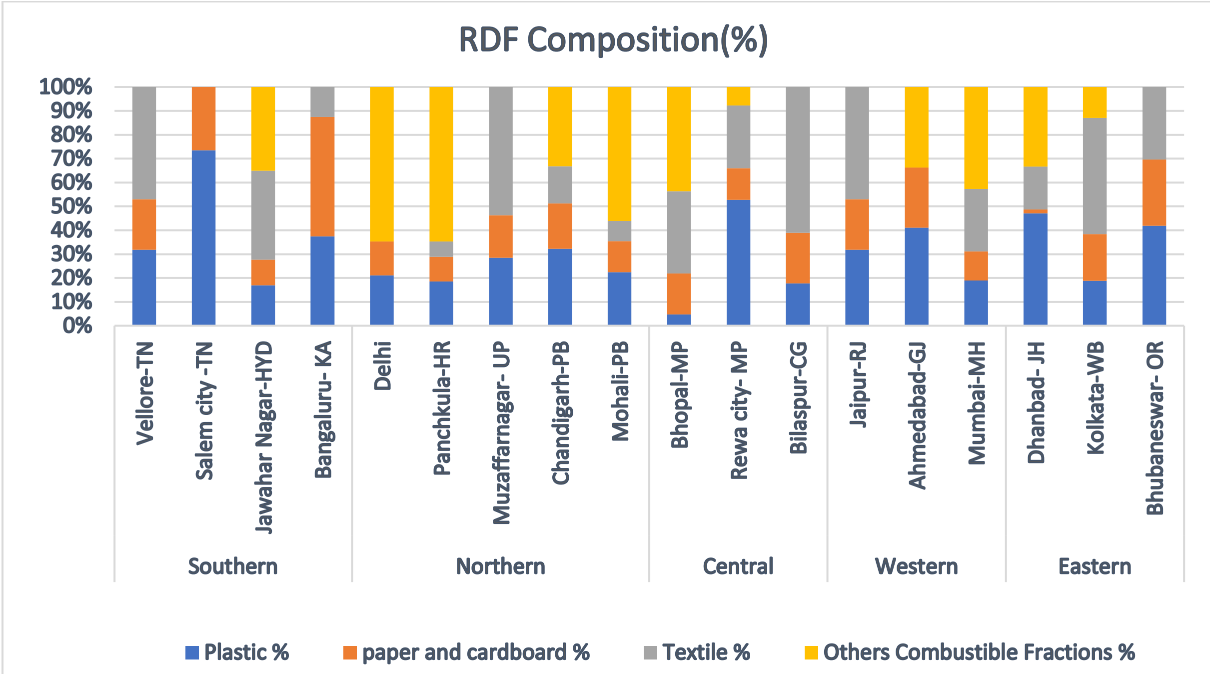


Fig. 5.2: Physical composition of fresh RDF

5.3 CHAPTER CONCLUSION

In this study, the physical composition of RDF derived from MSW in 18 Indian cities has been determined. Several statistical analyses have been performed to determine the RDF generation rate for different Indian cities. A standard grade of RDF that meets the needs of the end user may be produced through proper sorting and processing of the combustible fractions of MSW. It was observed that some cities have much more textile and yard waste than plastic, paper, or cardboard in their RDF fractions, which might result in the standard quality of RDF. In Indian cities, the proportion of RDF production is around 12.32% of the total MSW production, which is a little low since the percentage of recycled fractions for fresh waste is quite high.

CHAPTER 6.
CHARECTERIZATION OF FRESH RDF

6.1 PROXIMATE ANALYSIS OF FRESH RDF

Proximate analysis for the combustible components of RDF includes the moisture (loss of moisture when heated to 105°C for 1 hr), volatile combustible matter (Additional loss of weight on ignition at 950°C in a covered crucible), fixed carbon (combustible residue left after volatile matter is removed), ash content (weight of residue after combustion in an open crucible). The table in Annexure I (Table A2) provides the Proximate analysis results for fresh RDF samples from different cities.

6.1.1 Moisture Content

Moisture content is an important factor that affects the quality of RDF. To avoid burning at lower temperatures and increasing the possibility of toxic gas emissions, lower moisture content indicates higher calorific values [69]. The moisture content of the fresh RDF ranged from 6 to 25% and is presented in Fig 6.1.1. In comparison to other cities, Jawahar Nagar (20%) and Kolkata (20%) have higher than average moisture content. The study observed that moisture content is high due to the higher percentage of organic content (like wood and dry leaves, etc.) present in the RDF fractions. Additionally, it has been noted that climatic factors and seasonal variations are also responsible for these variations. For incineration, the moisture content of the feedstock should be less than 45% [70]. According to the study, the moisture content in the southern zone is around 9.7%, while it is 9.6% in the northern zone, 7.4% in the central zone, 9.4% in the western zone, and 10.7% in the eastern zone. The results are consistent with the data presented in previous studies by [71,72,73].

6.1.2 Ash Content

One of the major concerns with RDF combustion is the adverse effect of the fly ash produced on the boiler. The ash from RDF incineration has a high slagging and fouling tendency due to the large proportions of alkaline elements and volatile inorganic oxides such as Na_2O and K_2O in the ash [74]. The alkali metals in the RDF are released at lower temperatures, and once vaporized can react to form alkali silicates, sulphates, and chlorides [75]. The percentage of ash content lies 5 to 16% (as shown in Fig. 6.1.2) in the southern zone, 3.61 to 5.26% in the northern zone, 4.57 to 20.01% in the central zone, 3.92 to 18% in the western zone and 5.76 to 13% in the eastern zone. The US

EPA recommends that the acceptable range of ash content to achieve high efficiency in mass-burning incinerators be between 5-15% (dry basis) [11]. Except for Bhopal, Vellore, Jaipur and Kolkata, the ash concentration in the fresh RDF samples is within the acceptable limit in the cities listed below [76].

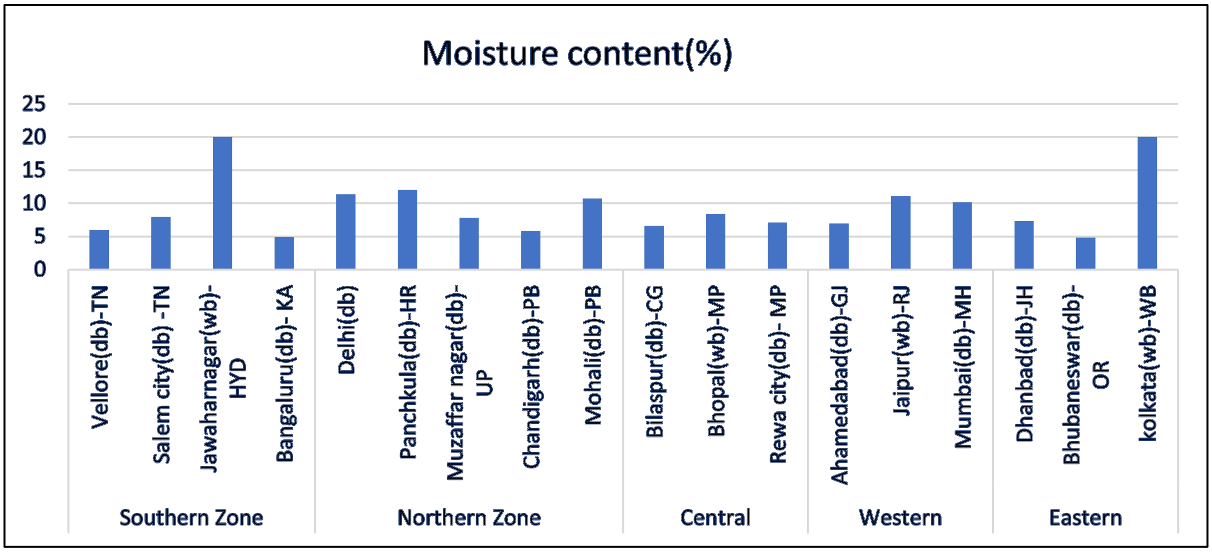


Fig. 6.1.1: Percentage of moisture content in fresh RDF

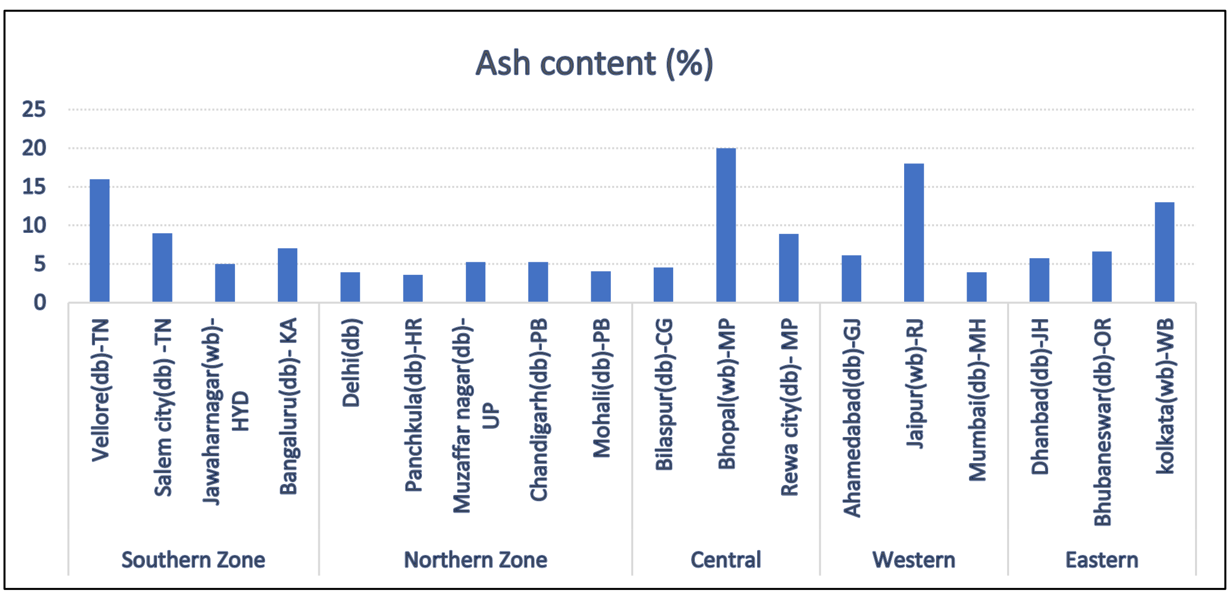


Fig. 6.1.2: Ash content in fresh RDF

6.1.3 Volatile Matter

The city of Rewa, located in the central zone, has a low volatile matter percentage of 8.45%. In contrast, Jawahar Nagar, situated in the southern zone, has a higher volatile matter percentage of 65% compared to the other city. This high volatile matter level indicates that fresh RDF (Refuse-Derived Fuel) has a significantly high amount of organic compounds. This high solid content is an indicator that high heat energy can be produced from such waste. In the southern zone, the percentage of volatile matter ranges from 58% to 65% (as shown in Figure 6.1.3), the northern zone has a range of 22.3% to 25.2%, the central zone has a range of 8.5% to 53.2%, the western zone has a range of 0% to 50%, and the eastern zone has a range of 0% to 55%.

6.1.4 Fixed Carbon

According to the study, the fixed carbon varied from 1.4 to 11.69% (dry weight basis) in various Indian cities. The high percentage of fixed carbon indicates longer retention times for combustion in incinerators [70].

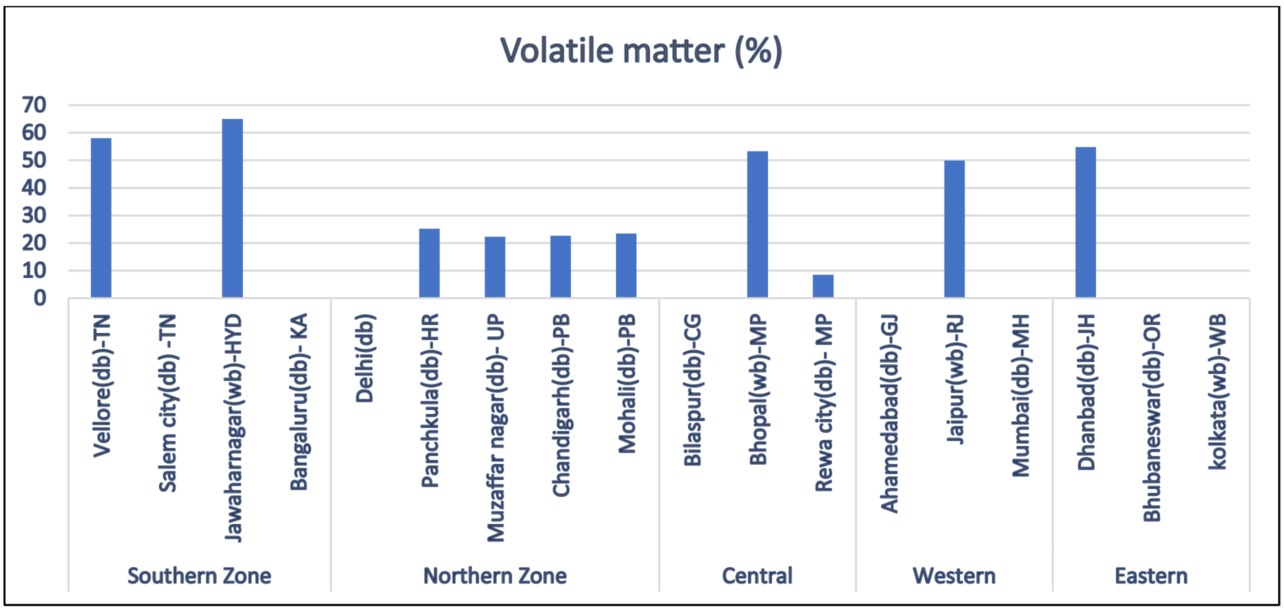


Fig. 6.1.3: Volatile matter in fresh RDF

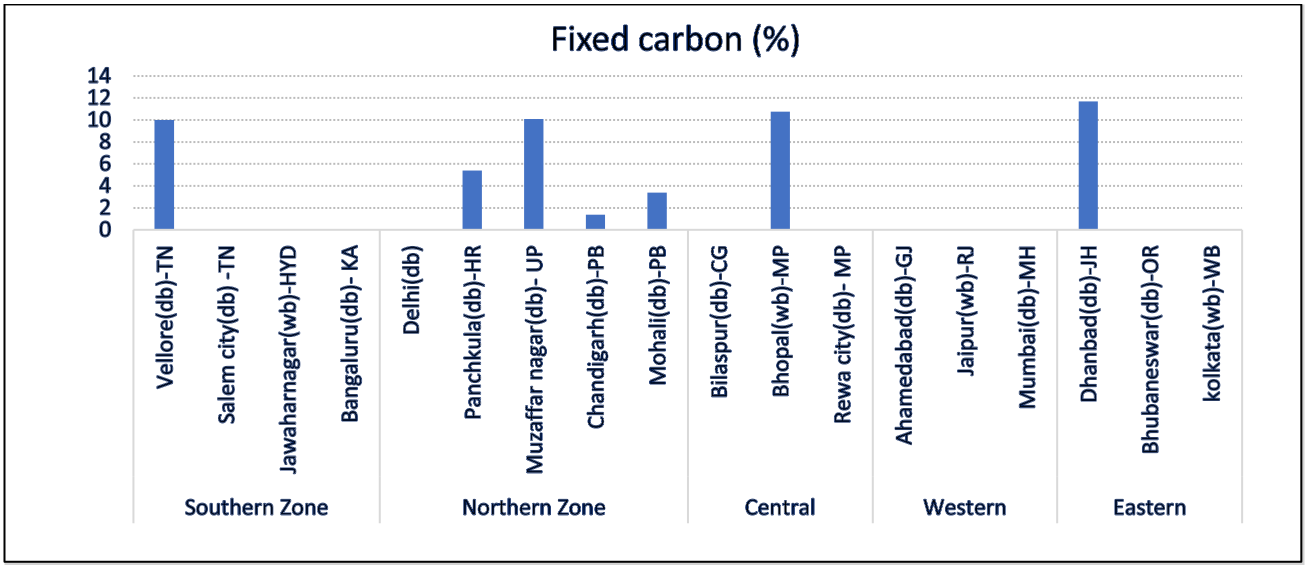


Fig. 6.1.4: Percentage of fixed carbon in fresh RDF

6.2 ULTIMATE ANALYSIS OF FRESH RDF

The ultimate analysis of a waste component typically involves the determination of the per cent C(carbon), H(hydrogen), O(oxygen), N(nitrogen) and S(sulphur). Because of the concern over the emission of chlorinated compounds during combustion, the determination of halogens is often included in an ultimate analysis. The ultimate analysis of fresh RDF from the various cities of the country is presented in Annexure II (Table B1. & Table B2.).

6.2.1 Carbon Content

When the carbon content of fresh RDF is measured on a dry weight basis, it is slightly higher at 40 to 58% compared to 27 to 37.5% when measured on a wet weight basis. The percentage of carbon content lies 38 to 58% (as shown in Fig. 6.2.1) in the southern zone, 51 to 54.4% in the northern zone, 27 to 54.4% in the central zone, 37.5 to 52.3% in the western zone and 52.1 to 55.34% in the eastern zone. Fresh RDF from major cities has a higher percentage of carbon (dry weight) due to the plastic content. The primary components of plastic are primarily carbon and hydrogen because it is a petroleum-derived product (a hydrocarbon molecule). In comparison to the remaining biomass, plastic wastes contain more carbon, leading to a higher calorific value [77]. Certain cities may have lower carbon content due to the presence of impurities such as soil and sand, which can be challenging to remove.

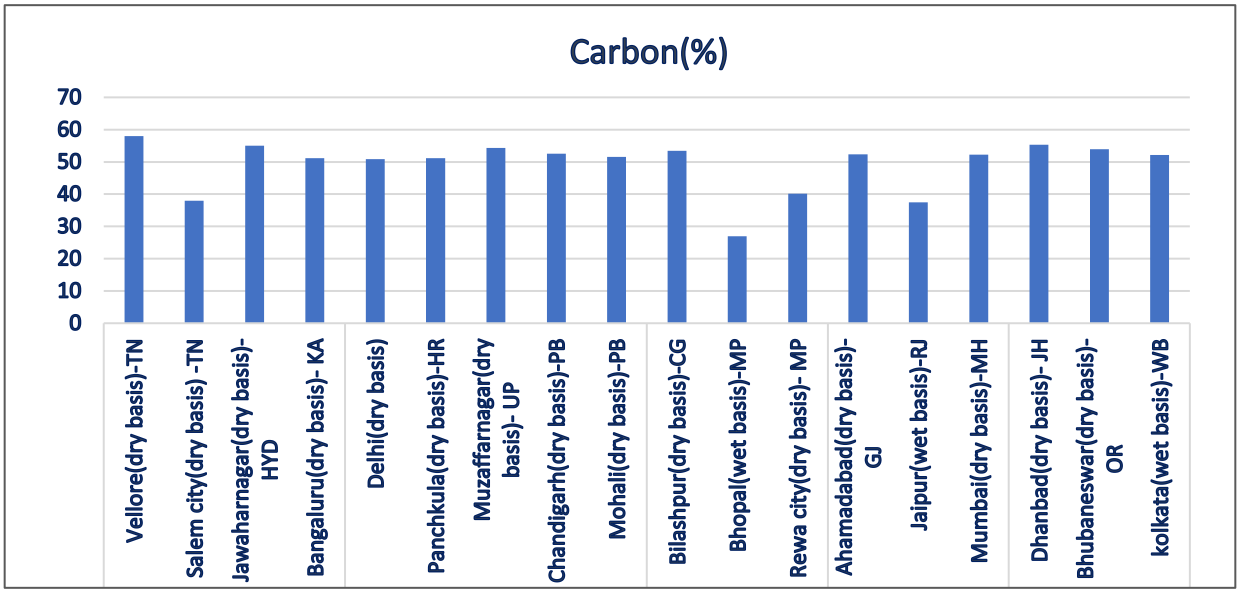


Fig. 6.2.1: Carbon percentage in fresh RDF

6.2.2 Oxygen Content

The percentage of oxygen content lies 28 to 34.5% (as shown in Fig. 6.2.2) in the southern zone, 31 to 38.8% in the northern zone, 25.5 to 34.8% in the central zone, 27.5 to 36.1% in the western zone and 31.2 to 38.9% in the eastern zone. The significant components like carbon and hydrogen in the fuel are indicative of a decent calorific value. However, a higher level of oxygen concurrently may reduce the prospect. The study observed a low percentage of hydrogen and nitrogen.

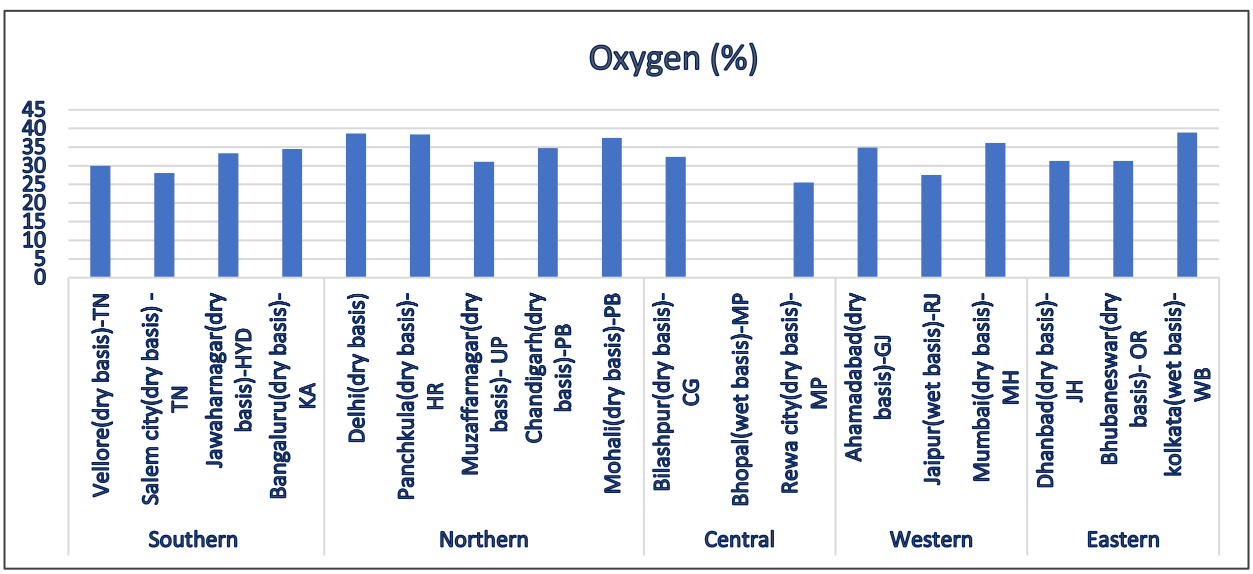


Fig. 6.2.2: Oxygen percentage in fresh RDF

6.2.3 Hydrogen Content

Significant hydrogen content in the fuel indicates an acceptable calorific value. In this study the percentage of Hydrogen lies at 6.5 to 7% (as shown in Fig. 6.2.3) in the southern zone, 6.2 to 6.6% in the northern zone, 6.6 to 10% in the central zone, 6.4 to 6.5% in the western zone, 6.6 to 6.7% in the eastern zone.

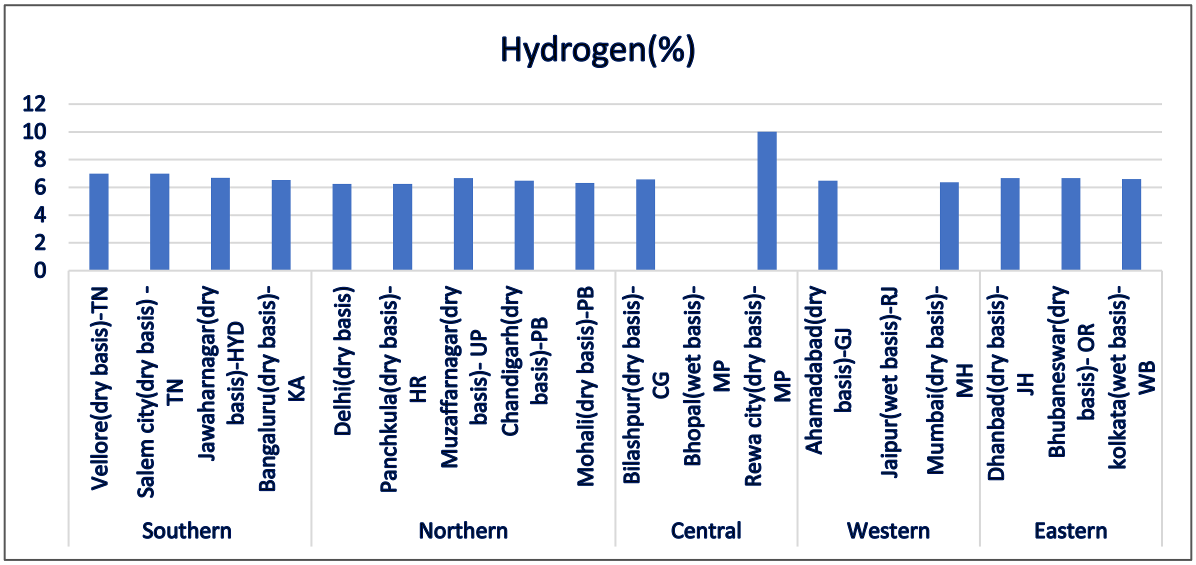


Fig. 6.2.3: Hydrogen percentage in fresh RDF

6.2.4 Nitrogen and Sulphur Content

In comparison to other zones, the central zone has a relatively higher average percentage of nitrogen (4.45%) and sulphur (1.23%). while nitrogen and sulphur present in the waste components produce NOx and SOx in the flue gas, which can contribute to environmental emissions and may corrode the equipment. According to Genon and Brizio (2008) [78], the formation of harmful substances is reduced at lower values of 0.3 to 0.5% wt. In this study the percentage of Nitrogen lies 0.21 to 1.25% (as shown in Fig. 6.2.4) in the southern zone, 0.17 to 2.57% in the northern zone, 0.7 to 9.7% in the central zone, 0.14 to 1.33% in the western zone, 0.89 to 2.2% in the eastern zone, and consequently sulphur content 0.12 to 0.51%(as shown in Fig. 6.2.4) in the southern zone, 0.09 to 0.13% in the northern zone, 0.13 to 2.33% in the central zone, 0.08 to 0.35% in the western zone, 0.06 to 0.2% in the eastern zone. The maximum value set as a standard for sulphur in RDF is 0.50% wt. [72].

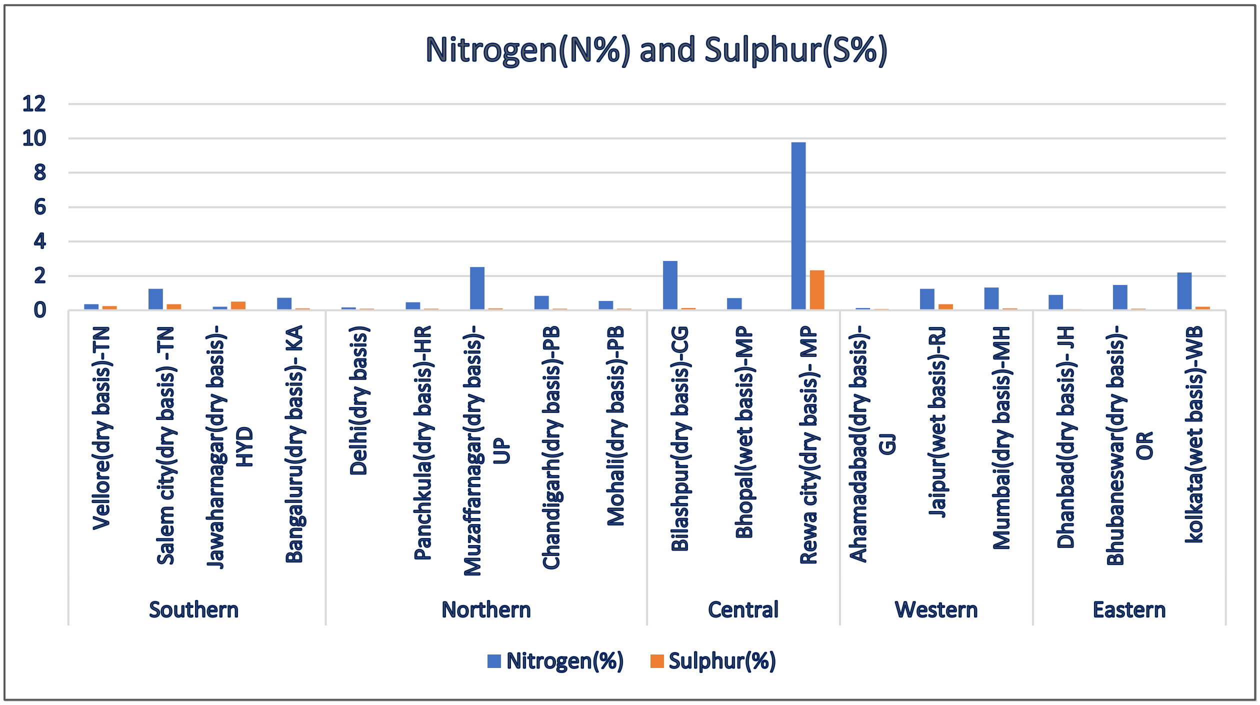


Fig. 6.2.4: Percentage of nitrogen and sulphur in fresh RDF

6.2.5 Calorific Value

The calorific value of the major city in the respective zone is presented in the following Figure 6.2.5. There are certain cities where the calorific value of refuse-derived fuel is higher than 5000 kcal/kg. This is because of the physical composition of refuse-derived fuel. A higher fraction of plastic content contributes to the higher calorific value of the fresh RDF sample. The average calorific value of the plastic material is 35 MJ/kg. The calorific value (HHV) of some cities is determined using modified Dulong's formula and some values obtained from the experimental analysis, which is gathered from the previous literature. As per SWM rules 2016, RDF samples prepared from solid waste are recommended to be utilized as fuel in incineration units if the calorific value is greater than 1500 kcal/kg. In a recent study, the calorific value of all the RDF samples prepared from fresh municipal solid waste can be used as a feedstock in mass-burn incineration plants. Proper segregation of MSW will increase the calorific value of RDF. In the southern zone, the average calorific value is 5151.8 kcal/kg, while in the northern zone, it is 4844.6 kcal/kg. The central zone has an average value of 4785 kcal/kg, while the western zone has a value of 40480.38 kcal/kg. The eastern zone has a value of 4640.7 kcal/kg.

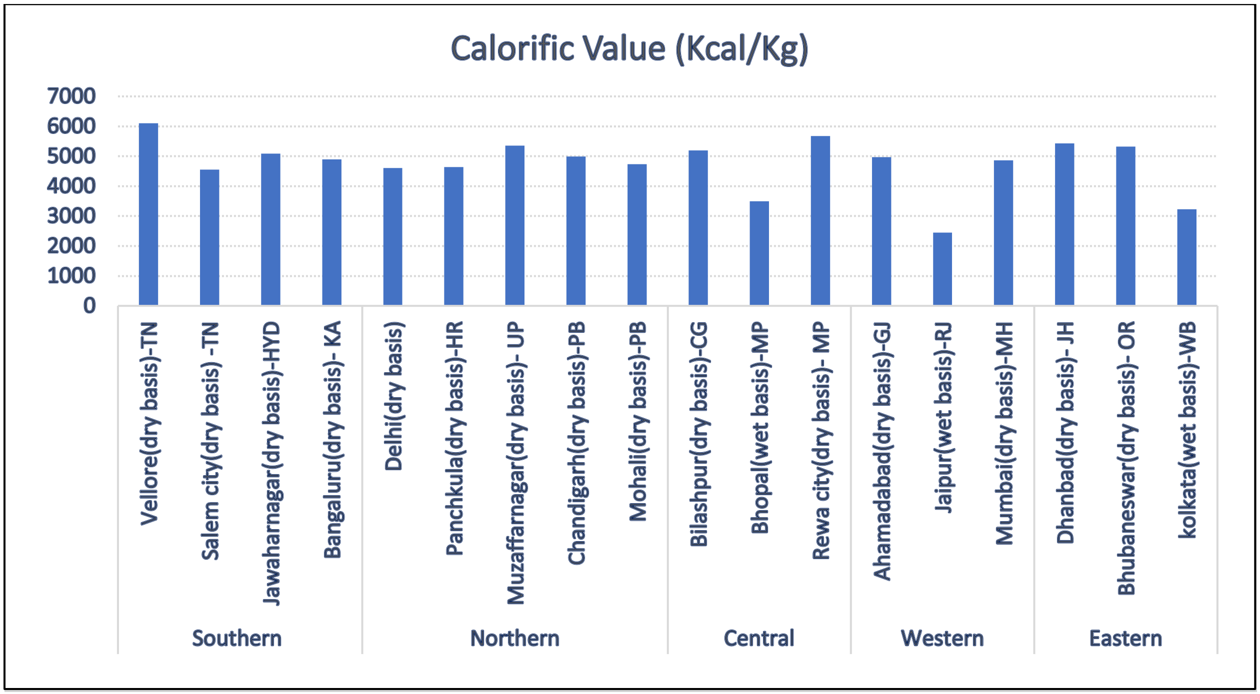


Fig. 6.2.5: Calorific value of the fresh RDF in the various cities

6.3 DISCUSSION AND CONCLUSION

The components of the proximate and ultimate analysis of fresh RDF for certain cities are theoretically calculated on a dry weight basis, while for other cities, it has been assessed from previous research. It is observed that the moisture content in the RDF fractions is within a reasonable limit except for Muzaffarnagar and Kolkata due to the presence of higher fractions of organic components. Higher concentrations of volatile matter and low moisture content may result in low ignition temperatures, and combustion can be initiated at low temperatures. The concentration of Ash in the RDF sample is one of the crucial factors. Except for Bhopal, Vellore, Jaipur, and Kolkata, the ash content in the fresh RDF samples is within the acceptable limit specified by CPHEEO. Sulfur and Nitrogen oxide (NOX) are major causes of smog, acid rain, and the formation of fine particulate matter (PM) in the atmosphere. In this study, in comparison to other zones, the central zone has a relatively higher average percentage of nitrogen (4.45%) and sulfur (1.23%). Therefore, its concentration in RDFs should be as low as possible for a health-friendly environment. Except in a few cases, it has also been found that the heating value of RDF is rather high. This finding indicates that RDF from MSW from the various cities in the country is potentially viable to use as an additive fuel in various industries.

CHAPTER 7.
ANALYSIS TOWARDS SUSTAINABLE BUSINESS MODELS OF FRESH RDF

In the current study, five different types of novel RDF business strategies are displayed.

Model-1: Generation of fresh RDF without incurring CAPEX or O&M expenses, considering transportation cost only (Tc).
Model-2: Generation of fresh RDF with CAPEX and O&M costs (ULB is fully responsible for all capital expenditures, operating expenses, and maintenance costs).
Model-3: Production of fresh RDF with CAPEX and O&M costs (government-sponsored capital investments, ULB fully responsible for operational and maintenance costs).
Model-4: Production of RDF pellets or briquettes with CAPEX and O&M costs (government-sponsored capital investments, ULB fully responsible for operating and maintenance costs).
Model-5: Production of RDF pellets or briquettes with CAPEX and O&M costs (ULB is fully responsible for all capital expenditures, operating expenses, and maintenance expenses).

In the Indian context, the primary challenge with this business strategy is the high cost of transportation. The utilization of RDF in India is primarily observed in the cement sector, wherein, it attains a thermal substitution rate of merely 2.5–3%. According to the guidelines set by the central public health and environmental engineering organization (CPHEEO), cement plants are responsible for transportation costs up to 100 km, while the ULB is responsible for costs beyond that up to 400 km [56]. There are numerous cement plants equipped with clinker facilities located near the RDF production city. However, most of the cement-producing industries are reluctant to use RDF as a supplemental fuel source, citing internal barriers as the primary reason. In the context of India, refuse-derived fuel generated within urban areas is being transported to faraway cement plants or other energy-intensive industries that possess coprocessing facilities. Annexure III (Table C1.) provides a comprehensive inventory of cement plants that are equipped with co-processing facilities. The Central Pollution Control Board encourages the use of RDF as an additive fuel for co-processing in industries like cement, iron, steel, and thermal power plants. As per the guidelines issued by the Central Pollution Control Board (CPCB), the co-processing activities carried out in the cement, power, and steel sectors must be situated within a 100-kilometer buffer zone of the waste-generating city. Currently, some municipalities are transporting RDF beyond the buffer zone designated by the Central Pollution Control Board (CPCB). As a result, the profitability of refuse-derived fuel is falling due to significant transportation costs.

Some assumptions behind these models are as follows:

The cost of transportation per kilometre for one metric tonne Refuse-derived fuel (RDF) is calculated based on the Waste Nationally Appropriate Mitigation Action (NAMA) report. RDF transportation cost as per waste NAMA report is shown in table 4.

Table 4: RDF Transportation cost as per waste NAMA report

Transportation distance (Km)	Transportation cost (Rs/Km/tonne)
0-30	10-12
30-120	7-10
120-250	4-7
250-600	3-4
600-1300	2.8-3.2

The basis assumption for these business models is that cities producing over 100 MT of RDF daily can sell a maximum of 100 MT of RDF per day to relevant cement plants. Figure 7.0 illustrates the daily quantity of RDF that can be sold to the relevant cement plants.

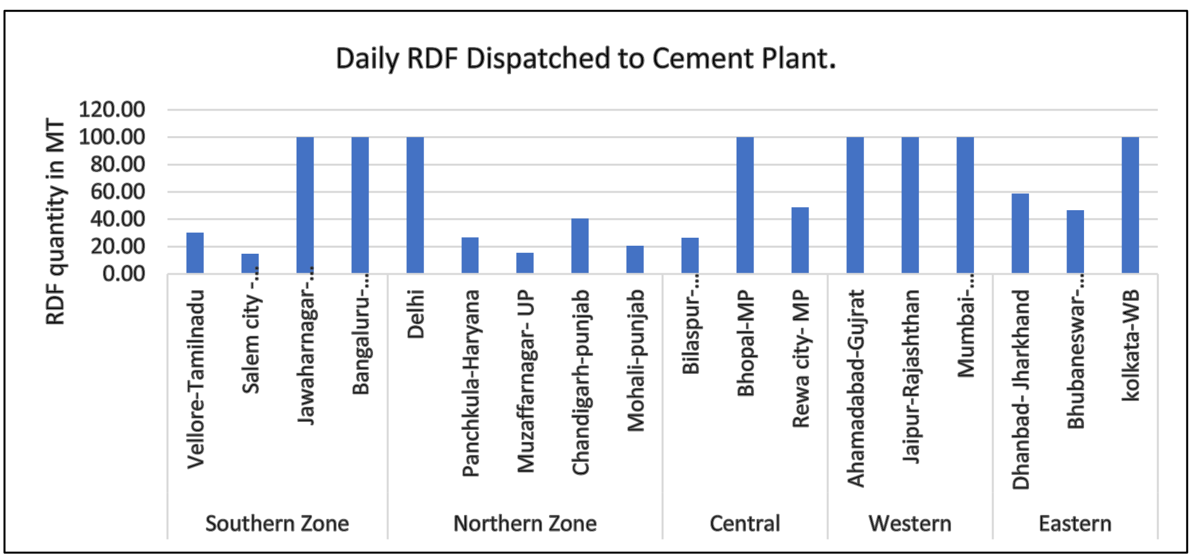


Fig 7.0: Quantity of RDF daily dispatched to the relevant cement plant

The members of the Swaccha Bharat Mission (SBM) committee have concurred that to introduce the use of RDF in the Indian cement industry, it is imperative to take into account the differing calorific values of various RDF types. Consequently, it is necessary to express the cost of each combustible fraction in INR per 1000 kcal/kg to ensure comparability. The members reached a consensus regarding the commercial viability of appropriately treated refuse-derived fuel (RDF) at a rate of Rs. 0.4 per 1000 kcal/kg, based on the specifications outlined in the guidelines. The proposal recommends that the pricing of RDF should be adaptable and correlated with the market value of coal. The present investigation considers the cost of refuse-derived fuel (RDF) at a rate of Rs. 0.4 to 0.5 per 1000 kcal/kg, by the guidelines put forth by the Central Public Health and Environmental Engineering Organisation (CPHEEO). However, the price of Refuse derived fuel in the form of pellets or briquettes is used in this study based on the current market pricing (collected through interviews from industry experts under Surat municipal corporation), which is between Rs. 0.9 and Rs. 1 per calorific value in kcal/kg.

Fig 7.1: Fluffy or loose RDF and RDF pellets

7.1 MODEL-1

Cost analysis of fresh RDF (capital, operational and maintenance cost not considered):

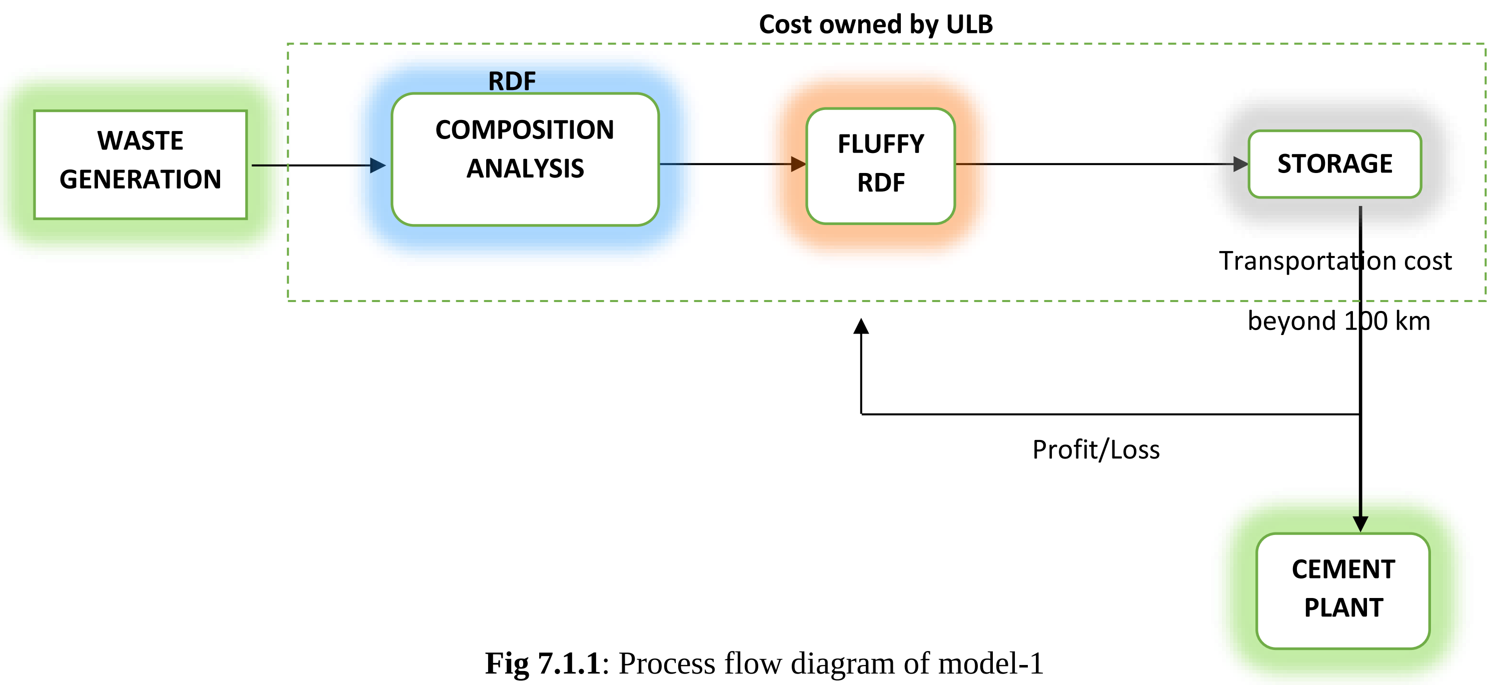


Fig 7.1.1: Process flow diagram of model-1

The flow diagram in Figure 7.1.1 outlines the cost analysis process for fresh RDF, excluding capital, operational, and maintenance expenses. At an MRF facility, municipal solid waste undergoes segregation, with the non-recyclable combustible fraction being referred to as RDF. A physio-chemical analysis is then performed on the combustible fraction, and the resulting fluffy RDF is stored at a storage center before being supplied to the corresponding cement plant for co-processing. It is important to note that this business model does not account for the costs associated with RDF production, such as capital and O&M expenses. The cement plant is responsible for transportation costs within 100 km, while any expenses beyond that distance are covered by the ULB. It is imperative to mention that all revenue generated from the sale of fresh RDF to the relevant cement plant goes directly to the ULB, and the urban local body is solely responsible for it.

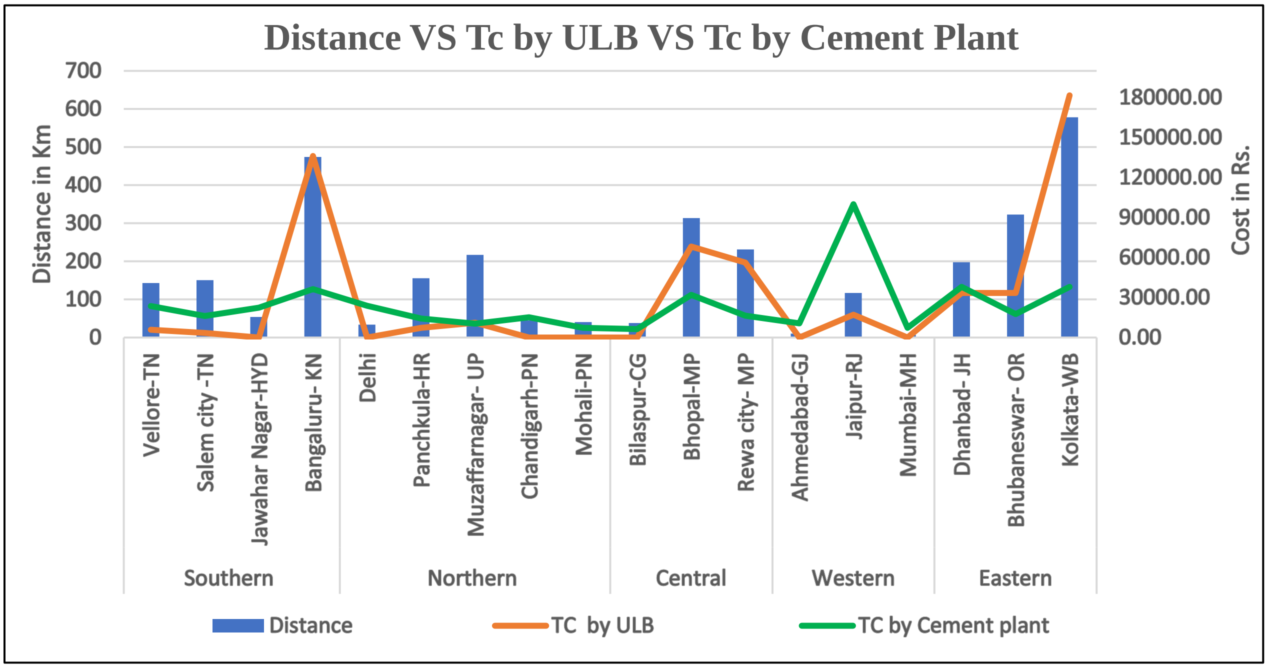


Fig. 7.1.2: RDF transportation cost concerned by ULB and Cement Plant with respect to RDF production city

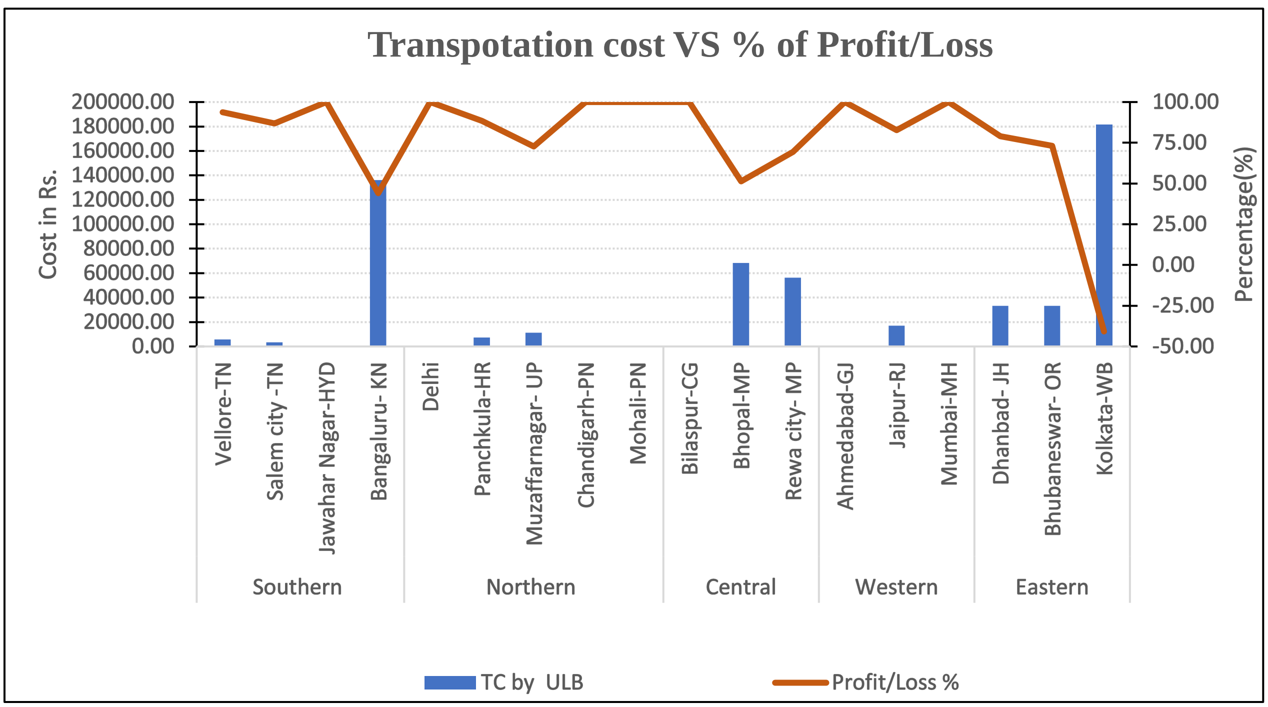


Fig. 7.1.3: Percentage of profit/loss with respect to transportation cost by ULBs

Southern Zone

From the southern zone of the country, some of the major cities like Vellore, Salem city, Jawahar Nagar, Bengaluru are considered for this study. The expense of transportation (Tc) incurred by the relevant ULB and cement plant from the city that produces RDF to the closest cement plant that is accessible for co-processing is depicted in Fig. 7.1.2.

In Bengaluru city in the southern zone, a cement plant with co-processing facility is located around 474 km from the RDF production unit. ULB covers transportation costs of Rs. 5,842.64 for the city of Vellore, Rs. 3,491.61 for the city of Salem, and Rs. 136136.00 for city of Bangalore in the southern zone. As the cement plant has a coprocessing facility within 100 kilometres, Jawahar Nagar City in the southern zone incurs no transportation costs (Tc). The cement plant in Bengaluru is situated a considerable distance from the processing plant, which has led to transportation costs of Rs. 136,136.00 that the ULB is obligated to cover. The high cost of transporting RDF to the nearest cement plant is a significant concern for the ULB.As a result of this research, Fig. 7.1.3 shows the percentage of profit or loss relative to transport expenses paid by ULB.

Based on the analysis, it has been shown that certain cities can earn 100% profits when considering only transportation costs (Tc) since their ULBs do not incur any transportation costs. In the southern zone, Vellore has a profit of Rs. 86250.59 (93.66% of total revenue), Salem City has a profit of Rs. 23270.28 (86.95% of total revenue), Jawahar Nagar has a profit of Rs. 3288088.13 (100% of total revenue), and Bengaluru has a profit of Rs. 107590.50 (44.14% of total revenue). In Bengaluru city, the Refuse-derived fuel business strategy is profitable despite the high transportation costs associated with the concerned ULB because the per day RDF production rate is higher than in other cities.

Northern Zone

For this study, cities such as Delhi, Panchkula, Muzaffarnagar, Chandigarh, and Mohali from the northern part of the country have been selected. All the cities except Panchkula and Muzaffarnagar are transporting their refuse-derived fuel nearest to the cement plant within a reasonable distance (100 km buffer zone). Thus, transportation costs associated with Panchkula and Muzaffarnagar are a little higher than those associated with the other cities. The cost of transportation that ULB covers is Rs. 7205.85 for the city of Panchkula, Rs. 11177.58 while Delhi, Chandigarh and Mohali in the northern zone incurs no transportation costs as the cement plant has a coprocessing facility within 100 kilometres.

In the northern zone, Delhi has a profit of Rs. 96841.44 (100% of total revenue), Panchkula City has a profit of Rs. 54767.00 (88.37% of total revenue), Muzaffar Nagar has a profit of Rs. 100577.55 (72.80%), and Chandigarh has a profit of Rs. 29917.99 (100%), Mohali has a profit of Rs. 48919.60(100%) in consideration with only transportation cost (Tc) scenario.

Central Zone

For this study, we have considered Bilaspur, Bhopal, and Rewa City from the central part of the country. In Bhopal and Rewa, the cement plant with the co-processing facility is located 313.2 km and 231.6 km from the production unit, which is beyond the limit mentioned in the guideline [56]. The cost of transportation covered by ULB is Rs. 68224.00 for the city of Bhopal and Rs. 56196.70 for the city of Rewa. On the other hand, Bilaspur in the central zone does not bear any transportation costs as the cement plant has a co-processing facility within 100 kilometres.

The business model is beneficial for all cities located in the central region of the country. ULB earns revenue by selling per tonne of fresh RDF, which amounts to Rs 68744.71 (100% of total revenue) for Bilaspur, Rs 71776.00 (51.27% of total revenue) for Bhopal, and Rs 95952.03 (69.40%) for Rewa city. The revenue generated from the RDF is higher than the transportation costs for these cities, making the business strategy profitable.

Western Zone

Ahmedabad, Jaipur, and Mumbai are the cities considered for this study from the western zone of the country. Municipal solid waste generation in these cities is high, as a result, the daily production rate of Refuse Derived Fuel (RDF) is also high. Therefore, the percentage of profit from these cities is a little bit higher. The RDF from these cities is mainly transported to the nearest cement plant, and the cost of transportation borne by the concerned Urban Local Bodies (ULB) is almost negligible.

The cost of transportation that ULB covers is Rs. 17000.00 for the city of Jaipur, whereas Ahmedabad and Mumbai in the western zone bear no transportation costs as the cement plant has a coprocessing facility within 100 kilometres radius. The amount earned by selling of fresh RDF is Rs 246998.5 (100% of total revenue) for Ahmedabad, Rs 81000 (82.5% of total revenue) for Jaipur, and Rs 242556.5 (100% of total revenue) for Rewa city.

Eastern Zone

For this study, Dhanbad, Bhubaneswar, and Kolkata are the cities selected from the eastern region of the country. In Dhanbad and Bhubaneswar, the daily RDF production rate is lower than in Kolkata (as shown in Fig 7.0). Most of the energy-intensive sectors in West Bengal are reluctant to use RDF as an additive fuel in their boilers due to some internal barriers. As a result, RDF is being transported from Kolkata to the Dalmia cement plant in Odisha, which is approximately 578 kilometers away. This transportation incurs excessive costs for Urban Local Bodies (ULBs) in Kolkata, making the business model unprofitable. Similarly, the high transportation costs make the business model less profitable for Dhanbad and Bhubaneswar as well.

The cost of transportation that ULB covers is Rs. 33347.85 for the city of Dhanbad, Rs. 33358.66 for the city of Bhubaneswar, and Rs. 181640.00 for the city of Kolkata respectively. In the eastern zone, Dhanbad has a profit of Rs. 125761.7 (79.04% of the total revenue), Bhubaneswar has a profit of Rs. 90413.61 (73.05% of the total revenue), while Kolkata city has a loss of Rs. 52640 (40.81% of the total revenue).

7.2 MODEL-2

Cost analysis of fresh RDF without government subsidy on capital investments:

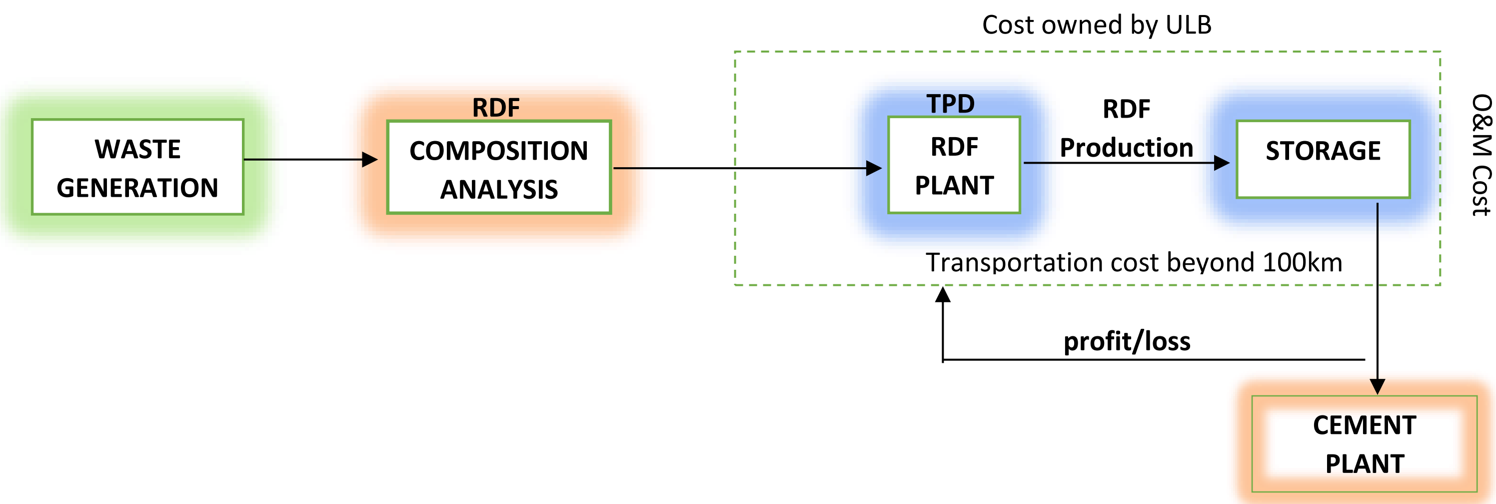


Fig. 7.2.1: Process flow diagram of model-2

The process flow diagram from RDF production to selling at a cement plant by considering capital expenditures (CAPEX), operational (OPEX), and maintenance expenditures owned by ULBs is shown in Fig. 7.2.1. Refuse-derived fuel is produced by separating the city's collected municipal solid waste into non-recyclable and combustible components. The physical and chemical composition of RDF is analysed by proximate and ultimate analysis based on secondary data that has already been discussed previously (Ref. Chapter 6.). The RDF produced from the MSW is stored in the MRF centre of the respective cement plant. The costs associated with producing refuse-derived fuel, such as capital expenditures (CAPEX), operating, and maintenance costs (OPEX), are taken into account in this business plan. Urban local bodies are responsible for making capital investments and paying O&M expenses. The ULB is solely responsible for the profit or loss of this business model, as there is no government subsidy involved.

Table C2. (In Annexure III) calculates and displays the capital expenditures for the infrastructure and equipment required for a plant with a 100 TPD capacity. Based on the requirements stated by the Swaccha Bharat Mission Commission [56], operational and maintenance expenses for a 100 TPD plant are computed here and shown in Annexure III (Table C3.). RDF transport expenditure paid by ULB along with total OPEX for the individual cities are presented in Fig. 7.2.2. Total operational and maintenance costs are obtained by multiplying the daily production of RDF by the operational and maintenance costs per tonne outlined in SBM standards. The operational and maintenance costs per tonne of RDF production are estimated at INR 1151.

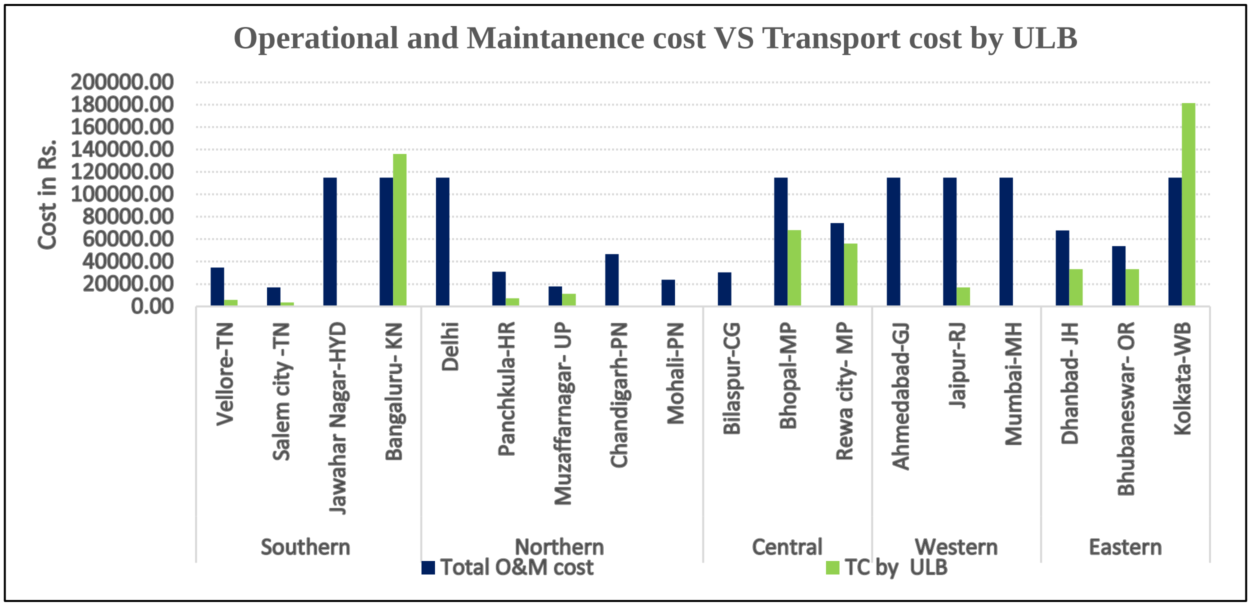


Fig. 7.2.2: RDF production cost and transport cost by ULBs for model-2

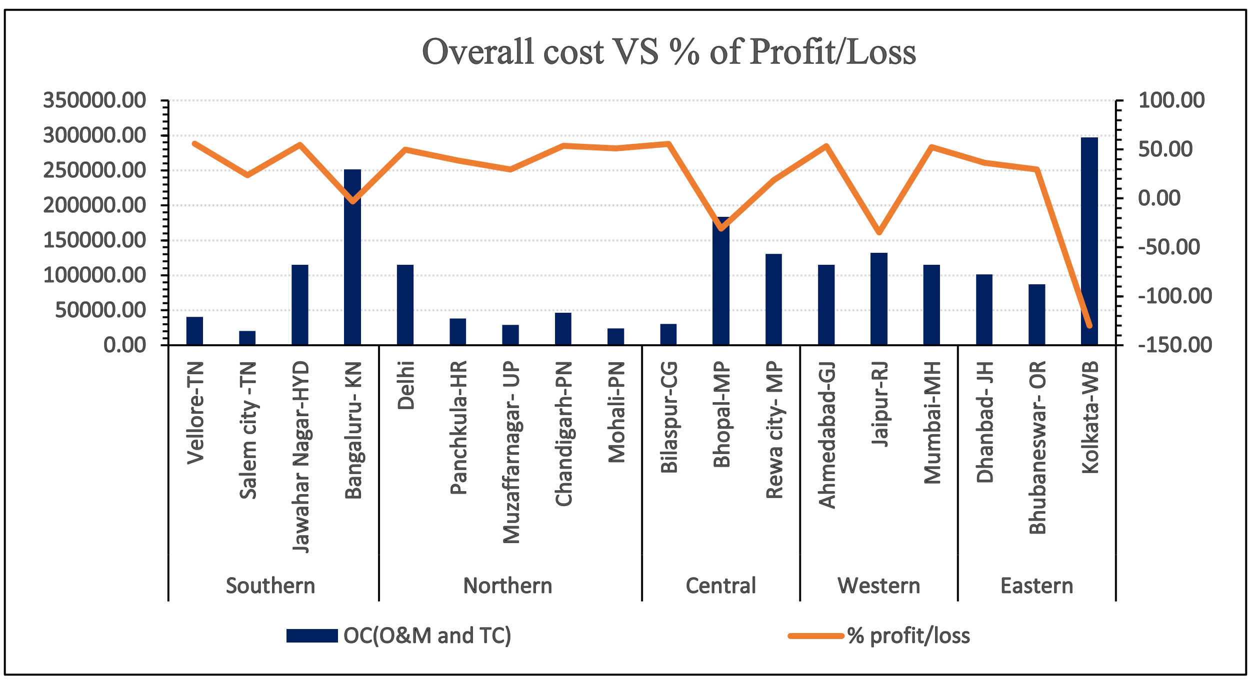


Fig. 7.2.3: Percentage of profit/loss with respect to overall cost (O&M and Tc) for model-2

Southern Zone

Based on this study, Fig. 7.2.3 shows the percentage of profit or loss concerning the transportation costs as well as operations and maintenance costs that ULB is obligated to pay. The analysis reveals that the business model of selling fresh RDF to cement plants is not viable for Bengaluru due to the high transport costs of Rs. 136136.00 for 474km, which ULB bears without any government subsidy on capital investments. ULB earned profits of Rs. 51496.72 (55.92% of total revenue) for Vellore city, Rs. 6338.15 (23.68% of total revenue) for Salem city, and Rs. 139150.00 (54.73% of total revenue) for Jawahar Nagar in the southern zone of the country by selling RDF to the respective cement plants. However, Bengaluru incurred a loss of Rs. 7509.50 through this model.

Northern Zone

Cement plants have co-processing facilities that are closest to the cities where RDF is produced in the northern zone of the country. For this reason, transportation costs that are borne by concerned ULBs are relatively low, and this business model is lucrative for all cities. The revenue earned by selling fresh RDF per plant is Rs 113957.00 for Delhi, Rs 23911.59 for Panchkula, Rs 12197.55 for Muzaffar Nagar city, Rs 53963.53 for Chandigarh city, and Rs 25023.87 for Mohali city. These profits constitute 49.75%, 38.58%, 29.68%, 53.65%, and 51.15% of the total revenue respectively, coming from the northern zone of the country.

Central Zone

This business model is profitable for all cities except for Bhopal in the central zone of the country. The revenue generated by ULB through the sale of fresh RDF per plant is Rs 38192.57 for Bilaspur, accounting for 55.56% of the total revenue, and Rs 25998.22 for Rewa city, accounting for 18.8% of the total revenue. However, Bhopal suffered a loss of Rs 43324.00 (30.95%) due to the exorbitant transportation costs of RDF (Rs 68224.00) borne by ULB and the lack of government subsidies for capital investments.

Western Zone

This business strategy is profitable for all cities except for Jaipur in the central zone of the country. In the western region, the sale of freshly produced RDF results in profits of Rs 131898.50 (53.30% of total revenue) for Ahmadabad and Rs 127456.50 (52.55% of total revenue) for Mumbai. However, Jaipur experiences a loss of Rs. 34100.00 due to the low-quality RDF produced within the city. The previous chapter's proximate and ultimate analysis confirms this, as the RDF has a calorific value of 2450 kcal/kg. Additionally, ULB bears a significant cost of Rs. 17000.00 for transportation of RDF.

Eastern Zone

In the eastern zone, Dhanbad has a profit of Rs. 57956.09 (36.43% of total revenue), Bhubaneswar has a profit of Rs. 36607.81 (29.58% of total revenue), while Kolkata city has a loss of Rs. 167740.00. Due to the significant RDF transport costs (Rs. 181640.00 for a 578km distance) and huge capital investment by the agency, this analysis shows that this business plan does not work for the city of Kolkata in the eastern zone.

7.3 MODEL-3

Cost analysis of fresh fluffy RDF with 100% government subsidy on capital investments:

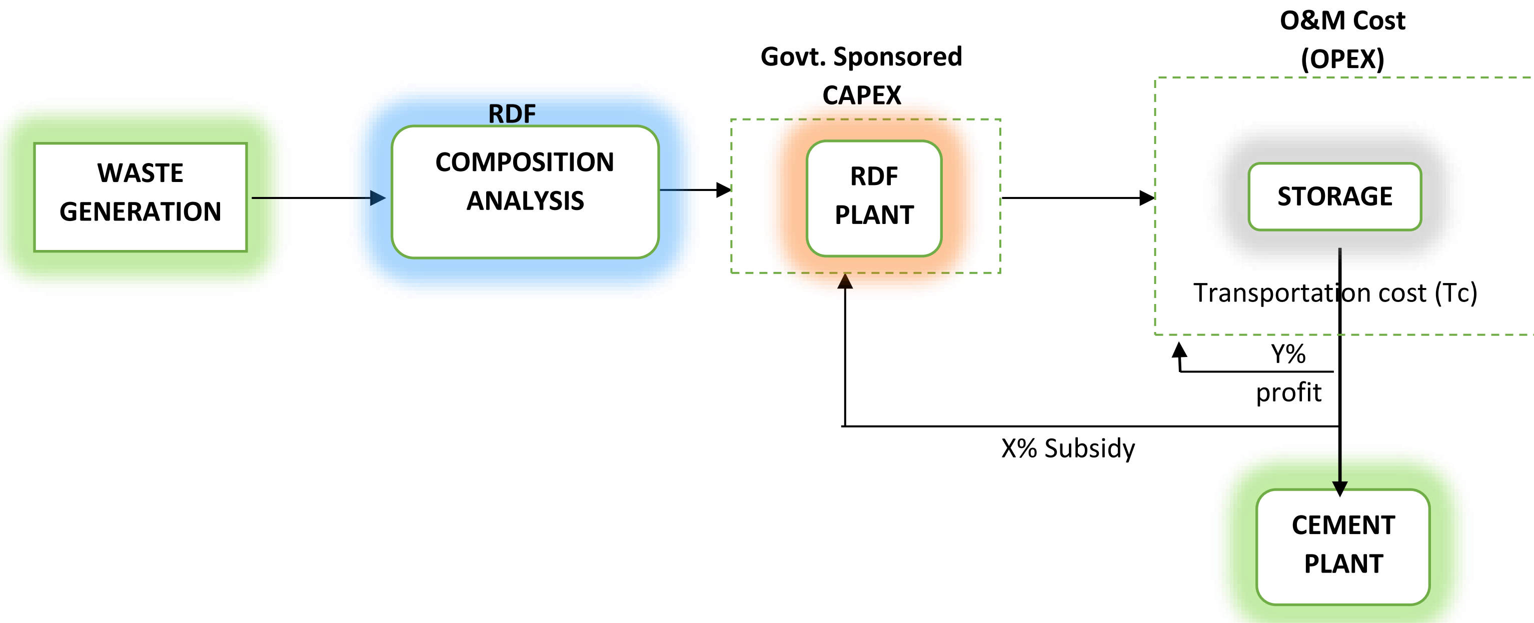


Fig. 7.3.1: process flow diagram of model-3

Under this business model, the government covers the capital costs (CAPEX) related to RDF production, while operational and maintenance costs (OPEX) are borne by the concerned ULB. The government receives 40% of the profits from this model, and the remaining percentage is borne by the concerned ULBs, as there is a government subsidy on capital investments (Assumption behind the revenue model).

This business plan takes into account the expenses involved in producing refuse-derived fuel, including capital costs, operational costs, and maintenance expenses. Annexure III (Table C2.) calculates and displays the capital expenditures for the infrastructure and equipment required for a plant with a 100 TPD capacity. Additionally, the operational and maintenance expenses for a 100 TPD plant are calculated under the requirements set forth by the Swaccha Bharat Mission Commission and detailed in Annexure III (Table C4.). It is further assumed that 40% of profits will be shared with the government on capital investments, and the remaining 60% will be retained by ULB. The expenses associated with transporting RDF, as well as overall operations and maintenance costs for individual cities, are presented in Fig. 7.3.2. The operational and maintenance costs per tonne of RDF production are estimated at INR 604[56].

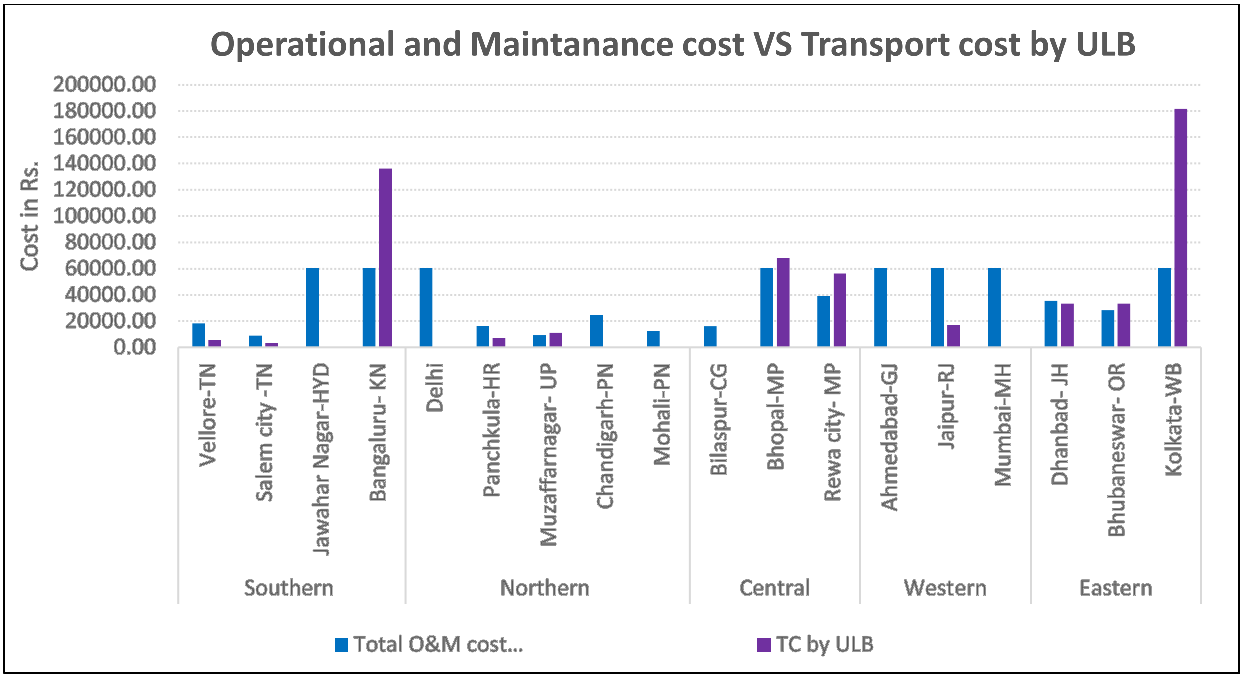


Fig. 7.3.2: RDF production cost and transport cost by ULBs for model-3

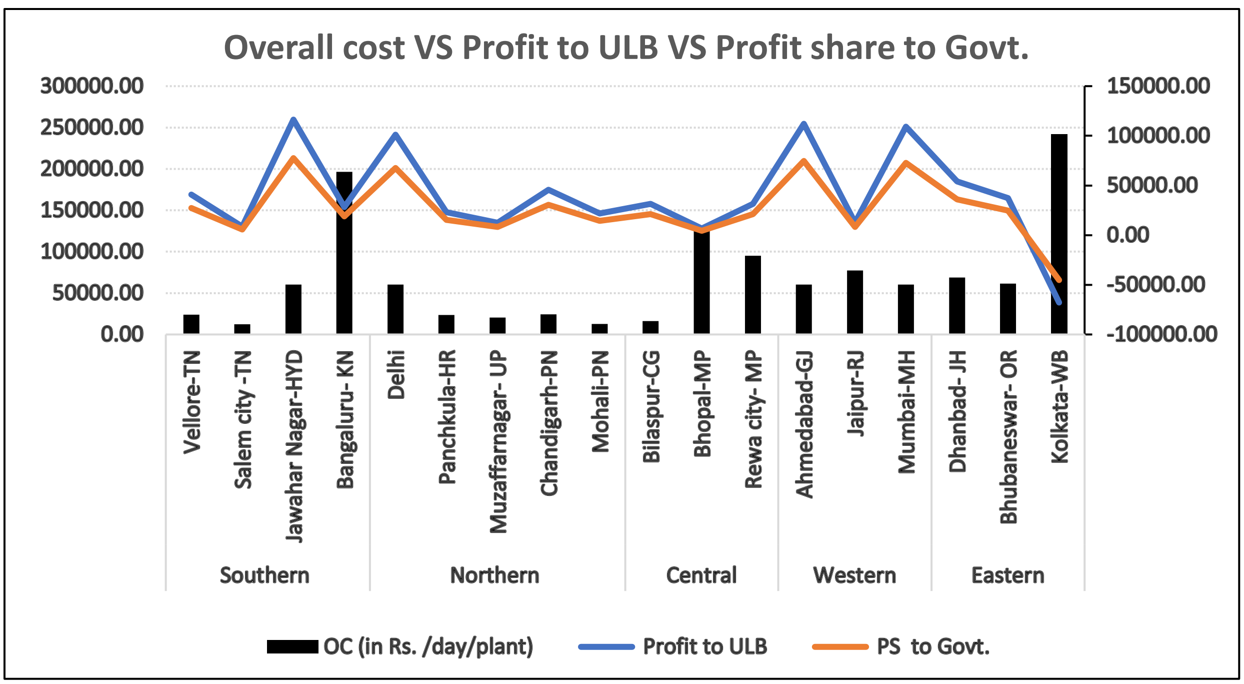


Fig. 7.3.3: Percentage of profit/loss with respect to overall cost (O&M and Tc) for model-3

Southern Zone

According to this study, the percentage of profit or loss for ULB in regards to transportation costs, as well as operations and maintenance costs, is displayed in Fig. 7.3.3. Due to government subsidies on capital expenditures, this economic plan is profitable for all cities in the southern zone, even with the significant RDF transport costs that ULB carries. ULB earns 60% of the total profit by selling fresh RDF to the corresponding cement plant, earning Rs. 40807.87 per day for Vellore city, Rs. 8630.97 per day for Salem city, Rs. 116310.00 per day for Jawahar Nagar, and Rs. 28314.30 per day for Bengaluru. The remaining 40% of the profit is shared with the government to cover interest and depreciation on capital investments.

Northern Zone

In the northern zone of the country, cement plants have co-processing facilities that are located closest to the cities where Refuse Derived Fuel (RDF) is produced. This reduces the transportation costs that are incurred by the Urban Local Bodies (ULBs) which is beneficial for all cities. ULB earned by selling per day of fresh RDF is Rs 101194.20 (60% of overall profit) for Delhi, Rs 23145.17 for Panchkula, Rs 12371.40 for Muzaffar Nagar city, Rs 45669.79 for Chandigarh city, Rs 21828.03 for Mohali city as profit from the northern zone of the country.

Central Zone

Due to government subsidies on capital expenditures, this economic plan is profitable for all cities in the Central zone, even with the significant RDF transport costs that ULB carries. ULB earned (60% of total profit) by selling of fresh RDF is Rs 31627.28 per day for Bilaspur, and Rs 6825.60 per day for Bhopal city, Rs 31584.93 per day for Rewa city.

Western Zone

This particular business strategy has positive implications for all cities in the western region of the country. The generated profits (60% of total profit) from this model are Rs 111959.10 for Ahmadabad, Rs 12360.00 for Jaipur, and Rs 109293.90 for Mumbai.

Eastern Zone

In the eastern zone, Dhanbad has a profit of Rs. 54107.96(60% of overall profit) per day per plant, Bhubaneswar has a profit of Rs. 37307.05 per day per plant, while Kolkata city has a loss of Rs. 67824.00 per day per plant. This research reveals that this business approach does not work for the city of Kolkata despite government subsidies on capital investments. This is due to the high RDF transport costs (Rs. 181640.00 for a 578km route) that ULB bears.

7.4 MODEL-4

Cost analysis of RDF pellet with government subsidy on capital costs:

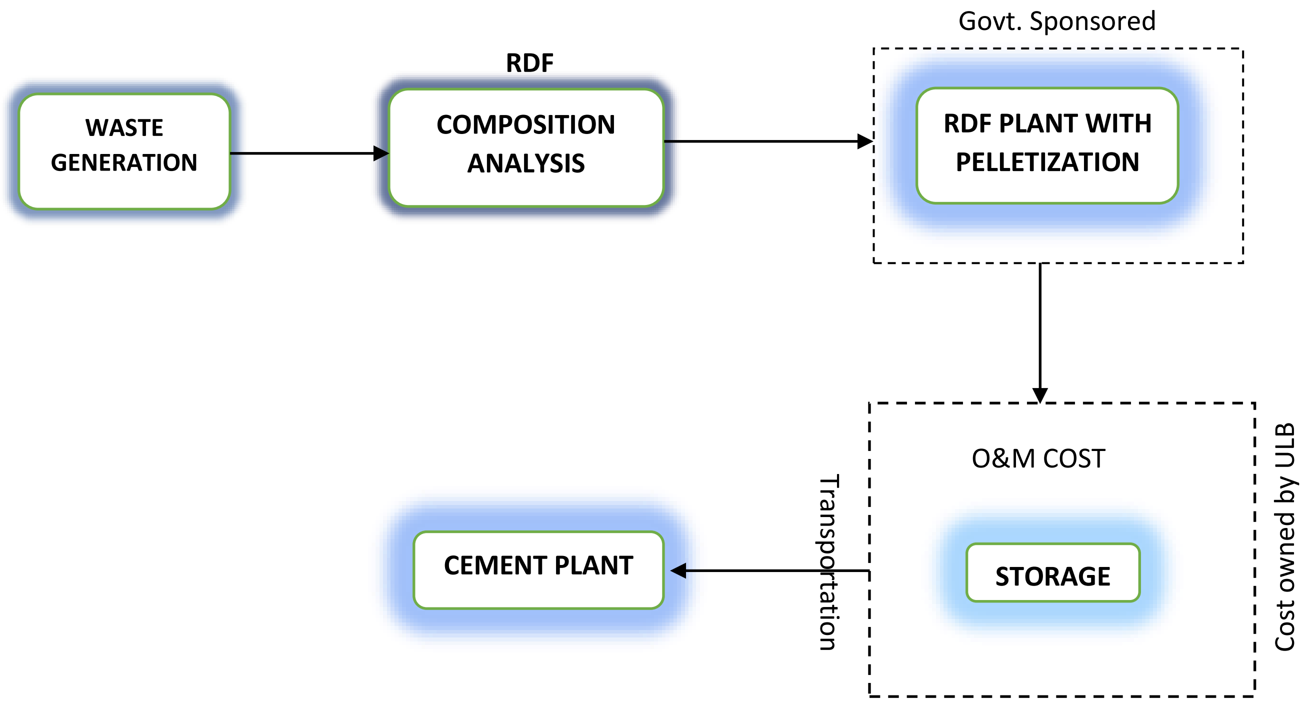


Fig. 7.4.1: process flow diagram of model-4

The government covers all the capital expenses for producing RDF through pelletization in this business model. Meanwhile, the respective ULB takes on the responsibility of operational and maintenance expenses. The selling price of RDF pellets is comparatively higher than that of fluffy or loose RDF. This is because RDF in pellet form is more manageable and burns uniformly. The government is entitled to 40 percent of the profit made from this business model, and the remaining percentage is the responsibility of the relevant ULB, as there is a government subsidy on capital investments. Fig. 7.4.2 depicts the total expenses incurred by ULB for RDF production and RDF transportation. The total operational and maintenance expenses per tonne of RDF production are expected to be INR 622(shown in Annexure III in Table C5) [56]. Pelletization costs are also accounted for in O&M. The key advantage of this business strategy is that RDF pellets have a higher market price than loose or fluffy RDF, despite having the same calorific value. This is because RDF in pellet form is more manageable, reduces storage requirements, and provides consistent energy [79].

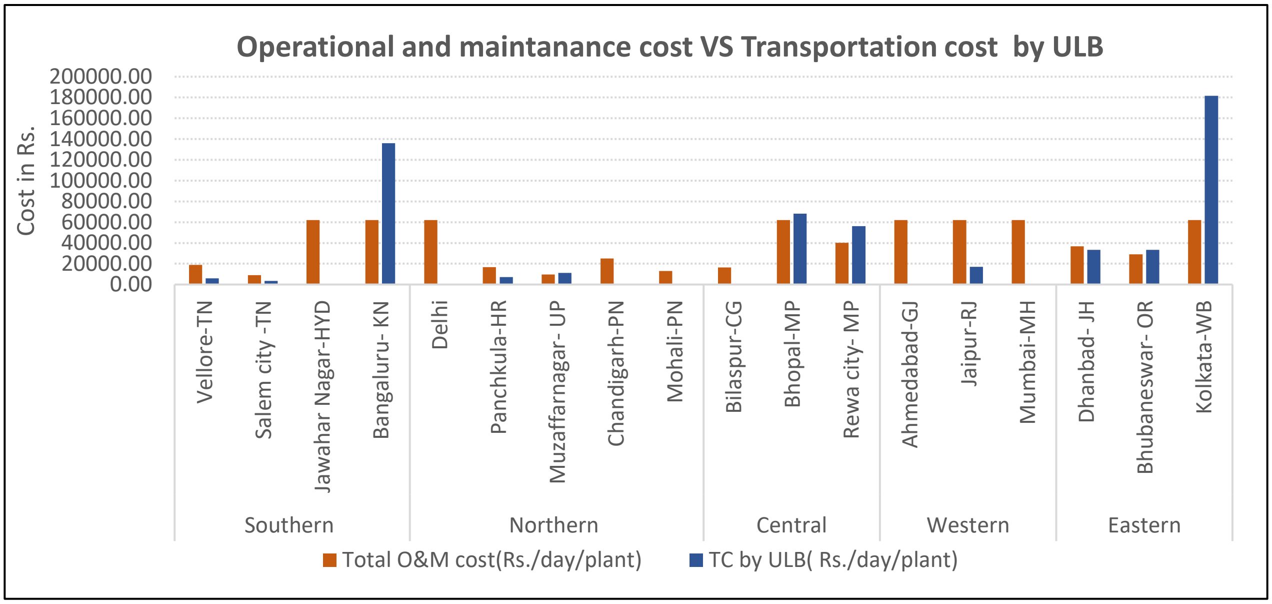


Fig. 7.4.2: RDF production cost and transport cost by ULBs for model-4

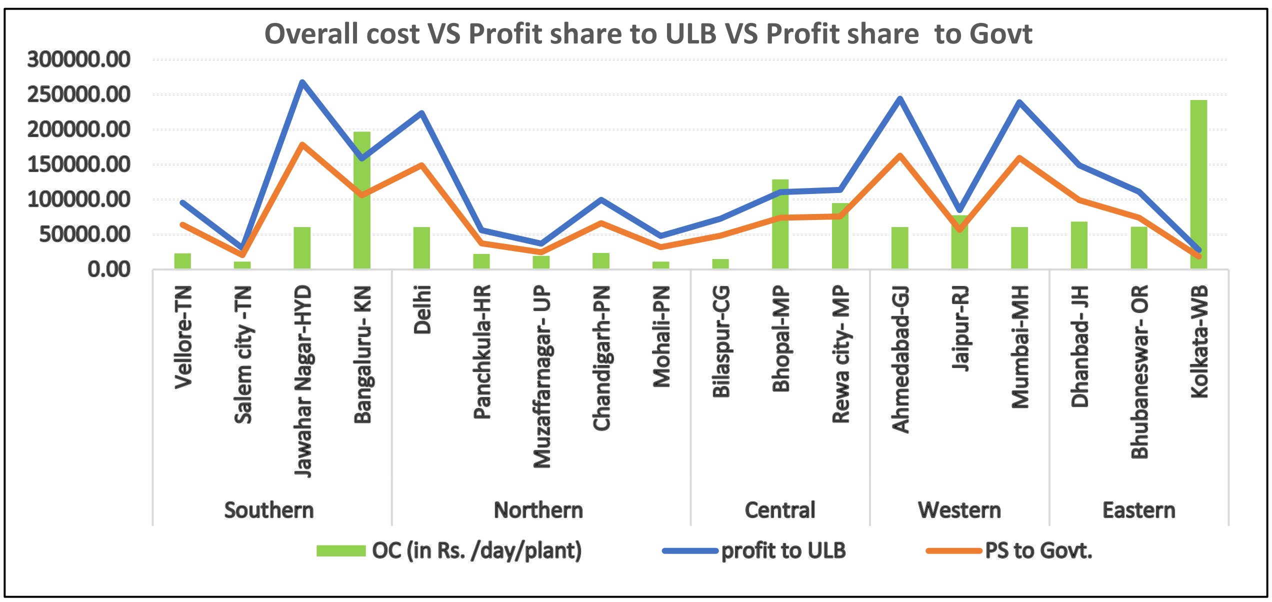


Fig. 7.4.3: Percentage of profit/loss with respect to overall cost (O&M and Tc) for model-4

Southern Zone

Based on this study, Fig. 7.4.3 shows the percentage of profit or loss incurred by ULB in terms of transportation costs and operations and maintenance costs. Despite the significant RDF transport costs that ULB has to bear, this economic plan is profitable for all cities in the southern zone due to government subsidies on capital expenditures. This is the most advantageous business approach because ULB earned sufficient profits even with the government's capital investment share. ULB received 60% of the overall profit by selling such fresh RDF to the corresponding cement plant, or Rs. 95737.70(51.98% of total revenue) for Vellore city, Rs. 30550.65(48.07% of total revenue) for Salem city, Rs. 267780.00(52.66% of total revenue) for Jawahar Nagar, and Rs. 158846.61(34.3% of total revenue) for Bengaluru. The remaining forty percent of the total profit is shared with the government for interest and depreciation on capital investments.

Northern Zone

In the northern region of the country, cement plants with co-processing facilities are located most conveniently near the cities where RDF is generated. This leads to lower transportation expenses for the Urban Local Bodies (ULBs), resulting in increased profitability for all cities.

The revenue earned from selling per tonne of fresh RDF is different for various cities in the northern zone of the country. For Delhi, the revenue is Rs 223804.98, which accounts for 51.42% of the total revenue. For Panchkula, it is Rs 56320.98, which accounts for 47.83% of total revenue. Muzaffar Nagar city generates Rs 36862.47, which accounts for 44.85% of total revenue. Chandigarh City generates Rs 99544.28, which accounts for 52.09% of total revenue. Lastly, Mohali city generates Rs 48020.40, which accounts for 51.66% of total revenue. The ULB receives 60% of the overall profit, while the remaining 40% is shared with the government to cover interest and depreciation on capital investments.

Central Zone

Due to government subsidies on capital expenditures, this economic plan is profitable for all cities in the southern zone, even with the significant RDF transport costs that ULB carries. ULB earns a total profit of 60%, accounting Rs 72587.43 (52.79% of total revenue) for Bilaspur, Rs 110745.60 (35.16% of total revenue) for Bhopal city, and Rs 113989.08 (41.23% of total revenue) for Rewa city.

Western Zone

This particular business plan has a positive impact on all cities located in the central region of the nation. ULB earns a revenue of Rs 244258.29 (which accounts for 52.05% of the total revenue) for Ahmadabad, Rs 84780.00 (which accounts for 38.45% of the total revenue) for Jaipur, and Rs 239194.41 (which accounts for 51.9% of the total revenue) for Mumbai. These profits accounted for 60% of the overall profits, with the remaining 40% to be shared amongst government agencies as interest and depreciation on investments.

Eastern Zone

In the eastern zone, Dhanbad has a profit of Rs. 148937.44(44.25% of total revenue), Bhubaneswar has a profit of Rs. 111065.54(44.87% of total revenue), while Kolkata city has a profit of Rs. 27846.00 (9.59% of total revenue) even with high transport costs (Rs. 181640.00 for a 578km route). In comparison to other cities in the eastern region, Kolkata's profit rate is quite low. Utilizing RDF in neighbouring energy sectors will significantly enhance profit margins in contrast to the overall revenue.

7.5 MODEL-5

Cost analysis of RDF pellet without government subsidy on capital costs:

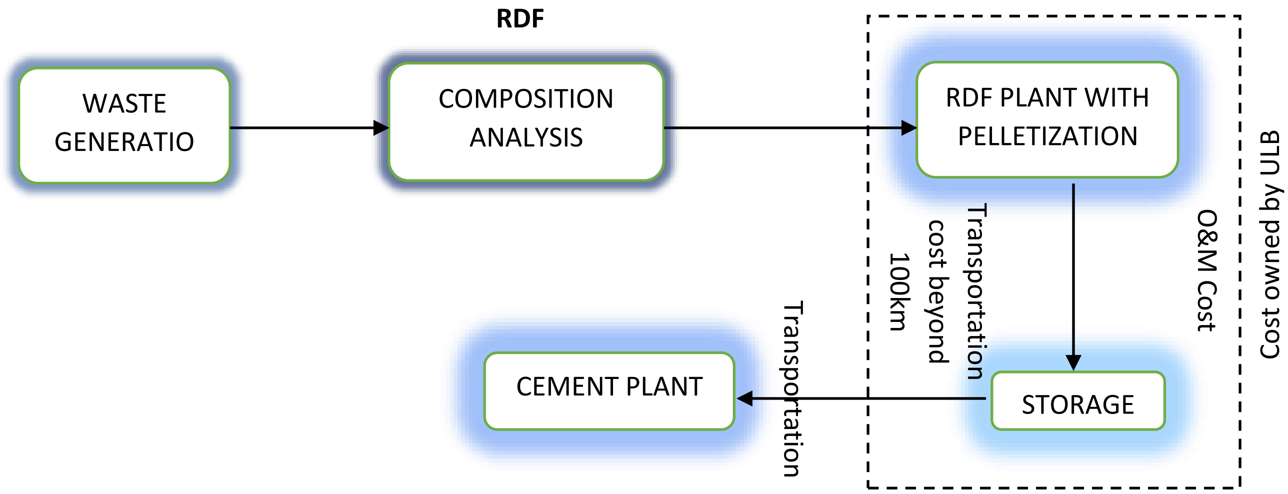


Fig. 7.5.1: Process flow diagram of model-5

This business model involves the ULB bearing all the capital costs associated with RDF production through pelletization, as well as the operational and maintenance costs. In this model, the selling price of RDF pellets is comparatively higher than that of fluffy or loose RDF. RDF in pellet form is the most manageable, and it burns uniformly. The ULB is completely responsible for the profit or loss as there is no government subsidy on capital investments.

Overall costs related to RDF production and RDF transporting costs borne by ULB are shown in Fig. 7.5.2. The operational and maintenance expenses for each tonne of RDF produced are estimated at INR 1180 [56] (as shown in Annexure III in Table C6). Pelletization costs are also accounted for in operations and maintenance. The advantage of this model is that the market price of RDF pellets is higher due to their manageability, which lowers transport expenses, increases uniform energy production, and decreases storage requirements.

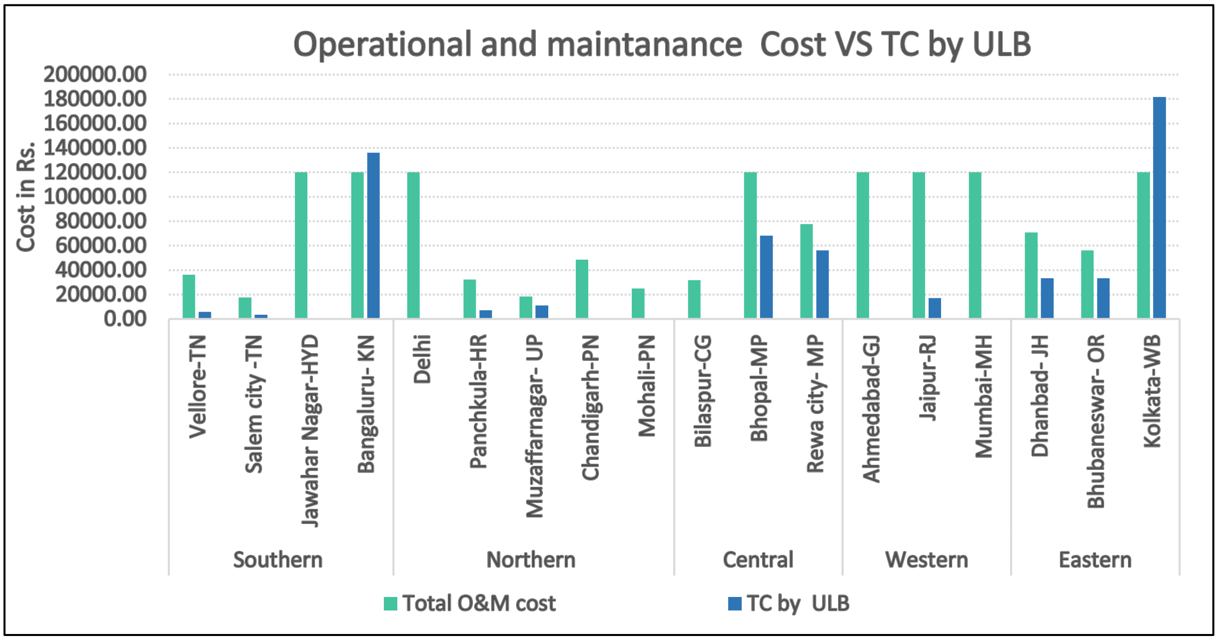


Fig.7.5.2: RDF production cost and transport cost by ULBs for model-5

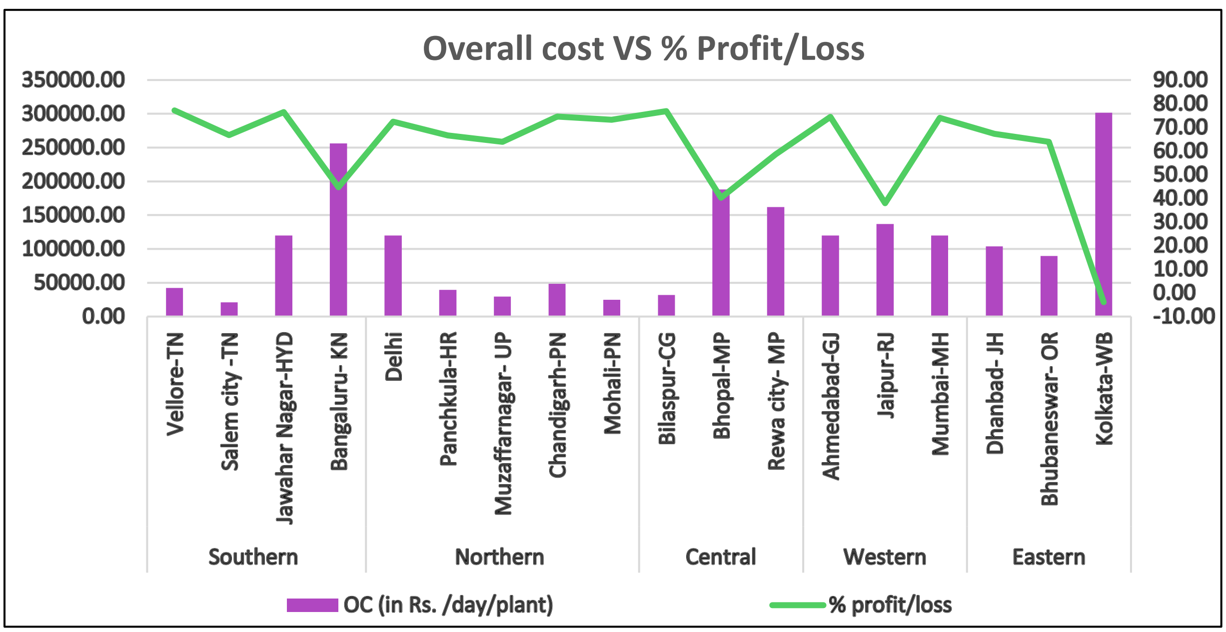


Fig. 7.5.3: Percentage of profit/loss with respect to overall cost (O&M and Tc) for model-5

Southern Zone

According to the study, Fig. 7.5.3 displays the percentage of profit or loss attributed to ULB for transportation costs and expenses related to operations and maintenance. ULB earned profits by selling fresh RDF to different cement plants. For Vellore City, ULB earned Rs 142110.41 (equivalent to 77.16% of total revenue). For Salem city, ULB earned Rs 42414.91 (equivalent to 66.73% of total revenue). For Jawahar Nagar in the southern zone, ULB earned Rs 388500.00 (equivalent to 76.40% of total revenue). However, Bengaluru only gained Rs 206944.35 (equivalent to 44.69% of total revenue) despite high transport costs (Rs. 136136.00 per day per plant for a 474km route).

Northern Zone

In the northern zone of the country, cement plants have co-processing facilities located near the cities where RDF is produced. As a result, the transportation costs for ULBs are relatively low, making this business strategy profitable for all cities involved.

ULB earned by selling per tonne of fresh RDF is Rs 315208.30 (equivalent to 72.43% of total revenue) for Delhi, Rs 78373.59 (66.56% of total revenue) for Panchkula, and Rs 52538.74 (63.92%) for Muzaffar Nagar city, Rs 142498.88 (74.57%) for Chandigarh city, Rs 68034.23 (73.20% of total revenue) for Mohali city as profit in the northern zone of the country.

Central Zone

This business strategy is profitable for all cities in the central part of the country. ULB has earned Rs. 105636.63 per tonne of fresh RDF, which accounts for 76.83% of total revenue, in Bilaspur. In Rewa city, ULB has earned Rs. 161869.46, which accounts for 58.54% of total revenue. Despite the significant RDF transport costs (Rs. 68224.00 per tonne of RDF) and the lack of government subsidy on capital investments in the central zone of the country, Bhopal has still managed to earn a profit of Rs. 126776.00, which accounts for 40.25% of total revenue.

Western Zone

This particular business strategy is profitable for all cities except for Jaipur located in the western zone of the country. In the western region, the sale of freshly produced RDF yields profits of Rs 349297.15 (74.43%) for Ahmadabad and Rs 340857.35 (73.96%) for Mumbai. However, Jaipur incurred a loss of Rs. 83500.00 (37.87%) despite producing low-quality RDF with a calorific value of 2450 kcal/kg. This is due to the high transport costs (Rs. 17000.00) that ULB has to bear.

Eastern Zone

Even though RDF is in the form of pellets, Kolkata still experiences a loss of Rs. 11390.00 (accounts 3.92% of the total revenue). On the other hand, Dhanbad has a profit of Rs. 214179.01 (accounts 67.31% of the total revenue) and Bhubaneswar has a profit of Rs. 158089.47 (accounts 63.86% of the total revenue). This study suggests that the business plan is not viable for Kolkata due to the high expenses involved in transporting RDF (Rs. 181640 per day for a 578km trip), as well as the lack of government subsidies on capital investments faced by ULB.

7.6 CONCLUSION

After analyzing sustainable business models, the biggest issue in India is the cost of transporting RDF from manufacturing units to energy sectors. Government assistance for capital expenditures is also crucial for these models to work. If the government is willing to invest in capital expenses, industries located near production units become more financially viable. Based on the findings of this research, the business model works best when industries are within 400 kilometers of RDF production cities. An exemplary analysis of the city of Kolkata with consideration of RDF production costs (CAPEX and OPEX) and huge transportation expenses revealed that this business model is not financially viable.

One major advantage of the study is the use of RDF pellets. Pellets have a higher market price than loose RDF, even with the same calorific value. Pellets are also easier to control, reducing transport expenses and storage requirements while increasing uniform energy production. If RDF is formed as pellets, the business model can still be financially sustainable in Kolkata despite high transportation costs, with the help of government subsidies on capital expenditures.

CHAPTER 8.
RDF FROM LEGACY WASTE

8.1 REFUSE-DERIVED FUEL FROM AGED MSW FRACTIONS

The composition of RDF from MSW will vary according to the origin of the waste material and the sorting or separation process. This will have a significant impact on the characteristics of RDF, including its calorific value. RDF fractions are typically non-recyclable combustible portions recovered from aged MSW. The average compositions of RDF recovered from aged waste at the Dhapa landfill site in Kolkata are shown in Figure 8.1.1. The principal components of the prospective RDF were plastic (~61.02%), Textiles and rags (~11.08%), rubber (~3.19%), paper (~6.79%), Cardboard (~12.97%), wood (~0.42%), thermocal (~1.08%), and coconut shell (~3.45%). The plastic content in the RDF from this study is higher than the other fractions. This is potentially attributed to the high level of single-use plastics and contamination levels in plastics for other uses in such contexts [88,89]. The presence of plastic waste in MSW is a serious concern for the environment to burn at low temperatures. The use of RDF in cement kilns takes care of the plastic waste for its eventual disposal [90]. The MSW recovered from the Dhapa Landfill site contains around 38% incinerable (having fuel value or calorific value) waste with an average moisture content of 40%, which can be converted into RDF. The average moisture content in RDF is around 18%, and the availability of RDF will be around 18.5% (after removing 20 to 22% moisture) out of the total MSW.

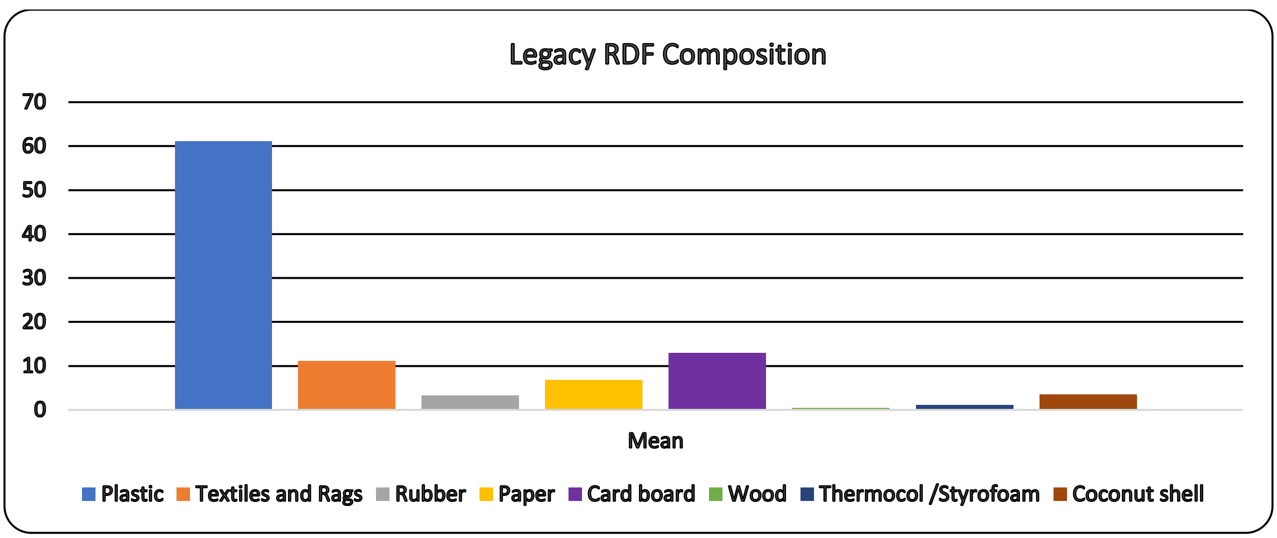
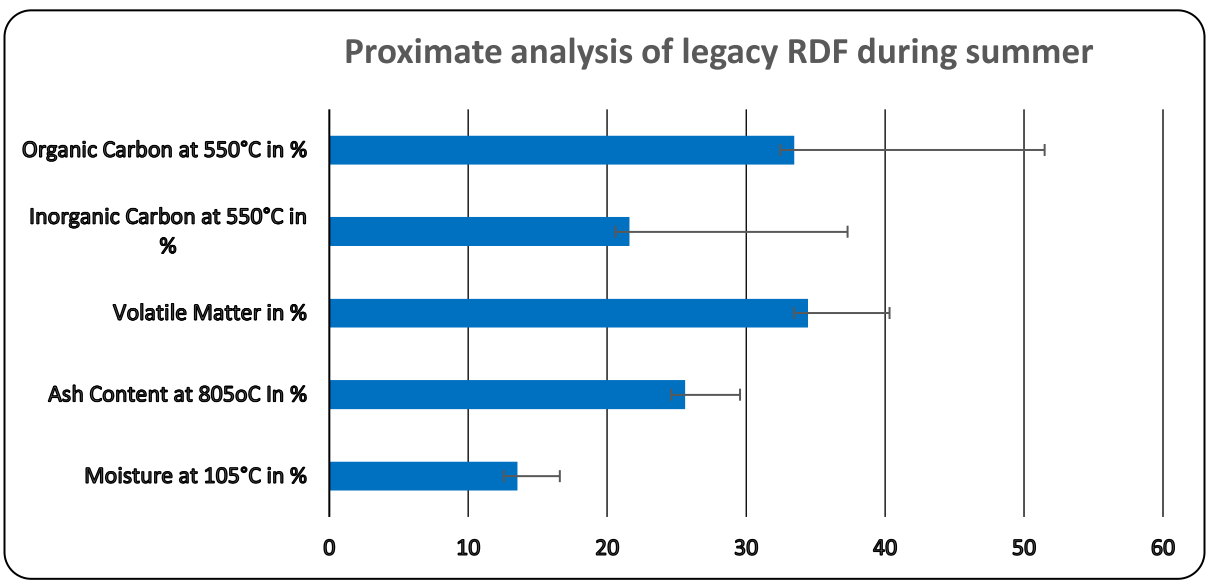


Fig. 8.1.1: Physical composition of legacy RDF

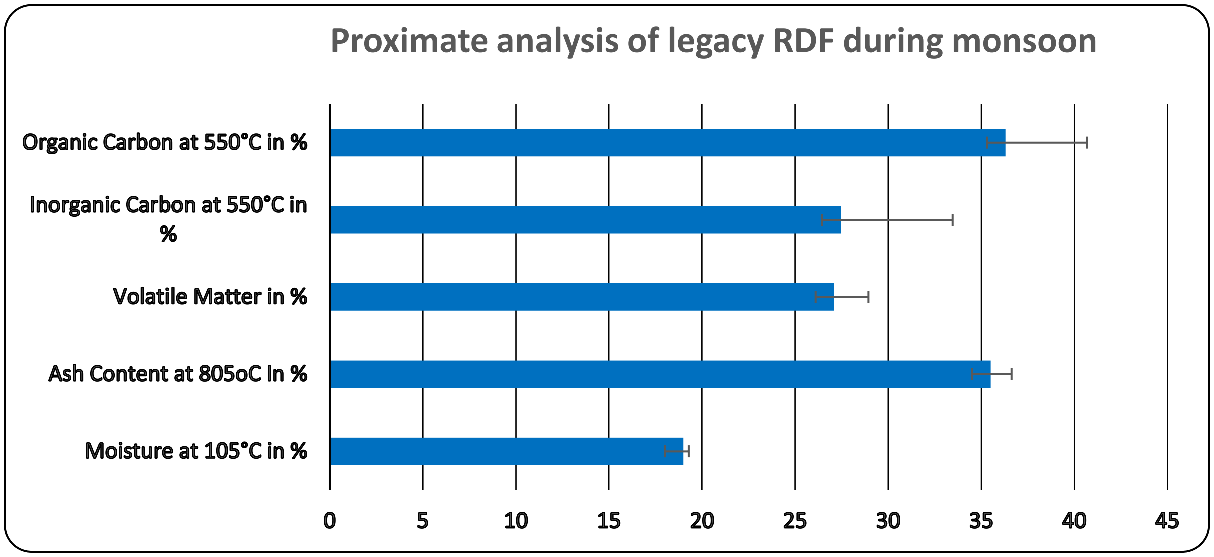
8.2 PHYSIOCHEMICAL ANALYSIS OF LEGACY RDF

8.2.1 Proximate analysis of legacy RDF

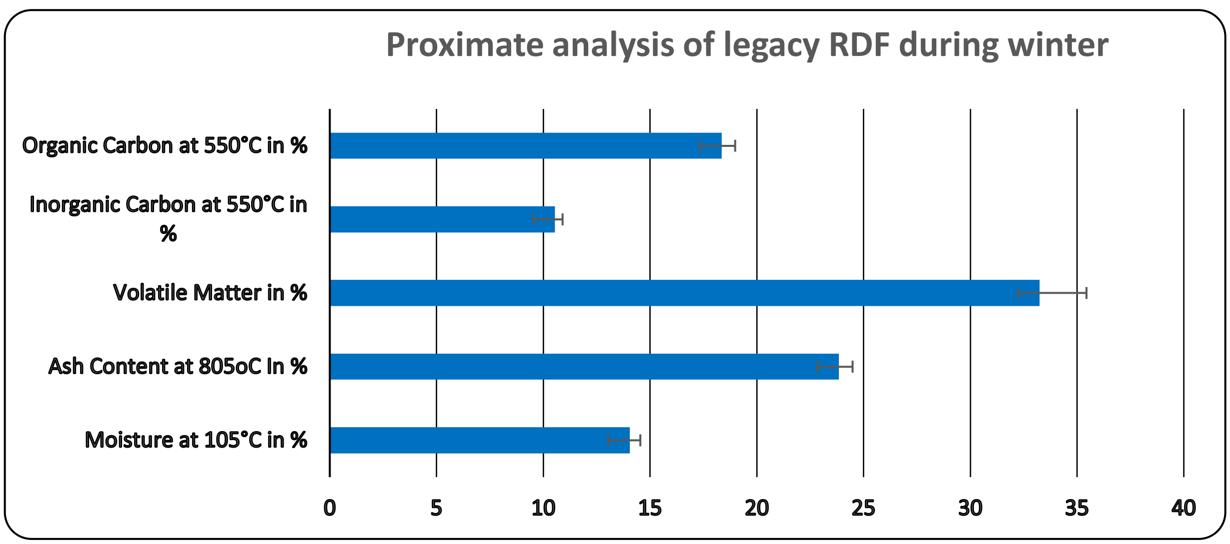
Proximate analysis of legacy RDF samples includes measurements of moisture content, loss on ignition, ash content, and calorific value. These variables play a crucial role in characterizing any RDF sample. A potential RDF sample has a lower moisture content, high loss on ignition, and a calorific value of approximately 2500 kcal/kg. The lower the moisture content indicates the higher the calorific value of the samples. At 105 °C, the moisture levels throughout the summer, winter, and monsoon seasons are 13.55%, 19.2%, and 14.05%, respectively. The annual average moisture content is about 15.53 percent. Due to the high moisture content during the monsoon season, it is recommended that RDF be pre-dried before being fed into the boiler [91]. Samples taken during the monsoon season also had a higher ash concentration of 35.5% compared to 25.6% during the summer and 23.85% during the winter. The sample's ash concentration is much higher than the standard limit of 15% suggested by the Ministry of Housing and Urban Affairs (MOHUA). The volatile matter content during the summer was 34.45%, during the monsoon it was 27.1%, and during the winter it was 33.25%.



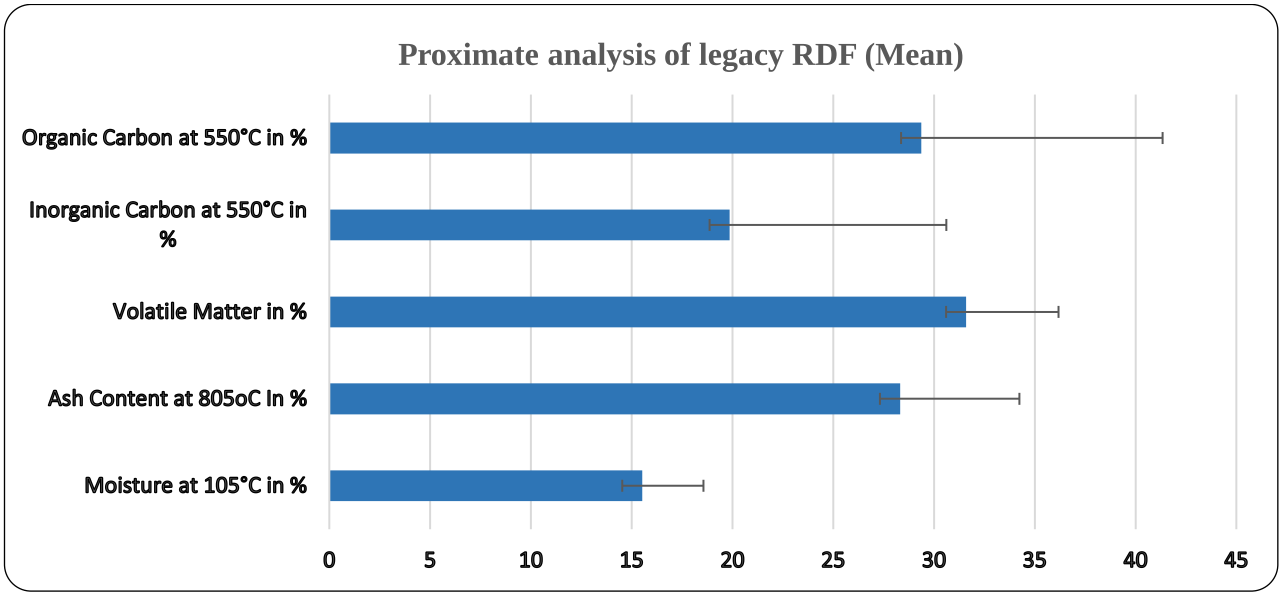
(a)


Proximate analysis of legacy RDF during monsoon
Organic Carbon at 550°C in %
Inorganic Carbon at 550°C in %
Volatile Matter in %
Ash Content at 805oC In %
Moisture at 105°C in %
0
5
10
15
20
25
30
35
40
45

(b)


Proximate analysis of legacy RDF during winter
Organic Carbon at 550°C in %
Inorganic Carbon at 550°C in %
Volatile Matter in %
Ash Content at 805oC In %
Moisture at 105°C in %
0
5
10
15
20
25
30
35
40

(c)



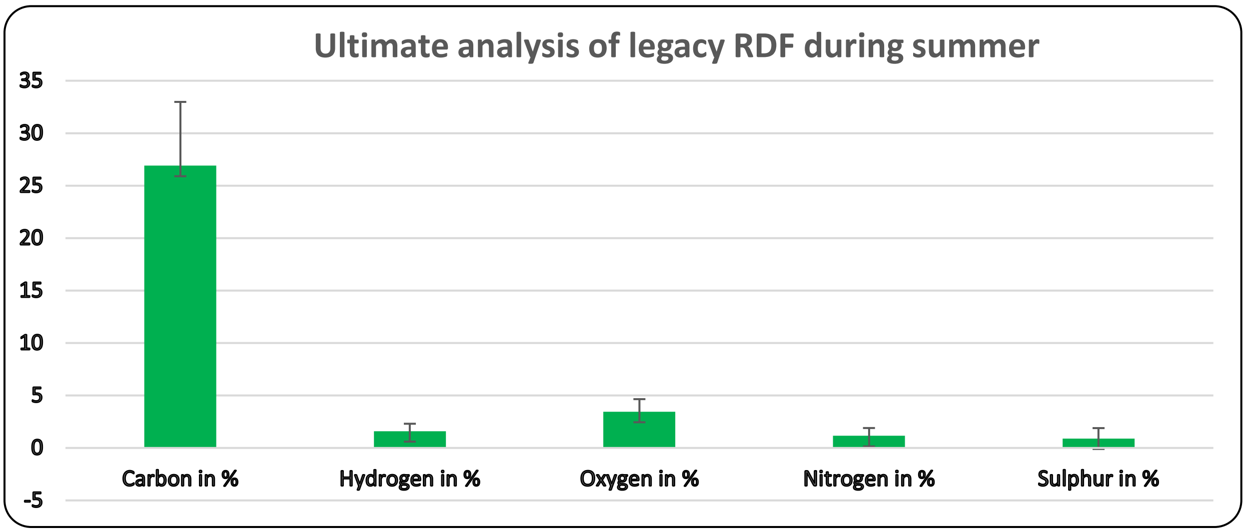
(d)

Fig. 8.2.1: Proximate analysis of Legacy RDF (a). During summer (b). During monsoon (c). During winter (d). Annual Average (mean)

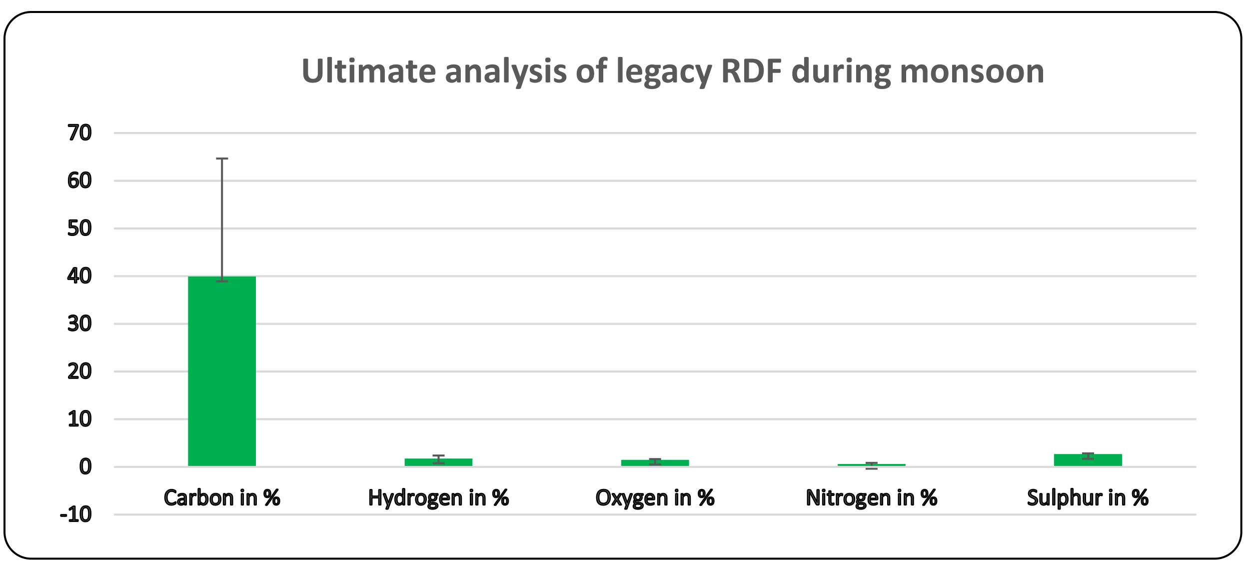
8.2.2 Ultimate analysis of the legacy RDF

The ultimate analysis of the samples involves the analysis of the various major and minor components. The main components, such as carbon and hydrogen found in fuel, contribute to its heating value. However, nitrogen and sulfur present in waste components can produce harmful emissions like NOx and Sox during combustion, leading to potential environmental damage and equipment corrosion [92]. In the present study, carbon levels ranged from 20.82% to 32.98% in summer, 15.16% to 64.64% in monsoon, and 27.92% to 29.88% in winter. Plastic had the highest carbon and hydrogen content, followed by rubber, paper, cardboard, and yard waste. Carbon and hydrogen are the most important elements for energy recovery as they produce carbon dioxide and water vapor during combustion [93].

Hydrogen content ranged from 0.9% to 2.3% in summer, 1.12% to 2.38% in monsoon, and 1.02% to 1.58% in winter. After carbon, oxygen was the second most prevalent element in the legacy RDF, with an average composition of 3 percent. The oxygen content ranged from 2.25% to 4.65% in summer, 1.36% to 1.64% in monsoon, and 3.84% to 4.26% in winter. Minor components such as sulfur, nitrogen, and chlorine can cause the formation of harmful gases during combustion. Nitrogen, for example, can lead to the formation of nitrogen oxides. Lower nitrogen values of 0.3%-0.5% by weight lead to lower formation of harmful products [94]. The nitrogen content found in the RDF samples during the study ranged from 0.54% to 1.96% by weight, which is consistent with the range described in [95]. Sulfur levels ranged from 0.03% to 2.49% wt., with a mean value of 1.26% wt. According [96] the maximum standard for sulfur in RDF is 0.50% by weight. The presence of yard (garden) waste is the primary contributor to sulfur content in the RDF samples.



(a)



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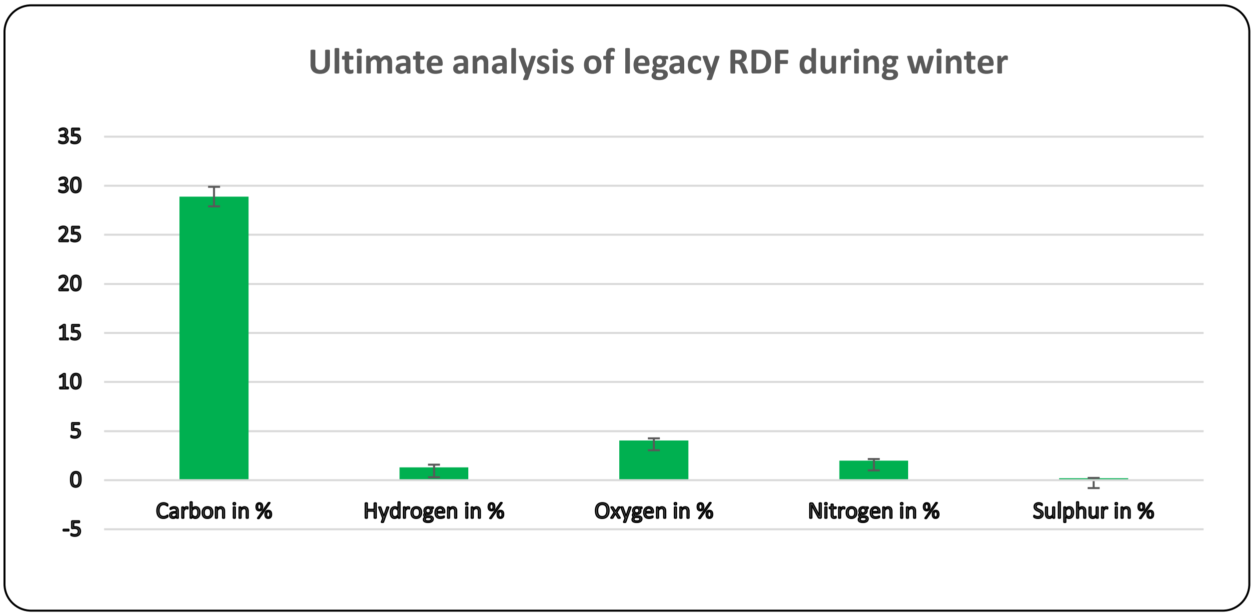
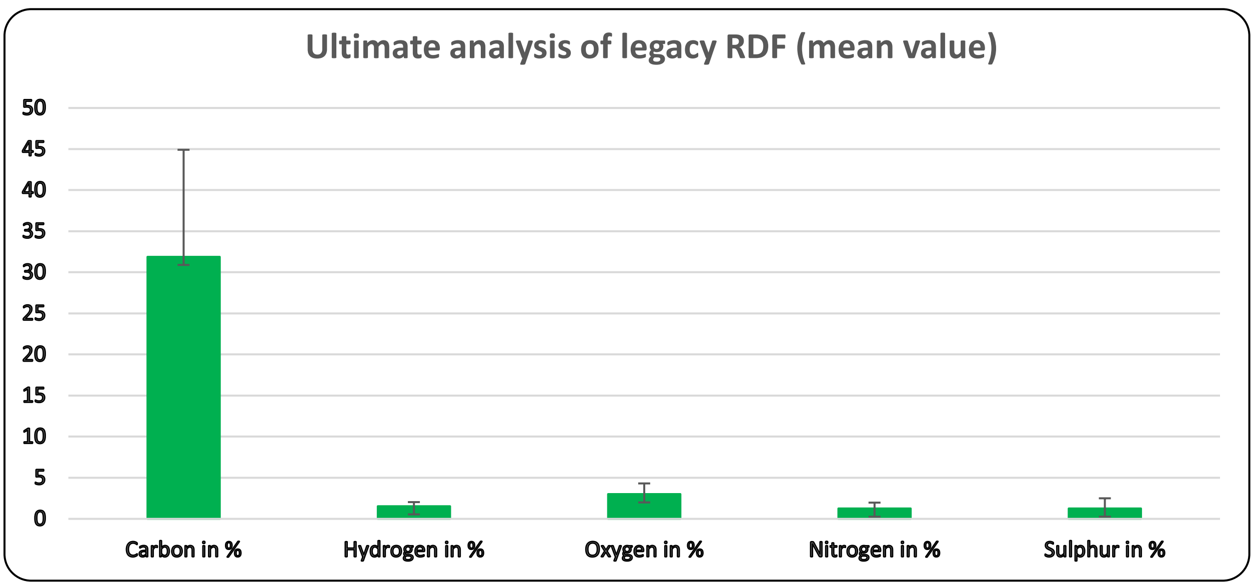


(c)



(d)

Fig. 8.2.2: Ultimate analysis of legacy RDF (a). During monsoon (b). During summer (c). During winter (d). Annual average

8.2.3 Calorific Value

The graph in Figure 8.2.3 shows the calorific value of the RDF from the Dhapa Landfill site throughout different seasons. The summer and winter seasons have a higher calorific value than the monsoon season due to the latter's higher moisture content. According to the study, the calorific value during the summer is 3536.5 kcal/kg and 3127 kcal/kg during winter, in comparison to 1870 kcal/kg during monsoon. According to SWM regulations from 2016, it is advised to use RDF samples made from solid waste as fuel in incineration units if the calorific content is greater than 1500 kcal/kg. Thus, this legacy RDF can be used as a feedstock in mass-burn incineration plants. However, inert components such as clay and silt increase the moisture content in RDF fractions during monsoon season, which cannot be removed through drying, shredding, and other procedures. Refuse-derived fuel may not burn clearly as a result of the presence of such inert components, and it may also produce a significant amount of ash, which could be detrimental to boiler maintenance and operation. Therefore, the boiler may be affected due to the higher moisture and inert fraction content during the monsoon season.

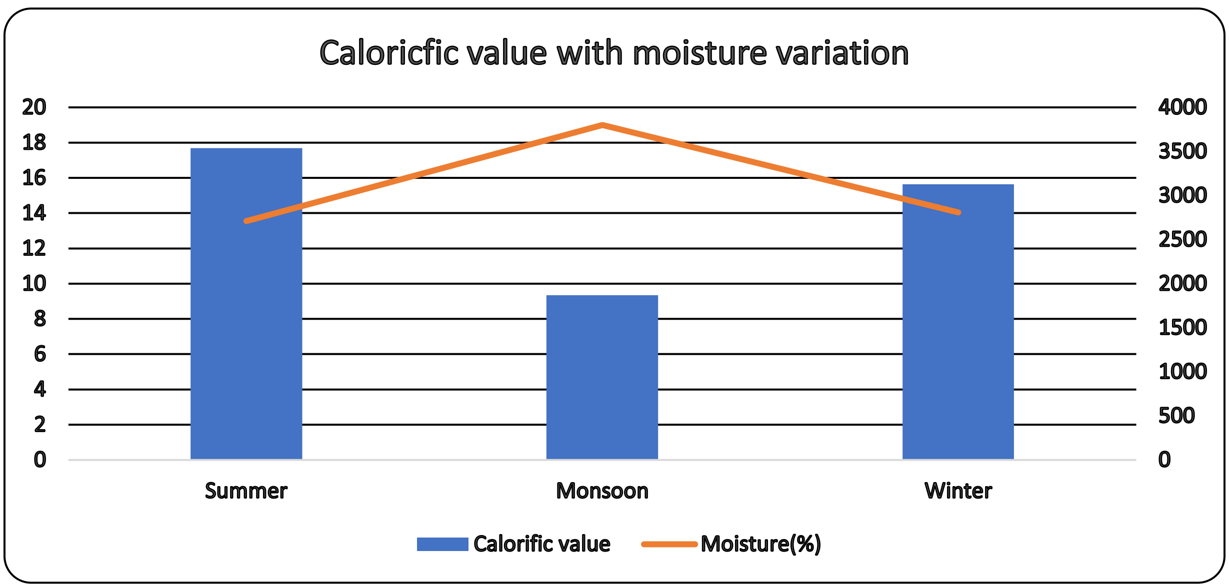


Fig. 8.2.3: Calorific value of legacy RDF with seasonal variations

8.3 ANALYSIS TOWARDS SUSTAINABLE MODEL

8.3.1 Business Model 01

Cost analysis of legacy fluffy RDF capital, operational and maintenance cost not considered (In relation to only transport costs):

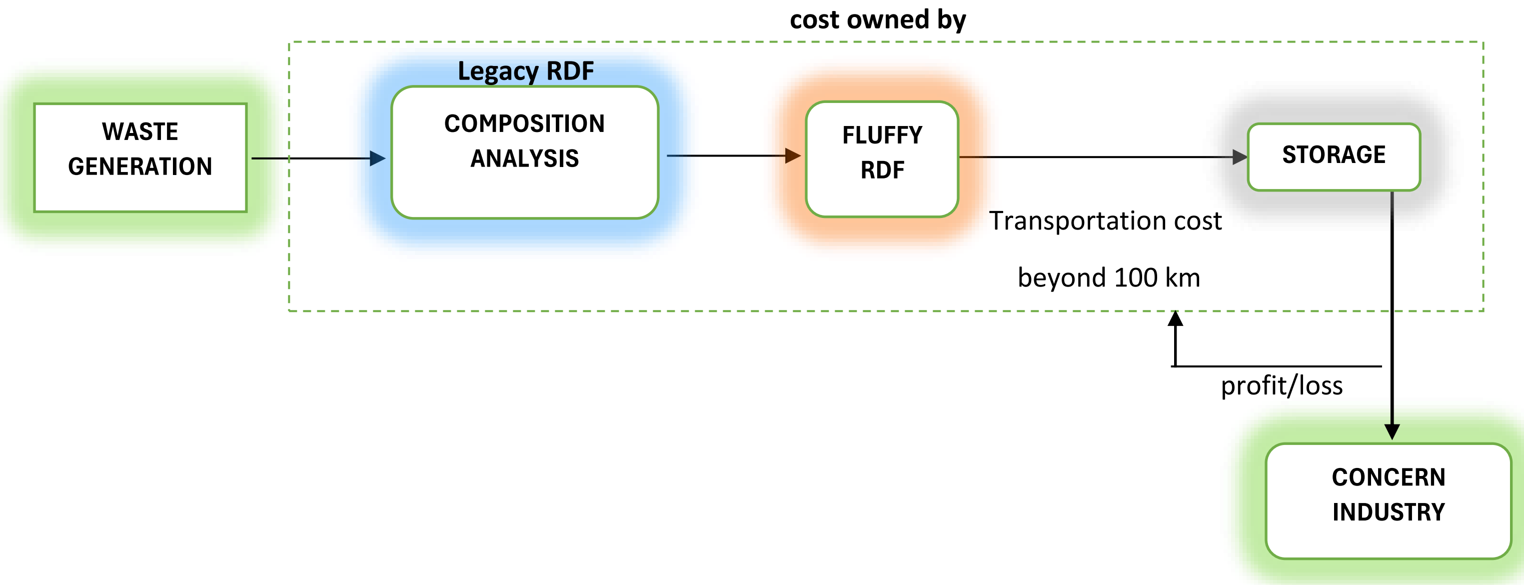


Fig. 8.3.1: Process flow diagram of legacy RDF from Dhapa landfill site

Fluffy or loose refuse-derived fuel is obtained mainly from aged or legacy waste through the process of bio-mining. The components of this fuel are separated and analyzed for their physical and chemical properties. The recovered refuse-derived fuel (RDF) is then transported to the closest storage facility of cement plants. The costs associated with the production of RDF, including capital, operational, and maintenance expenses, are not taken into consideration in this business model. As per the guidelines recommended by the Central Public Health and Environmental Engineering Organisation (CPHEEO), the cost of transporting RDF within a 100-kilometer radius is covered by the concerned cement plant, while beyond that radius, it is covered by the relevant ULB. The revenue generated from the sale of RDF is directly incurred by the concerned ULB.

In this study, different industries are classified based on their distance from the landfill site, and the per-tonne RDF transport costs for various distances are evaluated. The nationally appropriate mitigation action report (NAMA) calculates the cost of RDF transport at Rs. per tonne per kilometer, as shown in Figure 8.3.1.1. It is beneficial for the ULB if the industry is within a 100-

kilometer radius of the respective RDF production city. Otherwise, transportation costs can be enormous and may lead to losses in the business model.

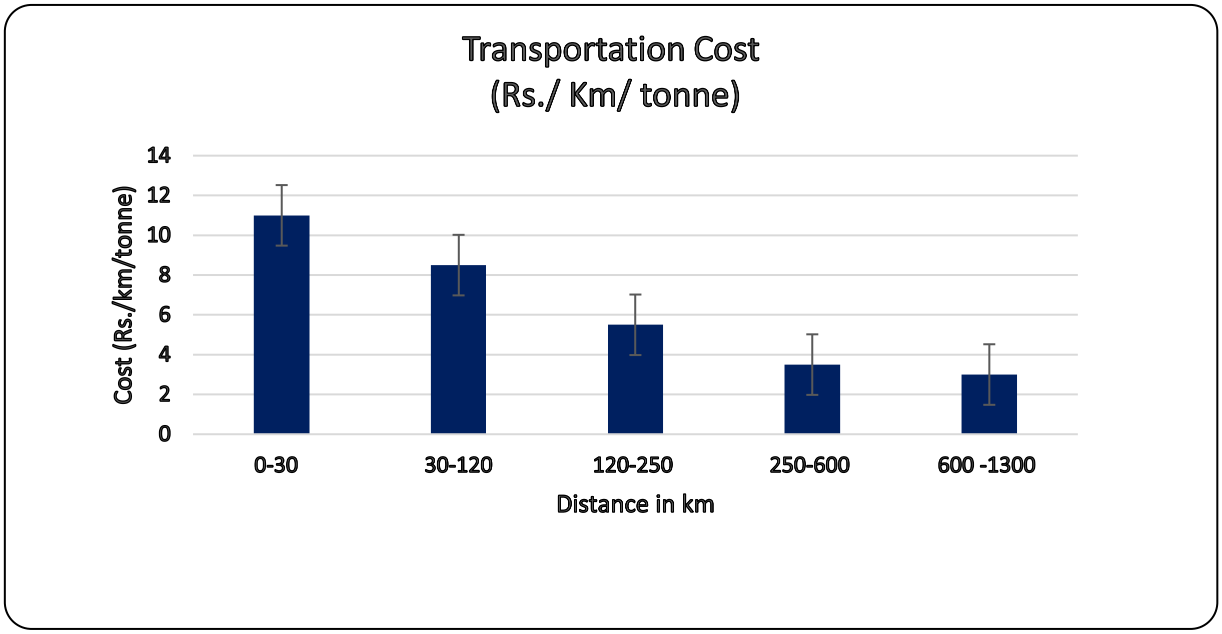


Fig. 8.3.1.1: Transportation cost of RDF as per waste NAMA report

RDF Transportation costs for various Thermal Power Plants

In this analysis, we have considered several thermal power plants in West Bengal and the ones closest to it with regard to their RDF-producing units. Based on the distance from the Dhapa dump site, Fig. 8.3.1.2 displays the transportation costs per tonne of RDF borne by the ULB and the transportation expenses incurred by the relevant thermal power plant. As per the study, ULBs do not have to bear RDF transportation expenses due to their proximity to the producing units of Budge Budge Thermal Power Plant (30 km) and Kolaghat Thermal Power Plant (74 km). On the other hand, ULBs have to bear a cost of Rs. 1860.3 per tonne of RDF for Hirakud captive thermal power plant (577 km), Rs. 1836.9 for Jharsuguda thermal power plant (571 km), Rs. 1398.12 for Talcher thermal power plant (482 km), Rs. 1221.2 for Patratu thermal power plant (444 km), Rs. 921.25 for Bokaro thermal power plant (375 km), Rs. 723.2 for Farakka thermal power plant (326 km), Rs. 952 for Sagar Dighi thermal power plant (240 km), Rs. 793.6 for Bakr Eshwar thermal power plant (224 km), Rs. 671 for Mejia thermal power plant (210 km), Rs. 552 for Durgapur STPP (196 km), and Rs. 504 for Durgapur thermal power plant (190 km).

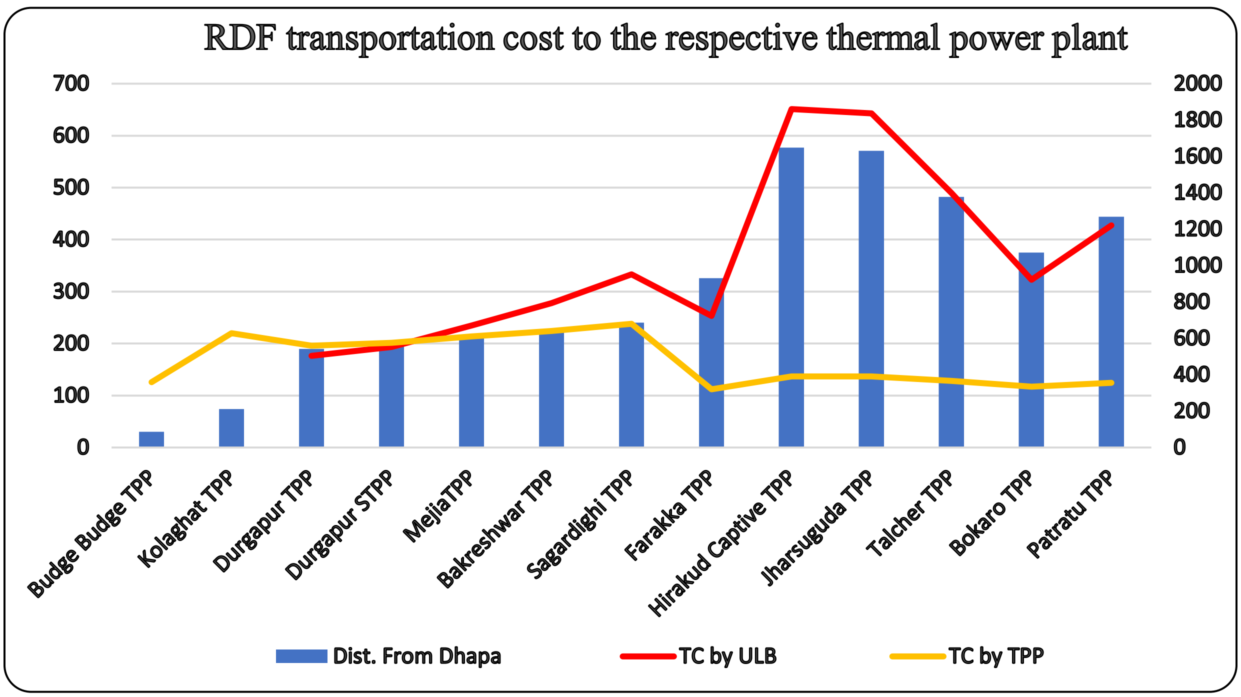


Fig. 8.3.1.2: RDF transportation cost from the production unit to the respective thermal power plant

RDF Transportation costs for various Steel Plants

For this analysis, we also took into account the number of iron and steel industries in proximity to the Dhapa dump site. Figure 8.3.1.3 illustrates the costs of RDF transport by ULB per tonne in relation to distance for various steel factories. The costs incurred by ULBs for transporting RDF to Alloy Steel Plant (SAIL) Durgapur is Rs. 504 (190 km), Durgapur Steel Plant (SAIL) is Rs. 520.72 (192 km), IISCO Steel Plant (SAIL) Asansol is Rs. 907.12 (236 km), Bokaro Steel Plant (SAIL) Bokaro Steel City, Jharkhand is Rs. 723.2 (326 km), Electro Steel Limited (ESL) Bokaro, Jharkhand is Rs. 650.96 (306 km), JSL Stainless Jajpur, Odisha is Rs. 927.36 (376 km), and MECON (company) Ranchi, Jharkhand is Rs. 1026.8 (402 km).

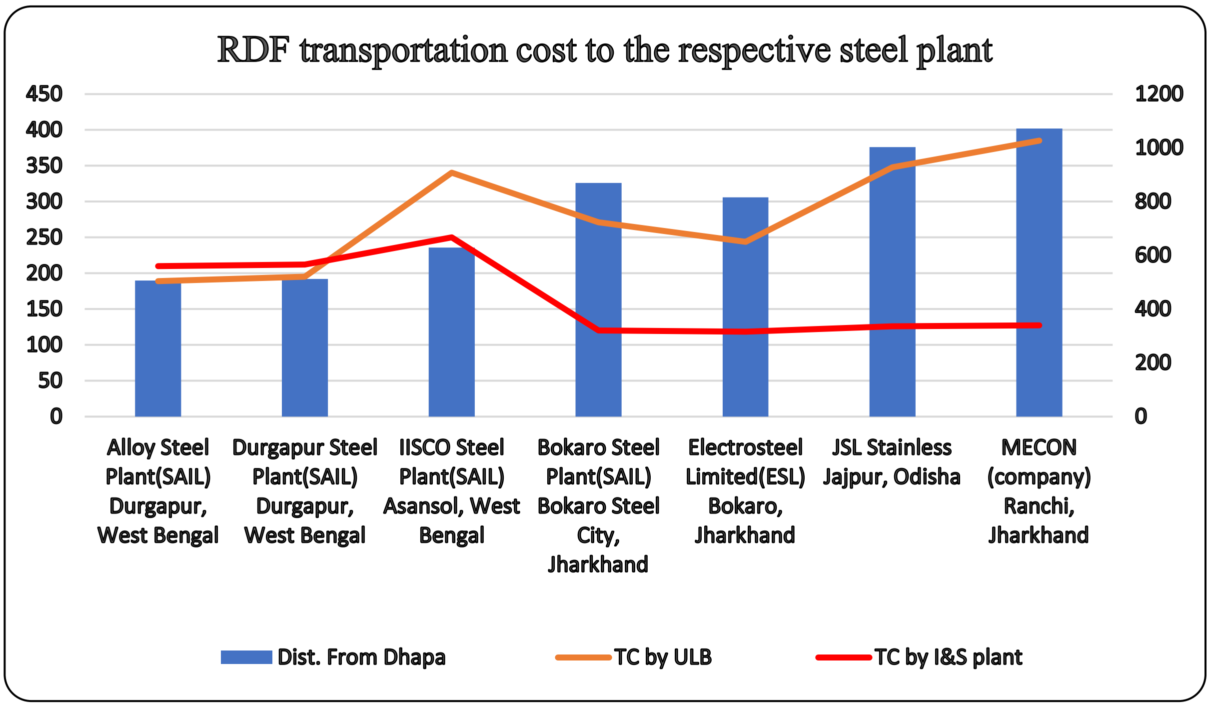


Fig. 8.3.1.3: RDF transportation cost from the production unit to the respective steel plant

RDF Transportation costs for various Cement Plants

In addition to considering the numerous cement plants in West Bengal and the surrounding states, this research also analyses the RDF transportation costs for which ULBs and industries are responsible (as shown in Fig. 8.3.1.4). According to the study, the Ramco Cement Plant in Kolaghat, which is situated 77km from the Dhapa Landfill site, incurs a higher transportation cost (Rs. 659.12 per tonne) compared to the Rawan Cement Plant in Chhattisgarh, which is approximately 842 km away from the landfill site. This is because the cost of RDF transportation per tonne/km decreases as the industrial distance increases(as shown in Fig. 8.3.1.1).

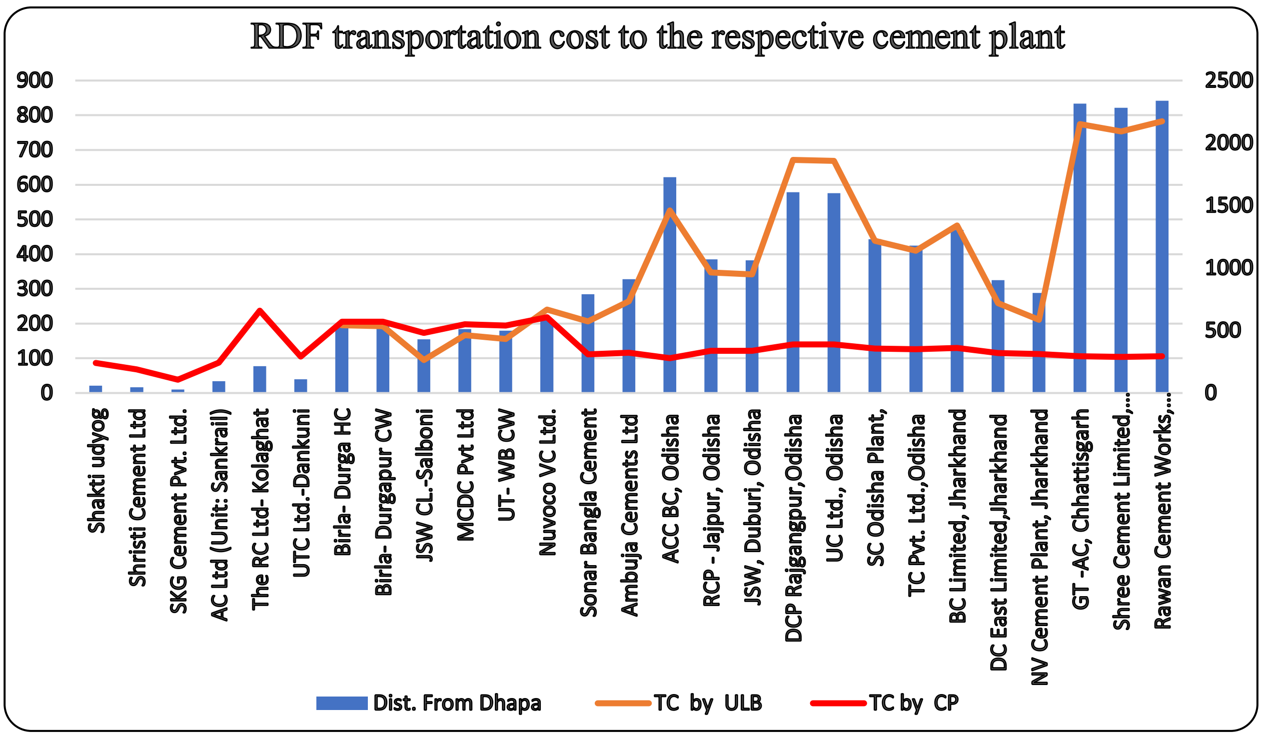
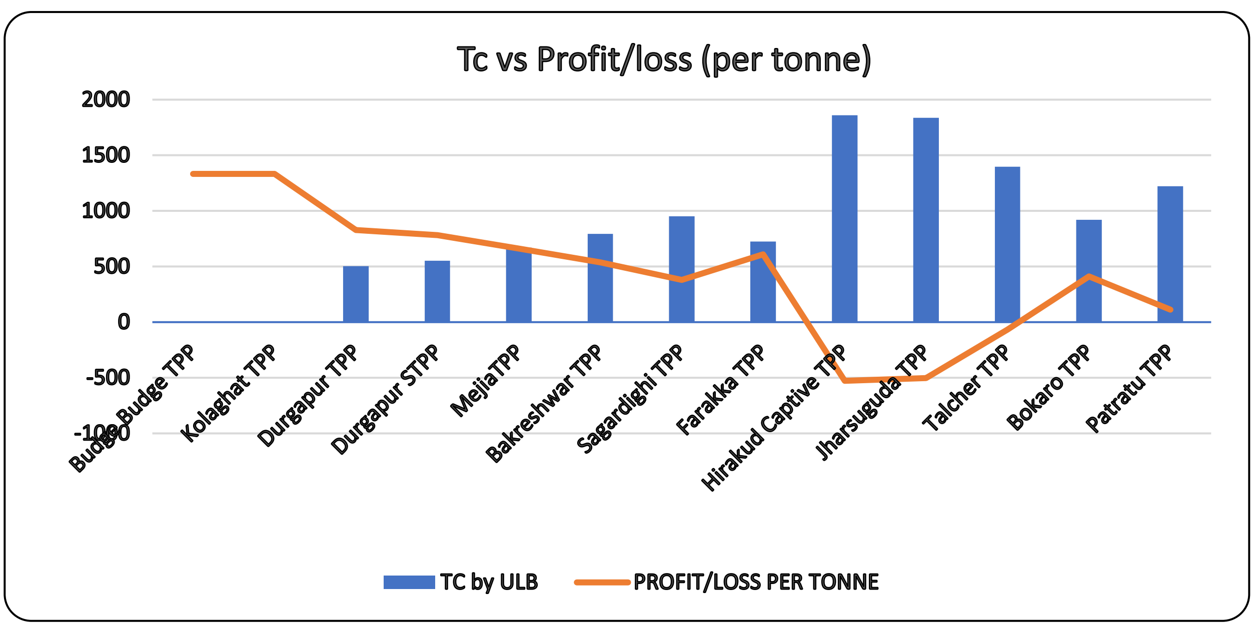


Fig. 8.3.1.4: RDF transportation cost from the production unit to the respective cement plant

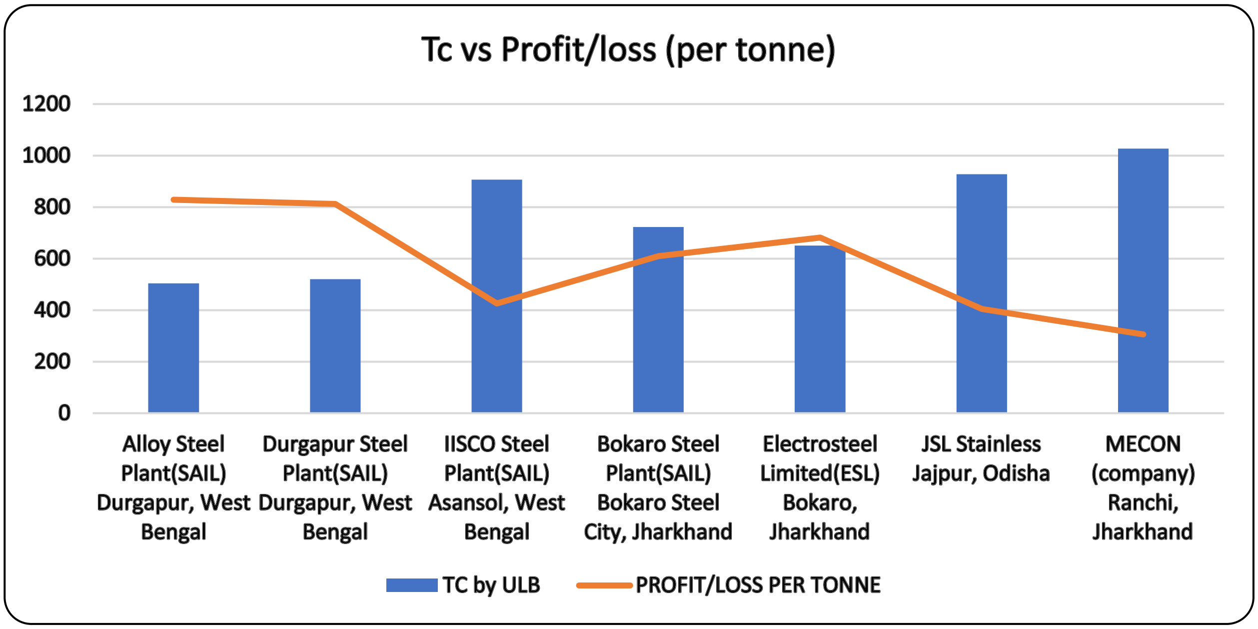
Profit or Loss analysis for various industries

Based on the study, the profit or loss of selling legacy RDF per tonne to various thermal power plants, iron-steel industries, and cement plants is shown in Fig. 8.3.1.5. The industry, which is situated far away from the Dhapa landfill site, delivers RDF at a loss per tonne. Due to high transport costs for the Hirakud captive thermal power plant (577 km), Jharsuguda thermal power plant (571 km), and Talcher thermal power plant (482 km), respectively, ULB loses Rs. 527.6, Rs. 504.2, and Rs. 65.42 for each tonne of selling legacy RDF. In cement plants like the Dalmia cement plant in Rajgangpur, the UltraTech cement limited in Odisha, the Burnpur cement limited in Jharkhand, the Ambuja cement limited in Chhattisgarh, the Shree cement limited in Chhattisgarh, and the Rawan cement works in Chhattisgarh, ULB suffers losses of Rs. 531.5 (578 km), Rs. 523.7 (576 km), Rs. 6.7 (470 km), Rs. 817(834km), Rs. 761.1 (822km) and Rs. 841.36 (842km) respectively. Transporting the RDF to such energy sectors is not feasible due to the distance and lack of financial benefit for ULBs.

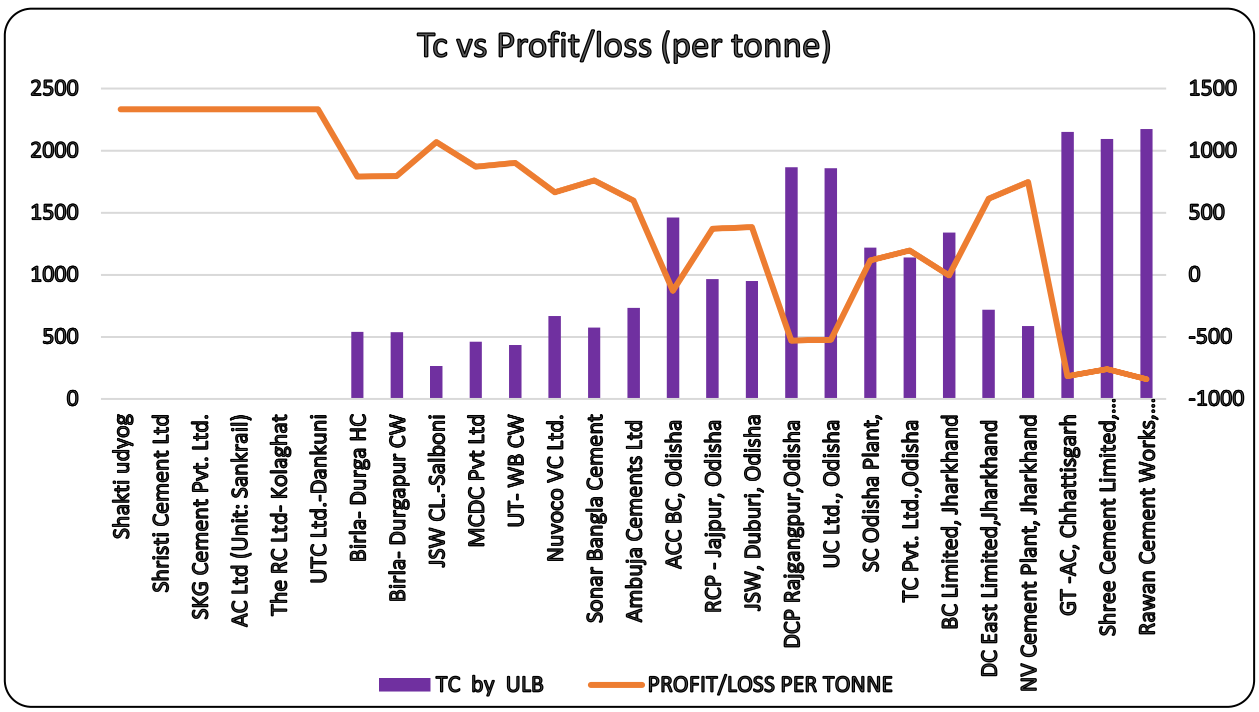
According to this study, the minimum loss was observed at Rs. 6.7 per tonne of legacy RDF for a distance of 470 km. The minimum profit is Rs. 115.05/tonne for a 443 km distance. Therefore, it can be concluded that the business model is not viable to deliver RDF to the energy sectors beyond 443 km. It can be inferred from the study that ULB's transportation costs will decrease, and the financial viability will increase if RDF is used as an additive fuel in the thermal power plants, iron-steel plants, and cement plants that are closest (within 100 km) to the Dhapa dump site.



(a)



(b)



(c)

Fig. 8.5.4.1: Profit or loss by ULBs in relation to transportation cost for various (a). thermal power plants, (b). steel plants and (c). cement plants.

8.3.2 Business Model 02

Cost analysis of legacy fluffy RDF without government subsidy on capital investments (O&M and transport costs included):

This business model involves the use of fluffy legacy RDF, taking into account the capital expenditures, operating expenses, and transportation costs of the ULBs. Based on this business model, ULBs or agencies are responsible for all capital investment, operational and maintenance costs, as well as transport costs up to 100km. The study revealed that ULBs could earn Rs. 181.7 per tonne of fluffy or loose legacy RDF by selling to energy-intensive industries located within 100km of the RDF production unit. However, beyond 100km, the model is not economically feasible due to the high costs borne by ULBs.

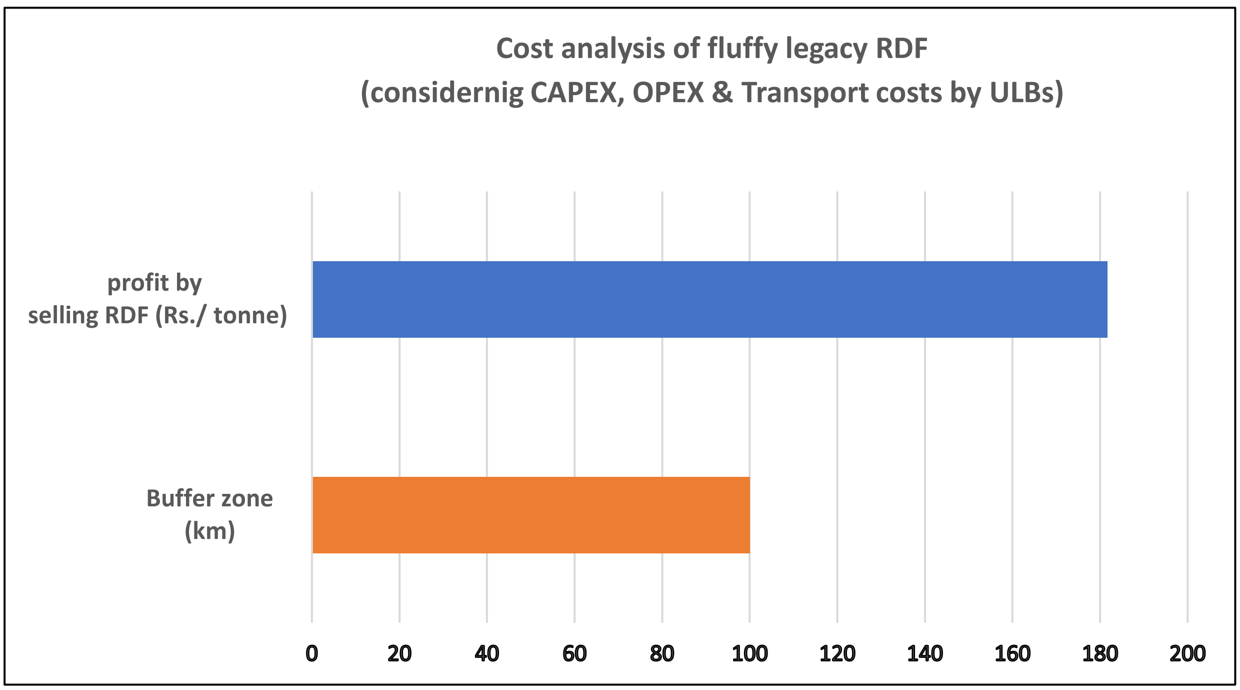


Fig. 8.3.2: Profit by ULBs in relation to transportation distance for business model 2

8.3.3 Business Model 03

Cost analysis of legacy fluffy RDF with 100% government subsidy on capital investments (O&M and transport costs included):

In this particular business model, a key factor to consider is the investment made by the government in capital expenditure. Based on the findings of this study, investing in CAPEX can make this business model viable for up to a 325km buffer zone. Within 100km, the profit is expected to be Rs. 728.7 per tonne. It has been determined that this business model is economically feasible up to 320km.

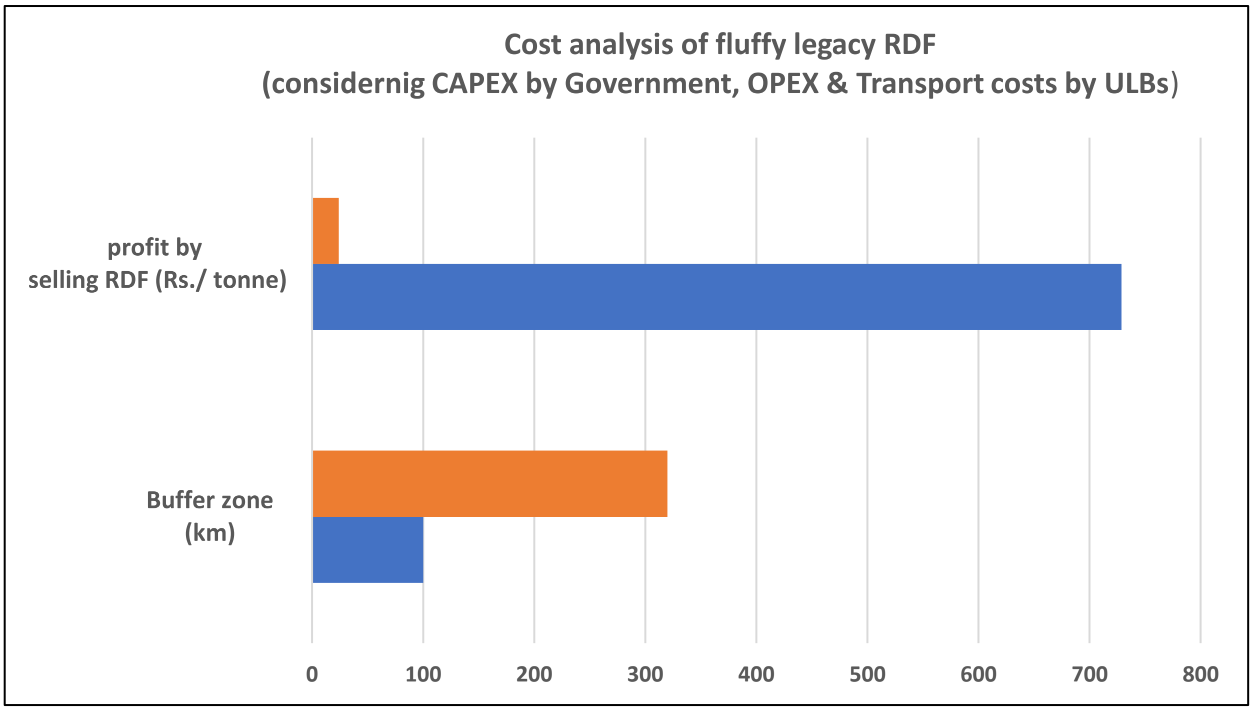


Fig. 8.3.3: Profit by ULBs in relation to transportation distance for business model 3

8.3.4 Business Model 04

Cost analysis of legacy RDF pellet with government subsidy on capital investments (O&M and transport costs included):

This particular business model is deemed most viable because the government has shown a willingness to invest in CAPEX. Additionally, the use of RDF pellets further contributes to its success. The rate of profitability is approximately Rs. 2543.2 per tonne for distances of 100km and Rs. 167 per tonne for distances of 900km. However, research suggests that beyond 900km, this business model may not be economically feasible for ULBs or Agencies.

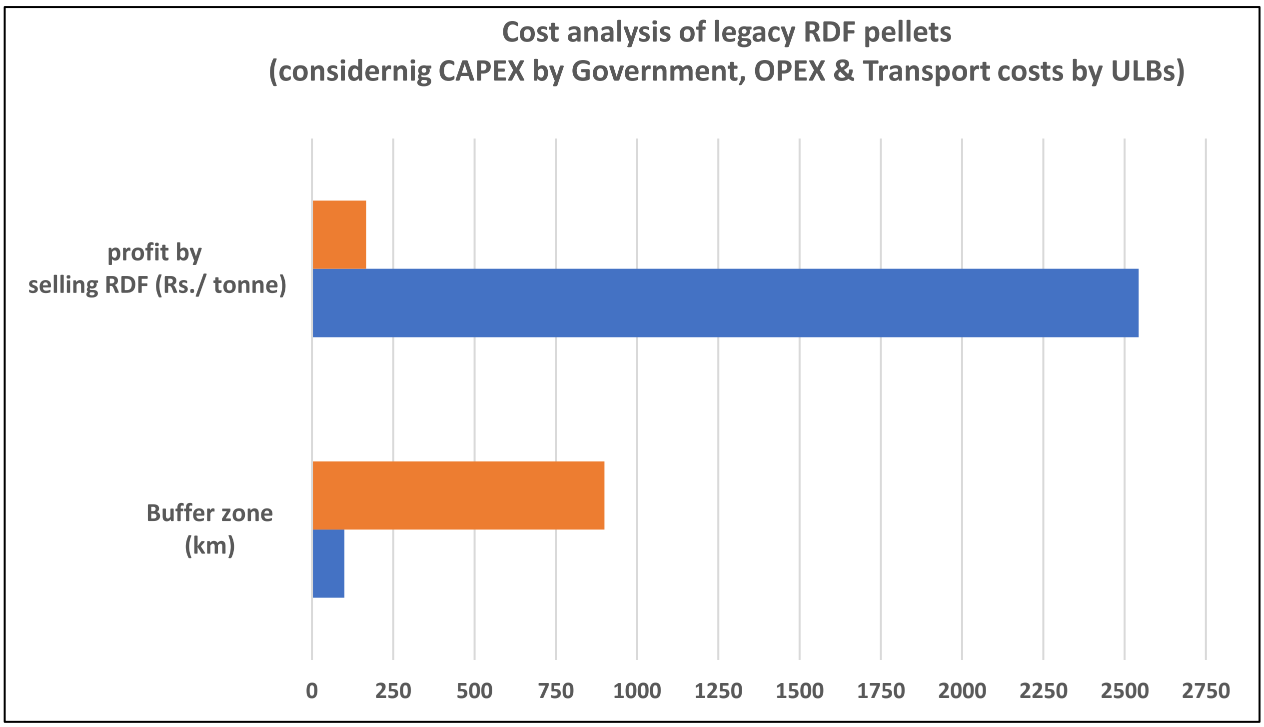


Fig. 8.3.4: Profit by ULBs in relation to transportation distance for business model 4

8.3.5 Business Model 05

Cost analysis of legacy RDF pellet without government subsidy on capital investments (O&M and transport costs included):

This business model can still be profitable despite high transportation costs, even up to 750km, without the need for any government investment in CAPEX. The profitability rate is around Rs. 1985.2/tonne and Rs. 113/tonne for 100km and 750km distance.

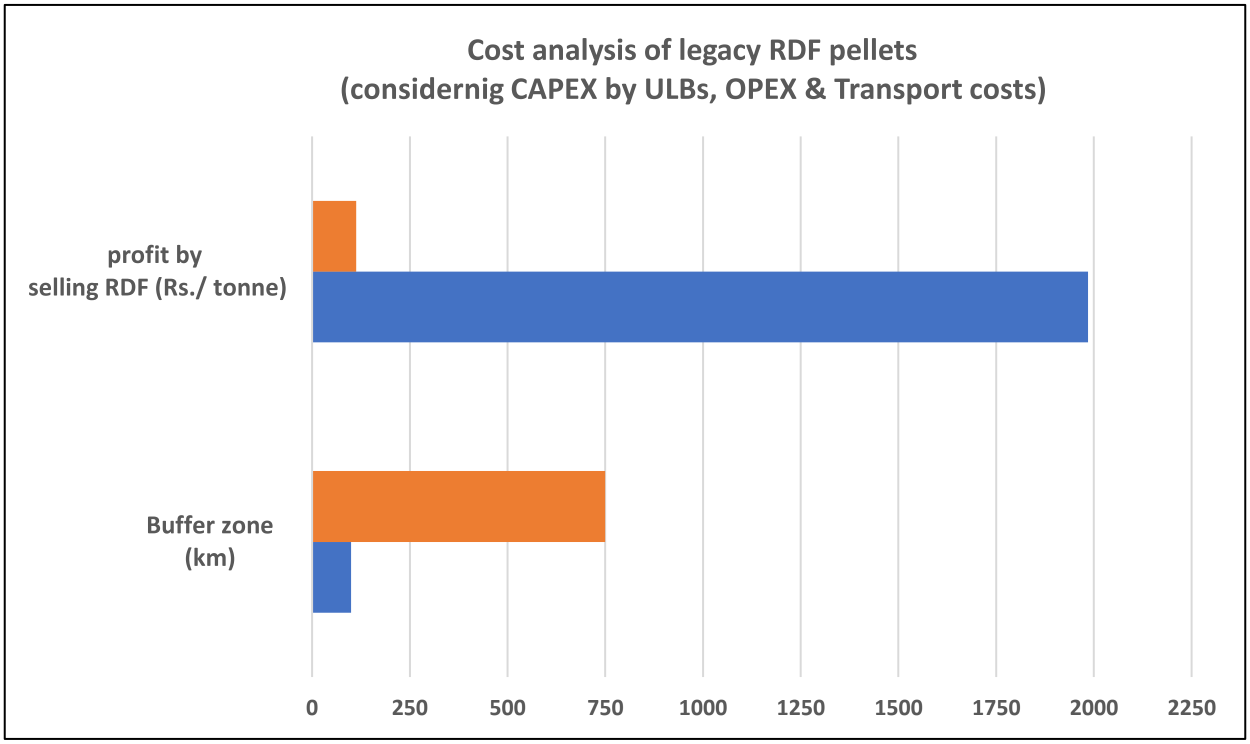


Fig. 8.3.5: Profit by ULBs in relation to transportation distance for business model 5

8.4 DISCUSSION AND CONCLUSION

Data was collected from the field study at the Dhapa dumpsite in Kolkata. This tells us that there is a huge potential for producing RDF from the non-recyclable part of the combustible waste dumped at this dumpsite for co-processing of RDF in various energy-intensive industries. As per the SWM regulations from 2016, it is advised to use RDF samples made from solid waste as fuel in incineration units if the calorific content exceeds 1500 kcal/kg, which is well within the recommended limit.

Based on the analysis of the business model, the feasibility of the business model in Kolkata is hindered by high transportation costs. The Dhapa landfill site is currently transporting RDF to the Dalmia cement plant in Odisha (578km from the landfill site), resulting in a low profitability rate for the concerned ULB. Despite the availability of numerous industries close to the Dhapa dumpsite that could co-process RDF, most industries are reluctant to use it, contributing to the low profitability rate. The study recommends that the production of RDF in pellet form is a crucial step to enhance the business viability. This will not only enhance business feasibility but also encourage industries to use RDF as an alternative fuel. In order to effectively promote a circular economy and manage waste in an environmentally sound manner it is imperative to produce good quality RDF and enforce industries to use it as an alternative fuel.

CHAPTER 9.
CONCLUSION AND FUTURE SCOPE

CONCLUDING REMARKS

In accordance with the Indian waste management hierarchy, waste that cannot be avoided, reused, or recycled but has the necessary characteristics for combustion must be processed and transformed into refuse-derived fuel (RDF), which may be used as an alternative fuel in a variety of sectors. The compositional data of urban MSW from 18 Indian cities revealed that the percentage of fresh RDF production in Indian cities accounts for 12.32% of total MSW generation, with an average NCV of 4,741.68 kcal/kg. However, this rate is relatively low due to the high percentage of recycled fractions for fresh waste. Apart from fresh RDF, the legacy RDF production rate is around 18% with an average NCV of 3,331.75 kcal/kg. The levels of critical parameters such as chlorine, sulfur, and nitrogen for the various cities in combustible waste components are within recommended limit values. Thus, size screening can easily enhance the NCV of MSW. The use of high-quality RDF can effectively replace fossil fuels, enhance India's waste management system, and reduce the adverse effects of MSW while achieving sustainable development goals. However, the use of RDF as fuel in Indian industries other than the cement industry is limited due to concerns about negative impacts on the production process or product quality.

To promote a circular economy in MSW, CPCB recommends using 25% RDF to replace coal standards in existing cement plants. Currently, only a few industries in India have achieved a 10-15% thermal substitution rate by using RDF as supplementary fuel [97]. Several major cities in India produced significant quantities of RDF, but low substitution rates prevent complete daily dispatch. Therefore, waste-to-energy technologies (such as pyrolysis, gasification, plasma, etc.) may be the possible way to utilize RDF properly.

Various business models analyzed indicate that RDF transport costs are a pressing issue in the Indian context. Based on the findings of this research, as transportation costs are the major issue in the Indian context, government investments in CAPEX are necessary for the viability of the business models. If the government is willing to invest in such business models, it is observed that the ULB may permit the transportation of RDF for up to 400-500km from the RDF production unit.

However, the distance limit may also be affected by the quantity and quality of RDF delivered to the industry on a daily basis.

An exemplary analysis of the city of Kolkata shows that most of the examined business models are not economically viable due to the high transportation costs (which is around Rs. 181,640.00 for 578 kilometres distance) and lack of government subsidies. The study found that cities transporting their RDF to nearby industries (within 100km) earned significant profits. Therefore, energy-intensive industries with coprocessing facilities must be compelled to use RDF.

FUTURE SCOPE

1. Based on this research, it has been found that some cities produce substantial amounts of Refuse Derived Fuel (RDF) due to the significant quantity of Municipal Solid Waste (MSW) generated every day. It is important to assess the industry's capability to replace fossil fuels with RDF (i.e., thermal substitution rate).
2. In India, most cement plants closest to RDF production cities are reluctant to use it. To promote a circular economy, it is important to investigate the specific reasons why potential users of RDF (refuse-derived fuel) may be reluctant to utilize it.
3. RDF has also been used in the thermal, steel, and brick industry in Europe. In this regard, it would be beneficial to explore the possibility of using RDF in these industries, apart from cement plants, in India.

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Annexure I.

Table A1. Calculation of quantity of RDF

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Vellore	350	**Plastic/polyethene**	7.00	24.50	2.00	24.01	60.00	14.41	9.60	31.81
		Paper & Cardboard	6.50	22.75	6.00	21.39	70.00	14.97	6.42	21.25
		Textile	5.00	17.50	10.00	15.75	10.00	1.58	14.18	46.95
		OCF	NA		20.00		10.00			
		Total		64.75		61.145		30.95	30.19	100

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Salem City	230	**Plastic/polyethene**	12.0	27.60	2.00	27.05	60.00	16.23	10.82	73.55
		Paper & Cardboard	6.0	13.80	6.00	12.97	70.00	9.08	3.89	26.45
		Textile	NA		10.00		10.00			
		OCF			20.00	0.00	10.00	0.00	0.00	0.00
		Total		41.4		40.02		25.31	14.71	100

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Jawahar Nagar	7000	**Plastic/polyethene**	8.00	560.00	2.00	548.80	60.00	329.28	219.52	16.97
		Paper & Cardboard	7.00	490.00	6.00	460.60	70.00	322.42	138.18	10.68
		Textile	8.50	595.00	10.00	535.50	10.00	53.55	481.95	37.27
		OCF	9.00	630.00	20.00	504.00	10.00	50.40	453.60	35.07
		Total		2275.00		2048.90		705.25	1293.2	100.0

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Bengaluru	6500	**Plastic/polyethene**	6.23	405.00	2.00	396.90	60.00	238.14	158.76	37.39
		Paper & Cardboard	11.6	754.00	6.00	708.76	70.00	496.13	212.63	50.08
		Textile	1.01	65.65	10.00	59.09	10.00	5.91	53.18	12.52
		OCF	NA		20.00					
		Total		1224.65		1164.75		740.18	424.56	

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Delhi	8700	**Plastic/polyethene**	6.0	522.00	2.00	511.56	60.00	306.94	204.62	21.13
		Paper &Cardboard	5.6	487.20	6.00	457.97	70.00	320.58	137.39	14.19
		Textile	NA		10.00		10.00			
		OCF	10.0	870.00	20.00	696.00	10.00	69.60	626.40	64.68
		Total		1879.20		1665.53		697.11	968.41	

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Panchkula	180	**Plastic/polyethene**	7.06	12.71	2.00	12.45	60.00	7.47	4.98	18.58
		Paper &Cardboard	5.43	9.77	6.00	9.19	70.00	6.43	2.76	10.28
		Textile	1.19	2.13	10.00	1.92	10.00	0.19	1.73	6.45
		OCF	13.4	24.08	20.00	19.27	10.00	1.93	17.34	64.69
		Total		48.70		42.83		15.83	26.81	100.0

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Muzaffarnagar	160	**Plastic/polyethene**	7.0	11.20	2.00	10.98	60.00	6.59	4.39	28.52
		Paper & Cardboard	6.08	9.73	6.00	9.14	70.00	6.40	2.74	17.82
		Textile	6.36	10.20	10.00	9.18	10.00	0.92	8.26	53.66
		OCF	NA		20.00		10.00			
		Total		31.128		29.3	Total	13.90	15.40	

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Chandigarh	456	**Plastic/polyethene**	7.30	33.29	2.00	32.62	60.00	19.57	13.05	32.22
		Paper & Cardboard	6.00	27.36	6.00	25.72	70.00	18.00	7.72	19.05
		Textile	1.70	7.75	10.00	6.98	10.00	0.70	6.28	15.50
		OCF	4.10	18.69	20.00	14.95	10.00	1.50	13.46	33.23
		Total		87.09		80.27		39.77	40.50	100.0

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Mohali	180	**Plastic/polyethene**	6.60	11.88	2.00	11.64	60.00	6.99	4.66	22.43
		Paper & Cardboard	5.30	9.54	6.00	8.97	70.00	6.28	2.69	12.96
		Textile	1.20	2.16	10.00	1.94	10.00	0.19	1.75	8.43
		OCF	9.00	16.20	20.00	12.96	10.00	1.30	11.66	56.18
		Total		39.78		35.51		14.75	20.76	

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Bhopal	950	**Plastic/polyethene**	2.0	19.00	2.00	18.62	60.00	11.17	7.45	4.76
		Paper & Cardboard	10.0	95.00	6.00	89.30	70.00	62.51	26.79	17.12
		Textile	7.00	66.50	10.00	59.85	10.00	5.99	53.87	34.42
		OCF	10.0	95.00	20.00	76.00	10.00	7.60	68.40	43.71
		Total		275.5		243.77		87.27	156.50	

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Rewa City	350	**Plastic/polyethene**	18.7	65.5	2.0	64.1	60.0	38.5	25.7	52.7
		Paper &Cardboard	6.6	23.1	6.0	21.7	70.0	15.2	6.5	13.4
		Textile	4.5	15.8	10.0	14.2	10.0	1.4	12.8	26.2
		OCF	1.5	5.3	20.0	4.2	10.0	0.4	3.8	7.8
		Total		168		164.22		55.52	48.71	100

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Bilaspur	400	**Plastic/polyethene**	3.00	12.00	2.00	11.76	60.00	7.06	4.70	17.72
		Paper & Cardboard	5.00	20.00	6.00	18.80	70.00	13.16	5.64	21.25
		Textile	5.00	20.00	10.00	18.00	10.00	1.80	16.20	61.03
		OCF	NA	NA	20.00		10.00			
		Total		52		48.56		22.02	26.54	100.0

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Jaipur	2000	Plastic/polyethene	7.0	140.0	2.0	137.2	60.0	82.3	54.9	31.8
		Paper& Cardboard	6.5	130.0	6.0	122.2	70.0	85.5	36.7	21.2
		Textile	5.0	100.0	10.0	90.0	10.0	9.0	81.0	46.9
		OCF	NA	NA	20.0		10.0			
		Total		370		349.4		176.86	172.54	100

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Ahmadabad	4000	Plastic/polyethene	6.7	268.0	2.0	262.6	60.0	157.6	105.1	41.1
		Paper& Cardboard	5.7	228.0	6.0	214.3	70.0	150.0	64.3	25.1
		Textile	NA	NA	10.0		10.0			
		OCF	3.0	120.0	20.0	96.0	10.0	9.6	86.4	33.8
		Total		616.0		573.0		317.2	255.8	100

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Mumbai	11000	**Plastic/polyethene**	9.00	990	2	970.2	60	582.12	388.08	19.00
		Paper & Cardboard	8	880	6	827.2	70	579.04	248.16	12.15
		Textile	6.00	660.00	10.00	594.00	10.00	59.40	534.60	26.18
		OCF	11	1210	20	968	10	96.8	871.2	42.66
		Total		3740		3359.4		1317.3	2042.0	100.0

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Dhanbad	545	**Plastic/polyethene**	13.0	70.85	2.00	69.43	60.00	41.66	27.77	47.15
		Paper & Cardboard	0.60	3.27	6.00	3.07	70.00	2.15	0.92	1.57
		Textile	2.40	13.08	10.00	11.77	10.00	1.18	10.59	17.98
		OCF	5.00	27.25	20.00	21.80	10.00	2.18	19.62	33.30
		Total		114.45		106.08		47.17	58.91	

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Kolkata	5000	**Plastic/polyethene**	3.2	160	2	156.8	60	94.08	62.72	18.85
		Paper & Cardboard	4.6	230	6	216.2	70	151.34	64.86	19.49
		Textile	4	200	10	180	10	18	162	48.68
		OCF	1.2	60	20	48	10	4.8	43.2	12.98
		Total		650		601		268.22	332.78	100.0

City	W. G (TPD)	Components	C.G (%)	C.G in TPD	M.C (%)	Dry weight	% Recycled	R. F (TPD)	RDF (TPD)	% of RDF
Bhubaneswar	500	**Plastic/polyethene**	10.0	50.0	2.0	49.0	60.0	29.4	19.6	41.9
		Paper & Cardboard	9.2	46.0	6.0	43.2	70.0	30.3	13.0	27.7
		Textile	35.0	17.5	10.0	15.8	10.0	1.6	14.2	30.3
		OCF	NA	NA	20.0		10.0			
		Total		113.5		108.0		61.2	46.7	100.0

W.G- Waste generation; C.G- Components generation (%); M.C - Moisture content (%); R.F - Recycled fraction

RDF- Refuse derived fuel

SAMPLE CALCULATION:

<u>BHUBANESWAR CITY</u>

Per day waste generation = 500 TPD

Plastic component

plastic generation in TPD = 500*10% = 50 TPD

dry weight = (50-(50*2%)) = 49 TPD

Recycled plastic fraction= (49*60%) = 29.4 TPD

plastic quantity as RDF Fraction = (49-29.4) = 19.6 TPD

Plastic percentage in RDF = (19.6/46.7) *100 = 41.9%

Similarly,

Paper and Cardboard (%) = (13/46.7) *100 = 27.7%

Textile (%) = (14.2/46.7) *100 = 30.3%

Other Combustible Fraction = N.A

Table A2. Proximate analysis of fresh RDF

Proximate Analysis of Fresh RDF							
Zone	**Indian city**	**moisture content (%)**	**ash content (%)**	**volatile matter (%)**	**fixed carbon (%)**	**mineral matter (%)**	**Source**
Southern Zone	Vellore(db)-TN	6	16	58	10	20	[80]
	Salem city(db) -TN	8	9	-	-	-	[58]
	Jawahar Nagar(wb)-HYD	20	5	65	-	-	[81]
	Bangaluru(db)- KA	4.89	7.06	-	-	-	[82]
Northern Zone	Delhi(db)	11.37	3.93	-	-	-	[60]
	Panchkula(db)-HR	12.05	3.61	25.2	5.4	-	[61]
	Muzaffar Nagar(db)- UP	7.83	5.26	22.3	10.1	-	[62]
	Chandigarh(db)-PB	5.87	5.25	22.66	1.39	-	[61]
	Mohali(db)-PB	10.72	4.07	23.45	3.4	-	[61]
Central	Bilaspur(db)-CG	6.61	4.57	-	-	-	[63]
	Bhopal(wb)-MP	8.44	20.01	53.29	10.76	-	[83]
	Rewa city(db)- MP	7.1	8.9	8.45	-	-	[84]
Western	Ahmedabad(db)-GJ	6.98	6.12	-	-		[85]
	Jaipur(wb)-RJ	11.1	18	49.9	-	-	[83,86]
	Mumbai(db)-MH	10.17	3.92	-	-	-	[87]
Eastern	Dhanbad(db)-JH	7.31	5.76	54.82	11.69	-	[66]
	Bhubaneswar(db*)-OR	4.85	6.61	-	-	-	[67]
	Kolkata(wb*)-WB	20	13	-	-	-	[68]

*- Not Available

***db-** dry basis

***wb-** wet basis

Annexure II.

Table B1. Calculation of components of ultimate analysis

City	Percent by weight (dry basis)							
Bengaluru	**Components**	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**
	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6
	Textile	100	55	6.6	31.2	4.6	0.15	2.5
	OCF	100	49.5	6	42.7	0.2	0.1	1.5

City	Total Weight (Dry basis)										
Bengaluru	**Components**	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**	**HCV**	**NCV**	**E.C(modified)**
	Plastic/polyethene	158.8	95.3	11.4	36.2	-	-	15.9	4896.6	4552.0	4874.53
	Paper & Cardboard	212.6	92.5	12.8	93.6	0.6	0.4	12.8			
	Textile	53.2	29.2	3.5	16.6	2.4	0.1	1.3			
	OCF	-	-	-	-	-	-	-			
	Total	424.6	217.0	27.7	146.3	3.1	0.5	30.0			
	percent		51.1	6.5	34.5	0.7	0.1	7.1			

City	Percent by weight (dry basis)							
Delhi	**Components**	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**
	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6
	Textile	100	55	6.6	31.2	4.6	0.15	2.5
	OCF	100	49.5	6	42.7	0.2	0.1	1.5

City	Total Weight (Dry basis)										
Delhi	**Components**	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**	**HCV**	**NCV**	**E.C(modified)**
	Plastic/polyethene	204.62	123	15	46.7	-	-	20	4602	4271.21	4581.14
	Paper & Cardboard	137.39	59.8	8.2	60.5	0.412	0.27	8.2			
	Textile	NA	-	-	-	-	-	-			
	OCF	626.4	310	38	267	1.253	0.63	9.4			
	Total	968.41	493	61	375	1.665	0.9	38	968.4		
	percent		50.9	6.3	38.7	0.172	0.09	3.9	100		

City	Percent by weight (dry basis)										
Panchkula	Components	RDF in TPD	C	H	O	N	S	Ash			
	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10			
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6			
	Textile	100	55	6.6	31.2	4.6	0.15	2.5			
	OCF	100	49.5	6	42.7	0.2	0.1	1.5			
	Total Weight (Dry basis)										
	Components	RDF in TPD	C	H	O	N	S	Ash	HCV	NCV	E.C(modified)
	Plastic/polyethene	5.0	2.99	0.4	1.14	-	-	0.5	4643	4311.94	4623.55
	Paper & Cardboard	2.7563	1.2	0.2	1.21	0.008	0.01	0.2			
	Textile	1.7292	0.95	0.1	0.54	0.08	0	0			
	OCF	17.34	8.58	1	7.4	0.035	0.02	0.3			
	Total	26.807	13.7	1.7	10.3	0.122	0.03	1	26.81		
	percent		51.2	6.3	38.4	0.457	0.09	3.6	100		

City	Percent by weight (dry basis)										
Muzaffar Nagar	Components	RDF in TPD	C	H	O	N	S	Ash			
	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10			
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6			
	Textile	100	55	6.6	31.2	4.6	0.15	2.5			
	OCF	100	49.5	6	42.7	0.2	0.1	1.5			
	Total Weight (Dry basis)										
	Components	RDF in TPD	C	H	O	N	S	Ash	HCV	NCV	E.C(modified)
	Plastic/polyethene	4.3904	2.63	0.3	1	-	-	0.4	5355	5002.76	5338.6
	Paper & Cardboard	2.7433	1.19	0.2	1.21	0.008	0.01	0.2			
	Textile	8.262	4.54	0.5	2.58	0.38	0.01	0.2			
	OCF	NA	0	0	0	0	0	0			
	Total	15.396	8.37	1	4.79	0.388	0.02	0.8	15.4		
	percent		54.4	6.7	31.1	2.522	0.12	5.3	100		

City	Percent by weight (dry basis)										
Chandigarh	**Components**	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**			
	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10			
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6			
	Textile	100	55	6.6	31.2	4.6	0.15	2.5			
	OCF	100	49.5	6	42.7	0.2	0.1	1.5			
	Total Weight (Dry basis)										
	Components	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**	**HCV**	**NCV**	**E.C(modified)**
	Plastic/polyethene	13.049	7.83	0.9	2.98	-	-	1.3	4988	4646.03	4966.95
	Paper & Cardboard	7.7155	3.36	0.5	3.39	0.023	0.02	0.5			
	Textile	6.2775	3.45	0.4	1.96	0.289	0.01	0.2			
	OCF	13.457	6.66	0.8	5.75	0.027	0.01	0.2			
	Total	40.499	21.3	2.6	14.1	0.339	0.04	2.1	40.5		
	percent		52.6	6.5	34.8	0.837	0.09	5.3	100		

City	Percent by weight (dry basis)										
Mohali	**Components**	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**			
	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10			
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6			
	Textile	100	55	6.6	31.2	4.6	0.15	2.5			
	OCF	100	49.5	6	42.7	0.2	0.1	1.5			
	Total Weight (Dry basis)										
	Components	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**	**HCV**	**NCV**	**E.C(modified)**
	Plastic/polyethene	4.657	2.79	0.3	1.06	-	-	0.5	4733	4398.69	4712.69
	Paper & Cardboard	2.6903	1.17	0.2	1.18	0.008	0.01	0.2			
	Textile	1.7496	0.96	0.1	0.55	0.08	0	0			
	OCF	11.664	5.77	0.7	4.98	0.023	0.01	0.2			
	Total	20.761	10.7	1.3	7.77	0.112	0.02	0.8	20.76		
	percent		51.5	6.3	37.4	0.539	0.09	4.1	100		

City	Percent by weight (dry basis)										
	Components	RDF in TPD	C	H	O	N	S	Ash			
Bilaspur	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10			
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6			
	Textile	100	55	6.6	31.2	4.6	0.15	2.5			
	OCF	100	49.5	6	42.7	0.2	0.1	1.5			
	Total Weight (Dry basis)										
	Components	RDF in TPD	C	H	O	N	S	Ash	HCV	NCV	E.C(modified)
	Plastic/polyethene	4.704	2.82	0.3	1.07	-	-	0.5	5192	4844.71	5179.68
	Paper & Cardboard	5.64	2.45	0.3	2.48	0.017	0.01	0.3			
	Textile	16.2	8.91	1.1	5.05	0.745	0.02	0.4			
	OCF	NA	-	-	-	-	-	-			
	Total	26.544	14.2	1.7	8.61	0.762	0.04	1.2	26.55		
	percent		53.4	6.6	32.4	2.871	0.13	4.6	100		

City	Percent by weight (dry basis)										
	Components	RDF in TPD	C	H	O	N	S	Ash			
Ahmadabad	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10			
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6			
	Textile	100	55	6.6	31.2	4.6	0.15	2.5			
	OCF	100	49.5	6	42.7	0.2	0.1	1.5			
	Total Weight (Dry basis)										
	Components	RDF in TPD	C	H	O	N	S	Ash	HCV	NCV	E.C(modified)
	Plastic/polyethene	105.06	63	7.6	24	-	-	11	4965	4622.13	4939.97
	Paper & Cardboard	64.296	28	3.9	28.3	0.193	0.13	3.9			
	Textile	NA	-	-	-	-	-	-			
	OCF	86.4	42.8	5.2	36.9	0.173	0.09	1.3			
	Total	255.75	134	17	89.1	0.366	0.21	16	255.8		
	percent		52.3	6.5	34.9	0.143	0.08	6.1	100		

City	Percent by weight (dry basis)										
Mumbai	Components	RDF in TPD	C	H	O	N	S	Ash			
	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10			
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6			
	Textile	100	55	6.6	31.2	4.6	0.15	2.5			
	OCF	100	49.5	6	42.7	0.2	0.1	1.5			
	Total Weight (Dry basis)										
	Components	RDF in TPD	C	H	O	N	S	Ash	HCV	NCV	E.C(modified)
	Plastic/polyethene	388.08	233	28	88.5	-	-	39	4868	4530.86	4851.1
	Paper & Cardboard	248.16	108	15	109	0.744	0.5	15			
	Textile	534.6	294	35	167	24.59	0.8	13			
	OCF	871.2	431	52	372	1.742	0.87	13			
	Total	2042	1066	130	736	27.08	2.17	80	2042		
	percent		52.2	6.4	36.1	1.326	0.11	3.9	100		

City	Percent by weight (dry basis)										
Dhanbad	Components	RDF in TPD	C	H	O	N	S	Ash			
	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10			
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6			
	Textile	100	55	6.6	31.2	4.6	0.15	2.5			
	OCF	100	49.5	6	42.7	0.2	0.1	1.5			
	Total Weight (Dry basis)										
	Components	RDF in TPD	C	H	O	N	S	Ash	HCV	NCV	E.C(modified)
	Plastic/polyethene	27.773	16.7	2	6.33	-	-	2.8	5427	5074.64	5401.8
	Paper & Cardboard	0.9221	0.4	0.1	0.41	0.003	0	0.1			
	Textile	10.595	5.83	0.7	3.31	0.487	0.02	0.3			
	OCF	19.62	9.71	1.2	8.38	0.039	0.02	0.3			
	Total	58.91	32.6	3.9	18.4	0.529	0.04	3.4	58.92		
	percent		55.3	6.7	31.3	0.899	0.06	5.8	100		

City	Percent by weight (dry basis)										
Bhubaneswar	**Components**	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**			
	Plastic/polyethene	100	**60**	7.2	22.8	-	-	10			
	Paper & Cardboard	100	43.5	6	44	0.3	0.2	6			
	Textile	100	55	6.6	31.2	4.6	0.15	2.5			
	OCF	100	49.5	6	42.7	0.2	0.1	1.5			
	Total Weight (Dry basis)										
	Components	**RDF in TPD**	**C**	**H**	**O**	**N**	**S**	**Ash**	**HCV**	**NCV**	**E.C(modified)**
	Plastic/polyethene	19.6	11.8	1.4	4.47	-	-	2	5317	4964.19	5295.41
	Paper & Cardboard	12.972	5.64	0.8	5.71	0.04	0.03	0.8			
	Textile	14.175	7.8	0.9	4.42	0.652	0.02	0.4			
	OCF	NA	-	-	-	-	-	-			
	Total	46.747	25.2	3.1	14.6	0.691	0.05	3.1	46.75		
	percent		53.9	6.7	31.2	1.478	0.1	6.6	100		

- Not Available R. F- Recycled fraction E.C- Energy content

Sample Calculation:

Bhubaneswar:

Plastic→

C (%) = 19.6*60% = 11.8;

H (%) = 19.6*7.2% = 1.4;

O (%) = 19.6*22.8% = 4.47;

Ash (%) = 19.6*10% = 2

Paper & Cardboard→

C (%) = 12.97*43.5% = 5.64;

H (%) = 12.97*6% = 0.8;

O (%) = 12.97*44% = 5.71;

N (%) = 12.97*0.3 = 0.04;

S (%) = 12.97*0.2 = 0.03

Ash (%) = 12.97*10% = 0.8

Textile→

C (%) = 14.18*55% = 7.8;

H (%) = 14.18*6.6% = 0.9;

O (%) = 14.18*31.2% = 4.42;

N (%) = 14.18*4.6 = 0.65;

S (%) = 14.18*0.15 = 0.02;

Ash (%) = 14.18*2.5% = 0.4

Others Combustible Fraction-- C (TPD) = N.A; H (%) = N.A; O (%) = N.A; N (%) = N.A; S (%) = N.A; Ash (%) = N.A

Overall Percentage:

C (%) = (Total carbon content / total RDF fraction) ==> 25.2/46.75= 53.9;

H (%) = (Total Hydrogen content / total RDF fraction) ==> 3.1/46.75= 6.7;

O (%) = (Total Oxygen content / total RDF fraction) ==> 14.6/46.75= 31.2;

N (%) = (Total Nitrogen content / total RDF fraction) ==> 0.67/46.75= 1.48;

S (%) = (Total Sulphur content / total RDF fraction) ==> 0.05/46.75= 0.1;

Ash (%) = (Total carbon content / total RDF fraction) ==> 3.1/46.75= 6.6;

Calorific Value:

Dulong's Formula → HCV = 1/100[8400*C+(H-O/8) +2240*S] ==> 1/100[8400*53.9+(6.7-31.2/8) +2240*0.1] = 5317 kcal/Kg

→ LCV = [HCV- 9/100 H X 587] kcal/kg = [5317- (9*6.7/100) *587] kcal/Kg = 4964 Kcal/kg

Modified Dulong's Formula → [337*C+1419(H-O/8) +93*S+23.26*N] *0.239 ==> 337*53.9+1419*(6.7-31.2/8) +93*0.1+23.26*1.48] *0.239 = 5295.4 Kcal/kg

Table B2. Ultimate analysis of fresh RDF

Ultimate Analysis of Fresh RDF									
Zone	**Indian city**	**C (%)**	**H (%)**	**O (%)**	**N (%)**	**S (%)**	**CV (Kcal/kg)**	**Remarks**	**Source**
Southern	Vellore (dry basis)-TN	58	7	30	0.35	0.24	6100	Collected from literature	[80]
	Salem city (dry basis) -TN	38	7	28	1.25	0.35	4548	Collected from literature	[58]
	Jawahar agar (dry basis)-HYD	55	6.7	33.3	0.21	0.51	5085	Collected from literature	[81]
	Bangaluru (dry basis)- KA	51.11	6.52	34.47	0.73	0.12	4874.53	Calculated	
Northern	Delhi (dry basis)	50.87	6.25	38.68	0.17	0.09	4581.14	Calculated	
	Panchkula (dry basis)-HR	51.19	6.26	38.4	0.46	0.1	4623.55	Calculated	
	Muzaffarnagar (dry basis)- UP	54.37	6.66	31.08	2.52	0.12	5338.58	Calculated	
	Chandigarh (dry basis)-PB	52.59	6.48	34.75	0.84	0.094	4966.95	Calculated	
	Mohali (dry basis)-PB	51.54	6.32	37.43	0.54	0.095	4712.68	Calculated	
Central	Bilaspur (dry basis)-CG	53.44	6.58	32.43	2.87	0.13	5179.68	Calculated	
	Bhopal (wet basis)-MP	27			0.7		3500	Collected from literature	[83]
	Rewa city (dry basis)- MP	40.15	10.01	25.54	9.77	2.33	5677	Collected from literature	[84]
Western	Ahmedabad (dry basis)-GJ	52.3	6.49	34.85	0.14	0.08	4939.97	Calculated	
	Jaipur (wet basis)-RJ	37.5	6.5	27.5	1.25	0.35	2450	Collected from literature	[82,86]
	Mumbai (dry basis)-MH	52.21	6.38	36.06	1.33	0.11	4851.13	Calculated	
Eastern	Dhanbad (dry basis)- JH	55.34	6.67	31.27	0.89	0.06	5401.77	Calculated	
	Bhubaneswar (dry basis)- OR	53.91	6.68	31.23	1.48	0.1	5295.41	Calculated	
	Kolkata (wet basis)-WB	52.1	6.6	38.9	2.2	0.2	3225	Collected from literature	[68]

Annexure III.

Table C1. List of cement plants coprocessing of RDF in the year 2019 (or before)

Zone	major city	Cement Plant	Distance from production unit(km)
Southern	Vellore-TN	M/s Chettinad Cement Corporation Ltd., Rani Meyyammai Nagar, Karikklai PO, Guziliamparai (via), DindigulDistt., Tamilnadu 624 703	143
	Salem city -TN	M/s Dalmia Bharat Cement, Ariyalur, Tamilnadu	150.5
	Jawahar Nagar-HYD	M/s India Cements Ltd., Malkapur Village, TandurMandal, Ranga Reddy Distt., Telangana 501 157	54
	Bangaluru- KN	M/s J.K.Cement Works, Muddapur, Bagalkot, Karnataka	474
Northern	Delhi	Cement Corporation of India Ltd-Core 5, scope complex,7 lodhi road, New Delhi- 110003	34
	Panchkula-HR	Cement Works UltraTech Cement Limited, Panipat, Haryana 132107	156
	Muzaffarnagar- UP	M/s Dalla Cement Factory, Village – Dalla, Dist. – Sonebhadra, UP 231207	217.1
	Chandigarh-PN	XG8F+85G, Bal Sanda, Rupnagar, Punjab 140001	45
	Mohali-PN	XG8F+85G, Bal Sanda, Rupnagar, Punjab 140001	40.7
Central	Bilaspur-CG	M/s ACC Ltd., Gagal Cement Works, P.O. Barmana, Distt. Bilaspur (HP), 174 013	38
	Bhopal-MP	M/s ACC Ltd., Kymore Cement Works, P.O. Kymore, Distt. Katni (MP), 483 880	313.2
	Rewa city- MP	M/s ACC Ltd., Kymore Cement Works, P.O. Kymore, Distt. Katni (MP), 483 880	231.6

Western	Ahmedabad-GJ	Ambuja cement	10
	Jaipur-RJ	M/s Ultratech Cement Ltd. P.O. Mohanpura, Tehsil Kotputli, Distt. Jaipur, Rajasthan- 303108	117
	Mumbai-MH	Near MMRDA Grounds, Kolivery Village,MMRDA Area, Bandra Kurla Complex, Bandra East, Mumbai, Maharashtra 400051	7
Eastern	Dhanbad- JH	M/s ACC Ltd., Chaibasa Cement Works, P.O. Jhinkpani, Distt. West Singhbhum Jharkhand 833 215	197.6
	Bhubaneswar- OR	M/s ACC Ltd., Bargarh Cement Ltd., Cement Nagar, PO Bardol, Distt. Bargarh (Orissa), 768 038	323
	Kolkata-WB	Dalmia Ocl India Ltd, Rajgangpur, Sundargarh, Odisha	578

Table C2. Tentative capital cost for setting up to 100 TPD plant

Tentative capital cost for setting up to 100 TPD plant		
Sl no	**Items**	**Cost (Rs lakh)**
1	Air shifter(1nos)	90
2	Shredder Metso (14tph @ 50mm X1 nos.)	325
3	Screen, Ecostar make for segregation & recycling 1 no. @12 tph	145
4	Baling Machine (1 X 15tph)	102
5	Magnetic band (1 no.)	3
6	Conveyors (50 mtrs length approx)	13
7	Weigh Bridge -60T	11
8	Electricals	
a	600 KVA transformer	10
b	1 no. of 365 KVA DG	22
c	Panel & cables	10
d	VCB	4
e	Earthings	5
f	Lighting of shed & boundary wall	15
9	Civil (Covers Boundary wall, office block, rain water harvesting, bore well, soaking pit, road, toilet etc.)	172
10	Covered Shed (2000 sqm)	200
11	Office furniture & computer	2.5
12	Lab equipment	10
13	Fire fighting	30
14	Reject collection Bins- 6 nos	3
15	Electrical Connection charges (govt. department)	10
16	Vehicle (JCB 1 nos. & Tractor 1 no.)	35
	Total	1217.5
	Contingency @3%	36.5
	Grand Total	1254
	Rounded Off	12.55cr

Table C3. Tentative O&M cost for setting up to 100 TPD plant (with government investment on CAPEX)

Sl No	Activity/Equipment	100 TPD Shredding line		
		Unit	**Cost (Rs)**	**Remarks**
1	Shredder consumables	per ton	110	Refer Metso mail
2	Others mechanical equipment consumable & maintenance	per ton	50	-
3	Power consumption for 8 hours (387.5.5 kwhr @ Rs.11 per kwhr) (Load factor = 0.8)	per ton	273	Air Shifter=20 kW Shredder=250kw Screen= 7.5kw Baling mc= 60 kW Conveyors= 20kw Lighting = 10kw Others = 20 kw **Total = 387.5 kw** (Assumed 80% load factor) (*(387.5 X 80% X 8 X 11)/100 = 272.8)
4	6 man-days @ Rs.600 per day for shredders & screen operation & manual sorting over the conveyors	per ton	36	-
5	Mechanical Handling (Man Power + JCB+ Tractor)			-
a	Vehicles charges for 8 hours@ Rs. 625 per hour	per ton	50	-
b	4 man-days @ Rs.600 per day	per ton	24	-
6	Staff & Technicians			-
a	Assistant manager (1 no. @ 5lakh per annum)	per ton	14	-
b	Accountant (1 no. @ 3lakh per annum)	per ton	9	-
c	Supervisor (1 no. @ 3lakh per annum)	per ton	9	-
d	Security (3 nos. @ 10244 per month)	per ton	11	-
e	Weigh bridge operator (1 no. @ 18000 per month)	per ton	6	-
f	Store man (1 no. @ 18000 per month)	per ton	6	-
g	Electrician (1 no. @ 18000 per month)	per ton	6	-
7	Interest (15%) & Depreciation on Capex on Rs. 1255 Lakh	per ton	547**	-
	Total (Rs. Per ton)		**1151**	-

Table C4. Tentative O&M cost for setting up to 100 TPD plant (without government investment on CAPEX)

Sl No	Activity/Equipment	100 TPD Shredding line		
		Unit	Cost (Rs)	Remarks
1	Shredder consumables	per ton	110	Refer Metso mail
2	Others mechanical equipment consumable & maintenance	per ton	50	-
3	Power consumption for 8 hours (387.5.5 kwhr @ Rs.11 per kwhr) (Load factor = 0.8)	per ton	273	Air Shifter=20 kW Shredder=250kw Screen= 7.5kw Baling mc= 60 kW Conveyors= 20kw Lighting = 10kw Others = 20 kw **Total = 387.5 kw**
				(Assumed 80% load factor)
				(*(387.5 X 80% X 8 X 11)/100 = 272.8)
4	6 man-days @ Rs.600 per day for shredders & screen operation & manual sorting over the conveyors	per ton	36	-
5	Mechanical Handling (Man Power + JCB+ Tractor)			-
a	Vehicles charges for 8 hours@ Rs. 625 per hour	per ton	50	-
b	4 man-days @ Rs.600 per day	per ton	24	-
6	Staff & Technicians			-
a	Assistant manager (1 no. @ 5lakh per annum)	per ton	14	-
b	Accountant (1 no. @ 3lakh per annum)	per ton	9	-
c	Supervisor (1 no. @ 3lakh per annum)	per ton	9	-
d	Security (3 nos. @ 10244 per month)	per ton	11	-
e	Weigh bridge operator (1 no. @ 18000 per month)	per ton	6	-
f	Store man (1 no. @ 18000 per month)	per ton	6	-
g	Electrician (1 no. @ 18000 per month)	per ton	6	-
	Total (Rs. Per ton)		**604**	-

Table C5. Tentative O&M cost for setting up to 100 TPD plant for RDF pellet (without government investment on CAPEX)

Sl No	Activity/Equipment	100 TPD Shredding line		
		Unit	Cost (Rs)	Remarks
1	Shredder consumables	per ton	110	Refer Metso mail
2	Others mechanical equipment consumable & maintenance	per ton	50	-
3	Power consumption for 8 hours (413.5 kwhr @ Rs.11 per kwhr) (Load factor = 0.8)	per ton	291	Air Shifter=20 kW Shredder=250kw Screen= 7.5kw Baling mc= 60 kW Conveyors= 20kw Lighting = 10kw Bio-pellet mc= 26kw Others = 20 kw **Total = 413.5 kw**
				(Assumed 80% load factor)
				(*(413.5 X 80% X 8 X 11)/100 = 291)
4	6 man-days @ Rs.600 per day for shredders & screen operation & manual sorting over the conveyors	per ton	36	-
5	Mechanical Handling (Man Power + JCB+ Tractor)			-
a	Vehicles charges for 8 hours@ Rs. 625 per hour	per ton	50	-
b	4 man-days @ Rs.600 per day	per ton	24	-
6	Staff & Technicians			-
a	Assistant manager (1 no. @ 5lakh per annum)	per ton	14	-
b	Accountant (1 no. @ 3lakh per annum)	per ton	9	-
c	Supervisor (1 no. @ 3lakh per annum)	per ton	9	-
d	Security (3 nos. @ 10244 per month)	per ton	11	-
e	Weigh bridge operator (1 no. @ 18000 per month)	per ton	6	-
f	Store man (1 no. @ 18000 per month)	per ton	6	-
g	Electrician (1 no. @ 18000 per month)	per ton	6	-
	Total (Rs. Per ton)		**622**	-

Table C6. Tentative O&M cost for setting up to 100 TPD plant for RDF pellet (with government investment on CAPEX)

Sl No	Activity/Equipment	100 TPD Shredding line		
		Unit	Cost (Rs)	Remarks
1	Shredder consumables	per ton	110	Refer Metso mail
2	Others mechanical equipment consumable & maintenance	per ton	50	-
3	Power consumption for 8 hours (413.5 kwhr @ Rs.11 per kwhr) (Load factor = 0.8)	per ton	291	Air Shifter=20 kW Shredder=250kw Screen= 7.5kw Baling mc= 60 kW Conveyors= 20kw Lighting = 10kw Bio-pellet mc= 26kw Others = 20 kw **Total = 413.5 kw**
				(Assumed 80% load factor)
				(*(413.5 X 80% X 8 X 11)/100 = 291)
4	6 man-days @ Rs.600 per day for shredders & screen operation & manual sorting over the conveyors	per ton	36	-
5	Mechanical Handling (Man Power + JCB+ Tractor)			-
a	Vehicles charges for 8 hours@ Rs. 625 per hour	per ton	50	-
b	4 man-days @ Rs.600 per day	per ton	24	-
6	Staff & Technicians			-
a	Assistant manager (1 no. @ 5lakh per annum)	per ton	14	-
b	Accountant (1 no. @ 3lakh per annum)	per ton	9	-
c	Supervisor (1 no. @ 3lakh per annum)	per ton	9	-
d	Security (3 nos. @ 10244 per month)	per ton	11	-
e	Weigh bridge operator (1 no. @ 18000 per month)	per ton	6	-
f	Store man (1 no. @ 18000 per month)	per ton	6	-
g	Electrician (1 no. @ 18000 per month)	per ton	6	-
7	Interest (15%) & Depreciation on Capex on Rs. 1280 Lakh	per ton	558**	-
	Total (Rs. Per ton)		**1180**	-

***Depending on cost sharing in form of grant, the cost of operation will reduce appropriately