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Waste to Resource: Lessons from Amager Resource Centre (Denmark) for India

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Abstract

The Indian government is thinking about how to manage ever growing waste everywhere from small village to the smart city, everywhere you will find that there is no proper process for waste management and there is no proper dumping ground for this waste. India has a massive population and an even larger landfill problem. The country generates an estimated 1.3 billion tons of trash every year, which is about one-third of the global total. And despite efforts One of the biggest challenges in waste management in India is that people simply don't have enough garbage collection infrastructures to handle the crushing of litter and garbage. The country has only 21 million garbage collectors, compared to China's 700 million, and the cost of hiring someone to do the job can be prohibitive for many municipalities. But this is not related to India only The global challenge of solid waste management has intensified due to rapid urbanization, population growth, industrialization, and changing consumption patterns. Developing countries like India face acute problems of open dumping, landfill overflows, environmental pollution, and public health hazards. In contrast, developed nations such as Denmark have adopted integrated waste-to-resource models that treat waste as an economic and environmental asset. This research paper presents an in-depth study of the Amager Resource Centre (ARC), Denmark, as a landmark example of sustainable waste management and circular economy practices. The paper critically analyses ARC's technological framework, governance structure, environmental safeguards, and social integration, and evaluates its relevance for underdeveloped and developing countries, with special emphasis on India. Using qualitative analysis and comparative assessment, the study proposes an adaptive framework suitable for Indian socio-economic conditions. The paper concludes that while direct replication of ARC is not feasible, contextual adaptation of its principles can significantly contribute to India's waste crisis resolution, climate mitigation efforts, and achievement of Sustainable Development Goals.

Keywords: Waste-to-Resource, Waste-to-Energy, Circular Economy, Amager Resource Centre, Solid Waste Management, India, Sustainable Development Goals

Introduction

Solid waste is any discarded material from daily life, industry, or agriculture that's no longer needed, including common trash like paper, plastic, food scraps, packaging, and larger items like furniture, but also industrial sludge, construction debris, and even hazardous electronic waste, encompassing solids, semi-solids, sludges, and contained gases from various sources like homes, businesses, and mines. Solid waste can come from a variety of sources and consist of multiple types of trash generated from different human activities. These waste types can be categorized into several groups based on their origin, composition and characteristics:

Municipal Solid Waste (MSW): This type includes everyday items discarded by households, such as paper, plastics, food scraps, textiles, packaging materials, yard waste and household hazardous waste like batteries or cleaning products.

Industrial Waste: Generated by industrial processes and manufacturing activities, industrial waste comprises materials like scrap metal, chemicals, solvents, sludge and other by-products from factories and production facilities.

Commercial Waste: Originating from commercial establishments such as offices, restaurants, shops and institutions, this waste type includes paper, packaging materials, food waste and other discarded items.

Construction and Demolition Debris (C&D): Generated from construction, renovation and demolition activities, C&D waste includes concrete, wood, bricks, asphalt, metals, drywall and other materials used in building structures.

Hazardous Waste: Materials that pose a risk to human health or the environment due to their toxic, flammable, corrosive or reactive nature are considered hazardous. This category includes items like batteries, fluorescent bulbs, pesticides, certain chemicals and medical waste.

Electronic Waste (E-waste): Discarded electronic devices and equipment, such as computers, televisions, smart phones and appliances, can contain hazardous materials like lead, mercury and other components that require specialized handling and disposal.

Agricultural Waste: Generated from farming activities, agricultural waste includes crop residues, animal manure, pesticides and other waste produced in agricultural processes.

The diverse types of solid waste outlined above each require different management approaches, including recycling, composting, incineration, landfill disposal or other specialized treatments to minimize their environmental impact and promote sustainable waste management practices.

Solid waste management has emerged as one of the most pressing environmental and governance challenges of the 21st century. The increasing pace of urbanization, rising consumerism, and the dominance of disposable lifestyles have resulted in unprecedented levels of waste generation across the globe. According to international estimates, global municipal solid waste generation is expected to increase by more than 70 percent by 2050, with the sharpest rise occurring in developing countries.

India is one of the most populous countries in the world, with over 1.3 billion people living there. That means a lot of waste is produced every year, and it's not getting any smaller. In fact, according to the World Health Organization (WHO), India produces more municipal solid waste than any other country in the world. And this isn't just an Indian problem it's a global problem that we need to solve fast if we want to live sustainably and protect our environment. India represents a paradox in this context. On one hand, it is witnessing rapid economic growth, urban expansion, and infrastructural development; on the other hand, it struggles with inefficient waste management systems characterized by open dumping, burning of waste, polluted water bodies, and landfill fires. Solid waste management in India is not merely a technical problem but a complex socio-economic and governance issue involving behavioral patterns, institutional capacity, and political priorities.

In contrast, Denmark has successfully demonstrated how waste can be transformed into a valuable resource through scientific planning, advanced technology, and citizen participation. The Amager Resource Centre (ARC) in Copenhagen is a globally recognized example of how waste-to-energy and circular economy principles can be integrated into urban systems. This paper seeks to explore how the ARC model can offer valuable lessons for India and other underdeveloped countries struggling with

excessive garbage generation. The Amager Resource Centre (ARC) project known as is a globally recognized example of a multi-functional waste-to-energy (WtE) plant that combines industrial energy production with recreational space, featuring a ski slope, hiking trail, and climbing wall on its roof, all while aiming for high efficiency and reduced emissions, serving as a landmark for sustainable urban development and innovative design.

Objectives of the Study

The present research paper is guided by the following objectives:

1. To examine the concept of waste-to-resource and circular economy in the context of modern waste management.
2. To study the operational, technological, and governance framework of the Amager Resource Centre (Denmark).
3. To analyze the environmental, social, and economic impacts of ARC's waste management practices.
4. To assess the current status and challenges of solid waste management in India.
5. To identify gaps between developed and under developing country waste management systems.

Research Methodology

- The present paper utilizes a desktop research method of collecting and analyzing relevant data from the existing literature, as utilized in some previous studies. The method consists of three iterative stages (a) scoping, (b) collecting relevant literature, and (c) data analysis. Firstly, the scoping stage involves defining and understanding the research problem under investigation and setting the study scope and boundary. The scope of the paper is to explore the waste management a comparative analytical approach has been used to evaluate differences in waste generation patterns, governance mechanisms, technological capacity, and socio-economic conditions between Denmark and India. The study is exploratory in nature and aims to develop policy-relevant insights rather than empirical generalizations in the last stage; the author organized, analyzed, and synthesized the data collected from the literature. The downloaded works were organized according to the similarity of topics. Then, each document was thoroughly examined, Finally, the themes were summarized in and discussed. Implications and recommendations of the findings are then highlighted. Data collected from multiple sources, including: Academic journals and research articles on waste management and circular economy, Government policy documents and official reports from India and Denmark, International agency reports on waste-to-energy and urban sustainability and Case studies and institutional publications related to the Amager Resource Centre.
- Conceptual Framework: Waste-to-Resource and Circular Economy
- The traditional "take, make, dispose" linear model depletes resources, but the Waste-to-Resource and Circular Economy frameworks offer a regenerative, closed-loop alternative, shifting focus from waste disposal to resource recovery by designing products for durability, reuse, recycling, and recovery, transforming waste into valuable materials to keep resources in use longer, minimize environmental impact, and create new economic value through systemic innovation, unlike the linear model's focus on extraction and discard.
- Traditional Linear Model ("Take, Make, Dispose")
- Process: Resources are extracted, manufactured into products, used briefly, and then discarded as waste.
- Focus: Volume-based production, cost efficiency, and fast turnover.

- Outcome: High resource depletion, pollution, and landfills.
- Waste-to-Resource (WTR) / Circular Economy Model
- Core Principle: A regenerative system that keeps products, components, and materials at their highest utility and value at all times.
- Key Strategies (The "R"s): Reduce, Reuse, Repair, Refurbish, Recycle, And Recover.
- Design Philosophy: Products are designed for longevity, disassembly, repair, and recyclability (cradle-to-cradle).
- Waste as Resource: Waste streams (like textiles, metals, electronics, construction debris) are seen as inputs for new production cycles.
- Supply Chains: Shift from linear to closed-loop systems with reverse logistics.
- Economic Value: Created by regenerating value, not just volume, through extended product life and resource efficiency.

In short Traditional waste management follows a linear model of "take, make, and dispose," which leads to resource depletion and environmental degradation. In contrast, the waste-to-resource approach is rooted in circular economy principles that emphasize reduction, reuse, recycling, recovery, and regeneration .That's why in a circular economy framework waste is considered a secondary resource and materials are kept in use for as long as possible. Even energy is recovered from non recyclable waste and Landfills are treated as the last option. The ARC model is a practical embodiment of this philosophy, demonstrating how technological innovation and policy support can transform waste systems into sustainable resource cycles.

- **Amager Resource Centre (ARC), Denmark: A Comprehensive Overview**

Institutional and Governance Structure

Amager Resource Centre (ARC) in Copenhagen, Denmark, isn't just a waste plant but a key municipal utility managed under Copenhagen's waste strategy, featuring a unique governance blending public service with innovative resource recovery, epitomized by the iconic Amager Bakke (Copenhill) waste-to-energy facility, serving residents with recycled materials, heat, and power, aiming for carbon neutrality with carbon capture tech, and functioning as a regional resource hub.

- Key aspects of ARC structure and Governance
- Public Utility**:** ARC operates as a vital public service, managing nearly all waste for the Danish capital, ensuring efficient resource handling.
- Resource Recovery Focus**:** Its core mission is to transform waste into valuable resources, providing electricity, district heating, and recycled materials to the city.
- Integrated Facility**:** The plant is central, combining advanced waste-to-energy incineration with public recreational features (ski slope, hiking trail) and integrated carbon capture technology, showcasing a new model for waste infrastructure.
- Circular Economy Goals**:** ARC aligns with broader city goals, like Copenhagen's Circular Copenhagen plan, aiming for high recycling rates and carbon neutrality in waste management.
- Technological Innovation: Governance supports advanced tech like demonstration units for industrial-scale CO2 capture, aiming to decarbonizes waste-to-energy processes.
- Strategic Partnerships: ARC works within Denmark's strong regulatory framework and collaborates on initiatives like the C40 Cities network for sustainable urban waste solutions.

- ARC operates the Amager Bakke (CopenHill) waste-to-energy plant, one of the most advanced facilities in the world. The plant processes non-recyclable municipal solid waste through controlled incineration. The heat generated is used to produce steam, which drives turbines to generate electricity and supplies district heating to thousands of households.
- Advanced flue-gas cleaning systems significantly reduce emissions of particulate matter, nitrogen oxides, sulphur dioxide, and dioxins, ensuring compliance with stringent environmental standards.
- Resource Recovery and Environmental Performance
- ARC prioritizes recycling and material recovery before energy generation. Metals are extracted from incineration residues, and bottom ash is reused in construction and infrastructure projects. Continuous monitoring and innovation ensure high energy efficiency and minimal environmental impact.
- Social Acceptance and Urban Integration
- One of ARC's most innovative features is its integration with urban life. The facility includes recreational infrastructure such as a ski slope, hiking trails, and educational centers. This approach demystifies waste management, promotes environmental awareness, and fosters public acceptance.
- In essence, ARC's structure is that of a forward-thinking public enterprise, blending essential waste services with urban integration and ambitious environmental goals, governed to drive innovation in resource management for Copenhagen.
- **Solid Waste Management in India: Status and Challenges**

India faces massive solid waste challenges due to rapid urbanization, generating over 170,000 tones of municipal waste daily, with projections reaching 435 million tons by 2050; key issues include low collection/treatment rates (only ~54% treated), poor segregation, insufficient infrastructure, and reliance on landfills, exacerbated by rising consumption. Trends show increasing generation (62-170k tones/day) with low processing (around 30-50%), demanding better source segregation, recycling, and formal infrastructure to combat pollution India has ranked among the world's 10 biggest producers of waste currently. It is now on the verge of becoming one of the top four countries producing waste within this decade. India caught up with developed countries in respect of consumption but suffers from deplorable practices of waste management by dumping 80% of waste in the open landfills without bothering about processing. It is high time we stopped giving excuses like paucity of municipal staff, lack of adequate funds and proper equipment etc. for the garbage piling up on the street. We should be questioning ourselves as to whether there are no better and scientific ways for disposing of garbage. Unfortunately, the citizens in the country are not able to appreciate the value of segregation of waste into different bins. Where waste management is concerned India faces difficult choices. We can either seek a new solution to waste management or emulate the technologies and experiences of countries like Germany, the Netherlands, Denmark and Australia etc. Whichever path we choose, the garbage disposal and sanitation do not mean merely the sweepers, and waste collectors available at our doorstep sat regular intervals. India has been a late comer to the field of scientific management of waste that involves using cost effective innovative technologies. Today our world is witnessing degradation in the quality of environment through the solid waste being produced in urban centers. It is believed that nearly 62 million tons of wastes are being generated every year in India. But of this vast quantity, only 75-80% is collected. What is worrisome is that of this huge quantity only 22-28% is being processed and treated (Breathe Booklet and Niti Aayog, 2018). Balasubramanian (2018) and Sharma and Jain (2019) have also analyzed the status of municipal waste management in India since 1999-2016. The research suggests

policy changes and its implications on the management practices in India. Mandal (2019) reviewed the evolution of waste management in India and explored its policy gaps. Further the blurring of the urban and semi urban boundaries is forcing a large portion of population to live around these dump sites. Lack of civic water supplies in these areas leads to the people utilizing the ground water in these areas as the prime source of drinking water. This enhances the risk of various health hazards arising because of these unorganized dump sites and health risks.

- Waste generation Trends
- Rapid Increase: India generates about 170,000 tones of municipal solid waste (MSW) daily, projected to hit 435 million tons by 2050.
- Drivers: Urbanization, economic growth, population increase, and changing consumer habits are fueling this surge.
- Per Capita: Average generation is around 370 grams/day, with higher rates in urban areas.
- Current Status and Challenges
- Collection Gap: Around 95% of waste is collected, but significant amounts remain uncollected or dumped.
- Low Treatment**:** Only about 54% of collected waste is treated, with a large portion (around 24%) ending up in landfills.
- Infrastructure Deficit: Inadequate infrastructure, inefficient collection, and limited treatment facilities hinder effective management.
- Poor Segregation**:** Waste segregation at the source (households/businesses) remains a major hurdle, complicating recycling.
- Landfill Burden**:** Increasing waste puts immense pressure on limited landfill space, creating environmental pollution.
- Health & Informal Sector: Improper disposal leads to health hazards, while thousands of informal waste pickers work in poor conditions.
- Structural and Operational Challenges

Despite of the various Indian policy reforms Indies waste management system faces multiple challenges like inadequate segration at various sources and limited processing and recycling capacity of the existing units. Most of the time

Despite policy reforms, India's waste management system faces multiple challenges:

- Inadequate segregation at source
- Limited processing and recycling capacity
- Overdependence on landfills
- Weak enforcement of regulations
- Financial and technical constraints of urban local bodies
- Low public awareness and participation

6.3 Informal Waste Sector

India's informal waste pickers play a critical role in recycling but operate under unsafe and exploitative conditions. Their exclusion from formal systems represents both a social injustice and a missed opportunity for improving waste management efficiency. India faces massive solid waste challenges due to rapid urbanization, generating over 170,000 tones of municipal waste daily, with projections reaching 435 million tons by 2050; key issues include low collection/treatment rates (only ~54% treated), poor

segregation, insufficient infrastructure, and reliance on landfills, exacerbated by rising consumption. Trends show increasing generation (62-170k tones/day) with low processing (around 30-50%), demanding better source segregation, recycling, and formal infrastructure to combat pollution and health risks.

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Current Status and Challenges

There is collection gap around round 95% of waste is collected, but significant amounts remain uncollected or dumped .There is only about 54% of collected waste is treated, with a large portion (around 24%) ending up in landfills. It happens due to inadequate infrastructure, inefficient collection, and limited treatment facilities hinder effective management. Most of the time Waste segregation at the source (households/businesses) remains a major hurdle, complicating recycling. Even due to the landfill burden increasing waste puts immense pressure on limited landfill space, creating environmental pollution. One of the most waste generated from health sector, its informal sector so mostly improper disposal leads to health hazards, while thousands of informal waste pickers work in poor condition. India's informal waste pickers play a critical role in recycling but operate under unsafe and exploitative conditions. Their exclusion from formal systems represents both a social injustice and a missed opportunity for improving waste management efficiency.

Comparative Analysis between Amager Resource Centre (ARC), Denmark and India.

Actually the comparative analysis between ARC and India highlights a persistent reform implementation gap while on the other side ARC provides a progressive, democratic road map which is based upon

citizen centric attitude whereas India's administrative system is a complex, multi-layered, and permanent machinery designed to implement policy, deliver public services, and maintain law and order, serving as the "steel frame" that ensures continuity regardless of political changes. ARC represents the reform vision and recommendations while India represents the ground level administrative reality. ARC has advisory and reform oriented body whereas India is having operational governance machinery. The most important objective of ARC is to improve efficiency, transparency, accountability and citizen partnership where in India front it maintain law, order, service, delivery and administration. The approach of ARC is normative, futuristic and citizen centric approach from Indian side it is based upon procedural, rule bound and hierarchical in nature. The overall focus of ARC is based upon good governance and Indian focus is based on administrative point of view. The accountability of ARC is having strong emphasis on public accountability and ethics whereas Indian accountability is based on more upward towards government than citizen accountability. The overall decision process of ARC is decentralized based upon participatory approach and Indian decision process is centralized one and based upon autocratic red tapeisam. ARC carries transparency proactive discloser, RTI is applicable and it is having open governance and Indian government is often reactive and compliance driven. The service delivery system at ARC is outcome based and citizen oriented and Indian service delivery system is process based and file oriented. The Arc perspective recommends lean government and they emphasizes on role clarity and they supports lateral entry, domain expertise and most importantly ARC carries mission mode governance on the contrary India is having large, multi layered bureaucracy and it is having dominance of generalist administrators and the decision process is slow its due to multiple clearance. Lastly ARC always strengthening Panchayats Raj institutions so they have clear devolution of funds, functions and functionaries and they have cooperative federalism whereas India is having uneven devolution across states and more often Panchayats raj Institution depends on state governments so the fiscal centralization remains strong. In short there is political resistance, bureaucratic inertia, capacity constraints due to federal diversity so there is lack of monitoring mechanism and reform fatigue these are the main reasons of gap between ARC and India.

To conclude the comparative analysis between ARC and India reveals that direct replication of the Danish model is neither feasible nor desirable due to India's distinct socio-economic conditions, scale, governance complexity, and federal diversity. However, the core principles underlying ARC—such as viewing waste as a resource, prioritizing segregation and recycling, adopting mission-mode governance, strengthening local institutions, fostering public participation, and integrating environmental goals with urban planning are highly relevant and adaptable to the Indian context. Contextualized adoption of decentralized waste-to-energy solutions, formal integration of informal waste workers, investment in capacity building of urban local bodies, and sustained citizen awareness campaigns can significantly improve India's waste management outcomes.

In conclusion, India's waste crisis should be seen not merely as an administrative burden but as an opportunity for environmental innovation, green employment, and sustainable urban transformation. By selectively adapting the lessons of the Amager Resource Centre within its own socio-economic realities, India can move closer to resolving its landfill crisis, reducing environmental pollution, mitigating climate change impacts, and advancing multiple Sustainable Development Goals. The transition from "waste disposal" to "waste as resource" is not just a technological shift, but a governance, behavioral, and cultural transformation that India must urgently embrace.

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