G20 भारत 2023 INDIA

RMI

CEEW THE COUNCIL

Unlocking India's Circular Waste Economy Potential for Sustainability

INSIGHTS ACROSS SEVEN KEY SECTORS

DECEMBER 2024

Disclaimer

This discussion paper, developed collaboratively by WRI India, RMI, and CEEW, details pathways to support circularity across the solar, battery, steel, construction, agriculture, wastewater, and organic waste sectors. The G20 Secretariat's priority to spur the advancement of a circular economy in India has guided the design of this piece. It is intended for initiating discussions on this topic among concerned officials and government departments and an expanded and peer-reviewed version of this paper will be publicly published in due course.

Unlocking India's Circular Waste Economy Potential for Sustainability

INSIGHTS ACROSS SEVEN KEY SECTORS

DECEMBER 2024

About These Papers

This discussion paper, developed collaboratively by WRI India, RMI, and CEEW, details pathways to support circularity across the solar, battery, steel, construction, agriculture, wastewater, and organic waste sectors. The G20 Secretariat's priority to spur the advancement of a circular economy in India has guided the design of this piece. It is intended for initiating discussions on this topic among concerned officials and government departments and an expanded and peer-reviewed version of this paper will be publicly published in due course.

Acknowledgements

- G20 Secretariat, India
- Sequoia Climate Foundation
- RMI
- CEEW
- WRI India

Note: Each paper has been edited by the organisation that has authored it and follows the editorial guidelines of the respective organisation.

Authors

G20 Secretariat, India

- Sujit Jena

CEEW

- Akanksha Tyagi
- Ajinkya Kale
- Saiba Gupta
- Nitin Bassi
- Kartikey Chaturvedi
- Ayushi Kashyap
- Clark Kovacs
- Adeel Khan
- Priyanka Singh
- Rahul Das
- Srishti Mishra

RMI

- Akshat Aggarwal
- Marie McNamara
- Akshima Ghate
- Tarun Garg
- Sai Sri Harsha Pallerlamudi
- Zoya Zakai

WRI India

- Sree Kumar Kumaraswamy
- Virabh Lad
- Sanjar Ali
- Prayash Giria
- Aditya Ajith
- Sampriti Baruah
- Nupur Kulkarni
- Kavita Sharma

Table of Contents

Foreword

अमिताभ कांत
Amitabh Kant
जी20 शेरपा
G20 Sherpa

सत्यमेव जयते

भारत 2023 INDIA

India has been a strong advocate of sustainable lifestyles and climate justice. **Under India's G20Presidency in 2023, through Lifestyles for Sustainable Development (LiFE)**, we focussed on adaptation-related lifestyles and highlighted the urgency of bringing in a paradigm shift from mindless and destructive consumption, such as excessive use of single-use plastics and non-essential goods, to mindful and deliberate utilization of resources. Under India's G20 Presidency, many significant institutional initiatives were announced, including the launch of the Resource Efficiency and Circular Economy Industrial Coalition (RECEIC), ending plastic pollution &reducing waste generation inter-alia by applying the waste hierarchy.

The same has been reflected in **Brazil's G20 Presidency in 2024**,which strongly advocated for the circular economy, mainstreaming LiFE, ending plastic pollution, and prioritizing prevention, reduction, reuse, and recycling of waste as the G20 countries contribute ~75% of global waste and the majority of the global consumption of natural resources.

As India experiences unprecedented economic growth, there is a significant opportunity to ensure that this growth is both resource-efficient and sustainable. By promoting circular economy principles across key sectors, India has the potential to lead the world in sustainable development. These sectors include solar panels, batteries, steel, construction and demolition, agricultural waste, wastewater, and municipal solid waste. The G20 Secretariat, India, is uniquely positioned to champion this transformation and support India's ambitions for sustainable economic growth, energy security, and climate action.

This discussion paper is a strategic tool for the G20 Secretariat to advance India's ambitions for circular and sustainable growth across key sectors. It is the result of a collaborative effort, with WRI, RMI, and CEEW playing a key role in shaping its insights and recommendations. Sequoia Climate Foundation's invaluable support in bringing together these key organisations and initiating thought leadership on this critical topic has been instrumental in advancing this work as we move towards a Viksit Bharat by 2047.

This paper presents a concise assessment of the current policy, market, and technological landscape of circularity across sectors. It also provides actionable guidance for ministries' key stakeholders to drive meaningful change and create circular supply chains. It seeks to identify near-term solutions curated for the Indian marketplace while also drawing on global best practices and collaboration where applicable. Each chapter unveils dynamic sector-specific strategies designed to forge a cohesive national policy framework, ignite stakeholder engagement, and drive innovation while enhancing workforce development. Furthermore, it emphasises integrating globally recognised tools, best practices, and global standards to establish vibrant circular value chains that propel India's economic growth and development.

Today, many of India's supply chains remain linear, heavily reliant on imports, and often result in the premature discarding of materials. An overreliance on imports, coupled with significant material wastage, underscores the inefficiencies within the current system. There is a critical need and opportunity to transition to a circular supply chain that emphasises reuse, repurposing, and recycling. This shift helps reduce waste, strengthens domestic supply chains, and reduces dependence on external resources. Such an approach improves efficiency, captures end-of-life value, and supports sustainable growth. Adopting a circular supply chain is both resilient and economically beneficial. Additionally, circularity can foster the growth of new industries, such as recycling& repurposing, contributing to job creation & sustainable development.

India must focus on strengthening policy and regulatory frameworks to incentivise recycling and promote resource efficiency. Equally important is investing in research and development to foster domestic technological innovation, advance recycling technologies, and support second-life applications for materials. Another critical step is developing infrastructure to enable efficient systems for material recovery, waste processing, and recycling. Moreover, fostering collaborative partnerships through inter-ministerial coordination and industry cooperation can create a positive ambition loop, where stakeholders move beyond competitive dynamics to achieve circularity for the benefit of all.

By embracing circularity, India will not only advance its net-zero and economic growth goals but also establish itself as a global leader in resource efficiency and sustainability. I am confident that this publication will inspire action and pave the way for transformative progress in addressing India's circular economy priorities as we move towards a more sustainable tomorrow.

(Amitabh Kant) 26/11

26/11/2024

वसुधैव कुटुम्बकम्

ONE EARTH • ONE FAMILY • ONE FUTURE

Tel : +91-11-24156460, 24156500 • E-mail : g20sherpaoffice@mea.gov.in / amitabh.kant@nic.in

भारत सरकार, जी20 सचिवालय, सुषमा स्वराज भवन, नई दिल्ली - 110021

Government of India, G20 Secretariat, Sushma Swaraj Bhawan, New Delhi - 110021

Executive Summary

India is experiencing significant economic growth, with its GDP reaching $3.4 trillion in 2023 and a projected growth rate of 7% through 2024. Industrial production and urbanisation are transforming the nation, driving an ever-increasing demand for resources. At this critical juncture, India faces two potential paths: continuing with the traditional *business-as-usual* approach to industrial development or embracing a more sustainable and regenerative model based on circularity. Circularity refers to an economic system designed to eliminate waste, maximise resource efficiency, and maintain products and materials at their highest quality for as long as possible. This approach addresses environmental externalities while fostering innovation, resilience, and long-term economic growth.

India can develop a growth trajectory that decouples growth from fossil fuel consumption and waste to become a global leader in circularity. However, realising this potential will require action from both the public and private sectors. India can create circular practices that generate economic prosperity and address environmental challenges by investing in R&D, improving policy frameworks, mobilising financing mechanisms, and fostering cross-sector collaboration.

This series of sector-specific discussion papers offers actionable guidance for advancing circularity across key sectors. These sectors include solar panels, batteries, steel, construction and demolition, agricultural waste, wastewater, and municipal solid waste. The papers highlight what is needed to shift from linear, import-reliant supply chains to a circular economy, emphasising reuse, repurposing, and in selected sectors of the economy where there is high feasibility. Each chapter provides a comprehensive landscape assessment, identifies market challenges, presents the business case for adopting circular practices, and explores actionable solution pathways to advance circularity within a particular sector.

Although each of the selected sectors in India face distinct challenges, there are key intervention points that can drive circular economy practices across industries. Below are eight critical areas that offer scalable pathways to promote circular economy practices:

Advancing Recycling Technologies and Innovation

India must invest in research and development to improve recycling technologies, enabling more efficient sorting and processing of metals and inorganic and organic materials.

Infrastructure Development

Building robust waste management systems and logistics networks is essential to ensure efficient collection, recycling, and recovery of materials, particularly in underserved regions.

Traceability

To address human rights and environmental concerns, optimise material recovery, and create a trusted and efficient circular economy, transparent and traceable value chains are essential. This can be achieved through robust monitoring systems, data-driven insights, and global standards.

Policy and Regulatory Frameworks

A cohesive policy framework, including clear targets for material recovery, Extended Producer Responsibility (EPR), and incentives for recycling, will create a conducive environment for circularity.

Investment in Circularity

Creating an attractive investment environment through public-private partnerships and financial incentives will support the scaling of circular practices, reducing barriers such as high upfront costs.

Circular by Design

To minimise waste, incorporate circular principles in product design, focusing on durability, reuse, repair, recovery, and recycling.

Workforce Development and Skill Building

Training workers in new circular economy industries will ensure a skilled workforce ready to drive innovation and operationalise circular practices. Workforce development in circularity presents a significant employment opportunity, creating jobs both nationally and for those who lead initiatives to drive circular practices.

Collaboration

Cross-sector collaboration involving government, industry, academia, and civil society is key to creating integrated solutions and accelerating the transition to a circular economy.

A collaborative approach across sectors, supported by innovation, infrastructure, and policy alignment, is key to positioning India as a leader in circular economy practices. This approach will help address environmental challenges while fostering economic growth. The guidance in each chapter aims to help develop regulatory frameworks, promote technology adoption, foster partnerships, and encourage business model innovation, all with the goal of advancing circularity across multiple industries in India. This work serves as a foundational framework, with more detailed techno-economic analysis and sector-specific roadmaps to be developed in upcoming publications.

Introduction

In India, the concept of circularity is not merely an emerging trend, but is deeply rooted in cultural traditions that prioritise conservation, sustainability, and respect for resources. These long-standing values provide a strong foundation for scaling circular economy principles across the country. This philosophy manifests clearly in daily life. For instance, *kabadiwalas*, or scrap traders, actively collect and recycle materials such as paper, metals, and plastics from households. Moreover, community initiatives prioritise reducing food waste and adopting practices aimed at minimising resource wastage. These traditions reflect India's inherent ability to operate with minimal waste, showcasing an existing cultural alignment with the principles of a circular economy.

By integrating these traditional practices with modern infrastructure, innovative policies, and technology, India can uniquely position itself to build a sustainable circular economy. This approach conserves resources and mitigates environmental impacts and honours the country's cultural values of stewardship and sustainability.

The Indian government has recognised the transformative potential of a circular economy, noting its capacity to drive environmental conservation, economic growth, and job creation. Circularity emphasises sustainable practices, including ensuring ethical working conditions, a priority reflected in India's Lifestyles for Sustainable Development (LiFE) initiative, which collaborates with various organisations to promote human rights across working environments.

As India embarks on this transition, it stands to unlock significant economic benefits for businesses and citizens alike, while simultaneously addressing critical challenges such as pollution, resource depletion, and waste. By adopting circular practices, the country can foster a more sustainable and resilient future, creating opportunities across sectors and improving the well-being of its population.

A circular economy is an economic system designed to minimise waste and maximise resource efficiency by reusing, repurposing, and recycling materials. It contrasts with traditional linear "take, make, dispose" models by emphasising closed-loop processes where resources are renewable, and products retain their value and quality for extended durations. This approach spans the entire lifecycle of products and materials—from design and production to consumption and end-of-life management—focusing on sustainable practices that enhance resource utilisation, material recovery, and promotion of environmental sustainability alongside economic growth.

Circularity is crucial for India's sustainable development, energy security, and climate action goals. Embracing a circular economy can foster the growth of new industries, such as recycling, remanufacturing, repurposing, creating jobs, and contributing to sustainable development. Environmentally, circularity reduces emissions, freshwater consumption, and the adverse effects of resource extraction.

To fully realise the ecological and social benefits of circularity, India must address several pervasive challenges that cut across policy, infrastructure, market dynamics, and social behaviour. These issues, though not uniform across all markets, arise from the inherent complexity of circular value chains, which involve multiple actors with varying priorities and challenges. Below are key market barriers that should be strategically addressed.

Policy and Government Coordination

Fragmented policies, weak enforcement, and inconsistent incentives fail to support the production and adoption of recycled materials effectively. Trade barriers can exacerbate resource shortages and supply chain disruptions, highlighting the need for policies that strengthen supply chains and incorporate circular economy principles to foster sustainable resource management. Furthermore, poor coordination among government bodies often results in overlapping or contradictory policies, slowing the momentum needed for systemic change.

Supply Chain Vulnerabilities

Given the interconnected and global nature of many supply chains, heavy reliance on imported metals and other products heightens supply chain risks. The inability to recycle and reuse materials domestically further exposes these supply chains to disruptions and geopolitical risk.

Lack of Traceability

Without reliable data on waste generation, composition, and material flows, planning and decision-making become reactive rather than proactive. The absence of lifecycle-tracking mechanisms to trace a product from cradle to grave leads to a lack of accountability.

Inefficiency and Stagnated Innovation Development

Limited adoption of advanced recycling technologies reduces operational efficiency and recovery rates. Inadequate investments in R&D stifle innovation. This technological gap prevents India from fully capitalising on the opportunities that circular systems can provide.

Infrastructure and Logistics Deficiencies

Inefficient transportation and logistical gaps increase costs, led to delays, and create bottlenecks in waste management systems. Poor handling practices during collection and sorting result in contamination, diminishing the quality and value of materials that could otherwise be reused or recycled.

Low Economic Viability and Market Development

Quality concerns and a lack of consumer awareness stifle demand for recycled materials. At the same time, high price volatility and slim profit margins deter investments in recycling and resource recovery operations. The absence of robust secondary markets limits scalability, trapping the sector in a cycle of underperformance.

Social and Behavioural Barriers

Limited awareness and insufficient capacity-development initiatives restrict community participation, making it difficult to shift consumer behaviour toward sustainable practices. Without broad stakeholder engagement, the circular economy cannot achieve its full potential.

Moving forward, India must adopt a comprehensive approach that aligns shared value creation with targeted incentives. By fostering innovation, building robust infrastructure, and addressing policy fragmentation, India can overcome the systemic challenges hindering its transition to a circular economy.

With its unique blend of traditional resourcefulness and emerging technological capabilities, India has the potential to lead globally in circularity, driving sustainable growth and resilience for future generations.

By addressing these challenges, India can transition to a sustainable growth model that balances economic development with environmental conservation. Circular practices not only drive resource efficiency but also transform waste into value, unlocking economic opportunities that align with India's climate and economic priorities. This transition holds the promise of creating a more resilient and sustainable future for India.

Overview of the Supply Chains Covered

This paper explores the reuse, recovery, processing, and recycling of metals, organic waste, and water, focusing on key sectors where circular economy principles can drive significant impact. The paper is strategically organised by material properties, with chapters sequenced to emphasise synergies between neighbouring sectors and reflect the interconnected nature of differing value chains and sectors. It begins with an examination of solar panel production, transitions to batteries, the steel value chain, and construction waste, and then shifts to agricultural waste. The paper concludes with an analysis of wastewater and municipal solid waste, presenting a holistic view of circularity across diverse sectors. A detailed look at the sectoral descriptions are as follows:

The **solar panel value chain** focuses on end-of-life recycling, with some discussions of manufacturing and reuse. Recycling is essentially the downstream value chain and includes dismantling (relevant for silicon-based modules and includes junction boxes and aluminium frames), delamination (backsheet, encapsulant, and glass), and metal recovery (silicon, silver, copper, etc.). The recovered materials can feed into other sectors depending on the purity grades. Here, the discussions cover technological and regulatory developments within India while drawing learnings from other major markets. The chapter also emphasises the opportunities in a closed circular economy loop, which will support strengthening the upstream solar value chain by offsetting the mineral requirement of various critical minerals such as silicon and copper.

The **battery value chain** begins with the upstream extraction of critical minerals like lithium, cobalt, and nickel, essential for production. These materials are then refined and processed in the midstream phase into components such as cathodes and electrolytes, often requiring advanced chemical techniques. In the downstream phase, these components are assembled into battery cells, modules, and packs, primarily for electric vehicles, with manufacturers scaling production to meet growing demand. At the end-of-life stage, batteries are either reused, repurposed for second-life applications, recycled to recover valuable materials, or ideally responsibly disposed of, with reverse logistics systems facilitating efficient collection and processing to support a circular economy.

This chapter covers batteries used in electric vehicles (EVs), consumer electronics like laptops and cell phones, and stationary energy storage systems, all of which share common materials and production processes. Emphasis is placed on EV batteries, as they represent the largest and fastest-growing segment of new demand. This discussions in this chapter address challenges such as inefficiencies in capturing value, waste collection, and the need for improved recycling technologies. It also highlights recommendations for promoting second-life applications, fostering public-private partnerships, and driving regulatory reforms and technological innovations to support battery circularity.

The **steel value chain** covers raw material extraction and ironmaking to steel production, rolling, finishing, and distribution. The upstream phase involves extracting and processing raw materials such as iron ore, coal, limestone, and natural gas, which are often processed into intermediate products like sinter or pellets to enhance metallurgical quality and processing efficiency in steelmaking. The downstream phase involves converting these intermediates into finished steel through sophisticated ironmaking, steelmaking, and rolling processes. Steel is 100% recyclable, allowing it to be systematically repurposed at the end of its lifecycle, supporting a circular economy and reducing environmental impact.

Steel is a versatile material used across various sectors, including construction, infrastructure, automotive, and manufacturing. Notably, the built environment—comprising the construction and infrastructure sectors—accounts for a significant portion of global steel demand and plays a key role in the steel value chain. These sectors' purchasing choices directly influence demand, resource efficiency, and environmental outcomes. By prioritising sustainable procurement practices and strategically selecting circular, low-emission steel products, end-use consumers can meaningfully contribute to advancing the circularity of the steel value chain.

Construction and Demolition (C&D) waste refers to residual materials from activities taken up during construction, renovation, and demolition of buildings and infrastructure. It may comprise concrete, soil, masonry, stone, metal, wood, glass, plastic, and hazardous substances like asbestos. High-value materials such as metal, glass, and wood are typically salvaged and reused by the industry. However, the bulk of C&D waste comprises of concrete, masonry, and soil, which typically ends up in unsegregated streams that are either used for backfilling or dumped in vacant lands. Today, only a small proportion of construction and demolition waste is diverted to processing facilities for recycling and reuse. This chapter addresses the ways in which policy, infrastructure, and waste management protocols can be improved to achieve a more circular value chain within the construction and demolition sector.

Agricultural wastes refer to materials produced during various agricultural activities and processes throughout the value chain. These wastes may include raw materials, byproducts, or residuals from different stages of agricultural operations. As these materials are no longer useful, they are classified as waste and are typically discarded. Agricultural waste is broadly classified into four categories—crop residues (such as rice straw, wheat straw, and barley straw), livestock waste (including animal excreta and carcasses), agro-industrial processing waste (such as sugarcane bagasse, rice bran, fruit peels, packaging materials, and fertiliser containers), and hazardous or toxic waste (including pesticides, insecticides, and herbicides). Unplanned growth in agricultural production inevitably leads to a rise in the generation of livestock waste, crop residues, and agro-industrial by-products.

The **domestic wastewater value chain** begins with the generation of domestic effluent, which consists of black water (excreta, urine, and faecal sludge) and grey water (from the kitchen and bathing activities). This wastewater is collected and transported via a sewerage network to wastewater treatment plants managed by local urban authorities. Wastewater treatment involves one or more processes of primary, secondary, tertiary, and advanced levels of treatment. Energy is required to pump wastewater into the sewerage network and in the treatment process. The treated wastewater (TWW) is then either discharged into surface water bodies or repurposed for various uses. Depending on the level of treatment, TWW can be reused for both potable and, more commonly, non-potable applications such as irrigation, landscaping in parks and gardens, road cleaning, vehicle washing, construction, industrial processes, commercial cooling, and water body rejuvenation. TWW is conveyed from treatment plants to the points of reuse through tankers or pipelines. Once reused, the water becomes wastewater again, continuing the cycle. A circular economy in urban wastewater management can improve the quality of local water sources and reduce the consumption of scarce freshwater resources.

The **organic waste management value chain** encompasses the journey of organic waste from its generation to its final treatment or safe disposal. The process begins with the generation of organic waste from various sources, including households, commercial establishments, and industries. Proper segregation at the source is critical, as it significantly influences the resource recovery from the waste. For instance, if the organic waste is mixed with domestic hazardous waste, it can contaminate the overall waste. Then, the waste is collected and transported to appropriate treatment facilities. The segregated organic waste is then collected and transported to appropriate treatment facilities.

Organic waste can be treated mainly in two ways: aerobic digestion (composting), which results in compost, and anaerobic digestion (biomethanation), which generates biogas and digestate. Compost can be used in various applications, including agriculture, gardening, and horticulture, while biogas can be used for thermal applications and power generation. Biogas can be further purified, processed, and compressed to become Bio-CNG or compressed biogas (CBG). Bio-CNG, with similar properties to natural gas, offers a renewable and cleaner alternative for transportation and industrial uses, accordingly contributing to a circular economy.

These sectors were specifically highlighted, given their outsized role in supporting economic development, environmental preservation, and social equity. Although it is acknowledged that this paper does not encompass every critical sector, the focus reflects a deliberate prioritisation of sectors currently of high strategic importance for government action. Each chapter defines the role of circularity within a specific sector, outlines actionable strategies, and concludes with recommendations for decision-makers. This structure provides a strategic guide for implementing policies, adopting global best practices when applicable, and building resilient circular value chains that support India's economic growth while promoting sustainability.

Integrating Circularity into a Broader Vision for Sustainable Development

Circularity plays a crucial role in achieving the Sustainable Development Goals (SDGs) by fostering an economic system that minimises waste, conserves resources, and optimises material use throughout supply chains. The principles of circularity directly align with SDG 8—Decent Work and Economic Growth, SDG 9—Industry, Innovation, and Infrastructure, SDG 11— Sustainable Cities and Communities, and SDG 12—Responsible Consumption and Production. Additionally, practicing circularity in sectors like agriculture and wastewater supports SDG 2—Zero Hunger, SDG 6—Clean Water and Sanitation, and SDG 14—Life Below Water. By transforming agricultural waste into valuable resources and adopting sustainable water management practices, circular economy principles can reduce environmental impact and enhance food and water security.

Given the wide-ranging impact of circular economy practices, India can address a variety of SDGs simultaneously. By focusing on organic waste management and water conservation, circularity supports reducing hunger, improving water quality, and protecting ecosystems. This is particularly crucial as only 17% of the SDG targets are on track globally. Adopting circular economy principles offers a pathway for accelerated progress, providing environmental and socio-economic benefits that help meet urgent sustainability challenges.

India's *Viksit Bharat @ 2047* vision is closely aligned with advancing sustainability, inclusive growth, and social welfare. These outcomes coincide with the principles of circularity, which will play a crucial role in helping the government meet its commitment to reducing emissions and promoting renewable energy use. Circularity can be a key lever in achieving these objectives by optimising resource use, reducing waste, and fostering a sustainable, low-carbon economy.

India's G20 Secretariat can play a pivotal role in championing circularity within India by partnering with government ministries and regional actors to emphasise its importance. Circularity offers a unique opportunity to balance rapid industrialisation with sustainability, fostering long-term economic resilience and environmental stewardship.

Unlike many Western economies, which have traditionally followed a linear *take-make-dispose* model, India's societal values and traditional practices inherently align with circular principles. This alignment, combined with India's entrepreneurial spirit and innovative drive, positions the country uniquely to lead on this critical development. By integrating circularity into economic growth strategies and fostering innovation across critical sectors—such as agriculture, water, energy, and manufacturing—India can solidify its position as a global pioneer in sustainable development, setting a benchmark for others to follow. These practices will also play a pivotal role in advancing India's energy transition and climate goals while generating new employment opportunities and driving inclusive economic growth.

This paper outlines a vision for embedding circularity into India's economic strategy, focusing on the solar, battery, steel, construction, agriculture, wastewater, and municipal solid waste sectors. By leveraging recognised tools, best practices, and standards, while fostering innovation, stakeholder collaboration, and workforce development, India can build resilient circular value chains. Through decisive action, India has the potential to lead globally in sustainable development, transforming challenges into opportunities while addressing critical environmental and economic imperatives.

1.0

Enabling a Solar Circular Economy in India

AUTHORS
Akanksha Tyagi and Ajinkya Kale

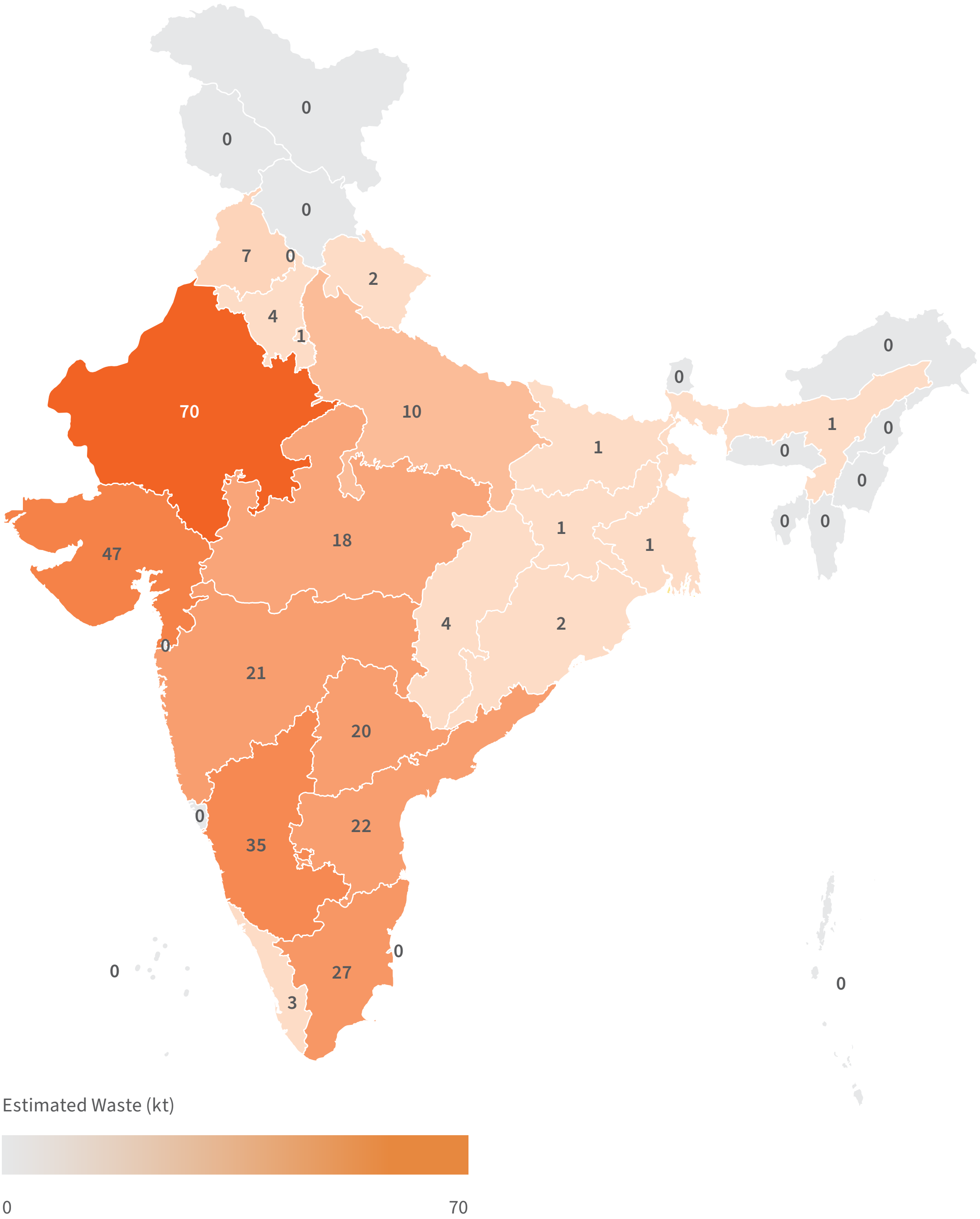
1.1 Introduction

> **A circular solar industry will enhance the resilience of domestic manufacturing industries and support accelerated clean energy transition.**

A sustained deployment of solar technology is imperative to India's climate ambitions. With 89 GW installed as of August 2024, solar photovoltaic (PV) technology represents about 58% of the country's installed renewable energy capacity, excluding large hydropower.[1] However, it must increase to more than 5,600 GW by 2070 for India to achieve a net-zero target.[2] These huge ambitions to deploy solar must accompany designing and implementing strategies to **enhance sustainability throughout the solar value chain** by reducing the material footprint, maximising the reuse of specific components or PV modules, and managing end-of-life (EoL) waste.

The recycling of solar panel waste has drawn particular attention from various stakeholders, with concerns about the safe disposal of waste arising from decommissioned solar projects and manufacturing gaining traction. A study by Council on Energy, Environment and Water (CEEW) estimates that India has about 100 kilo tonnes (kt) of solar waste as of financial year (FY) 2023 from the installed projects.[3] **It is expected to increase three times to reach 340 kt by 2030, representing about 5 GW capacity**. Around 67% of this waste is expected to be generated in five states: Rajasthan, Gujarat, Karnataka, Andhra Pradesh, and Tamil Nadu (see **Exhibit 1.1** on page 21). These waste panels are estimated to contain about 32 kilo tonnes of aluminium, 10 kilo tonnes of silicon, and 12 to 18 kilograms of silver (ibid). The quantum of solar waste will continue to increase as we manufacture and deploy more capacities to meet various near-term and long-term targets. For instance, the addition of new solar capacities by 2030 to meet our nationally determined contribution (NDC) targets (approximate 292 GW)[4] could take the cumulative solar waste to 19 million tonnes by 2050.

Exhibit 1.1 67% of India's Cumulative Solar Waste in 2030 is Expected to Originate from Five States



Source: MNRE and CEEW 2024

The unscientific handling of this waste can have significant environmental and economic implications for the country.

Environmental Implications

Solar modules have a complex material composition that varies with the technology. For instance, crystalline silicon-based (c-Si) modules contain silicon, silver, copper, and lead, polymeric encapsulant, backsheet, and glass. Similarly, one of the most common thin-film module technologies is based on cadmium-telluride (CdTe). Exposure to lead, cadmium and tellurium, beyond a certain threshold,[5] is known to be carcinogenic to humans.[6] Disposing solar waste in landfills can contaminate the environment due to leaching of metals in the soil. The extent of leaching depends on the damage to the solar panel and surrounding conditions. For instance, a non-encapsulated cadmium and telluride panel can see more than 73% of cadmium leaching in simulated acidic landfill conditions.[7] Responsible management of solar waste will prevent environmental contamination due to avoided metal leaching.

Economic Implications

India has classified silicon and copper as critical materials due to their high economic importance.[8,9] Hence, it is important for India to have a resilient supply of these materials to meet the growing demand. For instance, India's production of copper concentrate, as of 2022, was able to meet only 4% of the requirement of copper smelter/refineries, necessitating huge imports.[10] Furthermore, as of 2022, about 70% of copper production was concentrated in eight countries.[11] Recycling solar waste to recover copper could support offsetting this import demand.

Despite this necessity and opportunity, the adoption of circular strategies in the solar industry is limited. Multiple challenges pertaining to technology, markets, and government policies impede the unlocking of this sector's full potential. This whitepaper summarises the current status of circularity in the solar industry in India and highlights the priority areas for accelerating adoption in response to global trends.

1.2 How Does Solar Circularity Contribute to India's Climate Agenda?

Solar energy has emerged as a crucial driver of India's climate initiatives. Its extraordinary growth decade has enabled millions of people to access clean and affordable electricity while also helping to reduce the emission footprint of other sectors, such as industry and transport. Integrating circular practices into the solar industry's current linear economy model will further accelerate the climate agenda as discussed below.

Fulfilment of Various Sustainable Development Goals (SDG)

Creating a circular economy, in general, will help fulfil various SDGs such as **SDG 12**—Responsible Consumption and Production, **SDG 11**—Sustainable Cities and Communities, **SDG 9**—Industry, Innovation and Infrastructure, and **SDG 8**—Decent Work and Economic Growth. For the solar industry, these outcomes imply the following actions.

a. Improve product design to:[12]

- reduce embedded energy, such as using recycled aluminium in frames, solar glass in new modules
- reduce use of critical minerals, such as copper and silver in interconnections
- eliminate use of toxic metals, such as lead in soldering, and
- allow reuse of components, such as eliminating use of adhesives in module assembly

b. Reusing components in new modules, such as recovered solar cells from discarded modules in new modules

c. Recycling the solar waste to recover intrinsic materials of same purity grades that can feed back into the solar industry

Supporting Attainment of India's Nationally Determined Contributions (NDCs)

India's NDC targets include achieving 50% of power generation capacity from non-fossil sources.[13] A circular economy for solar can support these ambitions by enabling a resilient supply chain of minerals and components for domestic manufacturing industries. For instance, a report by CEEW-IEA-UC Davis and WRI India estimates that clean technologies could account for 43% of global copper demand by 2050 in case of a net-zero by 2050 scenario.[14] However, in the same scenario, systematic recycling of solar panels can meet 20% of the solar PV industry's demand for aluminium, copper, glass, and silicon between 2040 and 2050.[15]

1.3 Political Economy of Solar Circularity

A circular ecosystem requires comprehensive regulations, technologies and enabling markets. This section discusses the progress made on these aspects within India and other major solar markets.

Policies and Regulations

The regulatory frameworks for solar waste management are still evolving, with product stewardship and extended producer responsibility (EPR) being the two approaches being explored. The key difference between product stewardship and EPR is the discussed below:

a. **Applicable scope:** In EPR, the scope is limited to postconsumer waste (also called end-of-life stage) whereas product stewardship expands to the entire lifecycle of the product.

b. **Responsibilities:** In EPR, the financial and management responsibility lies exclusively on the producer,[16] whereas in product stewardship, other stakeholders, such as suppliers, retailers, and consumers, also play an important role.

c. **Implementation:** Product stewardship can be either voluntary or required by law, while EPR is largely legislative.

India regulates solar waste under the Electronic Waste (Management) Rules 2022, which are based on the EPR framework.[17] However, the **current regulatory mandates for the sector are not enough**. Under the rules, the solar cell/pane/module producers do not have any collection and recycling targets and must store the waste modules until 2034. The limited regulatory requirements operative today do not incentivise solar waste management, so India has yet to see commercial solar waste recycling.

Globally, the European Union (EU) is the only other legislation with national laws for solar waste management. It covers photovoltaic panels under the Waste Electrical and Electronic Equipment (WEEE) Directive, which sets collection, recycling, and recovery targets.[18] From 2019, the directive mandates collecting 65% of the weight of solar panels sold in the member state markets[19] in the last three years, recovering 85% of the collected waste and recycling or reusing 80% of it.[20]

Many former and current member countries, such as the United Kingdom, Italy, Germany, and France, have translated the WEEE Directive into national regulations. However, the producers' compliance has been low, with only six member countries reporting that they met the targets in 2021.[21]

Other large markets of solar panels such as China, the United States (US), and Australia are yet to have any national regulatory framework for solar waste management. Australia plans to take a different route by covering solar panels under the Product Stewardship Act 2011.[22] The scheme is expected to be introduced by 2025. The State of Washington in the US has passed legislation that requires manufacturers or distributors to implement a EOL stewardship plan starting in 2024.[23]

Other Government Initiatives

In addition to regulations, some proactive steps have been taken by different countries to nurture research, innovation, and private-sector partnerships in solar waste management. In India, the Department of Science and Technology (DST) invited research proposals on Recovery and Recycling of End-of-Life Solar PV Panels/Modules for designing equipment and recycling processes.[24] In 2021, NITI Aayog constituted 11 committees, including on solar panels, to expedite the transition of the country from a linear to a circular economy.[25]

In the US, the Department of Energy (DoE) has released a USD 20 million grant under its Solar Energy Technology Recycling Research, Development, and Demonstration Program for creating technological innovations to increase the reuse and recycling of solar modules.[26]

> **"India is among a few global legislations that have regulated solar waste management."**

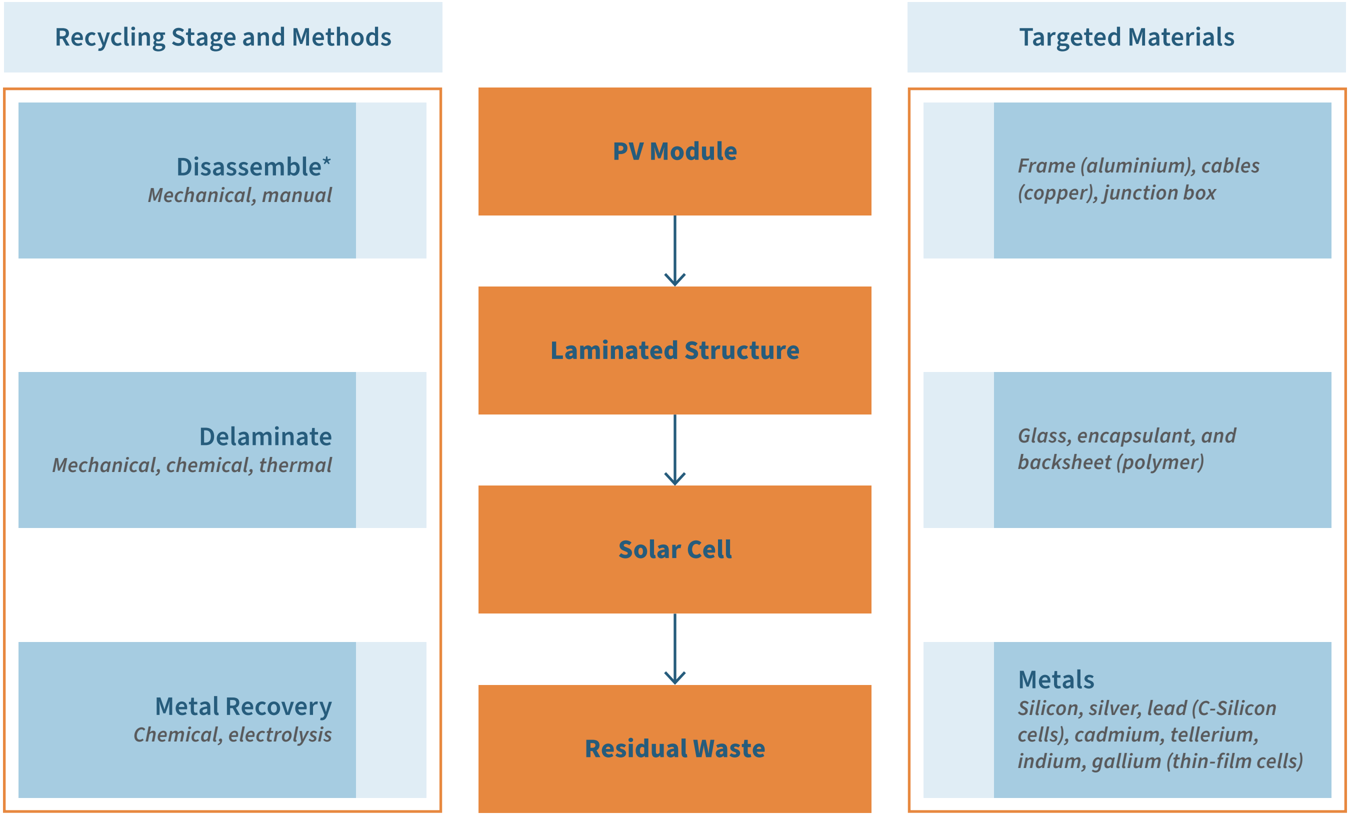
The Australian Renewable Energy Agency (ARENA) funded two projects from the University of New South Wales with AUD 2.92 million for developing solar PV recycling technologies.[27] Similarly, the New South Wales (NSW) government in Australia, under its Circular Solar Grants Program created an AUD 10 million fund to reduce landfilling of solar and battery systems in the region.[28]

In China, the Chinese PV Industry Association (CPIA) has developed various standards for recycling solar modules.[29] These include technical requirements for recycling and reuse of modules, requirements for recycling technology, and specifications for green module design. In 2022, multiple industry associations and academic institutions came together to found PV Recycle Industry Development Centre in China, a non-profit cooperative organisation. Its mandate is to undertake detailed studies on the market outlook, accreditation system, and life cycle emissions of solar module recycling.

Technology

Technology is a crucial enabler for a circular industry and there is a potential to improve the efficiency of current recycling processes. Solar module recycling, a multi-step process that usually involves a combination of mechanical, chemical, or thermal processes, is rapidly evolving (see **Exhibit 1.2**).[30]

Exhibit 1.2 Solar PV Module Recycling is a Multistep Process



Note: *This step is not applicable for thin-film modules recycling as these modules contain cells encapsulated between cover and substrate glass. **Source:** Tyagi and Kuldeep 2021

While improvements remain in efficiency and purity, the potential for further advancements is promising. Most of the available technologies can recover about 80% of the module weight, which mainly contains nonferrous metals such as aluminium and glass.[31] However, considerable improvements are needed to recover high-purity grade silicon, silver, and copper and recycle encapsulant and backsheet, which are often incinerated. Most available recycling options are in Global North countries, particularly the US, Germany, France, Australia, Japan and South Korea. In India, several recyclers have registered on the EPR portal to recycle solar waste, however a commercial full recycling of crystalline silicon solar panels is not known. First Solar, which operates 3.3 GW of module manufacturing facility in Tamil Nadu, has an in-house recycling facility for thin-film solar modules.[32]

Exhibit 1.3 lists the companies offering commercial solar waste recycling services in these countries. Outside this region, there are few recycling equipment manufacturers operating in China.

Exhibit 1.3 **Several Companies in the Global North are Offering Solar Module Recycling Solutions[33]**

REGION	COMPANY
Australia	PV Industries, Scipher Technologies, Solar Professionals, Reclaim PV Recycling, Solar Recovery Corporation, Lotus Energy Recycling, and Elecsome.
European Union	Reiling Unternehmensgruppe, First Solar,[34] Veolia, ROSI.
Japan	NPC Incorporated, Tokyo Power Technology Ltd., Toshiba Environmental Solutions Corporation, Kaneshiro Sangyou, etc.
South Korea	Yoonjin Tech, Wonkwang S&T, and Chungbuk Technoparl.
USA	Echo Environmental, First Solar, We Recycle Solar, etc.

Source: Authors' analysis. Adaptation from IEA PVPS TCP 2022.

Solar modules can also be reused, which is a preferred circular strategy over recycling. Although there are no harmonised standards for module reuse, some companies offer services. These include Rinovaso[35] and 2ndlifesolar[36] from Germany, FabTech Solar Solutions[37] from the US, and Blue Tribe Co. Pty. Ltd.[38] from Australia. Online market platforms like EnergyBin[39] and SecondSol[40] bring together buyers and sellers of used modules.

Market Strategies

The circular solar industry is an emerging market, and solar producers have yet to find an effective market strategy. Given the severity of waste volumes, the private sector has primarily focused on recycling strategies, with a negligible focus on the design and operational life of solar modules. Broadly, these strategies can be classified as adhering to regulatory compliance or maximising the value proposition to customers. A global review of the solar module manufacturers presents the following three prevalent strategies.

One known strategy is for **panel manufacturers to own solar waste recycling** and become an integrated manufacturer. This approach gives them greater control over waste traceability, better visibility of costs, and increased value creation for their customers. For instance, First Solar, a leading thin film panel manufacturer, offers take-back services for their modules and complete recycling.[41]

Manufacturers can also contract out waste processing to recyclers. This approach allows them to navigate through changing regulatory requirements across countries without incurring infrastructural and financial burden. For instance, Yingli Solar, a Chinese solar panel manufacturer, has partnered with ROSI, a French-based recycler, to recycle all their solar waste in Europe to comply with local regulations.[42]

Alternatively, **manufacturers can also seek the services of a third party**, called a producer responsibility organisation (PRO). A PRO completes all regulatory due diligence for producers in exchange for service fees. Besides the advantages of the previous strategy, this approach protects the customers from any waste management crises in case of insolvency of the manufacturer. PV CYCLE is a leading PRO offering solar waste management services in Europe.[43]

These strategies are still nascent and specific to certain markets. Their scalability and replicability, especially in India, remain unexamined.

1.4 What is the Business Case for Solar Circularity?

As mentioned in previous sections, a circular solar industry could unlock significant economic benefits, such as reduced imports, and environmental benefits, such as avoided contamination of land and water. Reduced environmental impacts and economic gains make a favourable business case for the circular solar industry. These benefits are qualitatively discussed below:

Avoided Cost of Imports

In its efforts to strengthen domestic capabilities, the Indian government has introduced import duties on various components of solar cells and modules. For instance, from October 2024, solar glass and tinned copper interconnect will attract 10 and 5% customs duty, respectively.[44] Recycling of solar waste will allow panel manufacturers to reduce these excess duties.

Competitive Exports

Many countries are introducing sustainability-driven non-tariff measures to improve the quality of imports.[45] Some prominent examples include the European Union's Carbon Border Adjustment Mechanism (CBAM) and the United States' (US) Inflation Reduction Act (IRA). As India is among the few countries that regulate solar waste, Indian solar manufacturers have an opportunity to meet these trade requirements. Maximising resource recovery and designing circular business models will allow Indian solar module manufacturers to become competitive in global markets.

New Value Creation Via Waste Management Services

Increasing sustainability requirements will create a demand for dedicated players to undertake waste management activities such as logistics, refurbishing, and recycling. Various actors within and outside the solar industry can take up these roles and generate revenue. Solar panel manufacturers entering these services are likely to benefit more by deeper integration in the upstream and downstream functions of the value chain as well as enhanced value creation for customers.

Improved Investor Confidence

There is a growing requirement for businesses to report on sustainable and responsible business practices. These disclosures are also reviewed by lenders and influence their investments. Hence, a circular model is likely to bring reputational gains to a company and help attract new investments.

1.5 Conclusion

Circular strategies strengthen the overall sustainability of the solar sector while bringing additional economic benefits. However, several barriers prevent the creation of a circular solar industry in India, as discussed below.

Lack of Comprehensive Policies and Regulations

A circular economy extends far beyond waste management, and the opportunity to maximise resource utilisation is reduced in the hierarchy (reduce, reuse, and recycle). However, the current regulatory guidance for the solar industry primarily focuses on recycling without nudging actions towards upstream value chain strategies such as design, reuse, and repair. The differentiated understanding of circular strategies across stakeholders, lack of sector-specific circularity indicators, lack of technical standards also leads to limited business interest.

Low Maturity and Limited Proven Feasibility of Recycling Technologies

Module recycling technologies are still evolving, and there is considerable scope for efficient recycling technologies with enhanced resource recovery and purity. Conventionally, glass and aluminium recycling is well-established, and many recyclers in India recover these components. The challenge remains in the economic recovery of solar-grade products, especially glass. On the other hand, the recovery of metallic elements such as silicon, silver, and copper has yet to be commercially proven in India.

Unfavourable Economics of Solar Module Recycling

Solar module recycling is not remunerative yet. A combination of the above gaps, coupled with weak market linkages for reclaimed materials and the distributed nature of solar waste, render solar waste recycling uneconomical.

1.6 Next Steps

Based on these issues, the following priorities are emerging for policymakers to create a solar circular economy:

Provide Clear Policy Signals for Circular Business Models to Nudge Industry Behaviour

The private sector relies heavily on policy certainty to invest in niche areas such as solar circular economy. The Ministry of New and Renewable Energy (MNRE) and the Ministry of Environment, Forest and Climate Change (MoEF&CC) should work together to design comprehensive policy frameworks for the solar circular economy. The broad intervention areas include:

Dedicated Solar Waste Management Regulations

MoEF&CC should exclude solar modules from the E-waste (Management) Rules and co-create a dedicated waste management framework with MNRE. The framework should set recovery targets for individual materials and incentivise higher purity grades to support uptake by domestic solar manufacturing. MNRE may support these mandates by creating market linkages for recovered materials by leveraging existing mechanisms, such as domestic content requirements and approved list of models and manufacturers (ALMM).

a. **Justification:** The solar industry is a strategic sector for India as it enhances energy security and decarbonisation efforts. It has several specificities, such as long product life, use of toxic metals in quantities higher than counterpart electrical and electronic equipment, and direct bulk import and use of panels by consumers. Waste management regulations should consider these factors while assigning responsibilities to various stakeholders and setting targets for collecting, recycling, and recovering materials. However, combining solar panels with general electrical and electronic waste makes it challenging. The extended producer responsibility framework might also not be the right approach, and other frameworks like product stewardship could be tested. Even in Europe, where solar panels have been under WEEE regulations for about eight years, the progress has been slow. Producers meet their recycling targets by either recycling other waste items or recovering materials like glass and aluminium, discarding the valuable metals. Hence, similar to battery waste, MoEF&CC should consider regulating solar waste via dedicated regulations that reflect the sector-specificities.

Technical Standards for Reuse of Modules

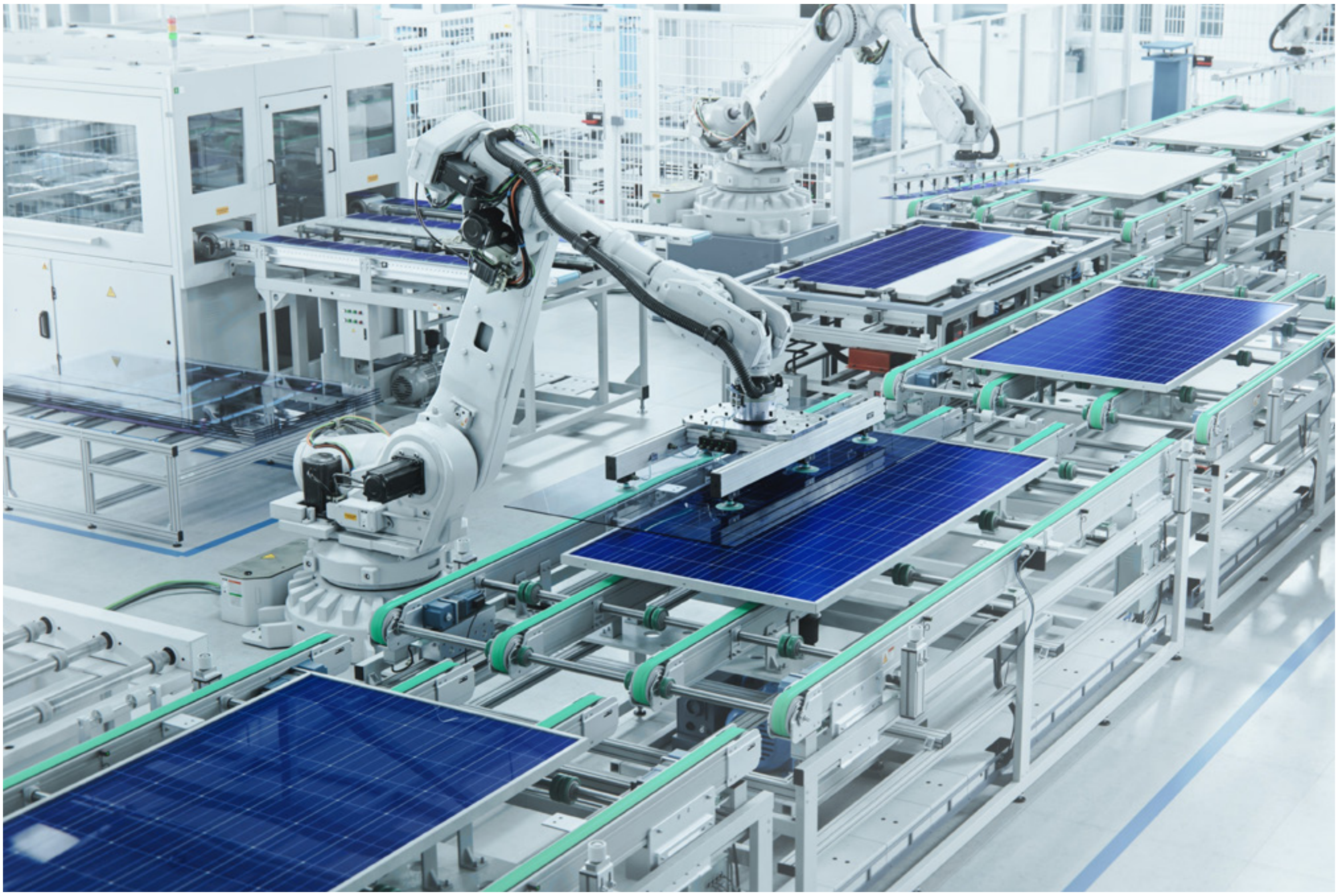
The Bureau of Indian Standards (BIS) should develop technical standards for the safety and performance of the second life of modules. Institutions like National Institute of Solar Energy (NISE) will also play an important role in developing these standards and guidelines. Typically, solar modules can perform at about 80% of their rated capacities at the time of decommissioning,[46] allowing alternate applications, such as street lights and other off-grid systems. The second life of modules can be achieved via direct reuse, repair or refurbishing. However, currently, there are no technical standards or tests to inform the second-life applications of modules. The lack of tests impacts the decision-making of producers and consumers, who might inadvertently channelise a decommissioned module to recycling. Furthermore, the lack of technical standards for second life threatens the safety, performance and market perception towards second life of modules.

Integrate Circular Practices in Existing Processes

Due to limited information about the economic viability and technical feasibility of circular practices such as module design, reuse, and recycling, mass adoption can be challenging. MNRE can help overcome this by identifying linkages with existing processes, such as building waste management costs in tenders and mandating use of recycled materials in procurement schemes, as well as production-linked incentives for recycling. This integration will create a level playing field for the private players, allow them to build in the necessary costs for implementation, and make a demand that should help develop markets.

Support Technology Development and Demonstration

Technological solutions to various circular strategies do not exist today. Considerable research is underway in academic institutions, but it does not necessarily meet industry requirements. Policymakers are crucial in fostering active collaboration between the private sector and academia to develop jointly efficient design, refurbishment, and recycling technologies. MNRE can leverage its Renewable Energy Research and Technology Development (RE-RTD) Programme to conduct pilot demonstrations of recycling technologies within academia and start-ups. They can also facilitate scaling these innovations by involving relevant ecosystem partners that can incubate and accelerate these innovators.



India-specific Evidence on Solar Circularity

The circular sector needs granular data on waste projection, recycling costs, and standards, among other things. This data will inform the design of policies and schemes to promote circularity and the deployment of waste management infrastructure. It will also answer a pertinent question: is there an immediate business case for a circular solar industry, and what market mechanisms are needed to make one? MNRE, with support from institutions such as the Solar Energy Corporation of India (SECI) and NISE, can commission detailed studies on these topics to generate India-specific data on solar circularity.

An ecosystem approach is needed to create and scale a circular solar industry. Achieving this will support India's ambition to develop while decarbonising.

References

1. **MNRE**. *Physical Achievements*. Accessed September 29, 2024. **https://mnre.gov.in/physical-progress/**.

2. **Chaturvedi, Vaibhav, and Ankur Malyan**. *Implications of a Net-Zero Target for India's Sectoral Energy Transitions and Climate Policy*. 2023. New Delhi: CEEW. **https://www.ceew.in/sites/default/files/ceew-study-on-implications-of-net-zero-target-for-indias-sectoral-energy-transitions-and-climate-policy.pdf**.

3. **MNRE and CEEW**. Enabling a Circular Economy in India's Solar Industry: Assessing the Solar Waste, 2024 New Delhi: CEEW. **https://www.ceew.in/sites/default/files/how-can-india-enable-circular-economy-with-solar-waste-management.pdf**.

4. **CEA**. *Report on Optimal Generation mix 2030 Version 2.0*. 2023. New Delhi: CEA. **https://cea.nic.in/wp-content/uploads/notification/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf**.

5. The thresholds vary across jurisdictions and usually specified in national regulations. For example, Electronic Waste Management Rules recommend the use of lead, as a homogeneous material in an equipment, below 0.1% by weight.

6. **Taylor, Curtis, Garvin Heath, Andy Walker, and Jal Des.** *Best Practices at the End of the Photovoltaic System Performance Period.* 2021. Golden, CO: NREL. **https://www.nrel.gov/docs/fy21osti/78678.pdf**.

7. **Ramos-Ruiz, Adriana, Jean V Wilkening, James A Field, and Reyes Sierra-Alvarez.** "Leaching of cadmium and tellurium from cadmium telluride (CdTe) thin-film solar panels under simulated landfill conditions." *Journal of Hazardous Materials 336 (2017): 57.* Accessed 07 September 29. **https://www.sciencedirect.com/science/article/abs/pii/S0304389417303084?via%3Dihub**.

8. **Ministry of Mines.** *Critical Minerals for India*. New Delhi: Ministry of Mines. 2023. **https://mines.gov.in/admin/storage/app/uploads/649d4212cceb01688027666.pdf**.

9. Silicon and copper are used in multiple sectors like information and communication, clean energy technologies, alloys (silicon) and automotive industry (copper).

10. **Ministry of Mines**. *Critical Minerals for India*. New Delhi: Ministry of Mines. 2023. **https://mines.gov.in/admin/storage/app/uploads/649d4212cceb01688027666.pdf**.

11. **CEEW, IEA, UC-DAVIS and WRII.** *Addressing Vulnerabilities in the Supply Chain of Critical Minerals*. 2023. New Delhi: CEEW. **https://www.ceew.in/sites/default/files/addressing-critical-minerals-supply-chain-vulnerabilities-india.pdf**.

12. **Bilbao, Jose I, Garvin Heath, Alex Norgren, Marina M Lunardi, and Alberta Carpenter**. *PV Module Design for Recycling Guidelines*. International Energy Agency (IEA) PVPS Task12. 2021. **https://iea-pvps.org/wp-content/uploads/2021/10/T12_2021_PV-Design-for-Recycling-Guidelines_Report.pdf**.

13. **PIB Delhi**. *Cabinet approves India's Updated Nationally Determined Contribution to be communicated to the United Nations Framework Convention on Climate Change*. 2022. 03 August. Accessed 10 10, 2024. **https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812**.

14. **CEEW, IEA, UC-DAVIS and WRII**. *Addressing Vulnerabilities in the Supply Chain of Critical Minerals*. 2023. New Delhi: CEEW. **https://www.ceew.in/sites/default/files/addressing-critical-minerals-supply-chain-vulnerabilities-india.pdf**.

15. IEA. 2022. *Solar PV Global Supply Chains*. Paris: IEA. **https://iea.blob.core.windows.net/assets/d2ee601d-6b1a-4cd2-a0e8-db02dc64332c/SpecialReportonSolarPVGlobalSupplyChains.pdf**.

16. 'Producers' include original equipment manufacturers, assemblers, and importers selling products and their components in the specified legislative region.

17. **MoEF&CC**. "E-Waste (Management) Rules." 2022. New Delhi. **https://cpcb.nic.in/uploads/Projects/E-Waste/e-waste_rules_2022.pdf**.

18. **European Commission**. "Directive 2012/19/EU of the European Parliament and of the Council." *EUR-Lex*. Accessed 10 10, 2024. **https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02012L0019-20180704**.

19. Alternatively, the collection target is 85% of the solar waste generated on the territory of that Member State.

20. ibid.

21. **European Environment Agency**. *Recycling materials from green energy technologies (Signal)*. 10 10. 2024. Accessed 10 14, 2024. **https://www.eea.europa.eu/en/european-zero-pollution-dashboards/indicators/recycling-from-green-technology**.

22. **Department of Climate Change, Energy, the Environment and Water, Australian Government**. *Product stewardship schemes and priorities- 2020-21 Product List*. Accessed 10 10, 2024. **https://www.dcceew.gov.au/environment/protection/waste/product-stewardship/products-schemes/product-list-2020-21**.

23. **Washington Government**. *Concerning the photovoltaic module stewardship and takeback program*. Accessed 10 10, 2024. **https://ecology.wa.gov/getattachment/2c1d2e4e-14ec-421a-92a4-61512bf61bc8/solar-panel-bill-draft091724.pdf.**

24. **DST**. *Recovery and Recycling of End-of-Life Solar PV Panels/Modules*. 2024. Accessed 10 10, 2024. **https://dst.gov.in/callforproposals/recovery-and-recycling-end-life-solar-pv-panelsmodules**.

25. **NITI Aayog**. *Govt Driving Transition from Linear to Circular Economy*. 18 03. 2021. Accessed 10 10, 2024. **https://pib.gov.in/PressReleasePage.aspx?PRID=1705772**.

26. **DoE**. *Funding Notice: Materials, Operation, and Recycling of Photovoltaics (MORE PV)*. 21 07. 2023. Accessed 10 10, 2024.

https://www.energy.gov/eere/solar/articles/funding-notice-materials-operation-and-recycling-photovoltaics-more-pv.

27. **ARENA**. *Closed-Loop Recycling and Remanufacturing EoL Solar PV*. 02 10. 2020. Accessed 10 10, 2024. **https://arena.gov.au/news/research-boost-for-solar-panel-efficiency-and-cost-reduction/**.

28. **NSW Environment Protection Authority**. *Circular solar grants program*. Accessed 10 10, 2024. **https://www.epa.nsw.gov.au/working-together/grants/infrastructure-fund/circular-solar-trials**.

29. **IEA PVPS TCP**. 2022. *Status of PV Module Recycling in Selected IEA PVPS Task12 Countries*. IEA PVPS. **https://iea-pvps.org/wp-content/uploads/2022/09/Report-IEA-PVPS-T12-24_2022_Status-of-PV-Module-Recycling.pdf**.

24. **DST**. *Recovery and Recycling of End-of-Life Solar PV Panels/Modules*. 2024. Accessed 10 10, 2024. **https://dst.gov.in/callforproposals/recovery-and-recycling-end-life-solar-pv-panelsmodules**.

25. **NITI Aayog**. *Govt Driving Transition from Linear to Circular Economy*. 18 03. 2021. Accessed 10 10, 2024. **https://pib.gov.in/PressReleasePage.aspx?PRID=1705772**.

26. **DoE**. *Funding Notice: Materials, Operation, and Recycling of Photovoltaics (MORE PV)*. 21 07. 2023. Accessed 10 10, 2024. **https://www.energy.gov/eere/solar/articles/funding-notice-materials-operation-and-recycling-photovoltaics-more-pv**.

27. **ARENA**. *Closed-Loop Recycling and Remanufacturing EoL Solar PV*. 02 10. 2020. Accessed 10 10, 2024. **https://arena.gov.au/news/research-boost-for-solar-panel-efficiency-and-cost-reduction/**.

28. **NSW Environment Protection Authority**. *Circular solar grants program*. Accessed 10 10, 2024. **https://www.epa.nsw.gov.au/working-together/grants/infrastructure-fund/circular-solar-trials**.

29. **IEA PVPS TCP**. 2022. *Status of PV Module Recycling in Selected IEA PVPS Task12 Countries*. IEA PVPS. **https://iea-pvps.org/wp-content/uploads/2022/09/Report-IEA-PVPS-T12-24_2022_Status-of-PV-Module-Recycling.pdf**.

30. **Tyagi, Akanksha, and Neeraj Kuldeep**. *How India can Manage Solar Photovoltaic Module Waste Better: Learnings from Global Best Practices*. 2021. New Delhi: Council on Energy, Environment and Water. **https://www.ceew.in/publications/how-can-india-manage-photovoltaic-solar-panel-waste-disposal**.

31. ibid.

32. **First Solar**. *"Sustainability Report 2024"*. 2024. **https://www.firstsolar.com/-/media/First-Solar/Sustainability-Documents/FirstSolar_Sustainability-Report_2024.ashx?la=en-IN**.

33. The companies' list is not exhaustive.

34. Across all markets, First Solar provides recycling services for its own panels, that are based on cadmium telluride (CdTe).

35. **Rinovasol**. *Rinovasol*. Accessed 10 10, 2024. **https://www.rinovasol.com/#:~:text=The%20Rinovasol%20solar%20recycling%20economy&text=By%20repairing%2Frefurbish-ing%20these%20modules,used%20solar%20and%20photovoltaic%20panels**.

36. **2ndlifesolar**. *2ndlifesolar*. Accessed 10 10, 2024. **https://2ndlifesolar.de/**.

37. **FabTech Solar Solutions**. *About us*. Accessed 10 10, 2024. **https://fabtech.net/**.

38. **Blue Tribe Company**. *About us*. Accessed 10 10, 2024. **https://bluetribe.co/project-profile-second-life-solar/**.

39. **EnergyBin**. *Home*. Accessed 10 10, 2024. **https://energybin.com/**.

40. **Secondsol GmbH**. Accessed 10 10, 2024. **https://www.secondsol.com/en/index.htm**.

41. **First Solar**. “Sustainability Report 2024” 2024. **https://www.firstsolar.com/-/media/First-Solar/Sustainability-Documents/FirstSolar_Sustainability-Report_2024.ashx?la=en-IN**.

42. **ROSI**. *ROSI and Yingli Solar establish a strategic partnership for a circular solar energy economy in Europe*. 20 11. 2023. Accessed 10 14, 2024. **https://www.rosi-solar.com/news/rosi-and-yingli-solar-establish-a-strategic-partnership-for-a-circular-solar-energy-economy-in-europe**.

43. **PV Cycle**. *Home*. Accessed 10 10, 2024. **https://pvcycle.org/**.

44. **Government of India**. “Budget 2024-2025: Speech of Nirmala Sitharaman, Minister of Finance.” 2024.

45. **Prabhakar, Prerna, and Hemant Mallya**. *Sustainability-driven Non-tariff Measures: Assessing Risks to India’s Foreign Trade*. 2023 New Delhi: CEEW. **https://www.ceew.in/sites/default/files/sustainability-driven-non-tariff-measures-and-assessing-risks-foreign-trade-risks-india.pdf**.

46. Typically, after 25 years of operation.

2.0

Circular Battery Solutions: Powering India's Sustainable Future

AUTHORS
Akshat Aggarwal, Marie McNamara, and Akshima Ghate

2.1 Introduction

The circular economy has emerged as a vital framework in addressing climate change and resource depletion, emphasising the need to extend the lifecycle of products and materials. Unlike the traditional linear model of *take, make, and dispose,* a circular economy focuses on reuse, repurposing, and recycling, crucial in sectors experiencing rapid growth, such as electric vehicles (EVs) and energy storage systems.

Within this context, battery circularity has become a key priority. Projections indicate that the global electric vehicle (EV) market will require 2.5 to 3 terawatt-hours (TWh) of battery capacity by 2030,[1] making up a significant portion of the total battery capacity needed for the global energy transition, estimated at around 6.5 TWh by 2030.[2] India's current demand for lithium-ion batteries is approximately 15 gigawatt-hours (GWh), and this figure is projected to grow significantly, reaching 127 GWh by fiscal year 2030.[3] This underscores India's pivotal role in the global battery supply chain and the importance of developing sustainable practices to meet both domestic and international energy needs. Circular practices in battery reuse and recycling will reduce reliance on imported materials, lower costs, and generate jobs, while minimising environmental impacts. This approach also supports India's clean energy transition and bolsters its position as a leader in the global battery ecosystem.

Environmental and Economic Impacts of Linear Battery Consumption

The linear consumption model for batteries poses significant environmental and economic risks:

Resource Scarcity

The demand for lithium, cobalt, and nickel has surged, contributing to supply chain vulnerabilities. Lithium, for example, is now primarily used for batteries, with 74% of its production allocated to this industry as of 2021.[4] Global reliance on a few countries for these materials heightens geopolitical risks, prompting initiatives such as India's Khanij Bidesh India Limited. (KABIL) to secure international lithium sources.

Waste Generation

End-of-life battery disposal presents major challenges. Current recycling methods, such as pyrometallurgy and hydrometallurgy, remain inefficient, with low material recovery rates of 7%–13%, especially for Lithium Iron Phosphate (LFP) batteries.[5] This inefficiency perpetuates the extraction of virgin raw materials, increasing environmental strain.

CO_2 Emissions

The battery production process is energy-intensive and reliant on carbon-heavy energy sources, particularly in China, which dominates 60% of global lithium processing.[6] Without advancements in low-carbon production methods and more efficient recycling, the environmental benefits of EV adoption may risk being overshadowed by the carbon footprint of battery manufacturing.

India's Path Forward in Battery Circularity

India, with its growing EV market and supportive policies like the Faster Adoption and Manufacturing of Electric Vehicles in India Phase II (FAME II) scheme and the Production Linked Incentive (PLI) scheme for the National Programme on Advanced Chemistry Cell (ACC) scheme, has the potential to lead in battery circularity. To reduce import dependence and localise battery production, the country must prioritise developing robust infrastructure for battery recycling and second-life applications. By focusing on sustainable lifecycle management, India can address both the environmental and economic challenges posed by linear battery consumption. The creation of a more circular battery supply chain can also partially address the challenge of securing access to minerals for batteries, positioning India as a key player in the global battery ecosystem.

India's net-zero commitment by 2070 makes battery circularity crucial for reducing emissions through recycling and sustainable sourcing. This approach aligns with global climate efforts discussed at CoP and G20, fostering collaboration towards sustainable energy solutions.

Global Commitments to Circular Economies and Established International Precedence

The global agenda increasingly emphasises circular economies to reduce resource dependency, stabilise supply chains, and mitigate the environmental impact of waste generation. With interconnected global supply chains for critical materials like lithium, circular practices are pivotal in reducing geopolitical risks and supporting sustainable development. UN SDG 12 specifically targets responsible consumption and production, aligning directly with circularity initiatives aimed at minimising waste and optimising resource use.

Circular economy discussions have been a recurring theme on global platforms. COP26 saw a notable shift toward circular frameworks, while G20 summits, like Osaka in 2019, highlighted the critical need for circular models in driving sustainable economic growth. Despite its expanding EV market and the pressing need for localised supply chains, India has yet to assume a leading role in global discussions on circularity. However, its potential contributions, particularly in advancing battery circularity, could be significant, driving meaningful progress in this area. Establishing a working group focused on circular economies at platforms like CoP or G20 could position India as a leader in advancing global circularity goals by harnessing its domestic resources and technological capabilities.

By emphasising resource efficiency, waste reduction, and energy security, battery circularity can help nations fulfil their obligations under global climate frameworks and accelerate the transition to a low-carbon, sustainable future.

Scope and Core Themes of this Paper

This paper targets the automotive, energy, and electronics sectors as key areas for advancing circularity. It proposes three major actions:

Promote Policy Action

Stronger regulatory frameworks will enhance circularity by closing policy gaps in battery management and materials reuse. The clear steps recommended in this paper can help governments to prioritise circular economy practices.

Drive Technological Innovation

There is a need for innovations in recycling, reuse systems, and sustainable collection practices, supported by data on the economic and environmental benefits of these investments.

Foster Collaboration

Collaboration across sectors and regions, specifically cooperation between policymakers, industries, international bodies, and civil society, will accelerate the adoption of circular practices through concrete models of joint action.

2.2 Current Landscape of Battery Circularity

The shift toward battery circularity is supported by multiple technologies that enable the reuse, repurposing, and recycling of batteries, especially those used in electric vehicles (EVs). Key technologies are described in **Exhibit 2.1** on the next page.

> **"To understand the current landscape of battery circularity, it's essential to address the challenges that restrict the adoption of reuse, recycling, and repurposing solutions. These impact the efficiency and scalability of circular practices."**

Exhibit 2.1 Key Technologies Enabling Circularity in the Battery Ecosystem

TECHNOLOGY	DESCRIPTION
Refurbishing/ Reconditioning	Batteries that still meet performance thresholds are refurbished or reconditioned for direct reuse in EVs, extending battery life and reducing the need for new raw materials.
Repurposing	Batteries degraded below EV standards are repurposed for energy storage systems (ESS) like solar/wind power backup, grid-balancing, or as replacements for diesel generators.
Mechanical Recycling	Shredding and sorting processes recover key materials like cobalt, lithium, and nickel from batteries, but their efficiency can drop when dealing with hazardous components like electrolytes. Handling these components safely requires additional steps, which can reduce the overall recovery efficiency and increase recycling costs.
Hydrometallurgical Recycling	Acid leaching extracts metals (e.g., lithium, cobalt) more efficiently than mechanical methods but generates chemical waste needing careful management.
Advanced Material Recovery	Direct recycling retains electrode materials in their original state, reducing the need for reprocessing and lowering energy consumption and costs. However, this technology is still in development and not yet scalable, requiring further advancements to achieve commercial viability.

Source: Industry stakeholder inputs. RMI analysis.

Key Stakeholders in Battery Circularity

The drive towards battery circularity involves a complex ecosystem of stakeholders who are essential in fostering a sustainable and efficient battery lifecycle. These stakeholders can be categorised into battery manufacturers, recyclers, policymakers, research institutions, and startups, each playing a critical role in advancing the circularity agenda (see **Exhibit 2.2**, on the next page).

Exhibit 2.2 Key Stakeholders in the India Battery Ecosystem

STAKEHOLDER	ROLES AND RESPONSIBILITIES	KEY PLAYERS IN INDIA
Battery Manufacturers	Design for recyclability, integrate recycled materials, manage take-back programmes for end-of-life batteries.	Log9 Materials , Ola Electric, Celex, Ampere, Pure EV
Recyclers and Reuse Facilities	Recover critical materials (lithium, cobalt), scale recycling infrastructure, develop second-life applications.	Log9, Pure, Okaya, Epsilon Advanced Materials, Vrinda Energy
Policymakers and Government Bodies	Create and enforce regulations, offer economic incentives for circular practices, align with international climate commitments.	Ministry of Mines, G20 Secretariat, Ministry of Science and Technology
Research Institutions and Universities	Innovate and test recycling material recovery technologies, support commercialisation.	VIT University, BITS Pilani, SRM University, Vels University, Jain University
Startups and Innovators	Develop disruptive recycling technologies and circular business models, especially in material recovery.	Altmin, Indi Energy
Renewable Energy Project Developers	Deploy battery energy storage systems (BESS), integrate circularity practices, and drive demand for second-life batteries.	Tata Power, Adani Green Energy, ReNew Power
Energy Storage Manufacturers	Develop and manufacture batteries for grid-scale and off-grid energy storage applications, focusing on circular design and lifecycle management.	Amara Raja, Exide Industries, Reliance Industries

Source: RMI analysis

Challenges

To understand the current landscape of battery circularity, it's essential to address the challenges that restrict the adoption of reuse, recycling, and repurposing solutions. These obstacles impact the efficiency and scalability of circular practices. By outlining these barriers, stakeholders can identify gaps and opportunities to advance circularity in India's battery sector. The following section highlights key challenges related to technology, economics, supply chains, and regulations that must be addressed for a fully circular battery economy (see **Exhibit 2.3**, on the next page).

Exhibit 2.3 Notable Challenges That Can Prevent Effective Circularity in the Indian Battery Ecosystem

CHALLENGES	DESCRIPTION
Value Capture	Expanding the secondary market for reuse can help capture more value and prolong battery life. Additionally, inefficiencies in recycling technologies like mechanical and hydrometallurgical processes limit full recovery of lithium, cobalt, and nickel. India's lack of refining capacity further reduces value capture, with investment needs for domestic recovery estimated at $250 million to $1 billion.
Economic Constraints	High capital costs and insufficient battery waste volumes make scaling recycling operations challenging. With lithium prices fluctuating between $10/kg and $75/kg, recycling profitability remains uncertain. As battery demand rises, more batteries will reach the end of their lifecycle, creating a larger volume of waste for recycling by 2030. While batteries typically have a lifespan of 7 to 15 years, the surge in EV and battery production over the past decade means that by 2030, a significant portion of early-generation batteries from electric vehicles, consumer electronics, and stationary storage systems will begin to reach end-of-life. This growing waste stream will create the necessary scale that justifies planning and policy directions now in order to catalyse investments in large-scale, economically viable recycling operations before the end of this decade.
Supply Chain Issues	Heavy reliance on imports for critical materials like lithium and cobalt, primarily refined in China, adds to India's supply chain vulnerabilities. Lack of domestic refining and difficulties in transporting hazardous materials further complicate effective recycling.
Regulatory and Policy Barriers	Weak enforcement of Battery Waste Management Rules (2022) and unclear accountability hinder progress. Although India's Extended Producer Responsibility (EPR) framework is a step forward, it lacks the comprehensiveness of frameworks in other regions. For instance, the EU's Battery Regulation incorporates mandatory battery passports, detailed recycling efficiency targets, and carbon footprint standards, ensuring end-to-end lifecycle tracking and sustainability.[8] Similarly, China mandates centralised data-sharing platforms and strict recycling quotas for manufacturers.[9] In contrast, India still lacks robust lifecycle tracking systems like battery passports and enforceable efficiency benchmarks, limiting its ability to compete with global best practices. Developing a framework similar to the EU's and China's could help India establish a more transparent and efficient battery recycling ecosystem.
Environmental Impact	Over 85% of battery waste (primarily lead acid) is managed by the informal sector,[10] leading to significant environmental degradation. This does not implicate EV companies or lithium-ion batteries, as most EV batteries are either in use or have not yet reached end-of-life. However, as EV adoption grows, the TERI and NITI Aayog-RMI reports highlight the risk of lithium-ion batteries entering informal channels without robust EPR implementation and formalised recycling systems. Strengthening EPR frameworks and collection infrastructure is critical to ensure safe and sustainable recycling practices.
Data and Transparency Gaps	Limited access to lifecycle data from manufacturers impedes efficient recycling and reuse. India lacks the traceability standards seen in regions like the EU, further restricting the development of a transparent battery circularity ecosystem.

Source: RMI analysis

2.3 Business Case for Battery Circularity

Economic Benefits

A circular battery economy can reduce raw material costs, as recycled lithium can be up to 40% cheaper than mined lithium.[11] This reduces import dependency, fosters profitability, and creates new revenue streams through second-life applications, positioning India's recycling market for significant growth by 2030:

Cost Savings from Resource Efficiency

Circular battery practices in India could lower raw material procurement costs by 25%–30% through recycling and reuse of critical materials like lithium, cobalt, and nickel.[12]

Reduced Dependency on Virgin Materials

Recycling can also cut India's import requirements for critical materials by 15%–20% by 2035,[13] easing its reliance on suppliers in countries like Australia, Chile, and China. This approach enhances resource security while complementing government initiatives like the PLI scheme to localise manufacturing and promote advanced battery storage solutions.

Long-Term Profitability

The Indian battery recycling market is poised to reach INR 8,400 crore ($1 billion) by 2030.[14] Companies such as Attero Recycling and Exigo Recycling are advancing infrastructure for lithium-ion battery recycling, achieving recovery rates of up to 85%–90% for critical metals like cobalt, nickel, and lithium in high-value chemistries such as Nickel Manganese Cobalt batteries (NMC).[15] However, for LFP batteries, which have lower critical metal content, recovery rates remain significantly lower, as the recycling focus shifts to iron and phosphorus, which are less economically viable to recover. This highlights the need for innovations to improve recovery rates across all battery chemistries.

"Circular battery practices in India could lower raw material procurement costs by 25%–30% through recycling and reuse of critical materials."

Second-Life Applications as Revenue Streams

The rise of second-life battery applications for energy storage systems and backup power solutions presents a significant opportunity for manufacturers. These applications allow repurposing of batteries no longer suitable for EVs, opening new revenue streams and enhancing profitability. Second-life batteries can be deployed in sectors such as renewable energy storage, microgrids, and telecom, creating value beyond their original lifecycle.

Job Creation

The transition to a circular battery economy can also drive economic growth by creating over 50,000 jobs across the battery value chain by 2030:

Expansion of Circular Supply Chains

This growth is primarily fuelled by the $ 152 billion EV market projected for the same period, which will create increased demand across the entire battery value chain.[16] Developing a domestic recycling ecosystem will reduce dependency on imported materials and create a thriving job market within the country.

Battery Refurbishment and Second-Life Applications

Battery refurbishment presents a growing market in India, with companies like Mahindra Electric exploring programmes that repurpose end-of-life EV batteries for energy storage and off-grid solar systems. This market could grow to over INR 5,000 crore ($650 million) by 2030,[17] creating new opportunities while addressing energy access issues in rural regions, further driving economic growth.

New Industry Development

India is emerging as a global hub for battery recycling and remanufacturing, supported by government policies like the Battery Waste Management Rules (2022) and the PLI schemes. These regulations, combined with significant private sector investment, are attracting foreign capital and fostering the growth of new industries, particularly in regions like Tamil Nadu and Maharashtra, which are becoming centres for battery manufacturing and recycling.

Environmental Benefits

Adopting a circular battery economy will significantly lower environmental risks, reducing the extraction of raw materials and cutting greenhouse gas emissions. By promoting battery reuse and recycling, India can decrease the ecological footprint of battery production, contributing to global decarbonisation efforts.

Reduction in Greenhouse Gas Emissions

Battery circularity significantly reduces the environmental burden associated with raw material extraction and refining, processes that are highly energy intensive. By recycling lithium, cobalt, and nickel, industries can lower energy consumption and CO_2 emissions across the battery lifecycle. Studies indicate that recycling reduces emissions by up to 30%–40% compared to producing new batteries from raw materials.[18]

Reduce Mineral Consumption

Circular battery practices reduce the need for extracting raw materials like lithium and cobalt, significantly decreasing the ecological damage caused by mining. Recycling can lower the demand for virgin lithium by up to 25% by 2030, contributing to the preservation of natural reserves and minimising the environmental footprint of battery production.

Mitigation of Pollution

Battery recycling prevents hazardous materials from contaminating soil and water. Newer methods, like hydrometallurgy, pollute less than traditional processes like pyrometallurgy, resulting in fewer toxic emissions and enabling the recovery of valuable materials that would otherwise be wasted.

The transition to a circular battery economy also mitigates key risks, such as supply chain disruptions and price volatility, by ensuring a steady supply of critical materials through recycling. This shift not only strengthens supply chain resilience but also reduces dependency on geopolitically sensitive regions for raw material imports

Mitigating Raw Material Scarcity and Price Volatility

The increasing demand for critical materials like lithium, cobalt, and nickel poses risks due to their limited supply and geopolitical concentration. Circular practices such as battery recycling and material recovery can reduce reliance on virgin resources, ensuring a steady supply of recovered materials, stabilising costs, and improving long-term profitability.

Regulatory Compliance and Changes

Regulatory landscapes globally are shifting towards more stringent environmental standards. In India, the Battery Waste Management Rules (2022) aim to enhance recycling and safe disposal. Adopting circular practices ensures companies align with these regulations, avoiding penalties and staying on track with global sustainability goals.

Enhancing Supply Chain Resilience

Dependence on global supply chains for critical materials increases vulnerability to geopolitical tensions, trade restrictions, and disruptions like the COVID-19 pandemic. Developing domestic circular supply chains, such as local recycling hubs, can help companies insulate from global shocks. According to the Federation of Indian Chambers of Commerce and Industry (FICCI), India's lithium dependency could be reduced by 25% by 2030 through local recycling initiatives.[19]

Addressing Geopolitical Risks

Many key raw materials for batteries are sourced from regions facing political instability, such as cobalt from the Democratic Republic of Congo (DRC). Circularity reduces dependency on these unstable regions by sourcing materials through local recycling programmes, mitigating geopolitical risks and lowering operational risks during times of political unrest or global trade disruptions.

2.4 Trends to Watch

To address the challenges India faces in scaling battery circularity, it's crucial to explore emerging trends that hold potential solutions. Given the inherently global nature of the battery value chain, these trends, such as advanced recycling technologies and regulatory shifts, provide a pathway for India to develop localised solutions. Customising global best practices for the Indian context could help mitigate challenges like limited recycling infrastructure and supply chain vulnerabilities. In doing so, India can capitalise on the global momentum while ensuring alignment with its specific needs.

Policy and Regulatory Frameworks

India's Battery Waste Management Rules (2022) provides an extended producer responsibility framework for the battery market and has been the most influential policy driving circularity and waste reduction to date. However, there are opportunities to expound upon this regulation and best practices are emerging globally. For example, Europe has one of the most robust policy frameworks on battery circularity, the EU Battery Regulation, which mandates that by 2026, batteries must contain a minimum percentage of recycled content for materials such as lithium (6%), nickel (9%), and cobalt (12%).[20] This regulatory push aims to reduce reliance on virgin materials and encourage the recovery of critical resources. The EU is also implementing battery passports, which will track the lifecycle of batteries, including recycling and reuse data, improving transparency across the value chain. This mirrors China's existing circularity initiatives, where similar regulatory frameworks are in place to manage battery lifecycles.

In the United States, the Bipartisan Infrastructure Law and initiatives such as the National Blueprint for Lithium Batteries emphasise the development of a circular economy for batteries, with significant investments in battery recycling and reprocessing facilities. Companies like Redwood Materials have emerged as pioneers in building large-scale recycling infrastructure, focusing on recovering lithium, cobalt, and nickel from end-of-life batteries.[21]

Cross-Border Collaborations

Cross-border collaborations have also gained momentum in the global push for battery circularity. The Global Battery Alliance (GBA), a public-private partnership, is working towards establishing a global framework for sustainable battery value chains, focusing on recycling, reuse, and responsible sourcing. The GBA has partnered with governments and industry leaders from various countries to drive policy changes and develop sustainable practices.

In Asia, countries like Japan, South Korea, and China have taken significant steps toward battery circularity by collaborating on recycling technologies. China, in particular, has developed a robust system for recovering critical materials from batteries, with companies like Contemporary Amperex Technology Company Limited (CATL) and Brunp Recycling leading the charge in the circular economy for batteries. These collaborations not only help in knowledge sharing but also drive economies of scale, making recycling technologies more cost-effective.

Multi-stakeholder collaboration is essential for driving battery circularity. Governments, industries, academia, and civil society must work together through public-private partnerships to promote innovation, implement effective recycling infrastructures, and encourage consumer engagement. In India, partnerships like those under the National Mission on Transformative Mobility can foster such coordination. Globally, alliances like the GBA provide platforms for cooperation, where countries and industries collaborate to improve circularity in battery value chains by setting sustainable sourcing and recycling standards.

Innovations in Battery Design

Another key trend is the push for innovations in battery design that enable easier recycling and reuse. Modular battery systems, which allow individual components to be replaced or upgraded, are being integrated into electric vehicles and energy storage systems. Companies like Tesla and BMW are investing in designs that prioritise disassembly and the recovery of high-value materials.

In addition, new battery chemistries such as solid-state batteries and lithium- sulphur batteries are gaining traction, with the potential to extend battery life and improve the recyclability of materials. Solid-state batteries, for instance, are considered safer and have fewer toxic materials than traditional lithium-ion batteries, which could simplify the recycling process.

Technological Innovation and R&D

Research and development should focus on improving battery recycling technologies, advancing second-life battery applications, and exploring sustainable alternatives to key battery materials like lithium, cobalt, and nickel. For example, mechanical and direct recycling methods are being explored to maximise material recovery and efficiency.

Emerging recycling technologies like hydrometallurgical and direct recycling are driving efficiency in recovering valuable battery materials, such as lithium and cobalt, with fewer emissions than traditional methods. These processes are key to expanding battery reuse, prolonging their lifecycle, and significantly reducing environmental impact. Their potential to scale circularity practices is essential for advancing sustainable battery systems.

Establishing robust public-private partnerships is key to driving innovation in circular battery systems. India's PLI scheme provides strong support for such collaborations, offering up to INR 18,100 crores (around $2.4 billion) in incentives to promote local battery production and related innovations.[22] However, the expense of developing cutting-edge technologies like advanced battery recycling infrastructure or solid-state batteries is substantial, often requiring significant government backing to offset initial R&D costs. For instance, the cost of scaling up lithium-ion recycling infrastructure is projected to exceed $1–2 billion,[23] underscoring the importance of government subsidies and international partnerships.

Infrastructure Development

To scale circular battery solutions effectively, India needs targeted investments in its battery waste management and recycling infrastructure, focusing on collection, sorting, testing, and recycling capabilities. For example, the Battery Waste Management Rules (2022) mandate the collection and recycling of waste batteries but fall short in addressing decentralised networks, especially in regions with poor logistics support. The role of smart logistics solutions and urban mining—leveraging existing materials from used batteries for new production—is essential in this context. Companies like Exigo Recycling have pioneered the use of digital platforms to track battery health, optimise resource recovery, and ensure compliance with recycling protocols. By establishing localised recycling hubs, particularly in smaller urban and rural areas, India can reduce the need for long-distance transportation of used batteries. This decentralised approach lowers logistics costs and enhances recycling efficiency by processing battery waste closer to where it's generated, while simultaneously supporting local economies through job creation and infrastructure development.

Case Studies of Successful Circular Economy Initiatives

Leveraging lessons from global actors is crucial as it enables India to adopt proven strategies and innovations, speeding up the development of efficient circular systems while avoiding costly trial-and-error approaches.

European Union

Northvolt (Sweden), a Swedish battery manufacturer, is a key player in the circular economy for batteries. The company has committed to producing batteries with 50% recycled materials by 2030. Northvolt's Revolt Ett facility, the first gigafactory-scale battery recycling plant in Europe, is designed to recycle up to 125,000 tons of battery waste annually. Northvolt's success is driven by supportive policies such as the EU Battery Directive, which mandates recycling targets and promotes the use of recycled materials in battery production. Additionally, strategic investments in advanced hydrometallurgical technologies, partnerships with automotive OEMs for a steady supply of waste batteries, and the use of renewable energy to power the facility have been critical enablers. Northvolt's approach shows the scalability of recycling infrastructure when supported by robust regulations, innovation, and collaboration.[24]

United States

Redwood Materials has become one of the largest battery recycling companies in the United States. The Nevada-based company recycles 95% of key battery materials such as lithium, cobalt, and nickel from end-of-life batteries, which are then supplied to battery manufacturers for reuse. The company has partnered with major automakers like Ford and Volvo to develop a closed-loop battery supply chain in North America. This partnership emerged as the United States is actively prioritising domestic battery production through incentives allocated through the Inflation Reduction Act of 2022 and manufacturers seek to diversify supply chains by emphasising material recovery to reduce reliance on virgin resources. Redwood's approach underscores the importance of vertical integration in the battery value chain and demonstrates the commercial viability of large-scale recycling operations.[25]

China

CATL, the world's largest battery manufacturer, has developed a comprehensive recycling ecosystem in collaboration with its subsidiary Brunp Recycling. CATL's recycling operations focus on recovering materials like nickel, cobalt, and lithium from used EV batteries. By leveraging China's dominant position in the global battery supply chain, CATL has achieved high material recovery rates and improved resource efficiency. The company has also invested in R&D for battery reuse, repurposing EV batteries for energy storage systems, further enhancing the lifecycle of batteries.[26]

Japan

Sumitomo Metal Mining, has pioneered hydrometallurgical recycling processes, enabling the efficient extraction of valuable metals from used batteries. In Japan, the company collaborates with Panasonic and Toyota to collect and recycle end-of-life batteries. Sumitomo's approach integrates closed-loop recycling into its battery production, which helps reduce reliance on raw material imports. This model has proven scalable and adaptable to Japan's evolving EV and energy storage markets, making it a potential blueprint for other countries seeking to develop circular battery systems.[27]

2.5 Conclusion and Next Steps

Fostering a Conducive Ecosystem for Battery Circularity

Building a robust ecosystem for battery circularity requires a focus on three critical pillars: workforce development, domestic research and development (R&D), and infrastructure deployment. These efforts should aim to improve battery recycling technologies, advance second-life battery applications, and explore sustainable alternatives to key materials such as lithium, cobalt, and nickel.

- **Workforce Development**
  A skilled workforce is essential to scale battery circularity solutions. Training programmes should focus on emerging technologies, safe battery handling, recycling techniques, and second-life applications. Empowering workers with these specialised skills will ensure efficient operations and drive innovation across the sector.

- **Domestic Research and Development (R&D)**
  Investment in domestic R&D is vital for advancing technologies that enhance recyclability and material recovery. Innovations, such as modular battery designs and improved recycling processes (e.g., hydrometallurgical methods) can significantly extend battery lifecycles, improve material recovery rates, and reduce environmental impact. Public-private partnerships should be leveraged to pool expertise and resources for developing cutting-edge solutions.

- **Infrastructure Deployment**
  Strategic investments in battery waste management and recycling infrastructure are critical. This includes creating efficient systems for collection, sorting, testing, and recycling, particularly in decentralised locations. Localised recycling hubs can minimise transportation costs and emissions while supporting regional economies and ensure the effective management of battery waste.

For Policymakers

India's policy and regulatory landscape is evolving to support battery circularity, yet a more comprehensive framework is needed. Strengthening regulations like Extended Producer Responsibility (EPR), aligning with international standards, and incentivising recycling and second-life applications are key to fostering circular practices. By encouraging public-private collaborations, India can build a resilient battery supply chain and meet its environmental and economic goals: Policymakers should push for consistent international regulations to harmonise cross-border circular battery management, ensuring the alignment of local laws with global best practices. Coordination at regional and national levels is necessary to ensure market-wide adoption of circular economy practices.

- **Regulation Can Drive Innovation**
  Strong regulatory frameworks, such as the EU's recycling mandates and U.S. infrastructure investments, create a supportive environment for battery recycling. Comprehensive policies that include incentives for recycling and penalties for non-compliance are essential.

- **EPR and Market Development**
  EPR policies hold manufacturers accountable for their products' lifecycle, ensuring sustainable practices. Coupled with this, developing markets for recycled battery materials drives demand and enhances the economic feasibility of circular systems. For India, implementing a closed-loop recycling policy is crucial to reducing import dependency, fostering resource security, and minimising environmental impact. This can be achieved through stricter enforcement of EPR rules, investments in advanced recycling infrastructure, and fostering public-private partnerships to integrate recycled materials into manufacturing.

- **Cross-Border Collaboration and Global Standards**
  International cooperation among governments, private industry, and research institutions, such as the Global Battery Alliance, is key to establishing consistent standards for battery recycling and reuse. Cross-border collaboration ensures effective circular battery systems.

- **Public Procurement**
  Public procurement policies could mandate the use of recycled or second-life batteries in large government projects, especially those related to infrastructure and energy storage, to stimulate market demand for circular battery solutions.

- **Financial Incentives**
  Significant investments in recycling infrastructure and technologies are needed for the commercial viability of circular battery initiatives. Financial incentives, such as tax breaks and grants, help attract private investment into recycling technologies and infrastructure. Additionally, by allocating more incentives to repurposers, incentive allocations can work more directly to support batteries being used in second-life applications like off-grid solar storage before being recycled.

For the G20

The G20 nations have a unique opportunity to lead the way in advancing battery circularity by fostering international cooperation, promoting resource-efficient practices, and addressing critical challenges like resource scarcity and waste management. Two critical activities that can be taken up are as follows:

- **Harmonising International Regulations**
  For battery recycling and second-life applications is essential to streamline cross-border trade and ensure the efficient movement of recycled materials.

- **Joint Ventures**
  India can play a pivotal role by strategically aligning with global players like Australia and Chile to secure ethically sourced lithium and cobalt through bilateral agreements. Such collaborations would not only bolster India's access to critical materials but also reinforce sustainable battery management practices.

Endnotes

1. Global EV Outlook 2023, International Energy Agency, 2023.

2. "Lithium-ion battery capacity to grow steadily to 2030," S&P Global, accessed on November 21, 2024, **https://www.spglobal.com/market-intelligence/en/news-insights/research/lithium-ion-battery-capacity-to-grow-steadily-to-2030**.

3. "Lithium-ion battery capacity to grow steadily to 2030," S&P Global, accessed on November 21, 2024, **https://www.spglobal.com/market-intelligence/en/news-insights/research/lithium-ion-battery-capacity-to-grow-steadily-to-2030**.

4. Lithium Consumption Has Nearly Quadrupled Since 2010," Visual Capitalist, accessed on November 21, 2024, **https://elements.visualcapitalist.com/lithium-consumption-has-nearly-quadrupled-since-2010/**.

5. Zhou, J. M., "Circular Economy in Lithium-ion Battery Recycling: Perspectives on Industrial Scale," Journal of Energy Storage.

6. "Challenging China's dominance in the lithium market," Chemical and Engineering News, accessed November 21, 2024, **https://cen.acs.org/energy/energy-storage-/Challenging-Chinas-dominance-lithium-market/100/i38**.

7. Upstream stakeholder. (2024, September). (RMI, Interviewer)

8. "Circular economy: New law on more sustainable, circular and safe batteries enters into force," European Environmental Agency, accessed November 21, 2024, **https://environment.ec.europa.eu/news/new-law-more-sustainable-circular-and-safe-batteries-enters-force-2023-08-17_en?utm_source=chatgpt.com**.

9. "Battery reuse & recycling expand to scale in China," Electrive, accessed November 21, 2024 **https://www.electrive.com/2022/01/29/battery-reuse-recycling-expands-to-scale-in-china/?utm_source=chatgpt.com**.

10. "Managing Waste: Battery recycling in the Indian scenario," RenewableWatch, accessed November 21, 2024, **https://renewablewatch.in/2022/06/09/managing-waste/?utm_source=chatgpt.com**.

11. "The lithium-ion battery end-of-life market – A baseline study," Circular Energy Storage, accessed November 21, 2024, **https://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf**.
12. "Battery recycling and repurposing," Lohum, accessed November 21, 2024, **https://lohum.com/**.

13. Lithium-Sourcing Roadmap for India, IISD, 2023.

14. "Lithium battery recycling: Opportunities, challenges, and sustainable practices," PV Magazine, accessed on November 21, 2024, **https://www.pv-magazine-india.com/2024/03/18/lithium-battery-recycling-opportunities-challenges-and-sustainable-practices/**.

15. Conference on Battery Circularity and Raw Material Security in India, Hyderabad.

16. "International News From the Field: India," Association of Manufacturing Technology, accessed November 21, 2024, https://www.amtonline.org/article/international-news-from-the-field-india-14.

17. Renewable Energy Investment Surges in India, Institute for Energy Economics and Financial Analysis, 2022, accessed November 21, 2024 **https://ieefa.org/sites/default/files/2022-06/Renewables%20Investment%20Trends%20in%20India-June_2022.pdf**.

18. Abdelaziz, O. R., "Sustainable Battery Recycling: Challenges and Innovations in Circular Economy," Journal of Cleaner Production, 2023.

19. New Age Energy Minerals, FICCI, 2023.

20. "EU battery passport regulation requirements," Circularise, accessed November 21, 2024, **https://www.circularise.com/blogs/eu-battery-passport-regulation-requirements**.

21. "Bipartisan Infrastructure Law: Battery Materials Processing and Battery Manufacturing Recycling Selections," Office of Manufacturing and Energy Supply Chains, accessed November 21, 2024, **https://www.energy.gov/mesc/bipartisan-infrastructure-law-battery-materials-processing-and-battery-manufacturing-recycling**.

22. PLI Scheme for National Programme on Advanced Chemistry Cell (ACC) Battery Storage, Ministry of Heavy Industries, accessed November 21, 2024, **https://heavyindustries.gov.in/pli-scheme-national-programme-advanced-chemistry-cell-acc-battery-storage**.

23. Upstream stakeholder. (2024). (RMI, Interviewer)

24. "Cell to cell: creating a circular European battery industry," Northvolt, 2020, accessed November 21, 2024, **https://northvolt.com/articles/industrializing-battery-recycling/**.

25. "Recycling batteries necessary to meet growing EV demand: Guidehouse," Utility Dive, accessed on November 21, 2024, **https://www.utilitydive.com/news/guidehouse-recycling-electric-vehicle-batteries-nickel-lithium-cobalt-Redwood-Materials/686667/**.

26. "Battery recycling and utilization for the development of a circular economy," CATL. (n.d.). accessed November 21, 2024, **https://www.catl.com/en/solution/recycling/**.

27. "Sumitomo Metal Mining," Sumitomo Metal Mining, accessed on November 21, 2024, **https://www.smm.co.jp/en/**.

3.0

Enabling Steel Circularity in India's Built Environment

RMI

AUTHORS
Tarun Garg, Sai Sri Harsha Pallerlamudi, and Zoya Zakai

3.1 Introduction

India, one of the fastest-growing economies globally, is witnessing rapid urbanisation and infrastructure development. India is the world's second largest steel producer, accounting for approximately 7.4% or 140 million tonnes (MT) of the world's total steel output.[1] India is also the second largest consumer of finished steel globally. India's current per capita steel consumption is about half of the global average. The Government of India aims to almost double India's steel production capacity to 300 million tonnes and consequently boost per capita consumption to 160 kilograms (kg) by 2030–31.[2]

Urban floor area is expected to double to 35 billion m^2 by 2040, driving a significant increase in demand for construction materials.[3] The buildings and infrastructure sectors consume 68% of the total steel produced in India.[4] Making steel one of the most consumed and emission-intensive construction materials, accounting for 20% of a building's embodied carbon footprint.[5] Government of India's push for infrastructure development through various initiatives such as the Pradhan Mantri Awas Yojna (PMAY), PM GatiShakti National Master Plan (PMGS-NMP), and others will provide the necessary catalyst to increase the demand and consumption of steel in the country.

> **The steel industry's energy-intensive processes, from raw material extraction to final product manufacturing, create an environmental burden. To mitigate these environmental impacts and ensure sustainable growth, adopting a circular economy approach in steel production and consumption becomes imperative.**

As the demand for steel increases, the corresponding CO_2 emissions of Indian steel sector are expected to almost triple by 2050.[6] The steel industry's energy-intensive processes, from raw material extraction to final product manufacturing, contribute significantly to this environmental burden. To mitigate these environmental impacts and ensure sustainable growth, adopting a circular economy approach in steel production and consumption becomes imperative. A thriving circular steel industry can not only reduce emission intensities and energy consumption but also create resilient supply chains, and unlock additional revenue and employment opportunities across the value chain.

Environmental Implications of Linear Steel Economy

Resource Consumption

The steelmaking process is resource-intensive, demanding significant quantities of raw materials (iron, coke, limestone alloying elements, etc.), and energy. India's steel industry consumed 225 million tonnes MT of iron ore, 72 MT of coking coal (58% of the total coking coal in India), 72 MT of non-coking coal (6.5% of the total non-coking coal in India), 1177 (million standard cubic metres) (MMSCM) of natural gas (2% of the total in India), and 75 MT Mtoe energy (9% of India's total energy consumption) in FY 2023–24.[7]

Waste Generation

About 1.6 tonnes of processed iron ore is required to produce one tonne of steel. The mining and processing of iron ore for impurities like alumina and silica generates substantial waste, with slimes and fines constituting about 35% and 10%–25% of run-of-mine output respectively.[8] Without beneficiation,[i] these wastes contribute to resource loss and environmental degradation.[9] Furthermore, each tonne of crude steel produces about 0.4–0.6 tonne of waste in the form of steel slag, furnace dust, mill scale, and zinc sludge.[10]

Carbon Emissions

The steel sector accounts for 10%–12% of India's total CO_2 emissions, with an average emission intensity of 2.54 tCO_2/t Crude Steel (tCO_2/tcs)[11] compared to the global average of 1.91 tCO_2/tcs.[12]

Decarbonisation is Driving Circularity within the Steel Sector

Promoting steel circularity is a critical priority for reducing industrial emissions and transitioning to low-carbon economies. The Paris Agreement's climate targets, along with regulatory mechanisms like the EU's Carbon Border Adjustment Mechanism (CBAM), have prompted industries worldwide to reevaluate and adapt steel production processes to better align with circular economy principles. Recent CoP meetings have further underscored the importance of redesigning production systems to optimise resource use and minimise waste, positioning circularity as a cornerstone of sustainable and resilient economies.

i. Benefication refers to the process of treating raw materials, like minerals or ores, to improve their chemical or physical properties. The intended outcome is to create a higher-value product.

India has also made notable progress in advancing the circular economy agenda under its G20 Presidency. A landmark initiative, the Resource Efficiency and Circular Economy Industry Coalition (RECEIC) was launched in July 2023 during the 4th G20 Environment and Climate Sustainability Working Group (ECSWG) meeting, where steel was identified as one of four priority areas for advancing the circular economy. This industry-led coalition, comprising 39 founding members from 11 countries, aims to promote resource efficiency and circular economy practices globally. Guided by principles of partnership, technology cooperation, and finance for scale, RECEIC serves as a collaborative platform for sharing knowledge, best practices, and sustainable innovations across industries.[13]

Core Themes of this Paper

This paper outlines critical challenges and opportunities for low-emission steel production, and explores key strategies to promote circularity in India's steel sector:

Supply Chain and Market Mechanisms

The paper identifies infrastructural and technological bottlenecks hindering the adoption of circular practices in the steel industry. It addresses concerns regarding the uptake of low-emission steel and proposes solutions to overcome these challenges.

Policy Action

The paper outlines robust policy frameworks to promote circular economy principles, including tax incentives and integrated standards, aimed at stimulating demand for recycled steel and incentivising sustainable steel production.

Collaborative Partnerships

The paper emphasises the importance of fostering collaboration among industry, government, and civil society to accelerate the transition to a circular steel economy. This includes promoting public-private partnerships, international cooperation, and stakeholder engagement.

3.2 Current Landscape of Steel Circularity in India

India holds a prominent position in the global steel market as the largest producer of sponge iron, with a production capacity of 55 MT, and the second-largest producer of crude steel, with a production capacity of 179.5 MT.[14] The country primarily employs three routes for iron production—which subsequently leads to steel production: Blast Furnaces (BF), Shaft Furnace Direct Reduced Iron (DRI) using natural gas or syngas or industrial gases, and Rotary Kiln DRI using coal as fuel. Hot metal from BF is converted to steel in Basic Oxygen Furnaces (BOFs), while DRI is processed in Electric Arc Furnaces (EAFs) or Induction Furnaces (IFs) for steelmaking.

As discussed earlier, the average emission intensity of steel produced in India is about 25% higher than the global average, driven by the following factors:

Low-Grade Input Materials

India's dependence on domestic low-grade iron ore, which contains high levels of silica and alumina, leads to increased energy consumption during processing and results in higher emissions. Of the total available iron ore reserves (24,058 MT), only 12% is high-grade, while 38% is medium-grade and 31% is lower-grade.[15]

High Dependency on Coal

Coal is extensively used across steelmaking processes as both a reducing agent and an energy source. Coking coal is employed in blast furnaces for iron ore reduction, while pulverised coal is used as fuel. Similarly, in DRI production, coal serves as both feedstock and energy, due to its abundant availability in India and the countries limited access to natural gas alternatives. Steel production also relies on coal for auxiliary processes such as sintering, coke which is carbon-rich solid material derived from coal, and power generation. Additionally, the sector remains heavily dependent on emission-intensive coal-based captive power plants and grid electricity, due to the lack of affordable alternatives.[16]

Limited Scrap Availability and Utilisation

India's domestic scrap availability ranged between 25–30 MT over the past five years, representing only about 15% of the country's total steel demand of 179.5 MT.[17] Scrap utilisation is observed to be low, with 10%–12% in the BF-BOF route and ranges between 30% and 80% in the IF route—where most of the scrap is consumed by different small manufacturers. Scrap usage varies widely influenced by factors such as seasonal availability, informal trade dynamics, and fluctuations in scrap prices.

Low penetration of RE-based power

Renewable energy accounts for just 7.2% of the steel sector's electricity consumption at about 5.6 TWh out of 78 TWh (excluding the electricity generated from waste heat recovery in FY 2021–22). The share of RE power in the case of the Integrated steel producers (ISPs) is only 3.1% and in the case of small units 11.3%.[18] This limited uptake of RE-based power worsens the sector's emission intensity.

India's reliance on low-grade raw materials, coal-based energy, and limited scrap and renewable energy integration presents significant challenges to achieving low-emission steel production. While long-term solutions such as hydrogen-based steelmaking and carbon capture, utilisation, and storage (CCUS) hold promise, their adoption remains at an early stage, hindered by high upfront costs, infrastructural limitations, and technical complexities. However, by adopting circular practices across steel production routes, India can meet the projected increase in steel demand while minimising environmental impacts and enhancing resource efficiency.

Pathways to Steel Circularity

A circular approach to steel encompasses a multifaceted strategy that includes reduction, reuse, remanufacturing, and recycling of materials and by-products.

Reduce

Minimise steel usage in construction through resource-efficient designs. Reduce energy demand through efficiency improvements, such as capturing and utilising waste heat and process gases—e.g., flue gases from coke ovens, BF, and BOF—for on-site energy generation or other industrial applications. Recirculating process water, especially for cooling, can further conserve critical resources in steelmaking.

Reuse and Remanufacture

Extend the lifecycle of steel components by repairing and reconditioning them for original or alternative applications, preserving their intrinsic value and reducing production emissions. For example, structural elements like steel beams and columns salvaged from demolished buildings can be reused in new construction. Additionally, by-products from steel production—such as blast furnace slag, sludge, mill scale, and manufactured sand—can be used in cement production, construction materials, chemical industries, and agriculture, thereby reducing waste.

Recycle

Enhance the recovery and processing of steel scrap through efficient collection systems, modernised sorting technologies, and advanced recycling infrastructure. Steel produced using scrap route has a significantly lower emission footprint compared to traditional steelmaking from iron ore, as it avoids energy-intensive processes required for ore-to-iron conversion. Expanding scrap utilisation reduce emissions, increases material efficiency, lowers energy consumption while improving quality control in production.

Key Technologies for Steel Circularity

Incorporating innovative technologies in material efficiency, by-product utilisation, and recycling will be crucial in enhancing circularity in steel production. **Exhibit 3.1** below presents key advancements in processes and technologies driving steel circularity.

Exhibit 3.1 Key Technologies for Steel Circularity

FOCUS AREA	TECHNOLOGY DESCRIPTION
Material Efficiency	**Beneficiation**: Transformation of low-grade iron and coal to enhance feedstock quality leads to reduced coke consumption, improved furnace productivity, and optimised energy use, and lower emissions.
	Pelletisation: Agglomerating fine iron ore particles into pellets for ironmaking significantly improves iron recovery and material handling, reduces waste generation, thereby enhancing resource efficiency and lowering energy consumption.
Waste/Byproduct Utilisation	**Slag Processing**: Repurposing steel slag for various applications such as road construction, preparation of fine aggregates, bricks, and clinker substitution in cement and concrete industries.
	Dust, Fume and Sludge Capture: Installing advanced filtration systems (such as fume extraction system) to recover valuable metals from dust, fumes and sludge for recycling.
Recycling	**Waste Heat, Gas and Steam Recovery:** Harnessing waste heat, process gases (such as coke oven gas and blast furnace gas) and steam from production processes for energy generation, chemical production or supply heat for internal operations, reduces energy waste, and improving energy efficiency. Purifying and reusing process water for cooling, quenching, and cleaning, minimising freshwater use and wastewater discharge.
	Technologies like Laser object detection (LOD): Leveraging laser technology for scrap metal processing to improve processing speed by up to 30%, retain more recyclable material, and reduce waste.

Key Stakeholders in Steel Circularity Ecosystem

Achieving steel circularity requires coordinated efforts from diverse stakeholders across the value chain. **Exhibit 3.2** below outlines the roles, responsibilities, and key players crucial to shaping this ecosystem in India.

Exhibit 3.2 Key Stakeholders in Steel Circularity Ecosystem

STAKEHOLDER	ROLES AND RESPONSIBILITIES	KEY PLAYERS IN INDIA
Producers and Suppliers	Optimise production processes to enhance material and energy efficiency, maximise waste utilisation, and integrate renewable energy sources. Explore the adoption of technologies like green hydrogen, Carbon Capture, Utilisation, and Storage (CCUS) to reduce emissions, while aligning with cost-efficiency goals.[ii]	Steel Manufacturers, Steel distributors, including Integrated steel plants (ISP) such as JSW, TATA, JSPL and Secondary Sector Industries (SSI) such as Kalyani Steel, SRJ Peety, ARS, and other producers.
Recyclers	Develop a formalised trade ecosystem and invest in advanced recycling infrastructure to enhance steel scrap recovery and processing.	Steel Scrap Dealers, Steel Recycling Facilities
Policymakers and Government Organisations	Formulate and implement policies, set environmental standards with permissible emission intensities, provide incentives, and ensure compliance through monitoring and enforcement.	Ministry of Steel, Ministry of Environment, Forest, and Climate Change, Bureau of Energy Efficiency (BEE)
Research and Academic Institutions	Conduct research on low-emission steel production, recycling, and sustainability, explore innovative technologies, business models and support with professional training and capacity building.	National Institute of Secondary Steel Technology (NISST), Indian Institute of Science (IISc), Council of Scientific and Industrial Research (CSIR), Universities and Colleges
Consumers	Incorporate procurement policies that signal market demand and support a premium pricing structure to incentivise the production of low-emission steel.	Central Public Works Department (CPWD), State Housing Boards, State Public Works Departments, Real Estate Developers, and Construction Companies

ii. Preliminary results indicate that, hydrogen DRI-EAF or the DRI-EAF with CCS pathways reduce the production cost in the long run. The deployment of CCUS/green hydrogen will depend on the level of carbon prices and financial incentives.

Key Government Initiatives around Steel Circularity

As India strives to achieve its 2047 developmental goals in tandem with its 2030 climate targets and 2070 net-zero commitments, decarbonising its critical manufacturing sectors becomes increasingly important. To promote circularity in steel production, the Government of India has enacted several key policies:

- **The National Steel Policy, 2017**
  Emphasises the importance of steel scrap recycling and promotes the use of Electric Arc Furnaces and Induction Furnaces

- **The Steel Scrap Recycling Policy, 2019**
  Aims to standardise the recycling process and encourage entrepreneurship in scrap collection.

- **Vehicle Scrappage Policy, 2021**
  Promotes recycling and resource conservation while contributing to a cleaner and safer environment.

- **IS 455: 2015, Bureau of Indian Standards**
  Specifies standards and guidelines for fly ash and slag-based composite cement, which is manufactured using 35%–65% Portland cement clinker/ordinary Portland cement combined with 15%–35% fly ash and 20%–50% granulated blast furnace slag as blending components.

- **Guidelines for Management of Pyro-metallurgical Slags, 2023**
  The Central Pollution Control Board, in December 2023, issued the Guidelines for Management of Pyro-metallurgical Slags (Iron and Steel), providing a standard operating procedure for the utilisation of resource materials from iron and steel slag, as mandated under the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016.

- **Other Relevant Regulations Include**
  The Environment (Protection) Act, 1986, Water (Prevention and Control of Pollution) Act, 1974, Air (Prevention and Control of Pollution) Act, 1981, Hazardous and Other Wastes (Management and Transboundary Movement) Rules 2016, Guidelines for environmentally sound management of ELVs (End-of-Life Vehicles), waste regulations notified by the Ministry of Environment, Forest, and Climate Change (MoEFCC).

- **Roadmap and Action Plan, 2024**
  The Ministry of Steel has released a comprehensive roadmap titled *Greening the Steel Sector* in India: Roadmap and Action Plan, which outlines a clear path towards decarbonising the steel industry.

While these government initiatives lay a strong foundation towards promoting steel circularity, the implementation and effectiveness of these policies reveal a complex landscape of challenges. These challenges—ranging from policy enforcement and supply chain infrastructure to financial mechanisms and market dynamics—require focused efforts to bridge gaps in policy execution and infrastructure development. The following section critically examines the key barriers and systemic constraints that must be overcome through strategic interventions for India's transition to a more sustainable and circular steel ecosystem.

Key Barriers and Challenges for Steel Circularity in India

India's steel industry, while a significant player in the global market, faces significant challenges in transitioning to a circular economy model. Several factors hinder its ability to efficiently recycle and reuse steel, thereby limiting both environmental sustainability and economic competitiveness and these have been detailed out in **Exhibit 3.3** below:

Exhibit 3.3 Key Barriers and Challenges for Steel Circularity in India

BARRIERS AND CHALLENGES	DESCRIPTION
POLICY	
Policy Enforcement	While the Ministry of Steel has introduced several policies as explained in the preceding section, the effectiveness of these policies in promoting circular practices, particularly in creating a structured scrap ecosystem, has been limited. The absence of a mandatory waste management framework undermines the effective implementation of recycling initiatives. Current policies on scrap utilisation primarily target specific end-of-life steel sources, such as the automotive sector, limiting the broader potential for metal recycling across additional sectors. Furthermore, India's recycling ecosystem is largely informal and fragmented, resulting in non-compliance with regulations, low-quality output, and minimal transparency across the value chain.
SUPPLY CHAIN INFRASTRUCTURE	
Scrap Availability	India currently faces a shortage of scrap as explained in the preceding sections. To supplement this shortfall, India imports around 7 MT of scrap annually.[19] The internal scrap generation (in steel production/processing units) rate is gradually decreasing due to the adoption of continuous casting and improved technologies in mills. The limited availability of end-of-life scrap in India results from its relatively short industrialisation history and the long lifecycles of steel products.

Exhibit 3.3 Key Barriers and Challenges for Steel Circularity in India (continued)

BARRIERS AND CHALLENGES	DESCRIPTION
Scrap Quality	The variability in scrap quality complicates the establishment of standardised pricing mechanisms, leading to market uncertainty. Improper sorting and handling of scrap result in contamination (e.g., copper and tin mixing with steel scrap), which reduces its value and suitability for applications, increases processing costs, and hinders recycling efforts. Additionally, the lack of energy management systems in manufacturing plants further hampers the ability to quantify the environmental benefits associated with scrap-based production.
Limited Recycling Facilities	India has a limited number of recycling facilities equipped with advanced technologies for efficient steel recycling and lacks a formal database of such facilities. Efforts to boost domestic recycling industry, such as scrapping of older vehicles, faces challenges due to low-capacity utilisation and the insufficient availability of end-of-life vehicles for recycling. While some regions like Maharashtra, certain regions such as Maharashtra and Gujarat in India have more developed recycling infrastructure in comparison with other states that lack adequate facilities, impeding scrap uptake in the steelmaking process for regional clusters.
MARKET INSTRUMENTS	
Scrap Pricing	Fluctuations in scrap prices (ranging from INR100–350/kg) due to seasonality and volatility significantly impact the cost of recycled steel, compressing profit margins and bringing the markup closer to that of primary steel.
Financial Mechanisms	Despite government incentives such as tax exemptions and subsidies, the higher GST rate on steel scrap likely impedes the broader utilisation of scrap in steel production. Additionally, the scale of incentives provided remains inadequate to support the sustained production of recycled steel.
Quality Apprehensions	The Ministry of Steel does not differentiate between production routes, requiring only compliance with BIS codes. However, apprehensions about the quality of recycled steel limit its market uptake, further affecting sale prices and production scale.
Trade	Restrictions on scrap steel exports from other regions like the EU, exacerbate the scrap supply shortage and hinder efforts to meet production targets.
Limited Resources	Small- and medium-sized enterprises (SMEs) face financial constraints in adopting circular economy practices such as material efficiency, waste management and disposal. For example, scrap is predominantly used in DRI-IFs operated by smaller players, whose limited production capacities (ranging from 8 to 60 tonnes)[20] and financial constraints prevent them from investing in advanced technologies.

3.3 The Business Case for a Circular Steel Economy in India

Structural steel is not just recycled; it is *multi-cycled*, continually reused in various forms and can be recycled repeatedly without losing its physical properties. This second-life processing requires meticulous quality control, as compositional variations in the material dictate its subsequent applications—from reuse in high-performance structures to repurposing for less demanding uses in lower-grade industrial components. By optimising raw material utilisation and minimising waste, almost every by-product generated during steelmaking can be repurposed.

Environmental Benefits

Steel recycling and enhanced material efficiency can lead to significant reductions in resource consumption, waste generation, energy usage, and carbon emissions, as detailed below.

Reduced Resource Consumption

Material efficiency and recycling of end-of-life steel (scrap) can offer numerous benefits in the steelmaking process, including reduced carbon emissions, resource consumption, and enhanced quality control. Each tonne of scrap saves 1.1 tonnes of iron ore, 630 kgs of coking coal, and 55 kgs of limestone. Additionally, it can reduce water consumption by 40% and greenhouse gas emissions by 58%.[21] It also leads to about 76% fewer water pollutants, 86% fewer air pollutants and 97% less mining waste.[22]

Waste Reduction and Utilisation

Improving material efficiency and utilising by-products can significantly reduce waste, limiting waste generation to a mere 2% of total.[23] This, in turn, can lead to a substantial increase in overall steel output. Key by-products include:

- **Slag**: One tonne of steel produced from iron ore, roughly produces 400 kg of slag, of which 275 kg come from the BF and the rest comes from a BOF. About 110 kg of slag is also generated while producing recycled steel in an electric arc furnace.[24] Slag, a versatile by-product of steelmaking, finds diverse applications in various industries. It can be used as a partial replacement for clinker in cement production, as an alternative to traditional aggregates in concrete and asphalt, and even used in road construction. It also finds applications in fertilisers production.

- **Dust and Sludge Recycling**: Steelmaking generates significant dust and sludge, which can be processed to extract valuable zinc (from electric furnace dust) for various applications, such as reagent in chemical processes and pigment in paints and coatings. Fine dust and sludge can be transformed into briquettes, facilitating their reintegration into the steelmaking process and reducing waste disposal needs.

- **Spent Refractories Reuse**: Spent refractories are crushed and sorted to recover reusable materials, which can be used to manufacture new refractory products or used as raw materials in other industries, such as cement.

Reduced Energy Consumption and Carbon Emissions

- Recycling scrap can significantly reduce energy consumption, leading to an energy savings of 16%–17%,[25] and adopting material efficiency strategies can reduce cumulative emissions by about 40%.[26]

- Data indicates that steel produced in the DRI-IF process with 99% scrap results in an emission intensity of 0.85 tCO_2e/t TMT—65% lower than the 2.4 tCO_2e/t TMT produced in the blast BF-BOF route with only 10% scrap.[27]

Economic Benefits

A circular steel economy can reduce production costs, import dependency, foster profitability, and create new revenue streams through using by-products.

Reduced Reliance on Imports

Due to low-grade virgin material availability of iron ore and high-ash content coal natively, India currently imports raw materials like coking coal, high-grade iron ore, and even scrap. Increased domestic steel recycling can reduce India's dependency on imports and ensuring a stable supply lowers production cost.

Increased Market Access

A circular steel industry can make Indian steel more competitive in global markets by reducing its carbon footprint. This will enable Indian steel producers avoid stringent import tariffs such as those envisioned under European Union's Carbon Border Adjustment Mechanism.

Job Creation

The steel recycling industry can create numerous direct and indirect jobs across scrap collection, processing, logistics, and recycling operations, generating employment opportunities across the value chain.

Revenue from Waste

By treating waste and end-of-life steel as a valuable resource, the steel industry can generate additional revenue. By-products like slag, dust, and sludge can be sold to other industries (such as cement and fertilisers) and contribute to their decarbonisation efforts. Additionally, recycling steel can reduce waste disposal costs, further boosting profitability.

Diversified Supply Chain

A circular steel industry can create a more diversified supply chain by integrating waste and end-of-life steel into the production process, reducing reliance on virgin raw materials. This diversification strengthens supply chain resilience and minimise vulnerability to price fluctuations and geopolitical risks.

3.4 Strategic Interventions for Steel Circularity in India's Built Environment

A multi-faceted approach is necessary to design impactful interventions that accelerate the transition to a circular economy. While integrating mandates into building codes and enhancing weightage of recycled products in green building certifications can foster adoption, developing supportive business models and creating initial demand through public procurement commitments can stimulate the market.

> **"To accelerate steel circularity in India's built environment, a multi-faceted approach is essential—integrating mandates into building codes, promoting recycled content in green certifications, and leveraging public procurement to create demand."**

Policy and Regulations

This section outlines key national and sub-national interventions to foster a favourable environment for steel circularity in India's construction sector.

Building Codes and Rating Systems

- Integrate whole building life cycle analysis (LCA) into building codes, especially embodied carbon reporting, to assess the environmental impact of materials and construction techniques throughout a building's lifecycle.

- Green rating systems (such as GRIHA, LEED, IGBC, EDGE) can drive recycled steel adoption by allocating advanced credits for projects using recycled steel.

Baselining and Benchmarking

- National agencies like the Ministry of Steel should establish clear benchmarks for permissible emission intensities of various steel grades used in different building types. Additionally, setting targets for reducing embodied carbon in buildings and incentivising the use of recycled materials like steel can significantly promote market uptake.

- Accurate emission intensity data is crucial for Indian producers to remain competitive, especially with developments like the Carbon Border Adjustment Mechanism. Relying solely on company-level data, as provided by the Business Responsibility and Sustainability Report (BRSR), may be insufficient; product-specific carbon footprint data is essential for effective participation in the global markets. It is critical to ensure mandatory reporting of the environmental footprint of the finished steel product and process emissions across the end-to-end value chain, facilitated by EPD programme operators (POs) and LCA consultants.

Green Public Procurement

- Enforce public procurement policies prioritising recycled steel and utilisation of steelmaking by-products like slag, artificial sand for government construction and infrastructure projects. National agencies like National Building Construction Company (NBCC), National Highway Authority of India (NHAI) and concerned ministries building public projects like Ministry of Road Transport & Highways, Ministry of Housing and Urban Affairs, Central Public Works Department (CPWD) should integrate recycled steel into standardised pricing structures to encourage broader adoption within the construction sector. Provide incentives or preference to developers and designers with a portfolio of recycled materials when bidding for government projects.

Second-Life Applications

Implement stricter regulations to mandate the recycling of steel scrap from end-of-life buildings, construction waste, akin to an extension of Extended Producer Responsibility.

Supply Chain Infrastructure Development

The Ministry of Steel's recent roadmap and action plan, *Greening the Steel Sector in India*, outlines a comprehensive strategy for decarbonising the steel supply chain.[28] This section explores interventions aligned with and extending beyond the roadmap, grounded in the realities of manufacturing practices.

Raw Material and Feedstock Usage

To eliminate inconsistencies in steelmaking process, it is important to establish optimal scrap-to-iron ratios. Upgrading the infrastructure for beneficiation, pelletisation , and scrap utilisation will further improve the efficiency of steel production. For instance, a 1% increase in iron content can boost blast furnace productivity by 2% and reduce coke consumption by 1%, lowering costs and minimising environmental impact.[29] Further improvement in raw material use can be achieved by developing infrastructure for gas-based DRI plants, including trade partnerships, and pipeline infrastructure to addresses issues around availability and reliability of natural gas.

Recycling Infrastructure

Offer grants or low-interest loans to existing recycling facilities to upgrade equipment and improve processing capabilities. Earmark funds to support the establishment of modern recycling plants equipped with advanced technologies like magnetic separation, density separation, and shredding.

Knowledge Exchange

Although the scrap ecosystem is fragmented, it is important to create platforms for knowledge-sharing about India's scrappage policies including scrap mobilisation, trade, recycling, pricing mechanisms, quality standards, guidelines for scrap generation, and environmental regulations.

Energy Systems

Adopt energy-efficient technologies like direct hot charging, advanced quenching and tempering systems to reduce energy consumption and enhance process efficiency. Invest in technologies for waste reduction, material recovery, and by-product valorisation to further reduce energy demand while generating additional revenue streams for manufacturers. Deploy energy management systems to monitor and track emissions effectively. Additionally, integrate renewable energy sources, such as solar and wind power, into steel production facilities to optimise energy use intensity and advance sustainability.

Industry Consortiums

Collaborate with research institutions like IITs, IISc, and CSIR to conduct joint research projects with steel companies, testing the scalability of modern technologies.

Market Instruments and Business Models

To stimulate demand and sustain the market for circular steel products, business models should incorporate financial incentives and price competitiveness. Several key strategies include:

Infrastructure Bonds for MSME

Issuance of state or city-backed green infrastructure bonds for MSME involved in the production of recycled steel using a higher percentage of scrap can overcome financial constraints in scaling production.

Green Building Financing

Partner with financial institutions to offer green mortgages with low- interest rates to developers adopting circular steel in the built environment.

Evidence-Backed Procurement

To drive sustainability in the supply chain, procurement policies should be enhanced to incorporate LCA-backed decision-making across the project lifecycle, from material selection to construction and operation, while prioritising purchases from suppliers with lower product carbon footprints and higher scrap utilisation.

Carbon Pricing and Emission Trading Framework

Implementation of a tiered carbon tax based on the carbon intensity of steel products used in the built environment. To further incentivise recycled steel adoption, offer tax credits for the use of recycled steel or steel produced using renewable energy sources.

3.5 Case Studies from Around the Globe

Global best practices provide valuable insights for India to adopt effective strategies, minimise inefficiencies, and accelerate the transition to circular systems. This section highlights a few notable initiatives and advancements by steel producers and consumers aimed at fostering circularity in steel supply chains.

Supply-Side: refers to the production and material recovery processes within the steel industry, highlighting practices by key manufacturers to integrate recycling, waste utilisation, and efficient resource use into their operations to promote circularity and reduce carbon footprints.

- **Nippon Steel (Japan):** Nippon Steel achieves a 99% overall recycling rate, with specific recycling rates of 100% for blast furnace slag, 100% of dust, 98% for steelmaking slag, and 90% for sludge. The company also utilises 76% of exhaust heat to generate steam, and sources 91% of its electricity internally, setting a strong benchmark on circularity for the global steel industry (Nippon Steel, 2024).[30]

- **Çolakoğlu Metallurgi (Turkey):** Çolakoğlu Metallurgi produces steel with 92% recycled content using ferrous scrap and Electric Arc Furnaces (EAFs). In addition to scrap utilisation, the company utilises 73% of the waste generated on site as by-products for other industries.[31]

- **Nucor Steel (United States):** Nucor utilises recycled ferrous scrap and Electric Arc Furnaces (EAFs) to produce steel with an average recycled content of 77%, with certain products reaching nearly 100%. In addition to scrap utilisation, the company recycles over 90% furnace dust, steel slag particulate emissions, and 90% of its water usage through advanced systems. This comprehensive recycling approach results in an estimated product carbon footprint of 0.77 tCO_2 per ton of steel—one-third of the global average (Nucor Steel, 2024).[32]

- **Structural Steel Recycling (United States):** Structural steel produced in the United States contains 93% recycled scrap on average, with domestic mills recycling over 70 million tonnes of scrap annually. At the end of a building's life, 98% of its structural steel is recycled into new products. Beams, columns, and other elements removed from buildings are re-fabricated for new structures, with remaining steel recycled into new products. Overall, 81% of all steel products are recovered for recycling, including 98% of structural steel, 85% of automobiles, 82% of appliances, 70% of containers, and 72% of reinforcing bar.[33]

Demand-Side: Refers to the actions and strategies of buyers, organisations, or governments that influence the demand for low-emission steel. These entities create demand by prioritising products and materials with lower environmental impacts, such as steel with high recycled content or near-zero emissions, through procurement policies, standards, and commitments to sustainable sourcing.

- **MetStructures (United Kingdom):** MetStructures, an off-site construction company, specialising in light gauge steel framed (LGSF) structures for the residential, hotel, care, and student accommodation sectors incorporates over 40% recycled steel content in its products. The LGSF solutions reduce embodied carbon by up to a 37% compared to traditional concrete frames. The company has committed to procuring, specifying or stocking 50% net-zero steel by 2030 and 100% by 2050.[33]

- **Buy Clean Task Force (United States):** The Buy Clean Task Force is a consortium of United States federal agencies working to integrate embodied carbon emissions into federal procurement policies. By prioritising low-carbon materials, such as steel and cement, in federal projects, the Task Force aims to reduce the environmental impact of the built environment. To promote transparency, it encourages suppliers to provide Environmental Product Declarations (EPDs) and offers technical assistance to domestic manufacturers to improve reporting and reduce emissions.[34]

- **Green Public Procurement Policy (European Union):** The European Union's voluntary Green Public Procurement Policy (GPP) seeks to minimise the environmental impact of public purchases. As part of Strategic Public Procurement, alongside Socially Responsible Public Procurement (SRPP) and Innovation Procurement, GPP utilises lifecycle analysis to establish procurement benchmarks, driving more sustainable purchasing decisions across public sector.[35]

- **The First Movers Coalition (Global):** The First Movers Coalition (FMC) aims to accelerate the adoption of clean technologies across eight industries, including steel. Its members have pledged to procure at least 10% of their steel from near-zero emission sources by 2030, with 27 member companies already committing to this target.[37]

3.6 Conclusion and Next Steps

Accelerating the shift to a circular steel economy in the built environment requires strategic interventions that address both the supply and demand aspects of the value chain. These efforts must focus on establishing standards for circular steel products, implementing green public procurement policies, enhancing recycling infrastructure, fostering international collaboration, and creating market incentives to mainstream the adoption of recycled materials. This section outlines these critical actions to advance steel circularity in the country.

Integrated Standards

Harmonise standards across trading partners to reduce technical barriers to trade. This includes unified reporting frameworks, impact assessment methodologies, material tracking, quality assurance, and environmental performance benchmarks. Consistency in specifications will build confidence in recycled steel and enable their seamless integration into production processes.

Regional Scrap-Exchange Platforms and Low-Emission Steel Trade Corridors

Develop regional scrap exchange platforms and establish specialised trade corridors to streamline cross-border transfer of scrap and low-emission steel products. Standardised documentation, digital systems, automated processing capabilities with dedicated infrastructure will reduce administrative burdens and ensure a steady supply of high-quality recyclable materials. These platforms will improve access to secondary markets, enhance distribution efficiency, reduce trade barriers, lower the costs of recycled steel, and strengthen circular supply chains.

Infrastructure Investment Fund for Innovation in Steel Recycling

Support the development of state of the art steel recycling facilities and R&D for advanced recycling technologies. Investments in modernising recycling plants, recovery technologies, and efficient logistics will enhance recycling efficiency and reduce over-reliance on primary steel production routes.

Green Financing for Steel Circularity

Develop green financing instruments such as green bonds, sustainable investment funds, tax incentives, and credit enhancement mechanisms, to support projects and businesses advancing steel circularity. These funds should have clear investment criteria, impact measurement, key performance indicators, and verification protocols aligned with circularity objectives.

Green Procurement Standards

Develop comprehensive procurement guidelines for preferential purchase of low-emission steel to stimulate market demand for circular steel products and establish them as a cornerstone of sustainable purchasing strategies.

Awareness, Training, and Capacity Building

Establish a centralised platform and foster cross-border research partnerships to facilitate knowledge exchange on steel circularity. Creating awareness and building capacity of stakeholders in the built environment will be critical for creating a market for low-emission steel products.

International Collaboration

The leadership of G20 nations will be crucial in advancing resource-efficient practices, building a global circular value chain, and tackling challenges related to resource scarcity and waste management. They collectively produce 85% of the world's steel and consume 80% of it. Coordinated action by the G20 countries, involving strategic partnerships, joint ventures, innovation and technology transfers, will be crucial in driving this transformation, and scaling-up circular steel solutions globally.

Endnotes

1. Annual Report 2023-24, Ministry of Steel, 2024.
2. Annual Report 2023-24, 2024.
3. From the Ground Up: A whole-system approach to decarbonising India's buildings sector, NIUA, RMI, 2022, **https://rmi.org/insight/whole-system-approach-to-decarbonize-indias-buildings/.**
4. Annual Report 2023-24, 2024.
5. Shu Su et al., "Considering critical building materials for embodied carbon emissions in buildings: A machine learning-based prediction model and tool," Case Studies in Construction Materials, Volume 20, (July 2024) e02887.

6. From the Ground Up, 2022.

7. Annual Report 2023-24, 2024.; Natural Gas Consumption, Petroleum Planning and Analysis Cell, 2024, **https://ppac.gov.in/natural-gas/consumption.**

8. Annual Report 2023-24, 2024.

9. Annual Report 2023-24, 2024.

10. Miguel A, Sellitto and Fábio K.Murakami, "Destination of the waste generated by a steelmaking plant: a case study in Latin America," Aestimum 77, (December 2020), 127–144, **https://doi.org/10.13128/aestim-9025.**

11. Annual Report 2023-24, 2024.

12. "Circular Economy Steel – the permanent material in the circular economy," World Steel Association, accessed November 1, 2024, **https://worldsteel.org/circular-economy/.**

13. G20 New Delhi Leaders' Declaration, G20, 2023.

14. Annual Report 2023-24, 2024.

15. Annual Report 2023-24, 2024.

16. Annual Report 2023-24, 2024.

17. Annual Report 2023-24, 2024.

18. Annual Report 2023-24, 2024.

19. Annual Report 2023-24, 2024.

20. Annual Report 2023-24, 2024.

21. Steel Scrap Recycling Policy, Ministry of Steel, 2019, **https://steel.gov.in/sites/default/files/Steel%20Scrap%20Recycling%20Policy%2006.11.2019.pdf**.

22. "Ferrous Metals," Material Recycling Association of India, last modified October 30, 2024, **https://mrai.org.in/theindustry/ferrousmetals.html**.

23. "Circular Economy Steel – the permanent material in the circular economy," World Steel Association.

24. Karan Kochhar, Towards a Circular Steel Industry, International Renewable Energy Agency, 2023.

25. National Steel Policy 2017, Ministry of Steel, 2017; Steel Scrap Recycling Policy, 2019.

26. Iron and Steel Technology Roadmap Towards more sustainable steelmaking, International Energy Agency, 2020, **https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf**.

27. JSW Group. "Environmental Product Declaration: Average of Finished Long Products," October 21, 2021 Environmental Product Declaration (EPD) Certificate for ARS Steels. ARS, 2024. **https://arsgroup.in/wp-content/uploads/2024/09/ARS-STEELS_EPD-CERTIFICATE-2.pdf**.

28. Annual Report 2023-24, 2024.

29. Annual Report 2023-24, 2024.

30. Nippon Steel. 2024. Nippon Steel. **https://www.nipponsteel.com/en/csr/env/warming/production.html**.

31. "Çolakoğlu Metallurgi," Çolakoğlu Metallurgi, accessed November 2, 2024, **https://www.colakoglu.com.tr/en**.

32. Nucor Steel. 2024. Nucor Steel. **https://nucor.com/sustainability/**.

33. "Recycling," American Institute of Steel Construction, accessed October 29, 2024, **https://www.aisc.org/why-steel/sustainability/recycling/**.

34. "What we do – Environment and Sustainability," MetStructures, accessed November 20, 2024, **https://www.metstructures.uk.com/environmental-sustainability.php**.

35. "Federal Buy Clean Initiative," Council of Environment Quality, accessed November 1,2024, **https://www.sustainability.gov/buyclean/**.

36. "Green Public Procurement," European Union, accessed November 5, 2024, **https://green-business.ec.europa.eu/green-public-procurement_en**.

37. "First Movers Coalition," First Movers Coalition, accessed November 19, 2024, **https://initiatives.weforum.org/first-movers-coalition/home**.

4.0

Accelerating Circularity of Construction and Demolition Waste

AUTHORS
Sree Kumar Kumaraswamy, Virabh Lad, Sanjar Ali, Prayash Giria, and Aditya Ajith

4.1 Introduction

The construction sector contributes to 8% of India's Gross Domestic Product (GDP) and employs the second largest share of workforce after agriculture (Ministry of Labour and Employment 2024). Its significance is expected to grow further given the ongoing urbanisation and physical development of the country. Between 2010–2050, it is projected that nation's urban population will more than double, and urban land cover will quintuple (Mathews, et al. 2018). Massive real estate and infrastructure development will be needed to accommodate this growth. The country is already adding 700–900 million square metres of floor space annually (Ministry of Housing and Urban Affairs 2024), while the National Highway network length grew by over 60% between 2014–2023 (Ministry of Road Transport & Highways 2024). Looking ahead, it is estimated that the country will need to develop 15 square kilometres of land every day up till 2050, in addition to redeveloping aging building stock, to accommodate forecasted growth in a business-as-usual scenario.

This growth implies an exponential increase in generation of C&D waste. While no formal and updated inventory of C&D waste generation is available in the country, various estimates have been put forward. In 2018, the Building Materials and Technology Promotion Council (BMTPC) estimated annual C&D waste generation at 100 million tonnes (Building Materials and Technology Promotion Council 2018) while in 2024, the Ministry of Housing and Urban Affairs offered a projection of 150–500 million tonnes per year (Ministry of Housing and Urban Affairs 2024). Central Pollution Control Board (CPCB) estimated solid waste generated across the country by 2030 to be 165 million tonnes per annum.

> **"The lost potential of C&D waste reuse and recycling leads to greater natural resource extraction. The National Resource Efficiency Policy, 2019, estimated a sixfold growth in resource consumption between 1970–2015, alongside a resource extraction rate per acre of three times that of the world average."**

C&D waste offers avenues for circularity through material recovery and reuse, as well as recycling into other building materials and products. However, in the absence of clear regulatory mandates and their enforcement, waste generators often consider alternative options such as easily accessible open and low-lying areas or private land to dump their waste for reducing transport costs and other user charges, to be paid for treatment. When the waste is not continuously fed to processors or recyclers, it affects their operational viability. It also undermines the ability to recycle valuable materials needed for sustained construction activity. As urbanisation continues to accelerate, ensuring a secure and resilient supply of construction materials becomes essential to support infrastructure development and economic growth. However, in practice, a significant quantity of C&D waste is handled informally, either through backfilling, or illegal dumping in vulnerable areas. This has health and environmental impacts such as aggravating air pollution and GHG emissions, soil contamination, impact on climate and flooding.

The crucial role of local governments in managing C&D waste is a relatively new understanding and continues to develop. Most of the efforts in management have been fragmented such as, while few of the ULBs have installed recycling facilities, they remain highly underutilised due to lack of clear regulatory mandates to ensure collection of waste. Some ULBs have stipulated mandates requiring waste generators to pay charges but have not developed a collection system, also lacking robust infrastructure and technology to recycle the huge amount of waste being generated.

The lost potential of C&D waste reuse and recycling leads to greater natural resource extraction. The National Resource Efficiency Policy, 2019, estimated a sixfold growth in resource consumption between 1970–2015, alongside a resource extraction rate per acre of three times that of the world average. At the same time, recycling rates were at 20%–25% (The Energy and Resources Institute 2019), as compared to above 90% in the United Kingdom (Department for Environment, Food and Rural Affairs, UK 2021), above 70% targets (2020) in the developed European countries (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, European Commission 2018) and above 88% in Japan (Zhao 2023).

Given the adverse environmental and health impacts of improper C&D waste management at both upstream and downstream stages, there is an urgency to enhance circularity in management processes. Value addition for the material through recycling would activate the ecosystem towards better management and reduce the impact on environment. This paper offers recommendations towards a pathway for circularity for the sector.

4.2 Sectoral Landscape

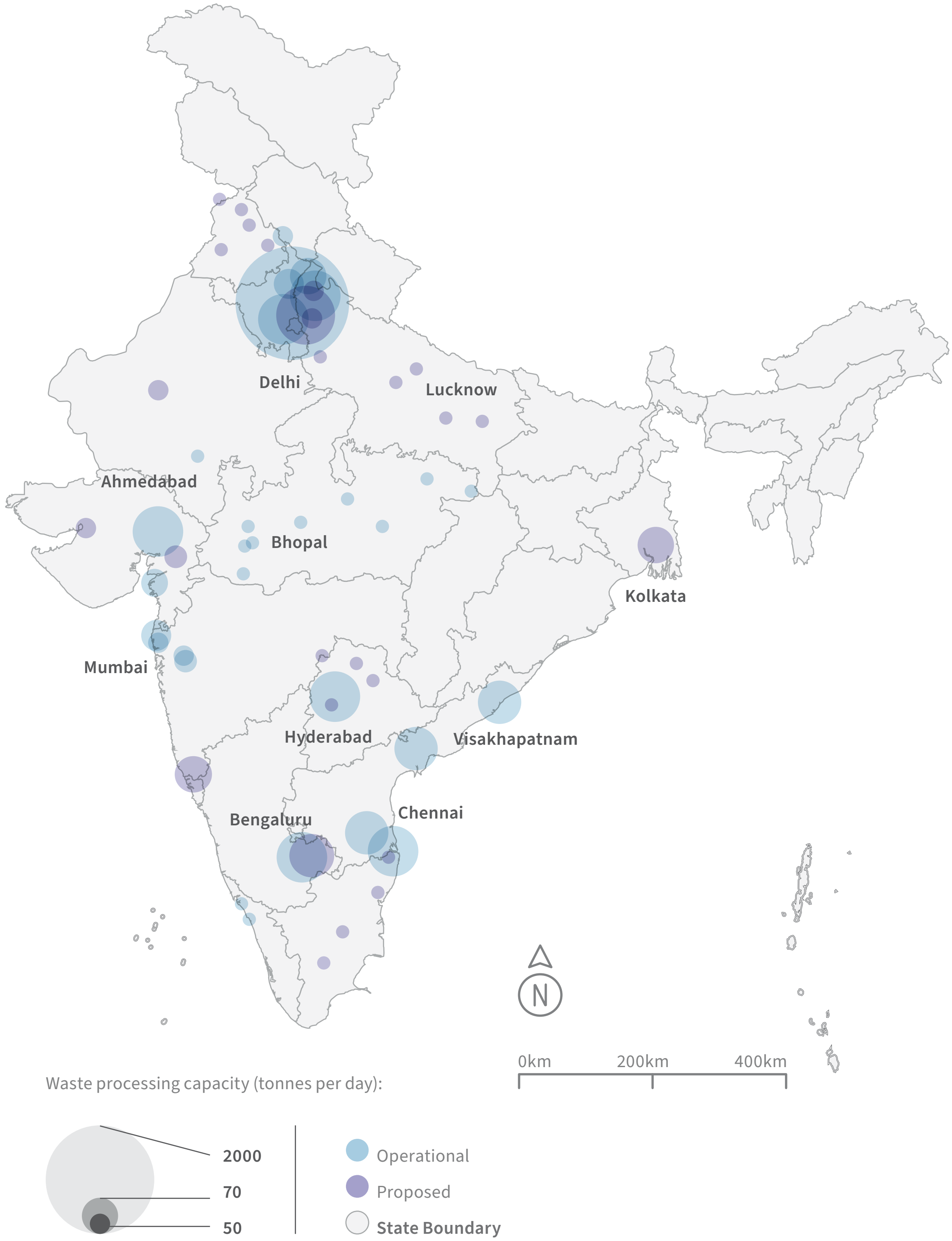
Following is a review of the broader sectoral landscape and its inherent gaps and opportunities.

Overview

The C&D waste management in India hinges on the diversion of debris from sites to processing plants, where they are recycled into resaleable building materials. At present, only a few cities have implemented one or more recycling facilities. Several other cities have sanctioned such plants. This capacity has been illustrated in the map below. These plants are typically operated through Public Private Partnerships (PPPs). Authorities or private contractors collect and supply C&D waste to such plants, where it is segregated and processed into resaleable derivative products such as paver blocks, kerb stones, cement concrete (CC) blocks, recycled aggregates, granular sub-base (GSB), soil and sand. The bulk of C&D waste in India consists of cement, concrete, and masonry. Materials like steel, wood, and glass are generally managed by existing recycling markets due to their high resale value and established processes. Cement, sand, and aggregates are typically diverted to recycling plants as mixed waste streams resulting in product quality that does not meet the market expectations. The knowledge and awareness amongst the stakeholders are limited. While there are rules and regulations, the on-ground enforcement remains a challenge. In absence of a formal C&D waste ecosystem, the waste is handled informally by transporters and demolition contractors.

"Cement, sand, and aggregates are typically diverted to recycling plants as mixed waste streams resulting in product quality that does not meet the market expectations."

Exhibit 4.1 Cities With Operational and Proposed Processing Facilities for C&D Waste



Data and Methods: Construction and debris waste processing facilities from Central Pollution Board Annual Report 2022–23. **Disclaimer:** This map is for illustrative purposes, and does not imply the expression of any opinion on the part of WRI India, concerning the legal status of any country or territory or concerning the delimitation of frontiers and boundaries. **Source:** WRI India

PM 10 and PM 2.5 Emissions from Construction Activities in India

C&D waste contributes significantly to PM emissions and construction activities across India contribute an estimated 3,291 Kilotons (Kt) of PM10 and 197 Kt of PM2.5 annually (TERI 2021). In million-plus cities, the contribution is substantial. In Delhi, annual emissions from construction activities were estimated at 14.2 Kt for PM10 and 2.7 Kt for PM2.5 (ARAI & TERI 2018). However, beyond construction activities, the untreated C&D waste in our cities, are likely to emit dust and particles into the surrounding environment for a longer period.

GHG Emission Reduction Due to Circularity

According to the Ministry of Environment, Forest and Climate Change's (MOEFCC), the energy sector was the largest contributor to greenhouse gas (GHG) emissions in India, accounting for 76% of total GHG emissions in 2019. Within this, the manufacturing industries and construction sectors alone contributed 17% of the national GHG emissions in 2019 (MoEFCC 2023). C&D waste and its circularity can help in reducing GHG emissions as circularity will promote reduced extraction of natural resources and recycle and reuse of available C&D waste near their sources.

Governmental Policies and Guidelines

C&D Waste Management Rules

The Construction and Demolition Waste Management Rules define the primary regulatory framework for the subject. They were notified by the Ministry of Environment, Forest, and Climate Change in 2016 (MoEFCC 2016), and further revised in 2024 (to be effective from 1 April 2025). The rules provide a framework for C&D waste management by defining the roles and responsibilities of waste generators and various stakeholders and emphasising segregation, recovery, recycling, and reuse at the source. The Ministry of Housing and Urban Affairs (MoHUA), through its strategy document on promoting the processing of C&D waste, has committed to supporting the implementation of the rules by assisting and capacitating ULBs.

While the 2016 rules did not set benchmarks for recycling or utilisation of recycled products, the 2024 draft has addressed such lacunae by setting targets for waste utilisation (up to 25% by 2030–31 for construction activities, and 15% for road construction specifically) (MoEFCC 2024) as well as mandating the inclusion of recycled products in schedules of rates. The 2024 draft further strengthens the accountability of waste generators by proposing Extended Producer Responsibility (EPR) towards better segregation, management, and reuse of C&D waste.

4.3 Gaps and Barriers

Following are the major barriers against enabling circularity in the ecosystem of C&D waste management:

Policy and Enforcement Gaps

The current framework of policies needs strengthening in the areas of regulatory enforcement with strong deterrents; enhanced role of government in providing incentives and government agencies taking the lead in enabling circularity; bringing together stakeholders for awareness and consensus building; enhancing the availability of technologies and standardising quality of products; digital monitoring to ensure compliance and supporting research and innovation.

Lack of Reliable Granular Data on C&D Waste Generation

There is currently no reliable estimate on C&D waste lying within the cities and being generated. There is no standard process for estimation at the state or central level. ULBs lack capabilities for ground-level data collection, making it difficult to not only validate estimations of C&D waste generation, but also mapping of material supply chains, generation hotspots, and dumping sites. In the absence of standardised protocols for such data capture, local governments' capacity to plan and implement effective waste management strategies stands compromised.

Ground-Level Interpretation of Regulations and Integration with Local Plans

The 2024 draft of the C&D Waste Management Rules addresses several lacunae like affixing roles and responsibilities of various stakeholders, setting benchmarks for recycling and reuse, and enforcing EPR. However, it offers only a national-level perspective and there will likely be challenges as most of the cities are yet to incorporate C&D waste management directives in their master plans or byelaws, making ground-level implementation and compliance difficult.

Lack of Coordination between Agencies and Stakeholders

C&D waste generation and management comes under the purview of various government agencies at local, state, and central levels, as well as a wider and diverse network of stakeholders comprising builders, contractors, residents, vendors, etc. The multiplicity of jurisdictions makes implementation, interpretation, and coordination especially challenging. The lack of capacity, stakeholder participation, and nodal coordination further compounds this challenge.

Supply-Side Gaps

Following are challenges faced by ULBs in ensuring availability of C&D waste towards circular processes:

Need for On-Site Management

Lack of awareness and knowledge among demolition and construction contractors, and developers has led to gaps in management and handling of waste generated at sites. The full potential of utilising the C&D waste within the site and for further recycling is not realised due to lack of sequential extraction, segregation and on-site storage.

Capacity Constraints of the ULBs

ULBs face challenges due to lack of awareness of C&D waste management rules and competing priorities, which leads to lack of enforcement along the various stages of the logistics chain including monitoring, collection, transportation, recycling and reuse. Lack of availability of rules in simple and understandable guidelines and proactive communication with users and contractors.

Poor Quality of C&D Waste

Lack of segregation of C&D waste at source leads to mixed waste streams that may be unfit for recycling as they may not meet standards of material composition, therefore, limiting the potential for recycling.

Limited Accountability of Waste Generators

The waste generators are often adopting the easiest and least cost solution of open dumping due to lack of collection facility, incomplete collection network, awareness and minimal fear of penalisation.

Demand-Side Gaps

Following are challenges faced by ULBs in enabling demand for resource recovery and recycling systems.

Resource-Intensive Operationalisation

Recycling plants and machinery are generally technologically advanced, capital intensive (100 TPD plants may cost ₹3.5–5.5 crore depending on the location) and require significant tracts of land for deployment (a 100 TPD plant will require 2 acres of land, with an additional acre needed per 100 TPD of extra capacity). ULBs often face challenges in finding land and lack financial capabilities to soundly procure and operationalise such facilities.

Limited Processing Capacity

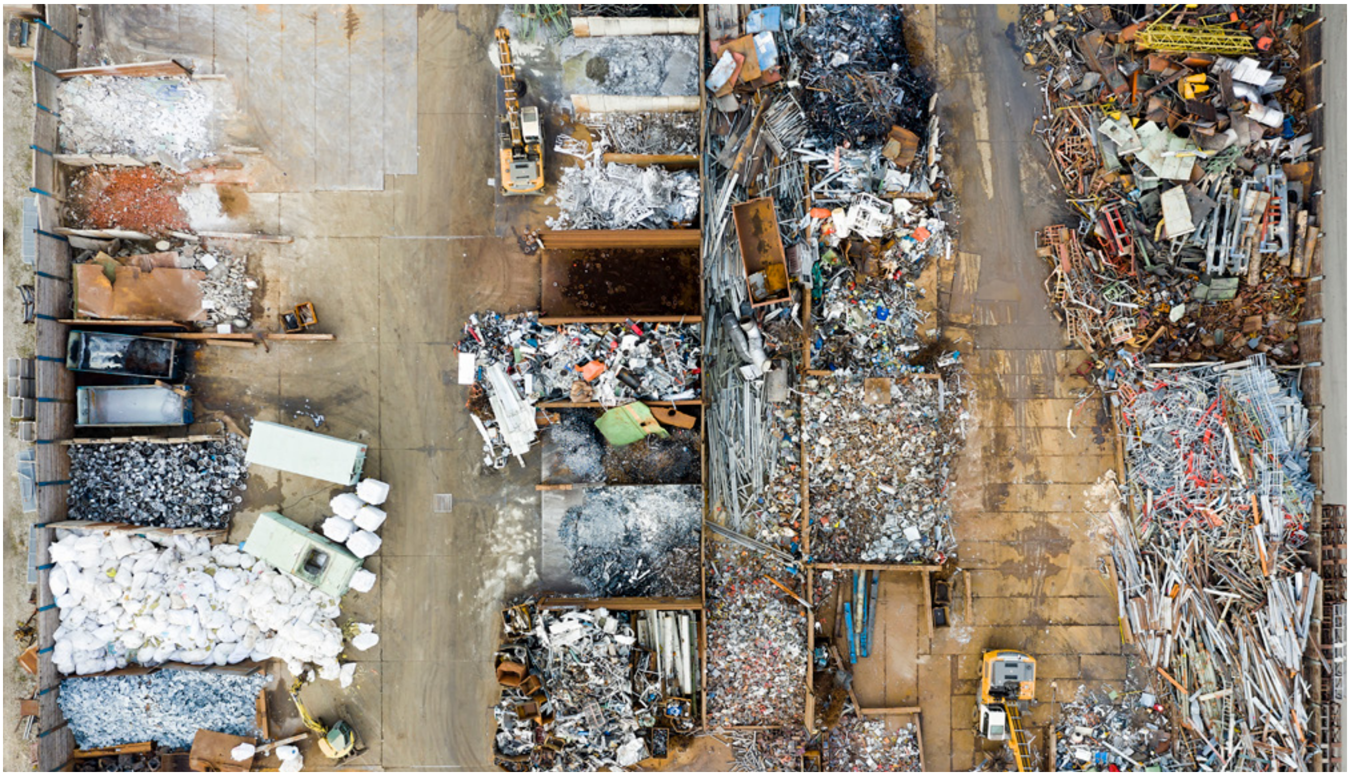
In many ULBs, the installed recycling capacity falls short of estimated C&D waste generation. This can be owed to inconsistencies in estimation itself, as well as challenges in attracting private players to operate recycling plants.

Limited Planning in Recycling and Collection Systems

C&D Waste Management Rules have specified criteria for siting of recycling plants (such as road widths, surrounding land uses, population density, etc.), while BMTPC has recommended that secondary collection points serve a catchment radius of not more than 3 km. However, due to limited availability of land, ULBs often site recycling facilities and collection centres in locations that end up far from C&D waste generation sites. This necessitates added expense and coordination effort towards transport from site to collection point/recycling plant.

Need for Standardisation of Operational Procedure and By-Products

Wide variations in collection methods, processing technology, quality of products, lack of testing and certification has led to a lack of standardised quality products available across the market. Such constraints also prevents from exploring other opportunities such as C&D waste contributing in cement clinker, which needs further detailed investigation.



Market Integration Gaps

Following are some of the barriers faced in achieving higher marketability of recycled products that need to be overcome:

Challenges in Financial Viability of Recycling Plants

In smaller cities, where C&D waste generation quantities are lower, prospective private operators of recycling plants find it challenging to achieve financial viability. As a result, many local governments are forced to resort to viability gap funding or user fee hikes, which is not viable for long- term sustenance.

Tax and Financial Disincentives for Recycled Products

While recycling plants are exempted from Goods and Services Tax (GST) protocols, recycled products manufactured by them are not. In many situations, recycled products attract much higher GST than virgin materials. As a result, virgin material is cheaper, and the marketability of recycled products remains a challenge.

Limited Research of Recycled Products

Due to a limited understanding about the strength of recycled products, the allowed utilisation of waste in plain and reinforced concrete is limited. For instance, NBC limits use of recycled concrete only to non-structural lean concrete. This limits the use-case of recycled products and affects their industry's uptake.

Limited Access to Information about Recycled Products

Potential buyers of recycled materials often lack information about the strength and benefits of using such materials. The lack of a common marketplace also makes access difficult for the vendors and users. This encourages buyers to opt for virgin materials instead, which can be easily purchased and is deemed more dependable.

4.4 Examples of Practices towards Circularity

There are several efforts across the country and international scenarios to accelerate C&D waste circularity, the following are few of the cases of emerging practices including some of the smaller cities advancing the pathways.

DELHI

Decentralised Collection and Capacity Matching

Delhi was the first city in India to set up a C&D waste recycling plant and developed a C&D waste processing policy. Through the Municipal Corporation of Delhi (MCD), New Delhi Municipal Corporation (NDMC), and Delhi Cantonment Board (DCB), the city maintains a granular network of 212 intermediate C&D waste collection points. This lowers waste transportation time, costs for builders and extends coverage to smaller (plot-level) sites as well. As a result, the city is able to process around 38% of total C&D waste generated which is 6177.5 TPD. The city is also expanding its processing capacity by another 3000 TPD with 2 additional plants being developed (Delhi Pollution Control Board 2023).

PIMPRI-CHINCHWAD

User Friendly Approach and Efforts in Marketing

Pimpri-Chinchwad Municipal Corporation (PCMC) operates a processing plant with a capacity of 200 TPD. Observing that transport costs of waste are considered prohibitively high and bothersome by generators, PCMC has opted for ease-of-use options and incentives to enable higher uptake of C&D waste recycling. A network of 8 collection points has been established within city limits to reduce travel distances and costs. Waste generators may also place collection requests and pay fees online, reducing time and effort required. Further, recycled products manufactured by the processing facility are sold at substantial discounts of 20% to encourage wider uptake in the industry (Roychowdhary, Sareen and Singh 2023).

SURAT

Integrated Clean Construction Guidelines and C&D Management

Surat Municipal Corporation has developed and endorsed guidelines for clean construction (Shaikh, Sharma and Nagpure 2020), emphasising minimisation of particulate matter emissions at all stages of construction activity. While focused on air quality management, the guidelines offer recommendations for the proper storage and handling of C&D waste, including phased deconstruction, on-site segregation, adequate covering of debris piles, and their secure transport to designated collection centres. Surat currently operates a C&D plant of 300 TPD capacity, collecting through 10 intermediate collection centres, for transport and management of their generated C&D waste.

UDAIPUR

Penalties on Illegal Dumping

Udaipur generates about 5600 metric tonnes (MT) of C&D waste annually and operates a processing facility Plant of 50 TPD. Due to increasing construction activities and urban infrastructure projects, there was C&D waste being generated and dumped illegally on the vacant plots and along the roads in the absence of formal collection. In 2019, Udaipur Municipal Corporation (UMC) started issuing penalties for the illegal dumping of C&D waste and initiated an online portal and helpline for C&D waste related complaint redressal. Further, a 20-TPD collection point for C&D waste has been identified near the transfer station. The city is also aiming towards mandating the use of recycled C&D waste products in government and municipal contracts (Roychowdhary, Sareen and Singh 2023).

EUROPEAN UNION (EU) AND UNITED KINGDOM (UK)

EU adopted Waste Framework Directive in 2008 which aimed to have 70% of C&D waste recycled by 2020. The EU Construction & Demolition Waste Management Protocol further aims to enhance confidence in C&D waste management processes and increase trust in re-used products and recycled materials.

Some of the steps which improved C&D Waste management in the EU are source separation for recycling and recovery, hazardous waste identification, improved waste logistics and quality management at all stages. EU reported over half of the member states already met the 2020 target in the 2013–2015 period, and some countries like UK and the Netherlands reported to be achieving over 90% recovery (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, European Commission 2018).

The Site Waste Management Plans (SWMP) in the United Kingdom ensure that building materials are managed efficiently, waste is disposed off legally, and material recycling, reuse and recovery is maximised. The Site Waste Management Plans (SWMP) in the United Kingdom England, Wales, Scotland and Ireland ensure that building materials are managed efficiently, waste is disposed off legally, and material recycling, reuse and recovery is maximised. Use of digital platforms to report traceability of C&D waste and online marketplace for re-useable products sale from dismantled buildings are some of the innovative ways deployed. The data reporting is also standardised across the member states with uniformity in the classification of waste with Use of digital platforms to report traceability of C&D waste and online marketplace for re-useable products sale from dismantled buildings are some of the innovative ways deployed. The data reporting is also standardised across the member states with uniformity in classification of waste with movement European List of Wastes (LoW).

JAPAN

In 2000, Japan enacted the Construction Waste Recycling Law, mandating demolition contractors to sort and recycle demolition waste for buildings with a total floor area exceeding 80 square metres (Joshi 2024). This helped in better documentation of disposal of C&D Waste. The contractors are required to segregate and recycle waste streams such as concrete, asphalt, and wood along with other construction wastes. Japan defines concrete class based on properties of recycled aggregates. In 2020 Japan reported recycling rate for C&D waste more than 88% (Zhao 2023).

Across the developed countries the required mandates were bought in early 2000 and which showed results after a decade. This emphasises upon the urgency to set the framework in place for Indian context. Beyond the legal frameworks, infrastructure, collection supply chain and recycling system needs urgent attention.

4.5 Opportunities, Solutions, and Innovations

While there are challenges faced by the current system, there are also several opportunities that can be leveraged to pave the pathway towards achieving circularity. The following section explores potential solutions that could be implemented to enhance circularity in management of C&D waste.

Improving Segregation and Recovery of Materials at Source

Influencing processes followed by waste generators towards segregating and channelling C&D waste towards recovery and recycling are basic steps towards enabling circularity.

Planning for C&D Waste Recovery

Contractors can be sensitised towards ‘planned deconstruction’, wherein design of buildings and project work plans reduce overall waste generation, enable on-site segregation, and boost recovery/reusability of materials. This can be significantly eased by mandating demolition plans and aligning them with building permissions process; and linking them with activity/material databases which can aggregate information about projects across the city.

Standard Operating Procedures (SOP) for Segregation and Management of C&D Waste

Segregation of waste requires additional manpower, finances, time, and training. Development of SOPs at city- and state-levels can guide contractors towards site-based segregation and handling of C&D waste and as a reference for ULBs to conduct audits of compliance.

Specific Actions for Various Waste Streams

Segregation of waste at source can aid specific action and enhance reuse and recycling of various waste materials. Recycling systems can be matched with quantities of waste projected to be generated. For instance, sand, soil, masonry, and aggregates typically form the bulk of C&D waste, followed by concrete, metals, and other materials. Emerging technologies such as wet processing and artificial intelligence (AI) can be applied towards the testing and recovery of these materials.

Expanding and Accelerating Coverage of Recycling at Local-Level

ULBs need to play a crucial role in ground coordination towards activating circularity. Following are the measures that can be explored for implementation –

Decentralised Collection Networks

A key best practice is the establishment of a dispersed and granular network of collection points that reduce distances between C&D waste generation and waste disposal sites. This increases buy-in for waste generators by reducing time and cost requirements towards waste handling.

Land Allocations at City and Neighbourhood Levels

By incorporating C&D waste management in City Master Plans, ULBs can reserve land parcels to develop support infrastructure such as collection points and/or recycling plants in localised areas, such as wards across the city.

Promoting Cluster-Based Approach to Enhance Circular Supply Chain

As high transport costs are a disincentive in handling of C&D waste, a cluster-based approach can be adopted for co-locating potential buyers near recycling and processing facilities. This can improve the manufacturing supply chain for enabling better access to recycled products.

Enabling Operational Feasibility of Recycling Facilities

To make recycling and waste collection more feasible, ULBs can consider charging contractors based on projected sizes and estimates of waste likely to be generated during the building permission process itself. The revenues collected can be used towards developing support infrastructure and formulating financial assistance such as Viability Gap Funding (VGF). Setting up of recycling facilities could be accelerated through measures such as preferential land clearances for plant establishment, lower tariffs for electricity and water usage, and access to loans.

Right-sizing of Recycling Infrastructure

Small-scale recycling plants are increasingly available in the global market. Such plants have lower cost, space, and volume requirements, and are thus ideal for expanding the coverage of C&D waste recycling. These plans can be used at smaller sites, sites which are far from larger plants, and in smaller towns and cities were setting up of larger plants may not be operationally feasible.

Boosting Marketability of Recycled Products at National- and Sub-National Levels

Recycled products can overcome the current challenges of viability and could become a beneficial alternative through following measures.

Tax Incentives for Recycled Products and Technologies

Recycled products made from C&D waste currently attract non-competitive GST rates that reduce their saleability in the market. Lowering of GST can make recycled products more affordable and appealing for prospective buyers. Such incentives may also be extended to recycling equipment to encourage their wider uptake.

Mandates for Recycled Material Utilisation

C&D Waste Management Rules 2024 set recycling benchmarks progressive increasing from 5% in 2026–27 to 20–25% in 2030–31 depending on project typology. However, incentives can be provided for Government and private agencies that set and achieve more ambitious targets. This will help set a precedent for other stakeholders to follow.

Policy Framework for Use of Recycled Products

Recycling mandates will need to be complimented with local byelaws, inclusion of recycled products in Schedules of Rates, incorporation of utilisation mandates in tender documents, and other directives to nudge stakeholders towards uptake. Agencies such as BIS and IRC may also need to undertake research to formulate dedicated guidelines for usage of recycled products in structural and non-structural construction applications.

Encouraging Technological Innovation and Production

Existing Government programmes like Make in India can be leveraged to promote and standardise domestic production of recycling technologies, as well as funding research organisations towards suitable innovations.

Marketplaces for Recycled Materials

Limited awareness of the range and usability of recycled materials often steer potential buyers towards virgin building materials. Institutional investments towards unified marketplaces such as virtual platforms and expos can play a role in stimulating market demand. It can also play a catalytic role in encouraging innovation, research, investments, and entrepreneurship.

Raising Awareness across Stakeholder Networks

Information, education, and communication (IEC) activities may be undertaken to enhance transparency and awareness around recycled materials. For instance, testing of recycled materials and establishing their durability can help build buyer confidence.

Improving Governance and Stakeholder Coordination

ULBs, State and National Government agencies need to recognise C&D waste management as a beneficial process towards sustainable development. Employing the following measures could strengthen pathways towards circularity.

Activity-Linked Databases to Monitor Circularity

Equipping ULBs to develop aggregated databases of projects, activities, and material flows can help optimise monitoring and enforcement at sources and ensure accountability and traceability of C&D waste, channelled towards recycling and minimising environmental impacts.

GIS-based Monitoring and Hotspot Mapping

Geographic Information Systems (GIS), camera-based surveillance, and ground inspections can help ULBs identify and map locations of C&D vendors, construction activity and illegal dumping. This data can help ULBs better plan critical decisions such as siting of collection facilities, scheduling of inspections, penalisation of violators, co-location of vendors and streamlining of collection logistics.

Enhance Awareness and Improve Stakeholder Coordination

Coordination and collaboration across stakeholders can be fostered through the formation of government institutional setups and private sector led forums, such as committees, coalitions, working groups etc. These can be anchored by key agencies such as Central and State Public Works Departments (PWD), Building Materials and Technology Promotion Council (BMTPC), Bureau of Indian Standards (BIS), Central Road Research Institute (CRRI), Central Building Research Institute (CBRI), technical research organisations, think tanks, real estate developer associations, green building certification organisations, etc.

Convergence with Other Schemes and Programmes

The government can prioritise convergence across various missions, schemes, and institutional commitments to frame mandates and ensure finance flows for circularity, such as Swachh Bharat Mission, National Clean Air Programme, fiscal incentives proposed by NITI Aayog, and commitments made through G20 and CoP.

Encourage Entrepreneurship in C&D Waste Circularity

Agencies like the Ministry of MSMEs, Ministry of Skill Development and Entrepreneurship (MSDE) and Department of Science and Technology can support entrepreneurship and promote small enterprises and start-ups by working on collection and processing of C&D waste supported by green finance and other financial instruments.

Boost Job-Creation Potential of Recycling

C&D waste management is a labour-intensive process. It can benefit with development of specialised short- and long-term vocational training avenues in fields such as collection, transportation, sorting and segregation, quality control, testing and analysis, project management, design, compliances etc. It is broadly estimated that strengthening collection and processing of C&D waste in the 154 priority cities identified by Swachh Bharat Mission (SBM) itself could result in creating more than 2,00,000 jobs and many more opportunities in the value chain.

4.6 Conclusion and Next Steps

The construction sector will require an enormous amount of materials to sustain forecasted urban and economic the country's growth. To ensure that this momentum is made resilient against wider environmental and economic pressures, it is critical that coordinated efforts be made towards building an ecosystem for promoting circularity in C&D waste. Following are pathways to support accelerating circularity of C&D waste management in India:

Encourage Data-Based Decision-Making

Support towards developing activity-linked databases will enable decision-makers to monitor and understand the material flow, implement localised management, ensure traceability and accountability of C&D waste, and inform regional and national efforts towards building and sustaining circular supply chains.

Strengthen Policy Eco-system for Circularity

In addition to the implementation of the C&D Waste Management Rules 2024, it is critical to converge the diverse set of ministerial and departmental guidance; establish a robust framework of incentives, penalties and enforcement; ensure robust data collection, analysis and transparency and develop localised policies and guidelines. This multi-pronged approach can enable all levels of governances to implement and enforce C&D waste management mandates and hold all stakeholders accountable.

Ensuring National-Level Monitoring and Coordination

Periodical monitoring system of C&D circularity needs to be institutionalised. Coordinated efforts across ministries are needed to incorporate recycled materials into mainstream construction practices to achieve circularity in C&D waste management. Introducing favourable taxation for recycled products, financial incentives, fostering marketplaces, and supporting skilling programmes can build capacity and boost adoption. Ministries and States need to monitor and provide periodic directives of higher targets to mandate the use of recycled C&D materials in all their public projects, ensuring alignment across policies and practices.

Enable Municipal-led Dedicated Action for C&D Waste Management

ULBs can be equipped to enforce C&D waste management protocols through integration with master planning, development of detailed SOPs, creation of activity-linked databases, boosting monitoring, and accelerating development of support infrastructure.

Reinforcing Mandates Towards Circularity

The current target for waste utilisation as mandated by the Rules needs to be gradually scaled with progresses made on the ground and all ministries and state governments involved in construction activities need to contribute towards embedding these mandates into policies and projects. Existing mandates for utilisation of recyclable materials can be extended from contractors and project execution agencies to material manufacturers as well to build a wider market for such products. These efforts will also need to be complemented with research and standardisation efforts to ensure materials meet quality standards as expected by the market.

Enhancing Resilience of Construction Industry Through Circularity

Focused engagement between industry and the government can ensure circularity by aligning sectoral demand for materials, and resource utilisation flows, with policies and programmes. This will enhance self-reliance, reduce dependence on imports, boost green employment opportunities, and sustain the momentum of growth and development. Such an orchestrated effort can help enhance the resilience of the construction industry.

Incentivise Recycling Processes and Products

Tax rates applied on products made from recycled C&D waste need to be reduced to make them more attractive for buyers. Further fiscal incentives may be explored to boost feasibility of recycled products, improve availability of recycling equipment and technologies and attract investments in C&D waste management.

Identify, Nurture and Propagate Best Practices

The government can identify emerging best practices, support ULBs and other public and private agencies in implementing best practices share their learnings to inspire others and update policies and processes to be followed.

Promote Research and Innovation

Stakeholder collaboration can be leveraged to catalyse innovation in C&D waste circularity through research, entrepreneurship, and awareness-building with the development programmes and platforms such as the Resource Efficiency and Circular Economy Industry Coalition under G20, and the India Alliance for Clean Construction (IACC).

References

- ARAI & TERI. 2018. “Source Apportionment of PM2.5 & PM10 of Delhi NCR for Identification of Major Sources.”
- Building Materials and Technology Promotion Council. 2018. “Utilisation of Recycled Produce of Construction & Demolition Waste A Ready Reckoner.”
- Delhi Pollution Control Board. 2023. Annual Report of NCT of Delhi on Implementation of C&D Waste Management Rules 2016. **https://www.dpcc.delhigovt.nic.in/uploads/pdf/Pi700AnnualReportCDDelhi2022-2023pdf-1c65cab277dfa0013fc3319067845658.pdf**.
- Deloitte. 2015. “Construction and Demolition Waste Management in France.”
- Department for Environment, Food and Rural Affairs, UK. 2021. “Waste Management Plan for England.”
- Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, European Comission. 2018. “EU Construction and Demolition Waste Protocol and Guidelines.”
- European Commission. 2014. “EU Construction & Demolition Waste Management Protocol, including guidelines for pre-demolition and pre-renovation audits of construction works.”
- Joshi, S. 2024. “Resource Efficiency and Recycling of Construction and Demolition Waste.” Anant National University.
- Mathews, R., M. Pai, T. Sebastian, and S. Chakraborty. 2018. State-Led Alternative Mechanisms to Acquire, Plan and Service Land for Urbanisation in India. World Resources Institute, Available online at **http://wrirosscities.org/our-work/research**.
- Ministry of Housing and Urban Affairs. 2024. “Press release available at **https://pib.gov.in/PressReleasePage.aspx?PRID=2007086**.”
- Ministry of Housing and Urban Affairs. 2021. “Swachh Bharat Mission-Urban 2.0 Making Cities Garbage Free - Operational Guidelines.” **https://sbmurban.org/storage/app/media/pdf/swachh-bharat-2.pdf**.
- Ministry of Labour and Employment. 2024. Press Release, available at **https://pib.gov.in/PressReleasePage.aspx?PRID=2036930**.
- Ministry of Road Transport & Highways. 2024. “Press release available at: **https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1993425**.”

- MoEFCC. 2023. “India: Third National Communication and Initial Adaptation Communication to the United Nations Framework Convention on Climate Change.”
- MoEFCC. 2016. “The Construction and Demolition Waste Management Rules 2016.”
- MoEFCC. 2024. “The Construction and Demolition Waste Management Rules 2024.”
- Roychowdhary, A., R. Sareen, and M. Singh. 2023. “Construction and Demolition Waste: Closing the waste loop for sustainability.” Centre for Science and Environment, New Delhi.
- Roychowdhury, A,, R. Sareen, and S. Grover. 2024. “Rubble recast: Navigating the Road to Efficient C&D Waste Recycling, ,.” Centre for Science and Environment, New Delhi.
- Shaikh, Z., B. Sharma, and Dr. A. Nagpure. 2020. “Handbook of clean construction practices in Surat.” World Resources Institute India.
- TERI. 2021. “Development of Spatially Resolved Air Pollution Emission Inventory of India.”
- The Energy and Resources Institute. 2019. “Reference Report For “National Resource Efficiency Policy” of India.”
- Zhao, Q. 2023. “How can C&D waste recycling do a carbon emission contribution for construction industry in Japan city?”

5.0 Charting a Pathway for Enabling Circularity in the Agricultural Waste Sector

AUTHORS

Sampriti Baruah, Nupur Kulkarni, and Kavita Sharma

5.1 Introduction

Waste is a consequence of rising population, urbanisation, and economic development (Kaza et al. 2018), with agricultural waste making up a significant component. Around 2.59 billion tons of waste is estimated to be generated globally by 2030. This figure could rise to 3.4 billion tons by 2050 (Saadatlu et al. 2022). Currently, the world produces about 1 billion tons of agricultural waste annually, contributing to roughly one-fifth of global greenhouse gas emissions (Karić et al. 2022).

Agriculture Waste in India

India produces an average of 750 million tons (Mt) of crop waste annually (Lok Sabha 2023), making it the second-largest global producer of agricultural waste after China. The country generates about 130 Mt of paddy straw—half is used as fodder while the other half is discarded (Koul, Yakoob and Shah 2022). As shown in **Exhibit 5.1**, the volume of India's agricultural waste is significantly higher than that of other selected countries in the region (Bhuvaneshwari, Hettiarachchi and Meegoda 2019).

Exhibit 5.1 Agricultural Waste Generation in India Compared to Other Select Nations in Asia

COUNTRY	AGRICULTURAL WASTE GENERATED (MT/YEAR)
India	500
Bangladesh	72
Indonesia	55
Myanmar	19

Source: Bhuvaneshwari, Hettiarachchi and Meegoda (2019)

Agricultural waste refers to materials produced during various agricultural activities and processes throughout the value chain. This waste may include raw materials, byproducts, or residuals generated at different stages of agricultural operations. As these materials are no longer useful, they are classified as waste and are typically discarded.

Generally, agricultural waste is categorised as crop waste/residue (rice straw, wheat straw, barley straw, etc.), livestock waste (animal excreta, carcasses), agro-industrial processing waste (bagasse, molasses, bran, husks, fruit peels, packaging material, fertiliser cans, etc.), and hazardous and toxic agricultural waste (pesticides, insecticides, herbicides, etc.) (Awogbemi and Kallon 2022; Seidavi et al. 2019; Tripathi et al. 2019; Duque-Acevedo et al. 2020; Koul, Yakoob and Shah 2022). Thus, poorly planned intensification of agricultural production inevitably leads to a substantial increase in livestock waste, crop residue, and agro-industrial byproducts, posing significant challenges to environmental sustainability and effective resource management.

The National Policy for Management of Crop Residue (NPMCR, 2014) states that the highest generation of crop residue occurs in Uttar Pradesh (60 Mt), followed by Punjab (51 Mt) and Maharashtra (46 Mt). Among crops, cereals produce the most residue (352 Mt), followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt), and sugarcane (12 Mt). Cereal crops, including rice, wheat, maize, and millets, account for 70% of the residue, with rice alone contributing 34%. With the increasing generation of agricultural waste in India, especially crop residue, its improper disposal by burning has been alarming. The practice of burning residue, specifically the large volume of paddy residue, known as 'parali burning,' contributes significantly to air pollution and raises public health concerns (Gadde et al. 2009; Kumar and Singh 2021; Koul, Yakoob and Shah 2022). The Policy for Crop Residue Management (2023–24) states that crop residue burning is predominantly high in Punjab, Haryana, Uttar Pradesh, Madhya Pradesh and the National Capital Territory (NCT) of Delhi.

According to the 20th Livestock Census (published in 2021), India's livestock population is 535.78 million, producing approximately 1,655 Mt of dung annually. Waste generated from the livestock and poultry industry includes a mix of manure (excreta), bedding materials (like wood shavings or straw), leftover feed, animal carcasses, broken eggs, feathers, and general farm waste. Like other agri-production activities, livestock farming also contributes to greenhouse gas emissions. The livestock categories contributing to emissions includes crossbred cattle (4.6%), indigenous cattle (48.5%), buffaloes (39%), goats (4.7%), sheep (1.8%), and other livestock (1.4%), including mules, yaks, camels, donkeys, pigs, mithuns, horses, and ponies (Parihar et al. 2019). Obsolete pesticide, insecticide and herbicide stocks, along with discarded bottles and packages of pesticides, insecticides, and herbicides containing residual chemicals, when carelessly dumped in fields, ponds, or improperly disposed of as waste, can significantly threaten human health and environmental safety (Damalas and Eleftherohorinos, 2011).

Thus, effective management of agricultural waste is crucial not only for sustaining natural resources but also for enhancing biodiversity and the quality of air, water, and soil.

Circular Economy in Agriculture

The circular economy is an economic system where the means of production are organised around reusing and recycling inputs. This is done to reduce environmental emissions and facilitate a sustainable and environment-friendly mode of production. With India's growing population, increasing urbanisation, environmental degradation, and increased climate impacts, there is an urgent need to transition toward a circular economy. It is a concept that focuses on minimising waste, maximising value, and closing the resource use loop. Circular economy is an economic system with closed loops, where resources are renewable energy sources and products maintain their value and quality for a longer duration (EMF 2013). It offers an alternative to the traditional and linear *take-make-dispose* economic model that puts stress on globally available resources. It is a strategy aimed at reducing resource consumption and waste generation, mitigating the negative impacts of agricultural ecosystems, and enhancing economic performance (Velasco-Muñoz et al. 2021).

In sustainable agriculture, this translates to designing farming systems that use resources efficiently while minimising environmental impact (Baruah et al. 2024). Crop rotation, mulching, composting, and integrated pest management are examples of circular agriculture methods that improve soil health, reduce chemical inputs and foster biodiversity. By adopting these practices, farmers can cultivate more resilient and sustainable agricultural systems. There are innovations that target utilisation of agricultural/crop waste for diverse eco-friendly end products, like packaging and construction material, and energy production (biogas, bioethanol, biochar). A circular economic approach in agriculture aims for zero waste and pollution, offering multiple benefits including improved health, environmental protection, economic savings, job creation and the preservation of biodiversity (Corral et al. 2022).

Agriculture has a profound environmental impact, affecting ecosystems and consuming substantial amounts of natural resources such as water and energy (Chen et al. 2020; Brunner & Rechberger 2016). Intensive farming contributes to the degradation of water, soil, air, biodiversity, and natural habitats while diminishing food quality and posing health risks due to exposure to toxic pesticides (EMF 2013). Practising circular economy in agriculture reduces the excessive use of chemical fertilisers and curbs greenhouse gas emissions. For instance, Castillo-Díaz et al. (2022) reported a 100% reduction in inorganic fertilisation by reusing crop waste along with other organic materials. This also lowered production costs by up to 4.8%. The core principles of the circular economy in agriculture—reuse, recycle, and reduce—include turning agricultural waste into fertilisers, improving irrigation, reusing water, transforming waste into packaging materials, and recycling plastics and packaging. The use of agricultural waste as fertilisers becomes more efficient and cost-effective when combined with bio-solarisation and bio-fumigation techniques for soil disinfection (Castillo-Díaz et al. 2021; Salinas et al. 2020; Duque-Acevedo et al. 2020b).

Using agricultural waste as fertilisers enhances soil physiochemical properties, leading to increased crop production (Marin-Guirao et al. 2016). Additionally, the closed-loop nutrient flow and valorisation of waste and byproducts reduce the need for external nutrient inputs in agriculture, thereby contributing to greater economic sustainability.

5.2 Review of Policy Landscapes in India

Over the past decade, the Government of India has introduced several policies to address agricultural waste management, particularly focusing on crop residue from paddy harvests, given the considerable crop residue generation. It has also introduced several strategies to manage agriculture waste effectively, such as providing subsidies, promoting the involvement of businesses and CSOs, creating formal and non-formal education programmes for farming communities, and developing long-term pathways for recycling agriculture waste.

State governments have also enacted various laws and introduced schemes for crop residue management through their respective state institutions. The Punjab government, through its Department of Agriculture, initiated various schemes and tied up with Punjab Agriculture University for research on minimising stubble burning and improving soil and environment health by utilising excess residue. Highlighting that the subject of agriculture falls under the purview of state governments, the Government of India has directed Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Tamil Nadu, and Uttar Pradesh to enact necessary laws and regulations, along with identifying interventions to monitor agricultural waste management practices regionally.

The NPMCR incentivises farmers to purchase machinery for in-situ management of crop residue (incorporation in soil, mulching, baling/binding for use as domestic/industrial fuel and fodder). The policy also extends a subsidy to farmers for hiring resource conservation machinery from Custom Hiring Centres (CHC) and for diversifying use of crop residue for charcoal gasification, power generation, as industrial raw material for the production of bioethanol (in PPP mode), as packing material, in the paper/board/panel industry, for composting and mushroom cultivation, etc. In Haryana, farmers showed a willingness to enter long-term contracts to sell their paddy straw for various industrial processes at a mutually agreed-upon price. But they also demanded that the crop residue must be purchased within 10 days. Government or non-government agencies may find this short time frame logistically challenging (Sanjay et al. 2021).

State governments and district administrations are offered access to satellite-based technologies to monitor crop residue management through the National Remote Sensing Agency (NRSA) and Central Pollution Control Board (CPCB). Various ministries also provide farmers and state agencies with financial support for innovation in crop residue management. Similarly, the Ministry of Agriculture and Farmers Welfare (MoA&FW) implemented the centrally sponsored Central Sector Scheme (CSS) between 2018–19 and 2021–22 to support the governments of Haryana, Punjab, Uttar Pradesh, and the NCT of Delhi in addressing air pollution and to subsidise crop residue management machinery. Under this scheme, financial assistance is also provided to the states and the Indian Council of Agricultural Research (ICAR) to conduct Information, Education & Communication (IEC) activities for mass awareness of farmers and other stakeholders. State governments, however, have not made significant progress in meeting the objectives of the NPMCR, except for satellite-based monitoring of crop residue burning by Punjab, Haryana, and Rajasthan.

> “State governments and district administrations are offered access to satellite-based technologies to monitor crop residue management through the NRSA and CPCB. Various ministries also provide farmers and state agencies with financial support for innovation in crop residue management.”

The Ministry of Power in 2022 mandated the blending of biomass pellets, made primarily of agro-residue and coal, through the ‘Revised Policy for Biomass Utilization for Power Generation Through Co–firing in Coal based Power Plants,’ under SAMARTH (Sustainable Agrarian Mission on use of Agri Residue in Thermal Power Plant) Mission in 2022. All thermal power plants have been mandated to use a 5% to 7% blend of biomass pellets. Another government intervention that has gained popularity is the setting up of biogas plants. The National Biogas and Manure Management Programme aims to provide clean fuel for cooking, lighting and meeting small power needs of farmers, small businesses, and households.

This programme was implemented under the government's waste-to-energy mission. Its objective is to support the setting up of waste-to-energy projects for the generation of biogas/bioCNG/power/producer or syngas from urban, industrial, and agricultural wastes/residue. Although some of these government interventions have been successful in reusing or recycling agricultural waste, a large amount is still not disposed of properly.

5.3 Relevance of Circular Economy for Agricultural Waste Management in India

Embracing a circular economy can significantly boost resource efficiency and minimise waste by encouraging reusing and recycling to extract maximum value from materials throughout their lifecycle. It is estimated that adopting a circular economy strategy could yield an annual profit of ₹40 lakh crore ($624 billion) for India by 2050 while also reducing greenhouse gas emissions by about 44%. Additionally, it could help mitigate congestion and pollution (ICEF 2022). Lately, India's circular economy strategies are playing a vital role in conserving the environment by incentivising reuse, recycle, and recovery of material to minimise waste generation (Agamuthu and Babel 2023).

India has begun efforts to recycle and reuse agricultural waste. For instance, the ICAR has developed 140 technologies aimed at recycling agri-waste, including waste from fisheries, animal husbandry, horticulture, and crop byproducts. Some of these technologies focus on creating high-value products from waste, such as:

- Corn cob powder for microbial protein production and traditional *kulhads* (handle-less drinking cups)
- Animal feed made from potato waste, groundnut shells, okara (a byproduct of soy milk), and fruit residue
- Paper plates made from natural fibre biomass
- Fashion and decor items from banana stem and jute waste
- Edible products like cookies and pickles from crop leftovers, such as grape pomace powder and basil seeds
- Biochar from agricultural waste material like coconut waste
- Green energy initiative through paddy straw-based biogas plant
- Soilless planting media using sugar industry residue
- Pineapple fruit residue silage as fodder source for livestock
- Green particle board from cassava stems using bio-adhesives
- Coco peat-based coco husk for soilless cultivation

These innovations offer promising pathways for transforming waste into resources, benefiting both farmers and the environment.

Current agricultural residue and waste management models, particularly the circular and bioeconomy frameworks, prioritise profitability, sustainability, technical feasibility, and adoption potential. These models advocate for an integrated approach that is scalable, tailored to specific crops and regions, socially inclusive, environmentally responsible, and technically advanced. Such an approach leverages the synergies among various alternative solutions, focuses on mitigating climate change, and actively contributes to achieving the Sustainable Development Goals (SDGs). By aligning agricultural practices with these principles, the circular and bioeconomy model ensures a more resilient and resource-efficient agricultural system (Venkatramanan et al. 2021).

5.4 Common Agricultural Waste Management Practices in India and its Socio-economic and Environmental Impacts

The environmental and socio-economic impact of agricultural waste depends not only on the quantity produced but also on the disposal practices used. Residue burning, animal bedding, livestock feed, soil mulching, biogas production, bio-manure/compost, thatching for rural homes, mushroom cultivation, biomass energy production, and fuel for home and industrial use are some of the most common uses for crop residue (Sharma and Iqbal 2022). Common disposal practices such as burning, can harm the environment (Agamuthu and Babel 2023). In many developing countries, agricultural waste burning is widespread, contributing to air pollution. This process releases harmful substances that lead to the formation of ozone and nitric acid. It increases the concentration of matters such as sulphur dioxide (SO_2), volatile organic compounds (VOCs), oxides of nitrogen (NOx), carbon monoxide (CO), and particulate matter (PM) in the atmosphere, leading to poor air quality and posing hazards to human life (Gadde et al. 2009). Further, greenhouse gas (GHG) emissions due to crop residue burning leads to global warming, loss of agricultural biodiversity, and degraded soil fertility (Lohan et al. 2018; Bhuvaneshwari, Hettiarachchi and Meegoda 2019). Animal waste also impacts the environment. While gases from animal respiration and fermentation are quickly released, microbial decomposition of excreted waste produces byproducts that pollute water, soil, and air.

The majority of agri-waste in India is burned or used as fuel and animal feed. Due to the lack of sustainable agricultural management practices, nearly 178 Mt of surplus crop leftovers and 92 Mt of crop trash are burned annually, causing significant air pollution (Sharma and Iqbal 2022). A large amount of crop residue is burned ‘on-farm’, mostly to prepare the ground for planting the next crop immediately. The mechanisation of rice paddy harvesting, that leaves behind 8 to 10 inches of paddy stalk, has increased the amount of crop residue generated per acre. A significant amount of post-harvest crop residue is left over in some states and burned throughout these regions. Every acre of paddy in the northern Indian states produces 2.5 tonnes of stubble. As the stubble is burnt in massive quantities in these states, the north-westerly wind carries this hazardous concentration of matter to nearby settlements. Air pollution, therefore, intensifies due to the residue burning of the Kharif harvest in October and November (Singh et al. 2022). ‘On-farm’ crop residue burning is widely practiced due to a number of factors, including increased crop yields, labour shortages, a brief period between the Kharif crop harvest and Rabi crop sowing, inadequate crop residue management technology, nutritionally deficient rice crop residue, limited financial resources, social influence, cost of logistics, and a lack of knowledge about the health risks associated with crop residue burning (Singh et al. 2022; Shinde et al. 2022; Venkatramanan et al. 2021). Nonetheless, in certain states, crop waste is often utilised sustainably to produce biochar, fodder, biofuel, mushrooms and energy (Singh et al. 2022).

5.5 Challenges, Opportunities and Solutions in Agriculture Waste Management

Challenges in Agriculture Waste Management

Identifying and addressing the major challenges and risks in agricultural waste management is a complex task due to its interdisciplinary nature, encompassing agronomy, microbiology, soil science, plant physiology, ecology, environmental science, and engineering—each with its own priorities and perspectives. Key challenges include the vast volume of waste, short turnaround time, and the lack of efficient waste management technologies and methods, such as low collection rates and difficulties in transportation and treatment. Further, limited knowledge and awareness among farmers, along with inadequate incentivisation through legislative frameworks, hinders effective waste management. Another significant barrier is developing technologies that can reduce contaminants in waste, while maintaining food safety standards (Bernal 2017). The collection and storage of agricultural waste poses significant challenges, as they come with risks such as degradation, unpleasant odours, greenhouse gas emissions, and the presence of pathogens.

While agricultural waste has the potential to be transformed into alternative energy sources, contribute to food security, and even create livelihoods, its effective use requires pre-treatment (Babu et al. 2022). Anaerobic digestion is one such well-established and effective method for converting biomass residue into bioenergy and biogases. However, due to transportation and economic constraints, large areas are often allocated to cultivating energy crops, limiting the use of agricultural waste in this process (Gontard et al. 2018). This also contributes to increased land use, emissions, and contamination from agrochemicals. Agri-waste can be turned into liquid hydrocarbons by producing bio-oil through pyrolysis, hydrothermal liquefaction, and Fischer-Tropsch synthesis (Babu et al. 2022).

Agricultural waste can also be converted to value-added processes like paper production, but this carries certain limitations. For instance, when agricultural residue is used for paper production and strong alkalis are added during pulp preparation, the silica in the waste dissolves in the alkali. This leads to silica precipitating on equipment during the alkali/liquor recovery process (Babyloni et al. 2022). Bioplastics are another value-added product of waste valorisation. However, their degradation releases greenhouse gases. To mitigate this, it is important to develop methods that can capture the released hazardous gases and emissions during decomposition, which can be used as fuel. Emissions can also be controlled by designing bioplastics that degrade more slowly. Another key challenge in agricultural waste management is the heterogeneity of waste, both in chemical and physical properties. Moreover, many waste valorisation techniques have only been validated at the laboratory level, necessitating optimisation and development of innovative technologies to enhance waste management, add value, and strengthen the national economy. (Menyuka et al. 2020).

While many innovators and startups are building and deploying solutions/technologies for effective in-situ and ex-situ management of crop residue, the lack of dedicated capacity-building support and financing poses significant barriers to scaling up solutions that could promote diverse utilisation of agri-waste for value added sustainable products.

WRI India's Land Accelerator programme has built the capacity of land restoration entrepreneurs by identifying and supporting startups working on innovative circular economy solutions for agri-waste management. These startups require active government support for testing, demonstrating, and implementing solutions, procuring sufficient agri-waste, engaging with farmers to raise awareness around avoiding unsustainable practices like burning, and establishing diverse supply chains for recycling or reuse of crop residue. They also need customised capacity-building support, including technical assistance to validate and scale their solutions. Additionally, they struggle to secure funding for expanding operations, conducting research and development (R&D), commercialising technology, and marketing. More financial support in the form of grants and concessional loans is needed to establish their creditworthiness and make them market-ready for private investment.

Opportunities in Agriculture Waste Management

Recognising the urgency of addressing agriculture waste management, several new initiatives have been proposed to build a supply chain for crop straw to generate bioenergy in the form of biogas, bioethanol and biochar. Bioenergy, as a climate-neutral energy source, can significantly reduce greenhouse gas emissions. It also enhances energy security and diversifies supply, reducing dependence on fossil fuels. Moreover, bioenergy is becoming increasingly cost-effective compared to other renewable energy sources and provides an additional income stream for farming communities.

Among the various uses of crop residue, biogas production is gaining more popularity among farmers compared to alternatives like paper, animal feed, or construction material. This suggests that alternative waste management measures can be successfully implemented if farmers are incentivised with competitive market prices for products made from crop residue. In this context, crop residue-based products that directly support the agricultural sector—ideally on-farm—may be the most viable option (Shinde et al. 2022; Venkatramanan et al. 2021; Bhuvaneshwari, Hettiarachchi and Meegoda 2019).

Policymakers have also proposed green microfinance (GMF) as a potential solution to crop residue burning. They argue that GMF is an emerging practice that could incentivise or reward farmers by providing access to financial services, contingent on their refraining from burning crop residue. In addition to protecting the environment, robust green microfinance could contribute to household income growth. Payment for ecosystem services (PES) could clearly encourage farmers to protect natural resources in developing nations (Singh et al. 2022).

There are significant opportunities for both the government and farmers to manage agricultural waste effectively using various in-situ and ex-situ machines, supported by NPCRM. Innovators are working to customise these machines for broader agricultural applications, ensuring year-round utility and encouraging farmers to purchase them through the custom hiring scheme. By collaborating with innovators, the government can address the issue of limited machine use during agriculture off-season, which currently discourages farmers from making purchases. There is significant potential for industries to recycle agricultural waste into valuable products by leveraging laboratory techniques, science and technology. Startups such as Dharaksha Ecosolutions, REVY Environmental Solutions, and FuMa Labs are using biotechnology-driven innovations to manage agri-residue and reduce stubble burning. WRI India, through its Land Accelerator programme, is helping these startups grow by providing support and expanding their networks.

Dharaksha specialises in creating sustainable and scalable biodegradable packaging materials and other alternatives to reduce stubble burning in Haryana and the NCT of Delhi. FuMa Labs produces high-quality, eco-friendly particle boards for the furniture industry and food-grade packaging from crop waste. REVY Environmental Solutions offers the innovative REVY-STUB, a DIY kit combining useful microbes and nutrients, to decompose paddy stubble and convert it into bio-compost, thereby restoring soil health.

The significant socio-economic and environmental impact of these startups is attracting interest from impact investors and gaining traction within the private investment community. However, they continue to face challenges in securing commercial finance and are seeking additional government support to scale and become market-ready with their proven technologies. The government has a major opportunity to develop innovative financing mechanisms, such as credit guarantees that enable commercial lenders to fund early-stage innovators or startups and create pooled funds to mobilise private investment through blended finance and dedicated policies.

5.6 Conclusion and Next Steps

Circular agri-waste management offers several benefits, including reduced waste and pollution, enhanced climate resilience, greater biodiversity, improved soil health, strengthened food security, and economic gains for farmers. Recognising the potential of circularity in enabling sustainable and profitable agriculture waste management practices, the following recommendations are proposed. These aim to foster a forward-thinking, collaborative approach that prevents environmental degradation, enhances air quality, creates livelihood opportunities, and diversifies income sources for farming communities.

Foster Innovation

Efforts should prioritise fostering innovation to design and customise in-situ and ex-situ agricultural waste management machines for flexible, year-round applications. Collaboration with government schemes is vital to incentivise farmers in adopting these technologies, ensuring equitable access through public programmes for widespread adoption. WRI India's learnings from working with innovators/startups in this space highlight the need for designing capacity-building programmes and innovative finance that encourages private investments for solutions that seek to enable circular economy in agri-waste management. Government support through grants and concessional loans can help them scale and access market-based finance.

Utilise Micro-Finance to Encourage Circularity Practices Among Producers

During a multistakeholder consultation on Sustainable Urban and Peri-Urban Agriculture (SUPA), WRI India identified micro-finance as a crucial tool for reducing and recycling agricultural waste. There is significant untapped potential in this area that requires financial support. Implementing a 'processing fee' model can promote resource circularity and waste reduction, wherein payments are based on the weight of recycled materials (e.g., compost generation) and the non-recyclable portion (Yadav and Gada 2022).

Collaboration with CSOs

This could mainstream the agriculture waste management techniques at local level. It can also build capacities of self-help groups, farmers groups, and Farmer Producer Organisations (FPOs), to recycle agricultural waste into valuable products using technology, thereby creating livelihood and employment opportunities.

Design Regionally Focused Campaigns for Awareness and Capacity Development

Lack of knowledge about agricultural waste management practices is a challenge that must be addressed. To encourage farming communities to adopt and implement existing provisions for agri-waste management, greater involvement is needed with FPOs, cooperative societies, NGOs, CSOs, and Krishi Vigyan Kendras. The private sector should be effectively leveraged to achieve this goal. The farming community must be informed about the financial and physical incentives available through best practices. Customised awareness campaigns should be designed for different agro-climatic zones, considering local challenges, cropping patterns, and key factors contributing to improper waste disposal.

References

- Adejumo, I. Oluseun, and O. Adebukola Adebiyi. 2020. "Agricultural solid wastes: causes, effects, and effective management." Strategies of sustainable solid waste management 8, (10): 5772.

- Agamuthu, Pariatamby, and Sandhya Babel. 2023. "Waste Management Developments in the Last Five Decades: Asian Perspective." Waste Management & Research 41 (12): 1699–1716.

- Awogbemi, Omojola, and Daramy Vandi Von Kallon. 2022. "Valorization of Agricultural Wastes for Biofuel Applications." Heliyon 8 (10).

- Babu, Subhash, Sanjay Singh Rathore, Raghavendra Singh, Sanjeev Kumar, Vinod K. Singh, S. K. Yadav, Vivek Yadav, et al. 2022. "Exploring Agricultural Waste Biomass for Energy, Food and Feed Production and Pollution Mitigation: A Review." Bioresource Technology 360 (September):127566.
- Baruah, Nijara, Abhijit Bora, and Nirmali Gogoi. 2024. "Agricultural Waste in Circular Economy: An Indian Scenario." In Emerging Trends and Techniques in Biofuel Production from Agricultural Waste, pp. 15-42. Singapore: Springer Nature Singapore.
- Batlles-delaFuente, Ana, Emilio Abad-Segura, Mariana-Daniela González-Zamar, and Francisco Joaquín Cortés-García. 2022. "An evolutionary approach on the framework of circular economy applied to agriculture." Agronomy 12 (3): 620.
- Bhuvaneshwari, S., Hiroshan Hettiarachchi, and Jay N. Meegoda. 2019. "Crop Residue Burning in India: Policy Challenges and Potential Solutions." International Journal of Environmental Research and Public Health 16 (5): 832.
- Brunner, Paul H., and Helmut Rechberger. 2016. Handbook of material flow analysis: For environmental, resource, and waste engineers. CRC press.
- Castillo-Díaz, Francisco José, José Ignacio Marín-Guirao, Luis Jesús Belmonte-Ureña, and Julio César Tello-Marquina. 2021. "Effect of repeated plant debris reutilization as organic amendment on greenhouse soil fertility." International Journal of Environmental Research and Public Health 18 (21): 11544.
- Castillo-Díaz, Francisco José, Luis Jesús Belmonte-Ureña, Francisco Camacho-Ferre, and Julio César Tello Marquina. 2022. "Biodisinfection as a profitable fertilization method for horticultural crops in the framework of the circular economy." Agronomy 12 (2): 521.
- Chen, Shuai, and Binlei Gong. 2021. "Response and adaptation of agriculture to climate change: Evidence from China." Journal of Development Economics 148: 102557.
- Corral, Francisco Javier García, Rosa María Martínez Vázquez, Juan Milán García, and Jaime de Pablo Valenciano. 2022. "The circular economy as an axis of agricultural and rural development: The case of the municipality of Almócita (Almería, Spain)." Agronomy 12 (7): 1553.
- Damalas, Christos A., and Ioannis G. Eleftherohorinos. 2011. "Pesticide Exposure, Safety Issues, and Risk Assessment Indicators." International Journal of Environmental Research and Public Health 8(5): 1402–19.
- Datta, A, M A Emmanuel, N K Ram and S Dhingra. 2020. "Crop Residue Management: Solution To Achieve Better Air Quality." TERI, New Delhi

- Duque-Acevedo, Mónica, Luis J. Belmonte-Ureña, Francisco Joaquín Cortés-García, and Francisco Camacho-Ferre. 2020. “Agricultural waste: Review of the evolution, approaches and perspectives on alternative uses.” Global Ecology and Conservation 22: e00902.
- Dutta, Asik, Abhik Patra, Kali K. Hazra, Chaitanya P. Nath, Narendra Kumar, and Amitava Rakshit. 2022. “A state of the art review in crop residue burning in India: Previous knowledge, present circumstances and future strategies.” Environmental Challenges 8 : 100581.
- Ellen MacArthur Foundation, 2013. Towards the Circular Economy: Opportunities for the Consumers Goods Sector. EMF. **www.ellenmacarth urfoundation.org/publication**
- Fraga-Corral, María, P. Ronza, Paula Garcia-Oliveira, A. G. Pereira, A. P. Losada, M. A. Prieto, M. I. Quiroga, and Jesús Simal-Gandara. 2022. “Aquaculture as a circular bio-economy model with Galicia as a study case: How to transform waste into revalorized by-products.” Trends in Food Science & Technology 119: 23-35.
- Gadde, Butchaiah, Sébastien Bonnet, Christoph Menke, and Savitri Garivait. 2009. “Air Pollutant Emissions from Rice Straw Open Field Burning in India, Thailand and the Philippines.” Environmental Pollution, Special Issue Section: Ozone and Mediterranean Ecology: Plants, People, Problems, 157 (5): 1554–58.
- Galik, Christopher S. 2015. “Exploring the Determinants of Emerging Bioenergy Market Participation.” Renewable and Sustainable Energy Reviews 47 (July):107–16.
- GHG Platform India. (2018). India’s AFOLU Sector GHG Emissions. Retrieved March 14, 2022, from GHG Platform India: **http://www.ghgplatform-india.org/afolu-sector**.
- GoI. 12 December 2023. Lok Sabha. Reply To Starred Question No. 130. Stubble Burning Incidents. Ministry Of Agriculture and Farmers Welfare, Department Of Agriculture And Farmers Welfare.
- GoI. 2019. Report of the committee on Review of the scheme “Promotion of Agricultural Mechanisation for in-situ Management of Crop Residue in States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi”. Deptt. of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India
- GoI. 2022. Central Sector Scheme on Promotion Of Agricultural Mechanization For In-Situ Management Of Crop Residue In The States Of Punjab, Haryana, Uttar Pradesh And NCT Of Delhi. Revised Guidelines. Ministry of Agriculture & Farmers Welfare, Department of Agriculture, Cooperation & Farmers Welfare. Government of India. New Delhi.

- GoI. 2022. Press Release. Press Information Bureau. Salient features of "Revised Policy for Biomass Utilization for power generation Through Co–firing in Coal based Power Plants". Delhi.
- GoI. 2022. Waste to Energy Programme. Programme on Energy from Urban, Industrial, Agricultural Wastes/ Residue . Ministry of New and Renewable Energy. **https://mnre.gov.in/waste-to-energy/#**.
- GoI. 2023. Forty first Report of the Standing Committee on Energy. "Bioenergy and Waste to Energy – Recovery of Energy from Urban, Industrial and Agricultural Wastes/Residue and role of Urban Local Bodies in Energy Management." Ministry of New and Renewable Energy. New Delhi.
- GoI. 2023-24. Crop Residue Management. Operational Guidelines. Department of Agriculture & Cooperation. Ministry of Agriculture, Government of India. New Delhi.
- GoI. July 2024. Press Release. Press Information Bureau. "Air Pollution caused by Stubble Burning." Ministry of Environment, Forest and Climate Change. Delhi.
- GoI. June 2022. Press Release. Press Information Bureau. "India has achieved the target of 10 percent ethanol blending, 5 months ahead of schedule." Ministry of Petroleum & Natural Gas. Delhi.
- GoI. Oct 2023. Press Release. Press Information Bureau. "The State Governments of Punjab and Haryana advised by CAQM to mobilize the entire State administrative machinery to take all preventive and corrective measure for control of stubble burning." Ministry of Environment, Forest and Climate Change. Delhi.
- GoI. Sept 2023. Press Release. Press Information Bureau. "Haryana to bring down fire counts substantially and will attempt near elimination this year, as per the Haryana State Action Plan for Management of Paddy Stubble Burning submitted to CAQM." Ministry of Environment, Forest and Climate Change. Delhi.
- Government of Haryana. 2024. State plan scheme for management of crop residue for the year 2024-25. Department Of Agriculture and Farmers Welfare, Haryana **https://www.agriharyana.gov.in/CRMCombineStrawLatest#:~:text=About%20Scheme,management%20of%20paddy%20crop%20residue**.
- Government of India (GoI). 2014. National Policy for Management of Crop Residue (NPMCR). Department of Agriculture & Cooperation. Ministry of Agriculture, Government of India. New Delhi.
- Government of Punjab. 2024-25. Action Plan for Control of Crop Residue Burning in the State of Punjab.

- He, Ke, Junbiao Zhang, and Yangmei Zeng. 2019. "Knowledge domain and emerging trends of agricultural waste management in the field of social science: A scientometric review." Science of the total environment 670: 236-244.

- Indian circular economy forum (ICEF) annual conference (2022). **https://ic-ce.corn/icef-2022/**.

- Karić, Nataša, Alexandra S. Maia, Ana Teodorović, Nataša Atanasova, Guenter Langergraber, Grégorio Crini, Ana RL Ribeiro, and Maja Đolić. 2022. "Bio-waste valorisation: Agricultural wastes as biosorbents for removal of (in) organic pollutants in wastewater treatment." Chemical Engineering Journal Advances 9: 100239.

- Koul, Bhupendra, Mohammad Yakoob, and Maulin P. Shah. 2022. "Agricultural Waste Management Strategies for Environmental Sustainability." Environmental Research 206 (April):112285.

- Kumar, Pravin, and Rajesh Kumar Singh. 2021. "Selection of sustainable solutions for crop residue burning: an environmental issue in northwestern states of India." Environment, Development and Sustainability 23: 3696-3730.

- Lindblom, Jessica, Christina Lundström, Magnus Ljung, and Anders Jonsson. 2017. "Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies." Precision agriculture 18: 309-331.

- Lohan, Shiv Kumar, H. S. Jat, Arvind Kumar Yadav, H. S. Sidhu, M. L. Jat, Madhu Choudhary, Jyotsna Kiran Peter, and P. C. Sharma. 2018. "Burning issues of paddy residue management in north-west states of India." Renewable and Sustainable Energy Reviews 81: 693-706.

- MacArthur, Ellen (EMF). 2013. "Towards the circular economy." Journal of Industrial Ecology 2, (1): 23-44.

- Marín-Guirao, Jose Ignacio, Miguel de Cara-García, Eduardo Crisol-Martínez, Miguel Ángel Gómez-Tenorio, Pablo García-Raya, and Julio César Tello-Marquina. 2019. "Association of plant development to organic matter and fungal presence in soils of horticultural crops." Annals of Applied Biology 174, (3): 339-348.

- Nagendran, R. 2011. "Agricultural waste and pollution." In Waste, pp. 341-355. Academic Press.

- National Policy for Management of Crop Residue, **https://agriwelfare.gov.in/Documents/NPMCR_1.pdf**.

- Nattassha, Ruth, Yuanita Handayati, Togar M. Simatupang, and Manahan Siallagan. 2020 "Understanding circular economy implementation in the agri-food supply chain: the case of an Indonesian organic fertiliser producer." Agriculture & Food Security 9: 1-16.

- Obi, F. O., B. O. Ugwuishiwu, and J. N. Nwakaire. 2016. "Agricultural Waste Concept, Generation, Utilization and Management." Nigerian Journal of Technology 35 (4): 957–64.

- Parihar, S.S., Saini, K.P.S., Lakhani, G.P., Jain, A., Roy, B., Ghosh, S. and Aharwal, B. 2019. "Livestock waste management: A review." Journal of Entomology and Zoology Studies, 7(3): 384-393.

- Prasad, Mrinalini, Rajiv Ranjan, Akbar Ali, Deepika Goyal, Arti Yadav, Teg Bahadur Singh, Preksha Shrivastav, and Prem Kumar Dantu. 2020. "Efficient Transformation of Agricultural Waste in India." In Contaminants in Agriculture: Sources, Impacts and Management, edited by M. Naeem, Abid Ali Ansari, and Sarvajeet Singh Gill, 271–87. Cham: Springer International Publishing. **https://doi.org/10.1007/978-3-030-41552-5_13**.

- Saadatlu, Elham Abdollahi, Farnaz Barzinpour, and Saeed Yaghoubi. 2022. "A sustainable model for municipal solid waste system considering global warming potential impact: A case study." Computers & Industrial Engineering 169: 108127.

- Salinas, Jerónimo, David Meca, and Fernando del Moral. 2020. "Short-term effects of changing soil management practices on soil quality indicators and crop yields in greenhouses." Agronomy 10 (4): 582.

- Sanjay, H. M. Swamy, Moro Seidu, and Sangram B. Singh. 2021. "Issues of Paddy Stubble Burning in Haryana: Current Perspective." Paddy and Water Environment 19 (1): 55–69. **https://doi.org/10.1007/s10333-020-00819-2**.

- Seidavi, Alireza, Hossein Zaker-Esteghamati, and Colin G. Scanes. 2019. "Poultry by products." Byproducts from agriculture and fisheries: Adding value for food, feed, pharma, and fuels: 123-146.

- Sharma, Ashu, and Tariq Iqbal. 2022. "Farm Waste Management and Crop Production: An Overview."

- Shinde, Reshma, Dhirendra Kumar Shahi, Prabhakar Mahapatra, Chandra Shekhar Singh, Sushanta Kumar Naik, Nandkishore Thombare, and Arun Kumar Singh. 2022. "Management of Crop Residue with Special Reference to the On-Farm Utilization Methods: A Review." Industrial Crops and Products 181 (July):114772.

- Singh, Devesh, Sunil Kumar Dhiman, Vijay Kumar, Ram Babu, Karuna Shree, Anjali Priyadarshani, Archana Singh, Leena Shakya, Aparna Nautiyal, and Shukla Saluja. 2022. "Crop Residue Burning and Its Relationship between Health, Agriculture Value Addition, and Regional Finance." Atmosphere 13 (9): 1405.

- "Standard Protocol for Estimation of Crop Residue Burning Fire Events using Satellite Data" Winter Session, STARRED QUESTION NO. 130, Lok Sabha, New Delhi
- Velasco-Muñoz, Juan F., Joan Manuel F. Mendoza, José A. Aznar-Sánchez, and Alejandro Gallego-Schmid. 2021. "Circular economy implementation in the agricultural sector: Definition, strategies and indicators." Resources, Conservation and Recycling 170: 105618.
- Venkatramanan, V., Shachi Shah, Ashutosh Kumar Rai, and Ram Prasad. 2021. "Nexus Between Crop Residue Burning, Bioeconomy and Sustainable Development Goals Over North-Western India." Frontiers in Energy Research 8 (January). **https://doi.org/10.3389/fenrg.2020.614212**.
- Verdonk, M., C. Dieperink, and A. P. C. Faaij. 2007. "Governance of the Emerging Bio-Energy Markets." Energy Policy 35 (7): 3909–24.
- Yadav, Seema, and Urja Gada. 2022. "Multi-Stakeholder Consultations on Sustainable Urban and Peri-Urban Agriculture in India," November.
- "Crop Residue Management Guidelines 2023-24 welcome move for bioenergy industry but concerns remain" **https://www.downtoearth.org.in/renewable-energy/crop-residue-management-guidelines-2023-24-welcome-move-for-bioenergy-industry-but-concerns-remain-94054**.
- "Dharaksha Ecosolutions Pvt. Ltd.: Innovating Packaging Solutions from Crop Stubble" **https://www.youtube.com/watch?v=JV8SmMYUYVA**.
- "Promotion Of Agricultural Mechanization For In-Situ Management Of Crop Residue In The States Of Punjab, Haryana, Uttar Pradesh And NCT Of Delhi" **https://www.agriharyana.gov.in/CenterStateSponsoredSchemes**.
- "Punjab, Haryana commit to 'eliminate' stubble burning this winter," September 23, 2024, The Hindu, New Delhi **https://www.thehindu.com/news/national/punjab-haryana-commit-to-eliminate-stubble-burning-this-winter/article68675052.ece**.
- 20th Livestock Census, 2021 **https://www.data.gov.in/catalog/20th-livestock-census?sortby=_score**.
- The Land Accelerator South Asia Cohort 2021 | WRI INDIA (**wri-india.org**)
- The Land Accelerator South Asia Cohort 2022 | WRI INDIA (**wri-india.org**)
- The Land Accelerator South Asia Cohort 2023 | WRI INDIA (**wri-india.org**)

6.0

Enabling Circularity in Wastewater Management in India

CEEW THE COUNCIL

AUTHORS
Saiba Gupta, Nitin Bassi, Kartikey Chaturvedi, Ayushi Kashyap, and Clark Kovacs

6.1 Introduction

India, the fastest-growing economy among emerging markets and developing countries (Ministry of Finance 2024), faces significant challenges in ensuring urban water security. The country's water resources are increasingly threatened due to climate-induced risks posed by droughts, floods and cyclones, growing water demand for various uses, and pervasive water pollution. A district-level climate vulnerability assessment by the Council on Energy, Environment, and Water (CEEW) found that 27 out of 35 Indian states and Union Territories are highly vulnerable to hydro-meteorological disasters (floods, droughts, and cyclones) and their compounding effects in 2021 (Mohanty and Wadhawan 2021). Additionally, by next year, 11 out of India's 15 major river basins will face water stress conditions (Gupta et al. 2023). Further, approximately 70 per cent of India's water supply is contaminated, impacting 75 per cent of the population (NITI Aayog 2019). These factors critically impact water security in urban areas with high population density, informal settlements, and poorly managed natural water bodies.

> **"Scaling up wastewater treatment and promoting its safe reuse can help augment the water supply, reduce pressure on existing freshwater sources, and abate surface water pollution."**

Projections suggest that by 2050, India will be home to a quarter of the global urban population residing in water-scarce regions (He et al. 2021). Urban areas are also experiencing in-migration, mainly seeking better employment opportunities. With mounting pressure on the country's freshwater resources due to urbanisation and growing economic activities, adopting a resource-efficient approach to water management is imperative, particularly in water-scarce cities. A circular economy approach to urban wastewater management is globally recognised as a solution to reducing pressure on freshwater resources and mitigating water stress (UNEP 2024, Delgado et al. 2021). Beyond environmental benefits, this approach can create economic opportunities by selling treated wastewater (TWW) for reuse in various sectors.

Nevertheless, India's sewage treatment infrastructure has not kept pace with its rapidly growing urban population. As of 2021, Indian cities generated over 72,000 million litres of domestic wastewater per day, yet only 28 per cent of this was treated (CPCB 2021). The failure to adequately treat wastewater leads to widespread contamination of surface water bodies, posing serious risks to communities and ecosystems dependent on these vital resources. Given the significant amount of wastewater generated in India, scaling up wastewater treatment and promoting its safe reuse offers a viable alternative to augment the water supply, alleviate pressure on existing freshwater sources, and improve the quality of urban water bodies.

A robust policy framework, with clear guidelines and legal provisions, is critical for integrating wastewater treatment and reusing TWW in urban landscapes. In recent years, the Indian government has made significant strides in promoting wastewater treatment, encouraging its reuse, and curbing water pollution through national policies and missions. The National Water Policy (2012) mandates the recycling and reuse of TWW, incentivising sectors such as industry and agriculture (National Water Mission 2012). Furthermore, the National Framework on Safe Reuse of Treated Water, launched in 2023 by the National Mission for Clean Ganga (NMCG), provides a guiding framework for states to develop their own reuse policies (NMCG 2021).

Other key initiatives include the Namami Gange Programme (NGP), the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) 2.0, and the Swachh Bharat Mission—Urban (SBM-U). Phase II of the NGP focuses on river rejuvenation and preventing the discharge of untreated wastewater by developing sewage treatment infrastructure and monitoring industrial effluents. Sanitation workers and operators of sewage treatment plants are being hired and trained under the programme, with capacity-building activities undertaken for workers engaged in faecal sludge and septage management (Khanduja et al. 2023). The Arth Ganga initiative under NGP promotes the monetisation of TWW reuse for irrigation and industrial uses (Ministry of Jal Shakti 2022). Under SBM-U Phase II, cities with populations under one lakh are encouraged to safely contain, transport, and treat wastewater, with an emphasis on maximising TWW reuse. AMRUT 2.0, aims at cities with a population over one lakh and provides funding to make urban areas water-secure through wastewater management, water body rejuvenation, and water conservation efforts. The mission has tremendous potential for creating jobs in urban areas, including plumbing, water supply, wastewater treatment operations and urban planning (Khanduja et al. 2023).

6.2 The Economic Case for the Reuse of Treated Wastewater (TWW)

As per CEEW analysis, over 96,000 million litres of TWW (urban domestic sewage) per day is available for reuse in India in 2050 (Bassi et al. 2023). This is based on the projected installed treatment capacity in 2050 (80 per cent of projected wastewater generation) (**Exhibit 6.1**), which is estimated with the compound annual growth rate in sewage treatment capacity in India between 2015–16 and 2020–21. Given the country's current and projected wastewater generation and treatment capacity, substantial market potential and economic value are associated with the reuse of TWW in India.

Market Potential and the Economic Value of Reusing TWW

Urban local bodies can realise immense market potential by selling TWW to different users. Based on the current market rate of TWW (MoHUA 2021), the daily market value of the total TWW available in 2021 is estimated to be over **INR 630 million (USD 8 million)**. At the current market rate, this would increase to INR 1.9 billion (USD 24 million) in 2050 (Bassi et al. 2023).

Additionally, there is a substantial economic value in reusing TWW in the irrigation sector in India, which consumes the majority of freshwater (Gupta et al. 2023). As per our analysis, about 8,603 million cubic metres (MCM) of TWW were available for the irrigation sector in 2021 (Bassi et al. 2023). This can irrigate 1.38 Mha of land, equivalent to about nine times the area of Delhi. About **INR 966 billion (USD 12 billion)** would be the revenue generated from the agricultural yield produced from this area of land. Further, the wastewater treated up to the secondary level, which is desired for irrigation, contains valuable nutrients such as nitrogen, phosphorus, and potassium (or NPK) (Hashem and Qi 2021). There would be savings worth **INR 50 million (USD 0.6 million)** from the reduction in fertiliser application due to this inherent nutrient content of TWW. By 2050, these values will increase further as approximately 24,058 MCM of TWW will be available for reuse in the irrigation sector, which can irrigate more than 3 Mha of land.

To realise the market potential and economic value, a city-level reuse plan needs to be prepared. Such a plan will enable reuse in identified reuse avenues, including irrigation, industrial users, construction activities, landscaping, commercial cooling, fire stations, and water body rejuvenation. Already, urban local bodies (ULBs) in cities like Chennai, Nagpur and Surat are selling secondary TWW to industrial users (Bassi et al. 2023). The revenue from the sale of TWW is being used to rejuvenate water bodies in Chennai. Delhi is utilising tertiary treated wastewater to recharge groundwater, thereby reducing the energy required for its extraction. Further, Delhi, Gwalior, and Kanpur use treated wastewater for irrigation in their suburban areas.

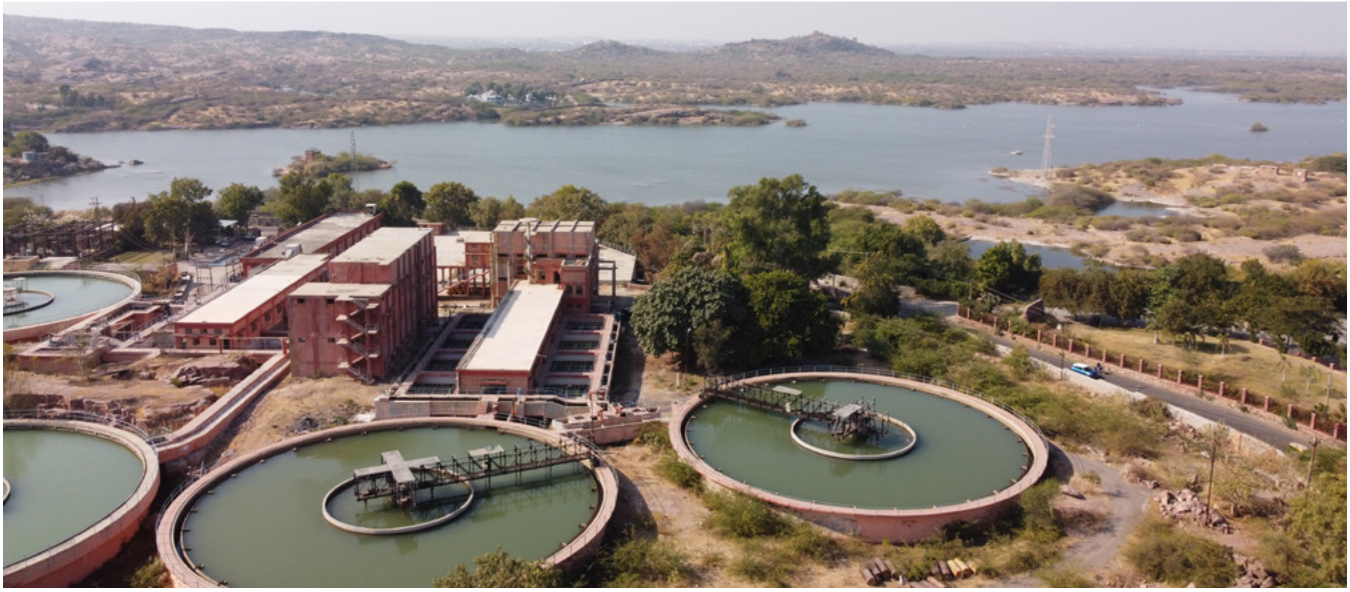
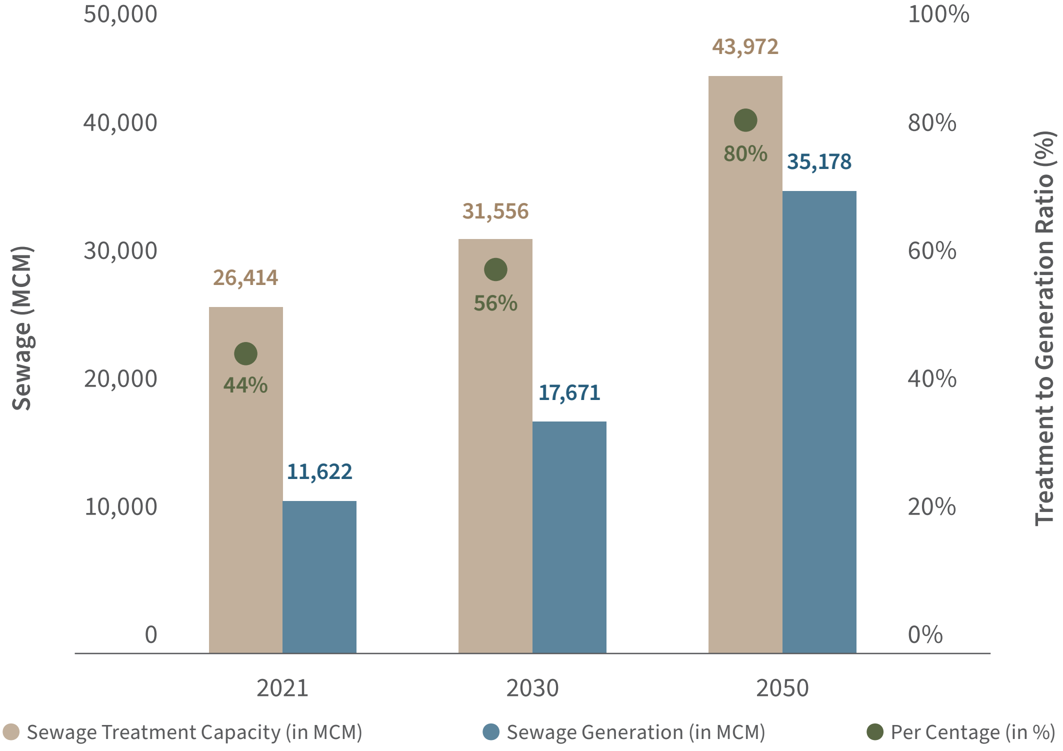


Exhibit 6.1 In 2050, India will Have the Capacity to Treat 80 Per Cent of Sewage Generation



Source: Authors' analysis, data from National Inventory of Sewage Treatment Plants (Central Pollution Control Board 2021); MCM = million cubic metre

Carbon Emissions Reduction Due to Reuse

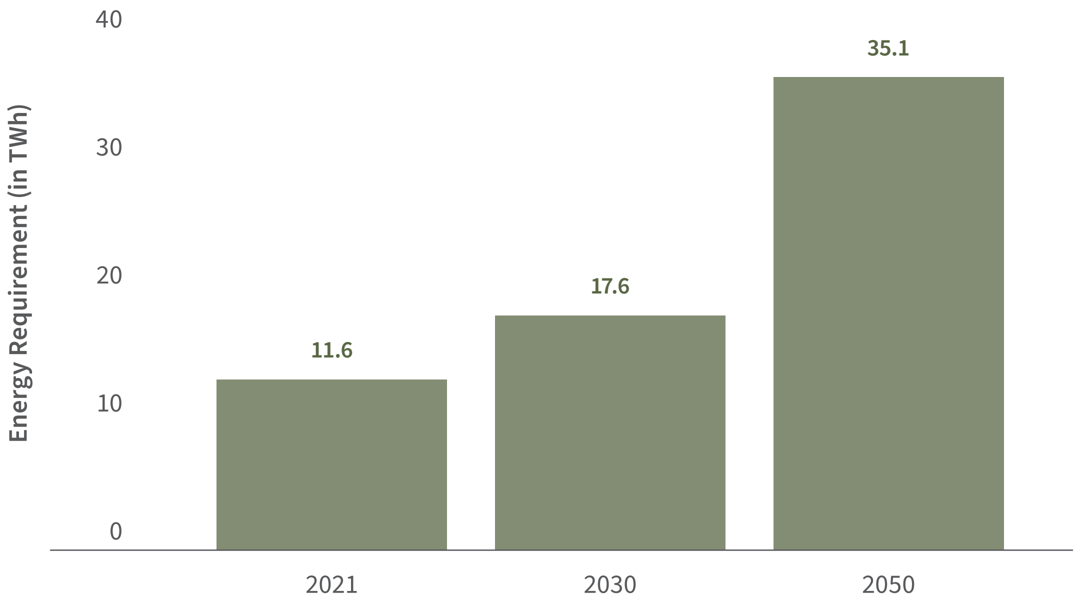
In addition to economic benefits, positive environmental externalities are associated with reusing TWW in the irrigation sector. First, it can reduce the pressure on groundwater sources, hence reducing the pumping requirements for extracting groundwater. Second, the inherent nutrient value of TWW can potentially reduce the dependence on synthetic fertilisers, hence reducing energy usage associated with their production. Our analysis suggests that both these factors combined could have contributed to the reduction in **GHG emissions by 1.3 million tonnes** in 2021, had the available TWW been reused for irrigation (Bassi et al. 2023).

Current and Projected Energy Requirements of Domestic Wastewater Treatment Technologies Deployed in India

Greenhouse gas (GHG) emissions from the waste sector in India amounted to 114.49 million tonnes of carbon dioxide equivalent (CO_2e) in 2018. Wastewater was the largest contributor, with domestic wastewater accounting for almost 56% (ICLEI 2022). In the wastewater sector, Scope 1 emissions are direct GHG emissions arising from the treatment process (aerobic and/or anaerobic) taking place in wastewater management systems. Scope 2 emissions are indirect GHG emissions arising from energy consumption of the treatment technologies deployed in the sewage treatment plants (STPs).

The energy requirement of the STPs deployed in India is estimated to be more than three times the current requirement in 2021 (see **Exhibit 6.2**).

Exhibit 6.2 **Energy Requirement of STPs in India is Expected to More Than Triple by 2050 in the Business-As-Usual Scenario**

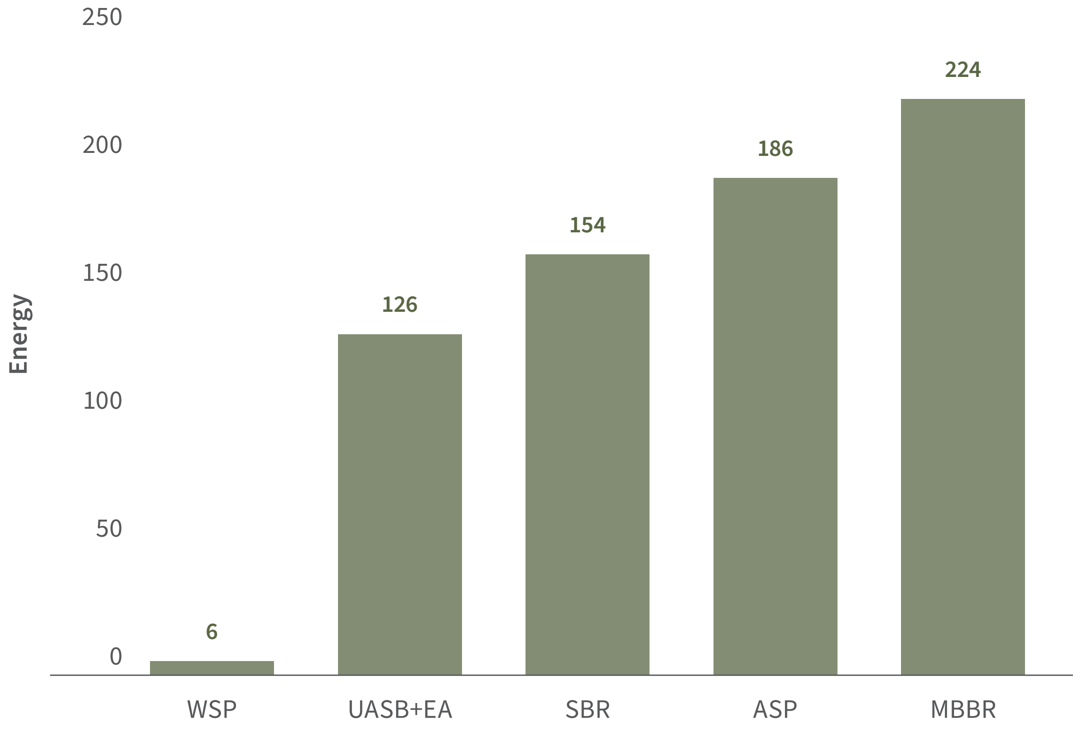


Source: Authors' analysis, data from Promoting wastewater treatment in India: Critical questions of economic viability (Bassi et al. 2022), National Inventory of Sewage Treatment Plants (Central Pollution Control Board 2021).

TWh = Terawatt-hour

Of the most common treatment technologies in India, Water Stabilisation Pond (WSP) and Up Flow Anaerobic Sludge Blanket Reactor and Extended Aeration (USAB+EA) technologies have the lowest energy requirements (see **Exhibit 6.3**). Prioritising the implementation of less energy-demanding technologies such as WSP and USAB+EA would reduce scope 2 GHG emissions. The other alternative is to provide energy generated through renewable sources, such as PV-based solar panels or the bio-energy obtained during the anaerobic wastewater treatment process to run the STPs. This will reduce the carbon emissions and make the treatment process greener. Also, for small towns with low population density, nature-based solutions that require no energy and minimal human intervention can be a better alternative (Bassi et al. 2022).

Exhibit 6.3 **MBBR and ASP Treatment Technologies Have the Highest Energy Requirements**



WSP: Water Stabilisation Pond; MBBR: Moving Bed Biofilm Reactor; UASB+EA: Up Flow Anaerobic Sludge Blanket Reactor and Extended Aeration; SBR: Sequencing Batch Reactor; ASP: Activated Sludge Process; KWh: Kilowatt-hour; MLD = million litres per day (of wastewater treatment). **Source:** Authors' analysis, data from Promoting wastewater treatment in India: Critical questions of economic viability (Bassi et al. 2022), National Inventory of Sewage Treatment Plants (Central Pollution Control Board 2021).

6.3 Sustainable Financing Options

Developing a market for the reuse of TWW is crucial for ensuring the financial sustainability of reuse projects. Several concessional financing tools and business models can be leveraged.

Green Credits

Wastewater treatment and reuse have been identified as credit-generating activities under India's Green Credit Programme, launched by the Union Ministry of Environment, Forest and Climate Change in 2023. The programme provides a trading platform for credits generated through the voluntary adoption of environment-friendly practices by individuals, industries, and local bodies (MoEFCC 2023). Green credits incentivise such practices by putting a value on them, going beyond the carbon price (covered under carbon markets). For instance, in the water sector, each green credit can represent a fixed volume of water that is conserved or generated through the adoption of a particular practice, such as reusing TWW. Such a market-based instrument can incentivise various stakeholders, including industries, private developers, and urban local bodies, to implement reuse projects (Gupta and Kashyap 2023).

Another example of a water credit system is the 'Water Quality Trading Policy' in the United States. Based on a 'polluter pays' principle, the programme enforces water quality standards and regulates water pollution by setting a cap on daily pollution load. Trading of credits enables pollution sources with high abatement costs to meet their obligations by purchasing equivalent pollution reductions from sources with lower abatement costs (US EPA 2003). This applies to both point (such as wastewater treatment plants and industrial facilities) and nonpoint sources (such as agriculture) of pollution. Such a trading system can be applied to wastewater management by setting a cap in the form of water reuse targets for different users. This is explored in the following section.

Wastewater Reuse Certificates

The 2030 Water Resources Group has developed a model called 'Wastewater Reuse Certificates (WRC)' based on a cap-and-trade mechanism. The implementing authority sets individual TWW reuse targets for bulk water users from different sectors, such as municipal, industrial, and agricultural. Users who exceed this target earn a WRC, which they can sell. Other users unable to meet their targets can buy the WRC to offset their shortfall. Each WRC is equal to a certain quantity of TWW reused (1,000 cubic metres), meeting the prescribed quality standard. Wastewater treated to higher grades generates more WRCs.

These certificates are issued electronically and are hosted on an online portal that facilitates user registration, baseline estimation, notification of reuse targets, monitoring and validation of user performance, and verification of WRCs for trading (2030 Water Resources Group 2022).

Maharashtra is exploring the implementation of the WRC system and is awaiting official government approval (Maharashtra Water Resources Regulatory Authority 2019). Like the Emissions Trading System, which works on a cap-and-trade principle, WRCs can incentivise large water users to invest in wastewater treatment and reuse.

Hybrid Annuity Model

India's National Mission for Clean Ganga introduced the Hybrid Annuity-based Public Private Partnership model to encourage private sector investment in sewage infrastructure projects. Under this model, the construction and operation and maintenance (O&M) of a sewage treatment plant is undertaken by a private investor for a 15-year period. The capital cost is paid as annuities along with the O&M expenses over the project's life by the Ministry of Jal Shakti (water resources). These payments are based on the treatment plant's performance in terms of adherence to pre-defined key performance indicators, ensuring the wastewater is treated to the required quality standards. Higher grades of TWW can increase and diversify its reuse across different applications, such as in industries and the construction sector.

> **"Developing a market for the reuse of treated wastewater (TWW) is crucial for realising its economic and market potential."**

The project assets are transferred back to the city at the end of the concession term. This model's novelty is its accountability and ownership, as the concessionaire not only creates an asset but also operates it for its entire life cycle (MoJS and CEEW 2023), ensuring it is well-maintained.

Corporate Social Responsibility

A key challenge for mainstreaming TWW reuse in Indian cities is cost recovery by urban local bodies. Implementing authorities in urban areas can recover the cost of wastewater treatment from revenues generated by selling TWW of a prescribed quality to users such as industries, private developers, and farmers. For instance, local authorities can provide TWW to industries at rates lower than industrial freshwater tariffs that would have been paid otherwise (Gupta et al. 2024).

Further, the private sector can also be approached to invest in wastewater treatment infrastructure under their corporate social responsibility (CSR) programmes. In the case of reusing TWW for agriculture, the implementing agency can engage private companies under their CSR programmes to train farmers on the safe reuse of TWW. Additionally, CSR programmes of supermarket chains can be leveraged to buy back crops from farmers practising safe cultivation using TWW.

6.4 Conclusion and Next Steps

The following recommendations could accelerate the mainstreaming of circularity in wastewater management in India.

Strengthen the Policy Environment for Wastewater Management

More than ten states in India have policies related to treated wastewater reuse. However, most of them were formulated before the National Framework on Safe Reuse of Treated Water released in 2023. There is a need to revisit the existing policies following the guidelines presented in the national framework to make them more comprehensive, especially for determining the reuse-specific effluent quality standards and business models for reuse projects. Further, the remaining states should also formulate reuse policies. Once done, this will lay the foundation for developing the ULB-level reuse plans.

Scale Up Sustainable Financing Options for Implementing TWW Reuse Projects

We have discussed various financing options for implementing reuse projects (**Section 6.3**). They need to be scaled up in all the ULBs in states that at least have a policy to ensure the sustainability of the reuse projects. The financing model will depend on the existing policy environment in the state, identified reuse avenues, the market for TWW reuse, the extent of availability of CSR grants, and awareness at the ULB level.

Design Innovative Technologies With Low-Carbon Footprint

There is a scope for innovation in technologies, especially in developing ones with low energy requirements and low carbon emission potential. Further, technologies that can offer multi-functionality, such as wastewater treatment, nutrient recovery and energy generation, should be preferred.

Strengthen Data on Wastewater Generation

One of the major challenges in managing wastewater, including carbon emissions, is the lack of data. Wastewater flow metres are needed to provide reliable estimates of the amount of wastewater generated. This will help assess the treatment capacity requirement and the gap that needs to be met, and finally, make the wastewater treatment reuse projects cost-efficient. Further, depending on the measured wastewater, more reliable estimates of carbon emissions can be prepared.

Design Innovative Behavioural Change Campaign to Increase Acceptance of TWW

Effective and innovative behaviour change campaigns are needed to make communities realise the importance of freshwater and that TWW is a resource that can reduce pressure on natural water systems and improve the water environment. It is important that such campaigns are designed with inputs from local communities.

References

- 2030 Water Resources Group. 2022. “Wastewater Reuse Certificates as Tradeable Permits: A Handbook for Roll Out.” 2030 Water Resources Group.

- Abinash, Mohanty, and Shreya Wadhawan. 2021. “Mapping India’s Climate Vulnerability.” CEEW. Council on Energy Environment and Water. October 24. **https://www.ceew.in/publications/mapping-climate-change-vulnerability-index-of-india-a-district-level-assessment**.

- Bassi, Nitin, Saiba Gupta, and Kartikey Chaturvedi. 2023. “Reuse of Treated Wastewater in India Market Potential and Recommendations for Strengthening Governance.” New Delhi: Council on Environment Energy, and Water. **https://www.ceew.in/sites/default/files/scaling-wastewater-reuse-treatment-and-management-india.pdf**.

- Bassi, Nitin, Saurabh Kumar, M. Dinesh Kumar, Sofie Van Ermen, and Paul Campling. 2022. “Promoting Wastewater Treatment in India: Critical Questions of Economic Viability.” Water and Environment Journal, June. doi:**https://doi.org/10.1111/wej.12810**.

- Central Pollution Control Board. 2021. “National Inventory of Sewage Treatment Plants.” Cpcb.nic.in. March. **https://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvMTIyOF8xNjE1MTk2MzIyX21lZGlhcGhvdG85NTY0LnBkZg==**.

- “CO2 Baseline Database for the Indian Power Sector.” 2023. Cea.nic.in. New Delhi: Ministry of Power, Central Electricity Authority. **https://cea.nic.in/wp-content/uploads/baseline/2024/01/User_Guide__Version_19.0.pdf**.

- Delgado, Anna, Diego J. Rodriguez, Carlo A. Amadei and Midori Makino. 2021. “Water in Circular Economy and Resilience (WICER).” World Bank, Washington, DC.

- Government of India. 2012. National Water Policy. National Water Mission. **https://nwm.gov.in/sites/default/files/national%20water%20policy%202012_0.pdf**.

- Gupta, Saiba, and Ayushi Kashyap. 2023. “What the National Green Credit Programme will mean for the water sector.’’ CNBC TV18. **https://www.cnbctv18.com/environment/ceew-what-the-national-green-credit-programme-will-mean-for-the-water-sector-18095791.htm**.

- Gupta, Saiba, Kartikey Chaturvedi, and Nitin Bassi. 2023. "The Value of Treated Wastewater." Urban Update. July 11. **https://urbanupdate.in/the-value-of-treated-wastewater/**.

- Hashem, M. S., and Xuebin Qi. 2021. "Treated Wastewater Irrigation – a Review." MDPI 13:1527.

- He, Chunyang, Zhifeng Liu, Jianguo Wu, Xinhao Pan, Zihang Fang, Jingwei Li, and Brett A. Bryan. 2021. "Future Global Urban Water Scarcity and Potential Solutions." Nature Communications 12 (1): 4667. doi:**https://doi.org/10.1038/s41467-021-25026-3**.

- Khanduja, Ekansha, Upasana Negi, Kartikey Chaturvedi, Saiba Gupta, and Nitin Bassi. 2023. "India's Sustainable Water Management Story." **https://www.ceew.in/sites/default/files/managing-indias-water-resources-in-sustainable-equitable-ways_0.pdf**.

- Maharashtra Water Resources Regulatory Authority. 2019. "Maharashtra Water Resources Regulatory Authority Water Entitlement Transfer (WET)and Wastewater Reuse Certificates (WRC) Platform Regulations, 2019". Mumbai: Maharashtra Water Resources Regulatory Authority. **https://mwrra.org/wp-content/uploads/2019/08/WRCRegulation-draft.pdf**.

- Ministry of Finance. 2024. "India Shines as IMF Upgrades GDP Forecast to 7% in FY24-25." Pib.gov.in. Press Information Bureau. **https://pib.gov.in/PressNoteDetails.aspx?NoteId=151934&ModuleId=3**.

- Ministry of Jal Shakti. 2022. "Wastewater Management for Efficacious Use of Water Resources." Pib.gov.in. **https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1884892**.

- Mishra, Prateek, Nikhil Kolsepatil, and Anandhan Subramaniyam. 2022. "Greenhouse Gases Emissions of India (Subnational Estimates): Waste Sector (2005– 2018 Series)." GHG Platform India. **https://www. ghgplatform-india.org/waste-sector/**.

- MoEFCC. 2023. "Green Credit Programme." New Delhi: Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India (GoI).

- MoJS and CEEW. 2023. Best Practices for Water Management. Ministry of Jal Shakti, New Delhi, India.

- National Mission for Clean Ganga (NMCG). 2022. "National Framework on Safe Reuse of Treated Water." NMCG. **https://nmcg.nic.in/writereaddata/fileupload/32_SRTW%20Framework_Final_23_11_2021%20(1).pdf**.

- Niti Aayog. 2019. “Composite Water Management Index.” **https://social.niti.gov.in/uploads/sample/water_index_report2.pdf**.
- United Nations Environment Programme. 2024. Water as a Circular Economy Resource - Foresight Brief No. 033 February 2024. **https://wedocs.unep.org/20.500.11822/44782**.
- United States Environmental Protection Agency. 2003. “Water Quality Trading Policy.’’ US EPA. **https://www.epa.gov/system/files/documents/2022-12/Water-Quality-Trading-Policy.pdf**.

7.0

Accelerating Circular Economy In India's Organic Waste Management

CEEW
THE COUNCIL

AUTHORS

Adeel Khan, Priyanka Singh, Rahul Das, and Srishti Mishra

7.1 Introduction

Rising municipal solid waste (MSW) and its management present a global challenge. In 2020, more than 2 billion tonnes of MSW was generated globally, which is projected to grow to 3.8 billion metric tonnes by 2050 (Lenkiewicz 2024). Out of this total global waste generated, around 38% was not managed properly. The number is alarming in Central and South Asia, where 80% of the waste ends up in open spaces, drains, and water bodies, or is burnt in the open. Improper waste management exacerbates this triple planetary crisis of climate change, biodiversity loss, and pollution.

In 2021, India generated about 1.6 lakh tonnes per day (TPD) of MSW, of which 95% was collected, but only 50% was treated, while 17.3% was sent to landfills (CPCB 2021). Typically, MSW in India contains about 50% biodegradable waste, 35% non-biodegradable, and the remaining 15% inert and other waste (MoHUA 2022). Biodegradable waste, which includes kitchen waste, contains about 75,000 TPD, which is projected to increase by 4.5% per year (CII 2024). Further, 50 cities with a population of more than a million in India contribute about 50% of the total waste generated in the country (SBM 2024).

> **"In India, by 2050, a circular economy could result in an economic benefit of INR 40 lakh crore (USD 624 billion) and reduce carbon emissions by 44%."**

Biodegradable Waste Management: An Opportunity for Meeting International Commitments and Global Goals

Solid waste management is directly linked to five Sustainable Development Goals (SDGs) (2, 6, 11, 12, 14) and indirectly impacts progress toward all SDGs (Kopecká, Hrad, and Huber-Humer 2024; Manzoor et al. 2024). While only 17% of the targets in the SDGs are on track, a circular economy approach presents a pathway for accelerated action (UN 2024). The circular economy approach focuses on reducing resource consumption at the source while transforming waste into valuable resources downstream. In India, by 2050, a circular economy could result in an economic benefit of INR 40 lakh crore (USD 624 billion) and reduce carbon emissions by 44% (Ellen MacArthur Foundation 2016). Recent studies highlight that the circular economy can play a crucial role in India's net zero commitments, it also provides opportunities for resource efficiency and sustainable growth (Selvaraj et al. 2024). India's G20 declaration also acknowledged the need for a circular economy and showed commitment towards reducing waste generation by 2030 and advancing scientific management of waste (G20 2023).

Relevance to Global Climate Agenda

Improper solid waste management contributes towards climate change. Waste (including wastewater) contributes up to 20% of all global methane emissions, which is the second most abundant greenhouse gas and with Global Warming Potential (GWP) between 84–87 when considering its impact over a 20-year timeframe (GWP20) (UNEP 2021; IEA 2021). According to the Global Methane Assessment study, the waste sector in India offers one of the highest and the most cost-effective potentials for methane mitigation (UNEP 2021). Through leveraging the circular economy approach, India has the potential to become a global leader in sustainable waste management and offer valuable lessons and strategies for other countries to follow.

7.2 Current Landscape of India's Initiatives Towards the Circular Economy

Policy and Technology Overview of Biodegradable Waste Management

India has taken multiple initiatives in terms of laws, regulations, policies, and a national programme towards improving waste management. **Solid Waste Management Rules, 2016** provide a regulatory framework that mandates source segregation and promotes resource recovery. Swachh Bharat Mission (SBM), launched in 2014, is the government's flagship programme towards solid waste management. With the advent of SBM, solid waste treatment has increased from 20% in 2015 to 50% in 2021 (CPCB 2021). The second phase of SBM (2021 to 2026) is envisaged to achieve the 'Garbage-Free' status for all cities, and sets a target of 100% processing of wet and dry waste (MoHUA 2021).

Biodegradable/organic waste, which contributes up to half of the MSW, can be treated primarily through biological conversion processes: composting and biomethanation, to produce compost/biomanure and biogas, respectively. Both the products, compost and biogas, have several applications. While composting can substitute fertilisers and find applications in agriculture, gardening, and horticulture, biogas can substitute fossil fuels and can be used for multiple purposes, including thermal applications and power generation. In addition to composting and biomethanation, organic waste can also be processed to make other products like biochar, pellets, briquettes, etc., that serve as alternatives to fossil fuels.

Organic waste management efforts in the country are supported by multiple ministries through multiple schemes and programmes. An example of such initiatives is GOBARdhan (Galvanising Organic Bio-Agro Resources Dhan) scheme, which aims to build an ecosystem for setting up biogas/compressed biogas plants to drive economic growth and promote a circular economy. In the Budget of 2023, the Government of India announced an investment of INR 10,000 crore for 500 'waste-to-wealth' plants, which includes 200 compressed biogas (CBG) plants and 300 community or cluster-based plants (GOBARdhan 2024). These plants will be developed through public-private partnerships (PPP) in collaboration with state governments and the private sector, including entrepreneurs and societies.

Exhibit 7.1 Key Initiatives and Programmes of Ministries and Departments for Organic Waste Management

Ministry of Housing and Urban Affairs (MoHUA)	• SBM (Urban) is being implemented by the Ministry of Housing and Urban Affairs (MoHUA). • Under the Policy on Promotion of City Compost, the ministry to take steps to increase setting up the compost plants across all states (Department of Fertilizers 2016).
Ministry of New Renewable Energy	• The Ministry of New and Renewable Energy (MNRE) has notified the National Bioenergy Programme, comprising of the Waste to Energy Programme (Programme on Energy from Urban, Industrial and Agricultural Wastes / Residues); Biomass Programme (scheme to support manufacturing of briquettes and pellets and promotion of biomass (non-bagasse) based cogeneration in Industries); and Biogas Programme. • Under the Waste to Energy programme, waste-to-energy projects for the generation of biogas/bioCNG/power/producer or syngas from urban, industrial, and agricultural wastes / residues are set up (MNRE 2024).
Prime Minister's Science, Technology & Innovation Advisory Council (Office of the Principal Scientific Advisor)	• The Waste to Wealth Mission is an initiative by the Office of the Principal Scientific Advisor to the Government of India. • Technological advancements that can drive effective waste management in India, such as automatic waste segregation and onsite waste processing like composting/biomethanation/ BioCNG, gasifiers/pyrolysis, etc., can transform the current waste management scenario in India (Invest India 2024).
Ministry of Petroleum & Natural Gas	• The Sustainable Alternative Towards Affordable Transportation (SATAT) initiative envisages setting up 5000 bioCNG plants with a production target of 15 MMT of BioCNG by 2023-24. The SATAT initiative encourages entrepreneurs to set up BioCNG plants and produce & supply BioCNG to Oil Marketing Companies (OMCs) for sale as automotive fuels (MNRE 2023).
Department of Drinking Water & Sanitation (under Ministry of Jal Shakti)	• The department launched the Galvanizing Organic Bio-Agro Resources Dhan (GOBARdhan scheme in 2018 as a part of the biodegradable waste management component under the Swachh Bharat Mission (Grameen) (SMB-G).
Ministry of Power	• Promoting energy efficiency and sustainable energy sources, including waste-to-energy and renewable energy initiatives (Ministry of Power 2021).
Department of Chemicals and Petrochemicals (under Ministry of Chemicals and Fertilizers)	• The department issued a policy on the promotion of city compost to be used by government departments and Central Public Sector Enterprises (CPSE) (Department of Fertilizers 2016; Department of Fertilizers 2017).
Department of Agriculture, Cooperation, and Farmers Welfare	• Carry out IEC (Information, Education, Communication) to educate the farmers on the benefits of city compost. Also, to monitor and facilitate the availability of an adequate quantity of city compost (Department of Fertilizers 2016)
NITI Aayog Circular economy cell	• Dedicated unit focussing on circular economy and primarily responsible for drafting circular economy action plans and coordinating among the ministries for plan implementation.

Source: Authors' compilation

Challenges and Barriers in Organic Waste Management

Organic waste management offers great opportunities, particularly in a developing country like India. According to 2023 data, India had the potential to generate 21,000 TPD of CBG from organic waste, which could potentially replace 200,000 barrels of crude oil per day (CII 2023). However, the adoption of a circular economy approach faces several barriers.

- **Technical barriers** include the quantity and quality of feedstock, poor infrastructure maintenance, and a lack of standardised plant designs (Mittal, Ahlgren, and Shukla 2018).

- **Policy and institutional barriers** can hamper the ecosystem, which includes issues like lack of accountability, limited coordination among institutions and stakeholders, inadequate information dissemination, weak policy execution on the ground, and limited training and capacity building.

- **Lack of reliable data** has been a primary factor responsible for the poor planning that leads to the failure of organic waste management projects.

- **Financial barriers** include high investment costs that include up-front installation, construction, labour, and equipment costs. High transaction costs that include high level of bureaucracy, absence of legal standards and procedural delays in getting the available financial support. Lack of financial mechanisms with barrier elements such as high-risk perceptions by financial institutions, high interest rates, and lack of long-term financial options.

- **Market barriers** like the lower uptake of the final products as they compete with other alternatives like firewood, coal, etc. in case of biogas and fertilisers in case of compost, as well as alternative technologies like RDF, incineration etc. Competing electricity markets such as low-priced electricity from coal and natural gas-fired power plants as well as other renewable sources like solar, hydro and wind.

- **Social barriers** such as cultural objections or the NIMBY (not in my backyard) attitude, lack of technology understanding, aesthetic concerns, preference for conventional methods, and safety concerns hinder the implementation.

Global Trends and Its Implications

The organic waste management market is experiencing transformation, driven by technological advancement, increased awareness and evolving regulatory framework. The global compost market is expected to grow by 7% and reach an estimated USD 13 billion by 2030 (Lucintel 2024). Similarly, the biogas sector experienced a growth rate of 19% in the last six years (2017–2022), with production reaching 445 TWh in 2022 (IEA 2023). Currently, the total production of biogas is concentrated in the US, Europe, India, and China, where Europe is responsible for about half the total production, and Germany is responsible for about 20% (IEA 2023). Further, the EU, as a part of the REPower EU Plan sets a target of generating 35 billion cubic metres (bcm) of biomethane per year by 2030 (European Commission n.d.). Major factors driving the success of biogas sector in these countries are favourable national and regional policies and schemes, technological advancement, and the upgradation of biogas to biomethane. It is also projected that this sector will see a growth rate of 32% in the near future between 2023 and 2028 for the IEA net-zero scenario.

For India, the biogas sector can play a crucial role in terms of energy security, reducing reliance on natural gas imports and meeting international commitments. It is projected that India could reduce its natural gas import bill by **USD 29 billion** between FY 2025 and FY 2030 by replacing natural gas consumption with biogas and biomethane to 20% by 2030 (Jain 2023). India launched the Global Biofuels Alliance (GBA) as a part of its G20 presidency, which aims to expedite the global uptake of biofuels through collaboration among governments, international organisations, and industries. Therefore, through supportive programmes and policies like SBM, GOBARdhan, and international alliances, organic waste products like biogas are positioned for growth and will play an important role in India meeting the SDGs and net zero commitments.

7.3 Business Case for Organic Waste Management in India: Driving Jobs, Growth, and Sustainability

The transition to circular organic waste management in India presents a significant opportunity for economic growth, job creation, and advancing sustainability. Currently, India generates about 75,000 TPD of organic waste, which is projected to increase at a rate of 4.5% every year (CII 2024). By 2030, it is estimated that the country will generate 1.1 lakh TPD of wet waste. Meanwhile, only about 50% (37,500 TPD) of the wet waste is treated. Based on the present capacity, India will require an additional wet waste processing facility of 56,000 TPD by 2026 and 74,000 TPD by 2030.

Economic Growth

Both composting and biomethanation offer economically viable solutions for wet waste treatment. Composting offers a low investment with minimal operational and maintenance cost options for organic waste management. For instance, windrow compost for the 50 TPD plant offers a net economic benefit of **INR 8750 per day** (MoHUA 2022).

Biomethanation requires greater capital and operational capacity but offers a higher economic return compared to composting. Producing CBG aligns with government programmes, such as the SATAT and GOBARdhan schemes, that provide market support for procuring CBG as per IS 16086:2016 standard at a rate of INR 46 per kg (IOCL 2023). A 50 TPD biomethanation plant is estimated to yield a net economic benefit of **INR 51,500 per day**, with a payback period of about 7.5 years. With a capacity of 50 TPD plants, India will need about 1,500 biomethanation plants to process organic waste scientifically by 2030. This expansion of CBG plants could unlock an economic opportunity worth **INR 2,800** crore annually.

Green Jobs

The expansion of organic waste management facilities like BioCNG will also create green jobs. There will be short-term jobs in construction and long-term jobs in the operation and maintenance of the plant. The CBG plants could create about **49,000 jobs by 2030**, out of which 26,000 would be short-term and 23,000 long-term.

Emissions Reduction and Sustainability

Biomethanation is one of the net negative emissions technologies (NETs) and can play an important role in decarbonising hard-to-abate sectors such as transport and industry. It is estimated that a one-tonne of BioCNG derived from organic waste can save about 40.93 tonnes of CO_2 equivalent (Kaushik et al. 2023). A 50 TPD BioCNG plant can generate about 2 tonnes of gas, and 1,500 plants across the country could produce around 3000 tonnes daily. This could result in the annual emissions reduction potential of **44 million tonnes of CO_2 equivalent**.

7.4 Case Studies and Global Best Practices

South Korea's Journey Towards Zero Food Waste

South Korea has emerged as a global leader in organic waste management, achieving a remarkable 100% recycling rate from 2.6% in 1996 (Kim 2023). The country's journey began in 2005 when it banned food waste dumping in landfills, followed by a ban on ocean dumping in 2013. Some of their key initiatives include:

- Implementation of a pay-as-you-trash system has incentivised residents to reduce waste. This system has led to a 47,000 tonnes reduction in Seoul alone over six years till 2019 (Broom 2019).
- Automated bins equipped with scales and RFID technology have streamlined waste collection and charged residents based on their waste generation.
- Mandatory use of biodegradable bags has contributed to efficient waste processing and reduced landfill waste.
- Promoted urban farming as a means to utilise recycled food waste as fertiliser and create community spaces.
- South Korea focused heavily on public education and awareness campaigns. The Korea Zero Waste Movement Network, a coalition of 180 environmental groups, conducted over 1,000 outreach events every year to promote responsible consumption (Kim 2023).

Decentralised Compost Plants in Mysore

Mysore generates about 535 TPD of municipal solid waste every day, of which 40% to 60% is organic. To minimise the processing load on the centralised wet waste processing plant, Mysore City Corporation planned to decentralise wet waste management and encourage public participation in the conversion of organic waste into resources (Down to Earth 2022). Thus, they established a decentralised waste management system that includes zero-waste management (ZWM) plants (Biswas et al. 2021).

- To convert wet waste into organic manure through aerobic composting methods employed at the zero-waste unit, such as pit composting and vermicomposting.
- The city has seven functional zero-waste management units, and each plant is responsible for handling waste from five wards.
- The USP of the system is the cradle-to-grave model, which reduces the amount of waste reaching landfills.
- The compost is sold to nearby farmers at a minimum cost of INR 1,200 per tonne, with 5% retained by the city corporation for horticultural purposes.
- The revenue generation is INR 15,000 to INR 30,000 per month.
- Decentralised waste management reduces the chances of mixing waste at the secondary centre, making the processing of biodegradable waste more accessible and convenient and material recovery more reliable and efficient.

BioCNG Plant in Surat Near a Vegetable Market

Surat Municipal Corporation, through a public-private partnership, set up a 50 TPD biomethanation plant next to the Agricultural Produce Market Committee (APMC). The key features of this plant include:

- The plant is a two-stage thermophilic biomethanation that ensures high efficiency in converting waste into biogas. The plant also has a multi-fed digestor to treat different types of wet waste.
- The plant takes organic waste, including spoilt vegetables from the market and food and kitchen waste collected from nearby hotels.

- The generated biogas is purified, compressed, bottled, and transported to end-users, including Indraprastha Gas Limited (IGL) and selected industries located within a 25 km radius. Additionally, the compost is sold to the farmers and other consumers visiting the market.

- The facility was built at an investment of INR 13 crore, has reached break-even within four years, and is currently profitable.

7.5 Conclusion and Next Steps

There is a clear economic and environmental rationale for managing organic waste through composting and biomethanation. However, multiple challenges and risk factors lead to the dysfunction or lower uptake of these plants. We provide the following recommendations and roadmap to address these challenges and support the ecosystem that enables a sustainable, carbon-negative, and scalable solution for organic waste management.

Strengthening and Monitoring the Segregation Levels

The quality and quantity of waste reaching the organic waste facilities directly impacts resource recovery. For instance, if biodegradable waste gets mixed with domestic hazardous waste, it can contaminate the overall waste. According to the Swachh Survekshan 2023, the segregation levels in the urban local bodies (LBs) are currently at 33% (MoHUA 2023). But certain ULBs like Indore or Surat are able to achieve more than 98% segregation levels. One of the key factors in their success, alongside extensive awareness campaigns, is localised monitoring. This highlights the need for hyperlocal (ward level) monitoring and development of key performance indicators (KPIs) for achieving the segregation targets. Further, a formal agreement between the concessionaires and ULBs on the segregation levels can support meeting the feedstock requirement.

> **"Closing the demand-supply gap is crucial for a successful waste management model. Developing the market demand for the end products is necessary to ascertain the economic viability of a waste processing facility."**

Building Workforce Capacities

Training and capacity building of the workforce at different levels of the supply chain is necessary for effective operations and maintenance of organic waste management. Thus, training and skilling personnel about feedstock use, understanding the supply chain, scientific knowledge about processing technology, and compliance with safety protocols and environmental standards are crucial. Additionally, capacity-building efforts through training workshops should be tailored to meet the needs of various stakeholders, from on-ground workers to ULB officials and plant supervisors.

The network of training centres, like the eight Biogas Development and Training Centres (BDTC) by MNRE, must be strengthened and expanded to other geographies of India. Training materials, including modules, instructional videos, user manuals, and operational plans, need to be made available in regional languages for both onsite and online training and simultaneously equip them with updated knowledge.

Streamlining the Project License and Compliance Through Single Window Clearance

According to the GOBARdhan portal, 760 BioCNG plants have been registered, but only 108 plants have been functional so far, and 180 plants are under construction (GOBARdhan 2024). However, about 465 plant constructions have not started. One of the reasons for the low uptake of these plants is that it requires a large set of regulatory approvals from multiple ministries, pollution control boards, ULBs and others. The longer approvals and clearance result in delays, which increase investors' costs. Hence, an integrated single-window clearance through a digitised platform can support the ecosystem for faster deployment of the BioCNG plants.

Monitoring and Evaluation Through Dashboards

Many cities in India face the challenge of not having updated baseline data, including waste generation and composition. The lack of data often results in inaccurate estimations of the infrastructure required for waste management. Therefore, a robust monitoring and evaluation system needs to be implemented to track the progress, which will promote transparency, accountability, and data-driven decision-making. Additionally, cities can develop data dashboards for effective monitoring and reporting.

Innovative Financing Mechanisms

ULBs inability to generate own-source revenue, poor accounting practices, and outdated systems create a chain of financial strains that lead to inadequate service delivery (Gupta and Sachdeva 2021). The first thing would be to strengthen the already existing green bond system. Currently, systemic issues within ULBs restrict them from fully utilising the benefits they provide. A modified system could be where the state acts as a formal guarantor; this would enhance investor confidence and ensure periodic payments through the escrow mechanism. To increase accountability, the state could then develop a repayment plan. However, this would need formal agreement between the state and the ULBs, as it is also a localised issue. Most cities also fail to meet bond-raising requirements mentioned by the RBI, but cities like Ahmedabad, Vadodara, and Indore, which have succeeded, could share the learnings with other ULBs.

The other financing option could be to use polled entities like Special Purpose Vehicles (SPVs) established under the Smart Cities Mission, to issue bonds. Due to better management practices, they could serve as intermediaries between the ULBs and investors. PPP models and projects based on Build-Operate-Transfer (BOT) have also shown positive results (Department of Economic Affairs 2022). Private entities should focus on core competencies like waste recycling, while ULBs should ensure seamless logistical support, such as providing well-segregated organic wastes. With appropriate support from larger municipalities, venture capital, and startups could further strengthen financing for ULBs.

Building Sustainable Markets for Offtake of Organic Waste Products

Closing the demand-supply gap is crucial for a successful waste management model. Developing the market demand for the end products is necessary to ascertain the economic viability of a waste processing facility. Mysore and Surat are great case studies to understand challenges and opportunities to develop markets for organic waste products. Similarly, other smart cities could serve as starting points for developing such markets. Mysore's market model was successful due to the several awareness campaigns conducted to drive demand for this compost among large buyers, such as nearby farms and nurseries.

Another market that could be explored is to integrate bio-methane, which could be used as supplementary fuel in transport and industries. For scaling bioenergy, the example of Surat's 50 TPD biomethanation facility, offers a successful model in this case. Though this is capital-intensive due to high CAPEX, these plants have the potential to generate revenue through biogas sales and byproducts.

Establishing Biomass depots or banks can help balance supply and demand with standardised contracts for guaranteed quantity, quality, and price (GGGI 2021). These depots could ensure a reliable supply of BioCNG, thereby making them available for projects as well as reducing risks.

R&D Support for Technological Advancement and International Collaborations

In India, the BioCNG market is growing, and many plants are being established across the country. However, many developers still lack extensive project experience. Scaling up has proven that mature technologies that can process different types of feedstocks simultaneously are essential for the successful operations of a plant. The Global Biofuel Alliance, launched as part of India's G20 presidency, can be instrumental in advancing the technologies through promoting research and acting as a central knowledge repository and expert hub. Further, India can also share learnings and best practices with other countries, fostering global progress and development in organic waste management technology.

References

- Andrew Jeong and Julie Yoon. 2024. "South Korea's food waste recycling model turns leftovers into energy." Dailyclimate.Org. August 12, 2024.
- Bakkaloglu, Semra, Jasmin Cooper, and Adam Hawkes. 2022. "Methane emissions along biomethane and biogas supply chains are underestimated." One Earth 5 (6): 724–36. **https://doi.org/https://doi.org/10.1016/j.oneear.2022.05.012**.
- Biswas, Atin, Kuldeep Chaudhary, Richa Singh, Shailshree Tewari, Siddharth Singh, and Subhasish Parida. "Waste-Wise Cities: Best practices in municipal solid waste management." Centre for Science and Environment and NITI Aayog, 2021. **https://www.niti.gov.in/sites/default/files/2021-12/Waste-Wise-Cities.pdf**.
- Broom, Douglas. "South Korea Once Recycled 2% of Its Food Waste. Now It Recycles 95%." World Economic Forum (WEF), April 12, 2019. **https://www.weforum.org/agenda/2019/04/south-korea-recycling-food-waste/**.
- Central Pollution Control Board (CPCB). "Annual Report on Solid Waste Management (2020-21)," 2022. **https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2020-21.pdf**.
- Confederation of Indian Industry (CII). "National Circular Economy Framework: Roadmap for a Sustainable & Resilient India," November 2023. **https://www.ciiwaste2worth.com/pdf/national-circular-economy-framework-compressed.pdf**.
- Chirag Motwani, and Ashlesha Pandey. 2023. "Green bond roadmap: Addressing challenges and unlocking sustainable finance in India." The Indian review of corporate and commercial laws. July 3, 2023.
- Cheela, V R Sankar, Ved Prakash Ranjan, Sudha Goel, Michele John, and Brajesh Dubey. 2021. "Pathways to sustainable waste management in Indian smart cities." Journal of Urban Management 10 (4): 419–29. **https://doi.org/https://doi.org/10.1016/j.jum.2021.05.002**.
- Dey, Akashdeep, and R Camilla Thomson. 2023. "India's biomethane generation potential from wastes and the corresponding greenhouse gas emissions abatement possibilities under three end use scenarios: Electricity generation, cooking, and road transport applications." Sustainable Energy & Fuels 7 (1): 209–41. **https://doi.org/10.1039/d2se01028c**.

- Department of Fertilizers, Ministry of Chemical and Fertilizers. "Implementation of policy on promotion of city compost". April 2017. **https://www.cbgaindia.org/wp-content/uploads/2017/07/IMPLEMENTATION-OF-POLICY-ON-PROMOTION-OF-CITY-COMPOST.pdf**.

- Department of Drinking Water and Sanitation, Ministry of Jal Shakti. "GOBARDhan". Accessed on 14 October 2024. **https://gobardhan.co.in/about-us**.

- Department of Fertilizers, Ministry of Chemical and Fertilizers. "Policy on the promotion of city compost". February 10, 2016, **https://fert.nic.in/sites/default/files/2020-082023-07/City%20Composed.pdf**.

- Department of Economic Affairs, Ministry of Finance. 2022. "Public Private Partnerships Toolkit for Public Private Partnership Frameworks in Municipal Solid Waste Management Volume I." Asian Development Bank. **https://ppp.worldbank.org/public-private-partnership/sites/ppp.worldbank.org/files/documents/India_SolidWasteMgmt_PPP_Tookit-Volume-I_EN.pdf**.

- Douglas Broom. 2019. "South Korea once recycled 2% of its food waste, now it recycles 95%." World Economic Forum. April 12, 2019.

- Down to Earth. 2022. "India's cleanest cities: Mysuru's sophisticated decentralised wet waste-to-compost system". January 22, 2022. **https://www.downtoearth.org.in/water/more-than-half-of-sewage-treatment-plants-fail-to-meet-standards-in-delhi**.

- European Commission. n.d. "Biomethane." European Union. **https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomethane_en#:~:text=The%20Biomethane%20Industrial%20Partnership%20**.

- Ellen MacArthur Foundation. "Circular Economy in India: Rethinking Growth for Long-Term Prosperity," 2016. **http://www.ellenmacarthurfoundation.org/publications/**.

- G20. "G20 New Delhi Leaders' Declaration." New Delhi, September 2023. **https://www.mea.gov.in/Images/CPV/G20-New-Delhi-Leaders-Declaration.pdf**.

- Global Green Growth Institute (GGGI). "Landscape Analysis of BioCNG in India," October 2021. **https://gggi.org/wp-content/uploads/2021/10/Landscape-Report-of-BioCNG-in-India-GGGI-1.pd**.

- Gupta, Shishir, and Rishita Sachdeva. "Revisiting the Role of Funding: Lessons from Expenditure and Performance on Cleanliness in Indian Cities," April 2021. **https://csep.org/wp-content/uploads/2021/04/WP_Revisiting-the-role-of-funding.pdf**.

- International Energy Agency (IEA). "Renewables 2023: Analysis and Forecasts to 2028," January 2024. **https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf**.

- IEA. 2021. "Methane and climate change." **https://www.iea.org/reports/methane-tracker-2021/methane-and-climate-change**.

- Indian Oil Corporation Limited (IOCL). "Purchase price of compressed biogas (CBG) under SATAT scheme" August 14, 2023. **https://satat.co.in/satat/assets/download/cbg%20Pricing%20Circular%20-%20stakeholders.pdf**.

- Invest India. "Invest India: Waste to Wealth". May 22, 2024, **https://www.investindia.gov.in/waste-to-wealth**.

- International Energy Agency. n.d. "An introduction to biogas and biomethane." International energy agency.

- Kaushik, Trinayana, Aparna Sajeev, Souvik Bhattacharjya, Arpita Pandey, and Mandavi Singh. "Comprehensive environmental and social sustainability: Assessment of Bio-CNG as a vehicular fuel in India." The Energy and Resources Institute, n.d. **https://www.teriin.org/sites/default/files/2024-02/Assessment_of_Bio_CNG_as_a_Vehicular_Fuel_in_India.pdf**.

- Kopecká, Romana, Marlies Hrad, and Marion Huber-Humer. "The Role of the waste sector in the Sustainable Development Goals and the IPCC assessment reports." Österreichische Wasser- Und Abfallwirtschaft 76, no. 5–6 (June 2024): 300–307. **https://doi.org/10.1007/s00506-024-01034-7**.

- Lenkiewicz, Zoë. "Global waste management outlook 2024." United Nations Environment Programme, 2024. **https://wedocs.unep.org/bitstream/handle/20.500.11822/44939/global_waste_managementutlook_2024.pdf?sequence=3**.

- Lucitel. "Compost market: Trends, opportunities and competitive analysis [2024-2030]." August 2024. **https://www.lucintel.com/compost-market.aspx#:~:text=Compost%20Market%20Trends%20and%20Forecast&text=The%20global%20compost%20market%20is,of%20chemical%20fertilizer%20and%20pesticides**.

- Manzoor, Sobiya, Ufaq Fayaz, Aamir Hussain Dar, Kshirod Kumar Dash, Rafeeya Shams, Iqra Bashir, Vinay Kumar Pandey, and Gholamerazi Abdi. "Sustainable Development Goals through Reducing Food Loss and Food Waste: A Comprehensive Review." Future Foods 9 (June 2024): 100362. **https://doi.org/10.1016/j.fufo.2024.100362**.

- Max S. Kim. 2019. "The country winning the battle on food waste." **Huffingtonpost.co.uk**. April 8, 2019.

- Max S Kim. 2022. "South Korea has almost zero food waste, here's what the US can learn." The Guardian. November 20, 2022.

- Max Kim. 2023. "How South Korea's composting system became a model for the world." LA Times. August 24, 2023.

- Mittal, Shivika, Erik O. Ahlgren, and P.R. Shukla. "Barriers to biogas dissemination in India: A review." Energy Policy 112 (January 2018): 361–70. **https://doi.org/10.1016/j.enpol.2017.10.027**. Ministry of Power. "No 23/26/2020 -R&R (Part I)" Office Order, Government of India. July 23, 2021, **https://powermin.gov.in/sites/default/files/uploads/Orders/B.2.1.pdf**.

- Ministry of Environment, Forest and Climate Change. 2023. "Notification issued for green credit program (GCP) and ecomark scheme under LiFE initiative to promote sustainable lifestyle and environmental conservation." PIB. August 13, 2023. https://pib.gov.in/pressreleaseIframepage.aspx?prid=1967476#:~:text=green%20credit%20program%20(gcp%20)notified%20on%2013th%20october,%202023%20is.

- Ministry of Housing and Urban Affairs (MoHUA). 2023. "Swachh Survekshan 2023". **https://ss2023.sbmurban.org/#/dashboard** Ministry of Environment, Forest and Climate Change. 2022. "Technological solutions for effective solid waste management." Press Information Bureau, Government of India. March 24, 2022.

- MoHUA. "Swachh Survekshan Toolkit 2024," 2023. **https://ss2023.sbmurban.org/#/dashboard**.

- MoHUA. 2021."Swachh Bharat Mission - Urban 2.0: Operational guidelines". **https://sbmurban.org/storage/app/media/pdf/swachh-bharat-2.pdf**.

- Ministry of Environment, Forest and Climate Change. 2023. "Notification issued for green credit program (GCP) and ecomark scheme under LiFE initiative to promote sustainable lifestyle and environmental conservation." Press Information Bureau, Government of India. August 13, 2023. **https://pib.gov.in/pressreleaseIframepage.aspx?prid=1967476#:~:text=green%20credit%20program%20(gcp%20)notified%20on%2013th%20october,%202023%20is**.

- Ministry of New and Renewable Energy. "Waste to Energy Programme". October 17, 2024, **https://mnre.gov.in/waste-to-energy/**

- Ministry of New and Renewable Energy. 2023. "Government initiates various steps under National Bioenergy Programme to promote and encourage establishment of new waste to energy plants". Press Information Bureau, Government of India. February 03. 2023, **https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1896067**.

- Niti Aayog. 2021. "Dry waste, wet waste, inert waste: promoting behaviour change for strengthening waste segregation at source." **https://www.niti.gov.in/sites/default/files/2021-12/promotingbehaviourchange-forstrengtheningwastesegregation-atsource-policguidelines.pdf**.

- Niti Aayog. 2022. "Youth leads citizen participation in the national campaign for segregation of waste at source." Press Information Bureau, Government of India, Ministry of Housing & Urban Affairs. October 20, 2022. **https://pib.gov.inpressreleaseshare.aspx?prid=1869560**.

- Selvaraj, Vinoth Kumar, Jeyanthi Subramanian, and Sri Sai Dutt. "Integrating Circular Economy Principles in Achieving Net Zero Toward Sustainable Futures: India's Perspective." Materials Circular Economy 6, no. 1 (December 2024): 53. **https://doi.org/10.1007/s42824-024-00144-7**.

- UNEP Finance Initiative. 2020. "Financing circularity: demystifying finance for circular economies."

- United Nations Environment Programme and Climate and Clean Air Coalition. "Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions." Nairobi: United Nations Environment Programme, 2021. **https://unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions**.

- United Nations. "The Sustainable Development Goals Report," 2024. **https://unstats.un.org/sdgs/report/2024/The-Sustainable-Development-Goals-Report-2024.pdf**.

Annexure 7.1: Proposed Targets With the Timelines

S. NO.	PROPOSED TARGET	TIMELINE	
		SHORT TERM (2026)	LONG TERM (2030)
1	Households practicing segregation in all ULBs	60%	100%
2	Target for setting up biomethanation plants	500+	1500+
3	Mandate for fertiliser units to utilise compost in their production units	5	15
4	Training of waste workers in the plants	10,000	50,000
5	IEC materials developed in the local languages	6	22
6	Treatment of organic waste	70%	100%
7	Elimination of open dumps	70%	100%
8	Number of cities developing data dashboard	50+	200+

Source: Adopted from the CII National Circular Economy Framework

Conclusion

As the world faces increasing environmental challenges, the concept of a circular economy offers a promising pathway for sustainable development. Circularity emphasises reducing waste, conserving resources, and optimising material use throughout supply chains, thereby ensuring the longevity of resources and minimising their environmental footprint. For India, adopting circular economy practices is critical to addressing key challenges, such as resource scarcity, environmental degradation, and growing energy demands, while also supporting economic growth and development. This paper explores how circularity can be integrated into India's industrial landscape across various sectors, from energy to manufacturing, and identifies the key strategies necessary for achieving a sustainable, circular economy.

By embracing circularity, India can build a strong framework to reduce its reliance on raw materials, encourage innovation, and boost economic resilience. This approach addresses the urgent need for responsible resource management and can enable new opportunities for growth, job creation, and technological advancement. However, for this transition to be successful, India must overcome infrastructure gaps, technological barriers, logistical challenges pertaining to material collection, and regulatory hurdles. This paper provides an overview of strategies, solutions, and policies, outlining how India can transition to a circular economy while ensuring sustainable growth and environmental stewardship.

Although each sector is distinct, the challenges mentioned above are cross-cutting, as are solution pathways to drive change. Below are eight critical intervention points to chart a path toward a circular economy.

> **Clear, measurable targets for material recovery and reuse across key sectors are essential. Equally important is the need to incentivise businesses to adopt circular models.**

Advancing Recycling Technologies and Innovation

Innovation and technological advancement are at the core of the circular economy. Advancing recycling and processing technologies is essential to creating a sustainable, closed-loop system for managing material waste by developing more efficient sorting and processing technologies for various waste streams, particularly for batteries, solar panels, steel, and construction waste. By promoting innovation and technological advancement, India can reduce waste and recover valuable materials from end-of-life products. This will support a circular economy and decrease reliance on virgin resources.

Infrastructure Development

There must be reverse logistic processing to collect and recycle materials. India must invest heavily in building robust infrastructure, including efficient waste collection systems and logistics networks to collect and transport materials to processing plants. This infrastructure will address material recovery challenges by enabling better integration of waste management and recycling operations across urban and rural areas, ensuring that materials are properly recovered and repurposed.

Transparency

Traceability is essential for advancing circularity in fragmented value chains. Opaque supply chains hinder accountability, making addressing issues such as human rights, environmental degradation, or material recovery difficult. Enhancing traceability allows industry and policymakers to pinpoint material origins, track resources, and optimise recycling or repurposing efforts. Actionable solutions include implementing robust monitoring systems and data dashboards that provide real-time insights into resource flows, waste composition, and infrastructure needs. Adopting global traceability standards and leveraging technology can drive accountability, improve decision-making, and build a transparent circular economy ecosystem that fosters trust and efficiency.

Policy and Regulatory Frameworks

Achieving a successful transition to a circular economy in India requires a concerted effort to strengthen and streamline policy and regulatory frameworks that create an enabling environment for circular practices. This involves developing unified, overarching policies that address recycling, resource efficiency, and waste reduction while aligning with national sustainability goals and international best practices. Clear, measurable targets for material recovery and reuse across key sectors are essential. Equally important is the need to incentivise businesses to adopt circular models. This can be achieved by offering tax benefits for using recycled materials, providing subsidies for innovative recycling technologies, and implementing recognition programmes for sustainable practices. Addressing enforcement gaps and establishing transparent, enforceable regulations will further promote recyclable product design and responsible waste management. Working together across industries, governments, and communities is crucial to creating solutions and applying circularity throughout value chains. By adopting these steps, India can lay the groundwork for a circular economy that supports resource conservation, economic growth, and sustainability.

Policy interventions should focus on establishing Extended Producer Responsibility (EPR) schemes, holding producers accountable for the entire lifecycle of their products, including end-of-life disposal and recycling. Additionally, the introduction of tax incentives, subsidies for recycled materials, and reduced GST rates for recyclable goods would further promote circular practices. Implementing single-window clearance would streamline the execution of such policies, ensuring efficient enforcement. Moreover, India must align its circular economy policies with international standards to enhance global competitiveness and facilitate trade in recycled materials. A strong, cohesive policy framework will send clear signals to businesses and consumers, incentivising the widespread adoption of circular practices across industries.

Investment in Circularity

Investment is crucial to propel the circular economy forward, and creating an environment that attracts capital is key to scaling growth in this area. This can be achieved by expanding the traditional lens of investment from one purely focused on financial returns to one considering the social and environmental outcomes of activities. By valuing and monetising the benefits of eliminating pollution externalities, the investment case for circularity becomes more compelling and robust. Additionally, fostering a conducive investment environment is essential. This can begin with establishing public-private partnerships to attract the necessary funding, research, and technology development needed to scale circular practices. To accelerate the adoption of circular practices, India must focus on reducing economic barriers for businesses, such as high upfront costs and limited demand for recycled materials. Financial incentives, including grants, tax exemptions, and preferential loans for companies adopting circular practices, can help bridge these gaps and make circular models more economically viable.

Circular by Design—Product Lifecycle and Design for Durability

The shift to a circular economy begins at the design stage. Circularity principles should be embedded in product design to ensure that materials can be reused, recycled, or repurposed at the end of a product's lifecycle. Manufacturers can minimise waste and optimise resource use by designing products for durability, repairability, and recyclability. For instance, designing for disassembly in industries can allow for easier recovery of valuable materials, reducing the need for virgin raw materials and minimising waste. Incorporating recycled materials into new products is another key aspect of circular design. By encouraging companies to adopt circular design principles, India can significantly improve resource efficiency, reduce waste, and drive sustainability across industries. This shift requires collaboration between product designers, manufacturers, and policymakers to ensure that circularity becomes a standard practice in industrial design.

> "By leveraging key pathways—such as collaboration, workforce development, circular design, investment mobilisation, and policy frameworks that incentivise circular practices—India can accelerate its transition to a circular economy."

Workforce Development and Skill Building

The transition to a circular economy will require a skilled workforce capable of driving innovation and managing new recycling and remanufacturing processes. Workforce development must be a priority, with training programmes designed to equip workers with the skills needed to operate in circular industries. This includes providing technical training for emerging fields like battery recycling, e-waste management, and material recovery. Capacity building at all levels of the supply chain will ensure that workers are prepared for the new opportunities that circularity creates, thus facilitating the growth of a green economy.

Collaboration

Collaboration across public and private sectors, as well as national and regional governments, is crucial to advancing India's transition to a circular economy. The G20 Secretariat can play a central role as the linchpin, coordinating efforts across diverse stakeholders. To succeed, academia and civil society must also partner in identifying challenges, developing solutions, and integrating global best practices to promote sector-specific circularity. No single actor has sufficient resources or capability to develop a circular supply chain on its own accord to meet India's climate goals. However, industry players, municipalities, end-consumers, academic institutions, civil society, philanthropists, and government bodies can forge cohesive strategies by working together. This collaborative approach will foster innovation, ensuring that circularity becomes a fundamental part of India's sustainable economic growth.

By leveraging key pathways—such as collaboration, workforce development, circular design, investment mobilisation, and policy frameworks that incentivise circular practices—India can accelerate its transition to a circular economy. These strategies, complemented by a commitment to increasing transparency and fostering innovation, aim to establish a self-sustaining ecosystem of circular practices. This would lead to reduced reliance on virgin materials, minimised waste generation, enhanced resource efficiency, and strengthened economic resilience, positioning India as a global leader in sustainable development.

India's cultural heritage offers a strong foundation for adopting circular economy principles. With traditions focused on resource management, mindful consumption, and waste reduction, the country's practices naturally support circularity. By blending these values with modern technologies, India can drive sustainable growth and build a resilient economy that serves as a global model. In summary, India's transition to a circular economy offers a transformative opportunity to address pressing environmental challenges and create economic opportunities. It also holds the potential to strengthen resilience against global supply chain disruptions. Achieving this vision will require advancements in recycling technologies, the development of robust infrastructure, and the implementation of clear, forward-thinking policies. Additionally, it will necessitate fostering a culture of innovation — supported by active collaboration among government, businesses, and civil society. With the right investments and strategic frameworks, India can spearhead the global adoption of circular economy principles, clearing the path for sustainable development both at home and worldwide.

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut climate pollution by at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; Abuja, Nigeria; and Beijing. RMI has been supporting India's mobility and energy transformation since 2016. Learn more about us at **https://rmi.org/**.

The Council on Energy, Environment and Water (CEEW) is one of Asia's leading not-for-profit policy research institutions and among the world's top climate think tanks. The Council uses **data, integrated analysis, and strategic outreach to explain—and change—the use, reuse, and misuse of resources.** CEEW addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public. CEEW has a footprint in over 20 Indian states and has repeatedly featured among the world's best managed and independent think tanks. Follow us on X (formerly Twitter) @CEEWIndia for the latest updates. Learn more about us at **https://www.ceew.in/**.

G20
भारत 2023 INDIA

RMI

CEEW
THE COUNCIL