Indian Council for Research on
International Economic Relations

SUMMARY
FOR POLICYMAKERS

Waste Input-Output (WIO) and Material Flow Analysis (MFA) For Scrap Steel Policy Impact Evaluation

Authors:
Dr. Amrita Goldar, Md Sarwar Ali,
Pranav Jha, Sunishtha Yadav,
Yamini Sant, Prem Surya Dharmalingam,
Manasa Pothkanuri

Introduction

Secondary steelmaking, which uses iron and steel scrap in Electric Arc Furnace (EAF) and Induction Furnace (IF) methods, is increasingly being seen as a strategic approach to decarbonize the steel sector. This method offers significant environmental and economic benefits saving 1.1 tonnes of iron ore, 630 kg of coking coal, and 55 kg of limestone per tonne of scrap used. It also reduces energy consumption by 16–17 percent, water use by 40 percent, and greenhouse gas (GHG) emissions by 58 percent (Ministry of Steel, 2019).[1] Given steel's recyclability, it plays a key role in promoting circular economy goals by reintroducing scrap into the production cycle. While countries like Japan, Australia, and China have achieved high recycling rates through organized systems, India lags behind due to inefficiencies in its largely unorganized scrap steel sector. Accurate data on scrap generation remains scarce, which limits effective planning and policymaking. The present study addresses this gap by tracking scrap steel flows across key sources such as machinery, end-of-life (EoL) vehicles, shipbreaking, railways, and scrap generated during processing as a part of steel production. Using stakeholder consultations and material flow analysis (MFA), the analysis evaluates the availability and movement of scrap steel. Despite its potential to create jobs and reduce dependence on virgin materials, the sector faces challenges in collection and processing that need to be addressed to fully realize the benefits of secondary steelmaking in India.

Policy Relevance and Research Objective

- By analysing the material flow of scrap steel, the study evaluates the effectiveness of the collection, processing, and recycling of scrap steel and identifies areas for improvement.
- A coupled dynamic Waste Supply Use Table (WSUT)-MFA model has been used to assess scrap steel availability and flows in India, providing insights into how the steel industry interacts with broader economic and environmental systems. The results are focused on promoting circularity in the system.
- Further, the study evaluates the impacts on the real economy and facilitates the transition to a low-carbon circular economy by promoting effective steel recycling through secondary processes and minimizing waste. By projecting different scenarios until 2047, the study seeks to inform government policy interventions in the steel sector.

State Selection for the Study

Selecting states to analyse scrap steel availability and flows is critical for ensuring a regionally representative assessment of scrap generation and utilization patterns. The state selection process involved a detailed analysis of multiple factors using the Annual Survey of Industries (ASI) data. The key factors considered were:

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[1] Available at: https://www.pib.gov.in/PressReleasePage.aspx?PRID=1591038 . Accessed on 5th May 2025

a) **Number of Sampled Scrap Steel Units:** Identifying states with a significant presence of industries utilizing scrap steel as an input.

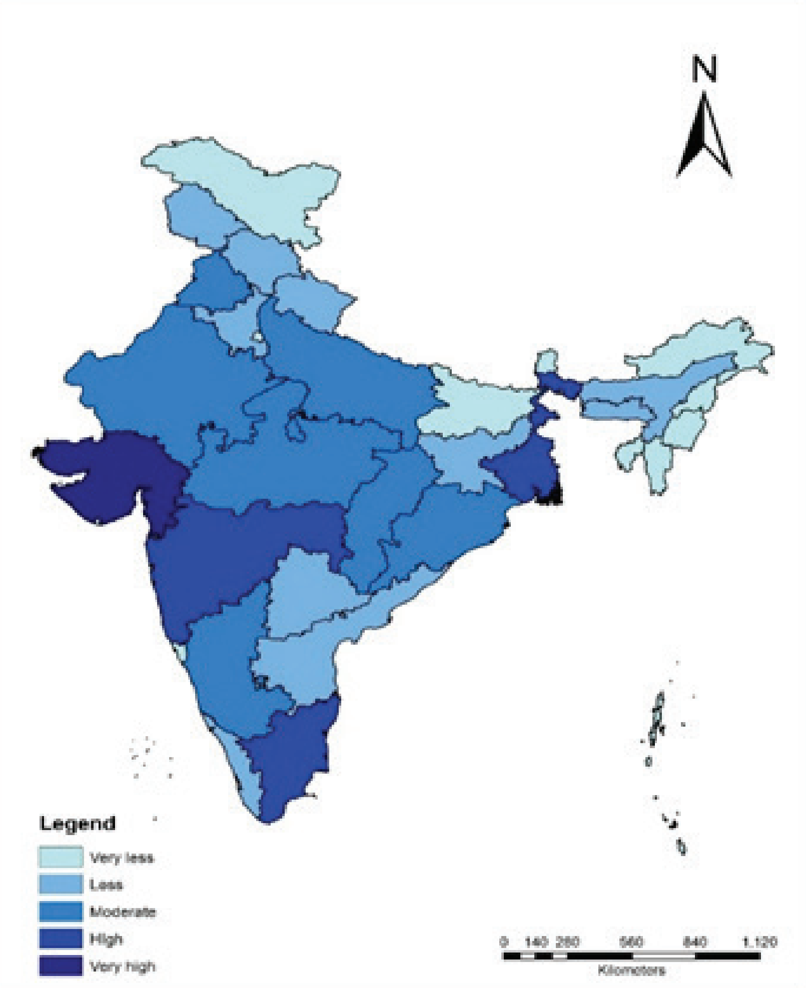
b) **Quantity of Scrap Steel Produced:** Assessing scrap steel produced with and without survey weights to identify states with high scrap steel output

c) **Cost of Operations:** Evaluating the cost-effectiveness of scrap steel processing to highlight states with growth potential and economic sustainability.

d) **Number of Steel Producers:** Prioritizing states with a robust steel industry, as indicated by the presence of numerous steel producers and established infrastructure for processing.

Using the ASI data, each state was ranked based on the aforementioned factors in descending order, from highest to lowest. **Gujarat and Maharashtra** emerged as the top states for scrap steel usage, as shown in Figure 1.

Figure 1: Scrap Steel Consumption by States

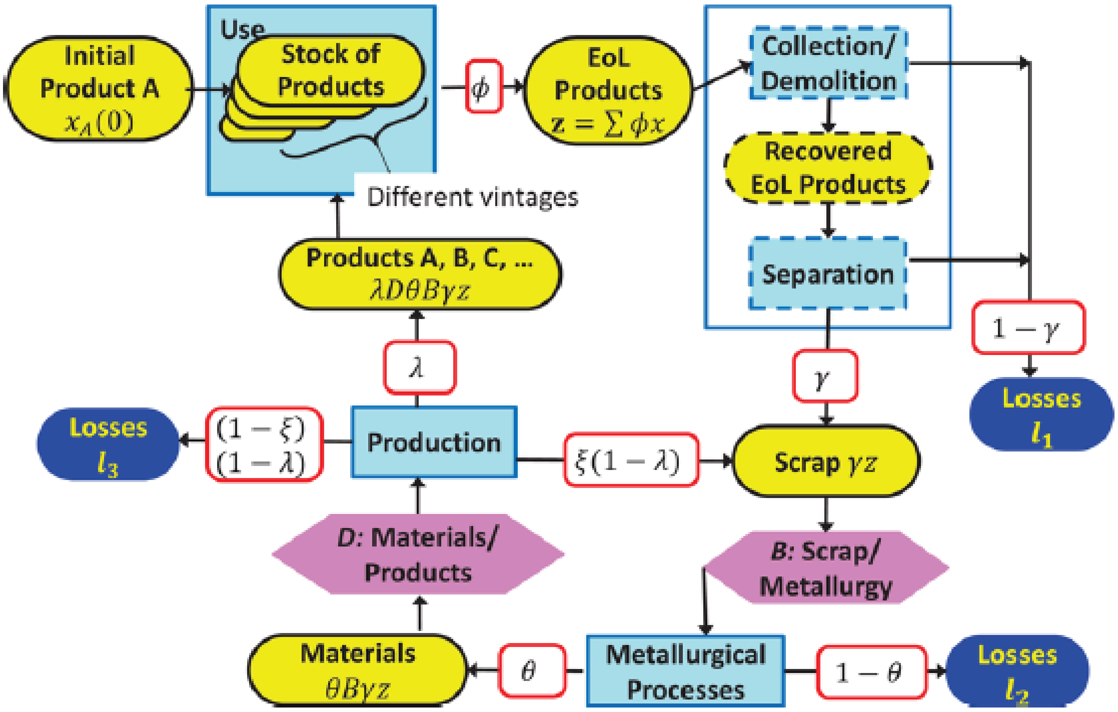


Source: Authors' Construction

Methodology

Component one involved a MFA, wherein the study quantified the inflow, outflow, and stocks of steel in the country (based on Figure 1). This was, in turn, used to develop the baseline scenario. The study also examined the potential sources of wastages (or leakages) within the system and explored ways of minimizing the same/closing the loop. The numbers used in the analysis were based on existing production technologies, recycling rates, and collection and processing efficiencies of existing waste treatment systems (e.g., material recovery facilities), etc. The study used an IO-based dynamic model of MFA that traced the fate of materials over time and across products in an open-loop recycling, with explicit consideration of losses and scrap quality. Figure 2 represents the architecture of the model. The ovals depict the flow of inputs and outputs, rectangles indicate processes where inputs are transformed into outputs, and hexagons denote allocation processes.

Figure 2: Architecture of the Model



Source: Nakamura et.al, 2014

Component two involved the creation of a Dynamic WSUT that distinguished between the flow of goods and waste in the economy, allowing for consistent modeling of circular economy efforts, with a specific focus on scrap steel. An enhanced version of the existing ICRIER ***Sampada*** WSUT model was used to assess the direct and indirect impact of waste management policies and consumption patterns on various macroeconomic parameters. The model incorporated data for monetary transaction values and physical quantities of waste flows, thereby making it capable of correctly evaluating all stages of the consumption process—purchase and use of products, and disposal of waste. Based on the principles of mass balance of waste, the framework encompassed the transition of waste from generation, recycling, treatment, recovery, and residue stages.

The ICRIER ***Sampada 4.0*** model development was based on the IO table framework, covering 37 goods and services-producing sectors of the Indian economy. With respect to the waste type classification, the model covers twelve types of wastes, namely non-steel dry municipal solid waste (MSW), scrap steel waste (vehicular metal scrap, shipbreaking, processed steel, machinery, railways), wet MSW, inert MSW, bio-medical waste, hazardous waste, plastic waste, and E-waste. Further, the model encompasses costs and technological efficiencies of six waste treatment technologies, which include material recovery facilities (MRF). These are further delineated into segregation technologies and recycling (including remelting), composting, incineration, sanitary landfill, and construction and demolition (C&D) waste management.

Forecasted Demand for Scrap Steel for 2047

Crude steel production in 2022 was about 120 million tonnes (MT). These estimates when matched against future demand, exhibit an expected rise to 381 MT by 2047 (Climate Group Report, 2023).[2] Using a simple calculation method, the analysis estimates that the installed capacity must reach 470 MT, assuming an 81 percent utilization rate. Further, it was assumed that production would be split between EAF/IF and Blast Furnace-Basic Oxygen Furnaces (BF-BOF) in the ratio of 55:45. Scrap needs overall are computed using scrap use differences by technology, i.e., EAF/IF assumed to require 710 kg per tonne, BF-BOF assumed to require 125 kg per tonne (MRAI, 2022). Using the above assumptions, we estimate the total scrap demand in 2047 to be 170 MT. Assuming the current split between foreign and domestic sources to prevail in 2047 as well, we can conclude that 119 MT (70 percent of total demand) is expected from domestic sources, underscoring the need for a strong scrap ecosystem in India's steel industry. Table 1 shows India's projected steel demand and capacity needs by 2047.

Table 1: India's projected scrap steel demand for 2047

Year	2047
Total crude steel demand (MT)	381
Capacity Utilization (in percentage)	81
Total Crude Steel Capacity (MT)	470
Total scrap steel demand (MT)	170
Domestic scrap demand (MT)	**119**

Source: Authors' Construction

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[2] Available at: India Net Zero Steel Demand Outlook Report | Climate Group. Accessed on 24th May 2025

Structure of the Model and Material Flow Analysis for Different Scrap Steel Generating Sources

As against the needs estimated above, the ICRIER ***Sampada 4.0*** model has been used in the present analysis to evaluate the availability of scrap steel in the economy under two different scenarios.

Sampada 4.0 WSUT Model – Baseline Scenario

The analysis applies the WSUT extension of Nakamura and Kondo's (2002) Waste Input-Output (WIO) framework, as developed by Lenzen and Reynolds (2014), to the Indian economy for the year 2021-22. The model has been further refined to track scrap steel flows across the entire economy. The WSUT (represented in Table 2) is constructed by integrating the S-matrix (or allocation matrix) into the WIOT. The WSUT extension of the WIO framework incorporates the flexibility of the (monetary) SUT concept, enabling waste data to be represented simultaneously by waste type and waste treatment method within a single table. This approach facilitates a comprehensive understanding of the full spectrum of activities related to waste generation and processing within the economy.

Table 2: Schematic for the WSUT (in units)

	Intermediate Demand Sectors 1....N_1	Waste Treatment Sectors 1...N_2	Waste Types 1...N_3	Final Demand Sectors 1...N_f	Gross Output
Intermediate Supply Sectors 1....N_1	T_{11} (INR Lakhs)	T_{12} (INR Lakhs)		f (INR Lakhs)	x_1 (INR Lakhs)
Waste Treatment Sectors 1...N_2			W_{23} (Mtpa)		x_2 (Mtpa)
Generation of Waste by Type 1....N_3	W_{31} (Mt pa)	W_{32} (Mtpa)		W_F (Mtpa)	x_3 (Mtpa)

The various components of the partitioned matrix are as follows:

a. Monetary Input-Output (Matrices T_{11} and f)

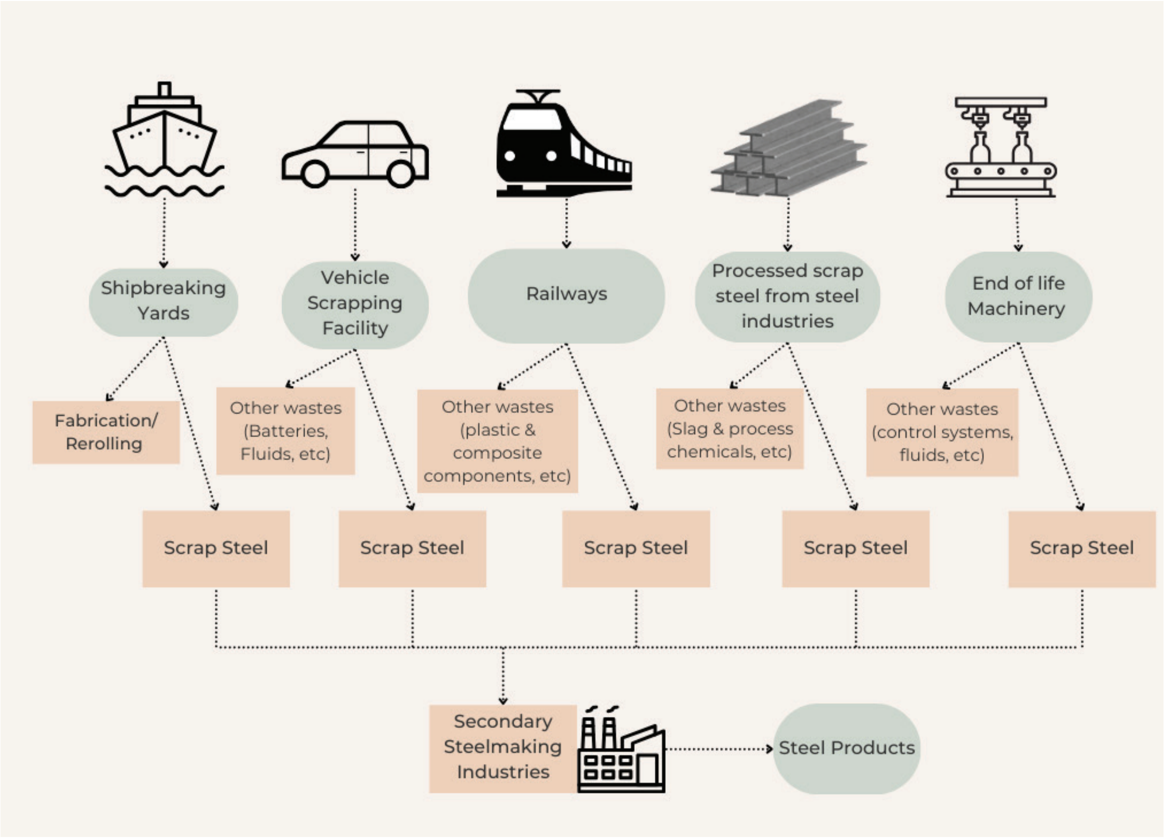
The WSUT for the baseline year 2021-22 is constructed using the national Input-Output Transaction Table (IOTT) developed by Chaudhari et al. (2024). To streamline the analysis, the original 137-sector model has been aggregated into a 37-sectors. The IOTT captures inter-industry demand, final demand, and output values in monetary terms.

b. Waste generation in India (Matrices W_{31} and W_F)

The WSUT has relied on data for waste generation and treatment across different types. Central Pollution Control Board (CPCB) has classified waste into five categories: MSW (later divided into dry, wet and inert MSW), hazardous waste, plastic waste, bio-medical waste, and E-waste. The dry MSW has further been bifurcated into non-steel dry MSW and scrap steel waste (vehicular metal scrap, shipbreaking, processed steel, machinery, railways). Both generation and treatment have been measured in Metric Tonnes per Annum (MTA) and captured as net generation (generation - recycling) in the W_{31} matrix. After estimating total waste generation, the next step was to distribute it across 37 intermediate sectors. Sectoral allocation was determined based on waste generation profiles and recycling data from the ASI. A concordance was developed to map these profiles to twelve designated waste categories, including the five steel scrap categories. Net waste has then been calculated by subtracting recycled waste from gross generation. The generation of steel waste data has been validated using MFA as well.

To delve into the scrap steel numbers further, as mentioned earlier, the key contributing sectors from scrap steel generation include vehicular metal scrap, processed steel from steel plants, end-of-life machinery, railways, and shipbreaking (refer to Figure 3).

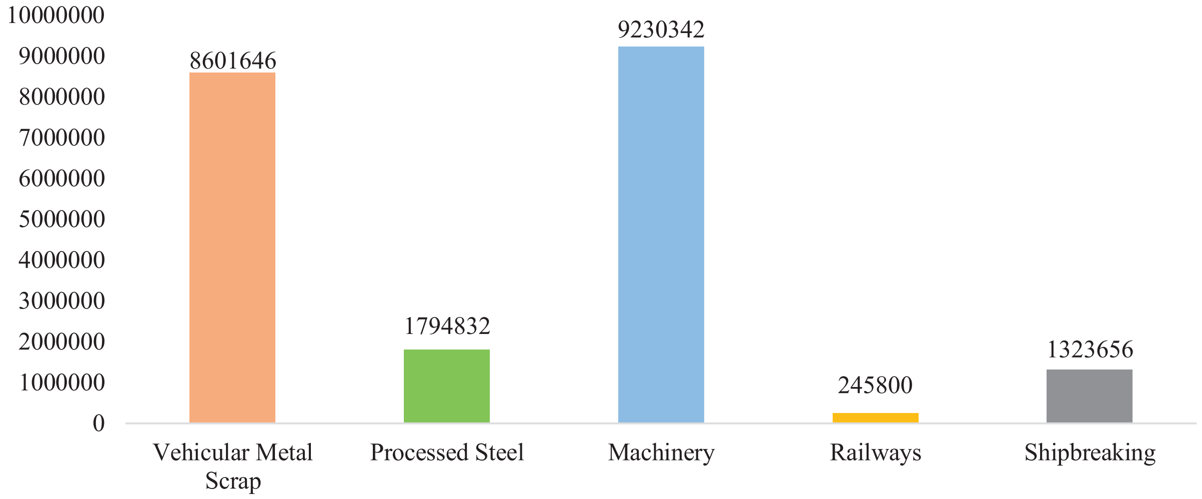
Figure 3: Scrap Steel Generation from Different Key Sectors



Source: Authors' Construction

The amount of scrap steel generation estimated across key contributing sectors is shown in Figure 4. These estimates have been derived using secondary literature, data sources such as ASI, Joint Plant Committee (JPC) reports, and stakeholder consultations conducted in selected states.

Figure 4: Amount of Scrap Steel Generated from Different Sectors (MTA)



Source: Authors' Construction

The analysis also attempted to allocate the above-mentioned steel waste generation figures into the quality of scrap generated. Thus, an attempt was made to identify scrap steel grades such as SS 304 and SS 316 that are primarily used in secondary steel making, as was indicated during the field survey and secondary literature. These grades are commonly utilized in the manufacturing of components for the automotive industry, defence equipment, heavy machinery, material processing machines, valve and windmill industries, compressors, and various casting applications. Other grades of scrap steel, such as SS 310 and MS 513, are largely recovered from categories like vehicular metal scrap and machinery. These grades are primarily used in the production of automotive components, heavy machinery parts, and related applications (refer to Table 3).

Table 3: Scrap steel generation by grades and their use cases

Scrap Steel Grades	Total (MTA)	Additives (in percentage)	Use cases of these scrap steel grades
SS 304	6959129	20	Used in the manufacturing of parts for the automotive, defence, and heavy machinery industries, as well as castings for material processing equipment, valves, windmills, and compressors
SS 316	5990597	35	Utilized in producing components for the automotive, defence, and heavy machinery sectors, along with castings for machines, valves, etc.
SS 410	1704633	16	Used to produce ingots, machine components like pumps and valve parts
SS 201	641000.3	23	Used to produce new stainless-steel products such as sheets, utensils, pipes, and automotive components.
SS 310	2587944	25	Used to produce springs, automotive components, structural parts, and heavy machinery castings.

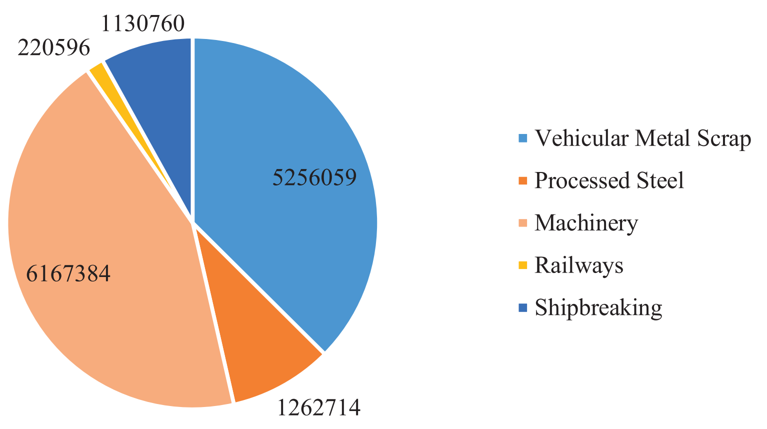
Scrap Steel Grades	Total (MTA)	Additives (in percentage)	Use cases of these scrap steel grades
SS 204	1102517	25	Used to manufacture chemical and food processing equipment, automotive components, etc.
MS 513	641000.3	0.95	Used to manufacture engineering components, fabricated parts for machinery and equipment, household items, furniture, etc.
IS 3039	1323656	1.40	Used to manufacture bars, pipes, machinery components, and other construction applications.
IS 3195	245800	0.60	Used to produce automobile parts, construction materials, etc.

Source: Authors' Construction

Following this, a systemized and quantitative study of the Indian steel cycle was carried out using MFA based on an economic modelling approach. Scrap availability was modeled alongside actual recycling rates to evaluate the effectiveness of current scrap management and identify areas for improvement.

Given the estimated scrap steel generation from different categories, the scrap steel recovered (refer to Figure 5) from these key sectors was evaluated based on certain assumptions for segregation as well as remelting efficiency, in order to recover usable grades of scrap steel. Many scrap steel-using firms reported that their recovery efficiency ranges from 85 percent to 95 percent, after accounting for losses such as material loss during the segregation and remelting processes.

Figure 5: Scrap Steel Recovered (MTA)



Source: Authors' Construction

c. Waste Treatment & Waste Disposal Techniques (W_{23} Matrix)

After collecting waste generation data, information on waste treatment was compiled from various CPCB annual reports. Table 3 presents the volume of waste treated across seven streams, offering insights into India's current waste management practices. As noted by Nakamura and Kondo (2002b), multiple waste types can be treated by a single process, and one type may undergo several treatments. Treatment technologies were selected based on waste characteristics, recovery potential, costs, legal requirements, and feasibility. Key methods include incineration, composting, landfilling, material recovery, and C&D waste management.

d. Waste-to-Waste Generation Matrix (W_{32} matrix)

Waste disposal techniques can alter but not fully eliminate waste, leaving residues that are typically sent to landfills. Since current technologies cannot restore closed landfills, they remain the final destination for residual waste, contributing to environmental emissions. Landfills release pollutants such as CO_2, NO_x, SO_x, BOD, COD, nitrates, and phosphates into air and water. Waste treatment methods produce varying by-products, with ash being a key residue from combustion. Incineration typically yields about 5.4 percent ash (Nakamura and Kondo, 2002), while post-treatment of C&D waste generates around 4 percent. The W_{32} matrix captures waste from various treatment processes, including leakages during handling.

Note however, that to have a balance in the waste material accounts, the value of recycled products subtracted in W_{31} are accounted for here as positive recovered in the MRF-recycling and MRF-segregation technologies. While the ash generation mentioned above is a pure waste product generated as part of waste management, these recovered materials from MRF are economic goods that are there upon circulated within the production system as secondary materials.

e. Cost of Treatment Technologies (T_{12} Matrix)

Costing of waste treatment techniques is a crucial component of the WSUT analysis. Different waste treatment methods have varying capital and operational requirements, which are essential to consider in the assessment. The cost estimates in the study have been derived from extensive stakeholder consultations and secondary literature.

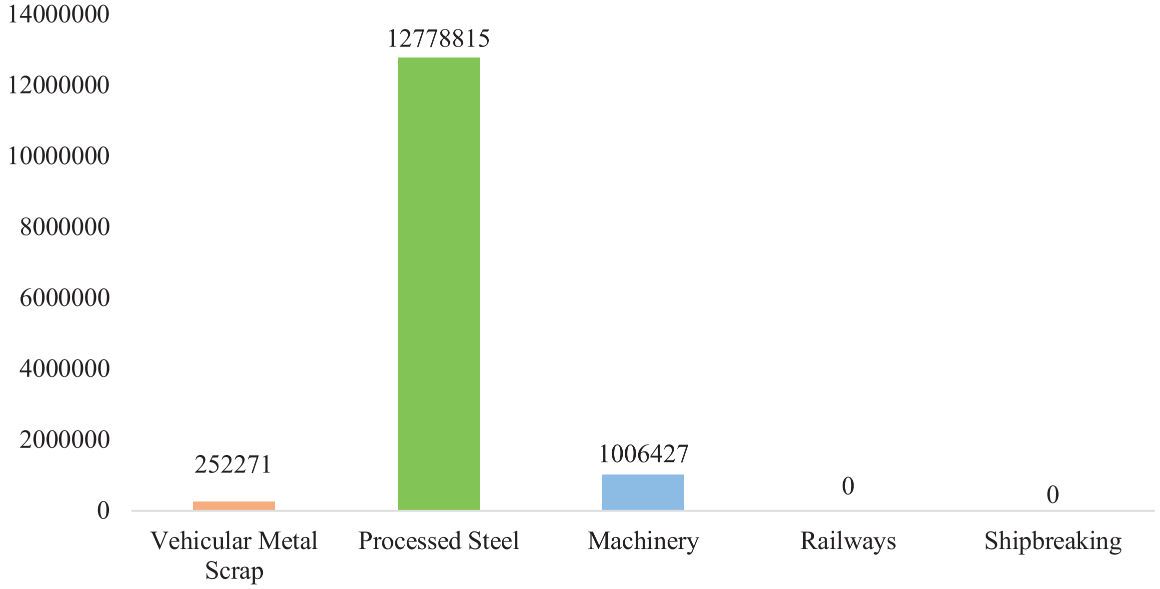
Looking specifically at technologies relevant for the scrap steel sector, MRF has been divided into two sub-categories: one facility specialized in segregation and another facility that also involves dismantling and remelting. The segregation-only facility has significantly lower capital and operational costs compared to the latter, that requires extensive chemical treatments and power utilisation. As such, these additional costs must be factored into the analysis. Segregation facilities are less power-intensive compared to full recycling units. The costing exercise has accounted for these distinctions to make the analysis more comprehensive.

f. Recovery Matrix (Product to Uses matrix)

The total quantum of recovered materials depends on the quantity of waste generated, the material embedded, and the losses incurred during processing, refining, and production. Once the total quantum has been determined, it was allocated to various end-uses or products based on the purity and quality of the recovered material. Based on data derived from ASI on iron and steel waste material usage, it was observed that approximately 90 percent of the recovered secondary material has been redirected to the basic metals sector, while a limited portion has been used in the production of new machinery and vehicles.

Nevertheless, the scrap steel recovered from these categories is further used to manufacture components or parts for the same categories. Sectors such as railways and shipbreaking are not significantly involved in using recycled steel, whereas several grades of scrap steel are used to manufacture parts for the automotive industry, defence equipment, heavy machinery, material processing machines, etc. Figure 6 depicts the usage of scrap steel recovered in different sectors.

Figure 6: Usage of scrap steel recovered (MTA) in different sectors



Source: Authors' Construction

Sampada 4.0 WSUT Model – Alternative Scenario.

There could be a number of ways in which the alternative scenarios could be potentially designed. They could be based on: quality of recovered material, refining/remelting technology that improves recovery efficiency, material embedded in scrap and so on. However, the alternative scenario developed in this study is based in improved recovery efficiency. Improvements in recovery yields have been differentiated into collection efficiency (or processing), recovery efficiency, refining efficiency, and production efficiency. The ***Sampada 4.0*** alternative scenario has introduced technological changes, such as increased recovery efficiency and associated cost increases, to analyse changes in refined material allocated to final products. In this analysis, open-loop recycling is considered. The open-loop recycling is more common for metal scrap recovered from end-of-life (EoL) products, as the mixing of different metal types often results in scrap quality that does not match the original material and the end-uses also get modified accordingly.

To summarize, the amount of final products that can be obtained from secondary materials recovered from EoL products depends on the efficiency of the entire recycling process. Scrap recovered from these is processed into refined materials, which are then used to manufacture final products, as shown in Figure 7. However, this process is subject to various losses that occur during the collection of EoL products, refining of scrap, and manufacturing of final products. The alternative scenario, therefore, tries to minimise possible efficiency losses at all these levels.

Figure 7: Representation of methodology used in the alternative scenario

$$x_k(t) = \underbrace{\boxed{\sum_{m=1}^{n_R} d_{km} \underbrace{\boxed{\theta_m \sum_{s=1}^{n_S} b_{ms} \underbrace{\boxed{\sum_{j=1}^{n} \gamma_{sj} \underbrace{\boxed{\sum_{r=0}^{t} \phi_j(t-r)\, x_j(r)}}_{\text{EoL products}}}}_{\text{Scrap recovered}}}}_{\text{Refined materials}}}}_{\text{Refined materials allocated to final products}}$$

Source: Nakamura et.al, 2014

Results

Baseline Results:

As outlined in Table 1, India's potential scrap steel demand by 2047 is estimated at 119 MT. However, the availability of domestic scrap under the baseline scenario is projected to reach only around **47 MT** in 2047. This translates to roughly 40 percent of the total estimated demand. The significant gap underscores the urgent need to either enhance domestic scrap collection and recycling mechanisms or explore alternative technological strategies as considered in the ***Sampada 4.0*** alternative scenario.

Alternative Scenario Results

In the alternative scenario, recovery improves to ~**49 MT**. This is because recovery efficiencies considered in the baseline scenario are already quite high (0.95), and not too many improvements are technically possible.

In this scenario, the study assumes an improvement in recovery efficiency from 0.95 to 0.99. While this reflects enhanced material recovery, it also results in a change in production costs. This cost increase is mainly because of the adoption of more advanced technologies in scrap recovery—such as increased use of machinery in MRFs rather than manual labor, and improvements in infrastructure and equipment. As a result, the cost of production rises from INR 1,175.38 per tonne in the baseline scenario to INR 1,425 per tonne under the alternative scenario in the base year.

While the analysis paints a dismal picture of future scrap availability, all is not as it seems. It has been observed that the metal waste generation figures reported by CPCB may not fully reflect the ground reality, largely due to data limitations. To elaborate, using CPCB's estimates for MSW treatment, it was found that 20.05 MT of dry waste is treated. Sub-dividing this number further, we get a figure of 14.03 MT of scrap steel-related dry waste in 2021–22. As compared to this, ASI data indicates significantly higher domestic scrap usage—around **31.5 MT (2.25 times)**. This number is likely even higher when accounting for informal producers involved in manufacturing items such as utensils and metal rods.

This gap suggests that actual scrap usage may be much greater than what is officially reported, pointing to the extensive role of informal intermediaries in the scrap supply chain. These actors often remain unaccounted for in formal datasets, highlighting a key limitation in the comprehensiveness of CPCB's data. Therefore, it is possible to hazard a guess that the actual availability of scrap from domestic sources may be much larger than estimated by the present analysis. This issue of informal scrap supply chain actors and their potential, thus, merits further investigation.

Policy Recommendations:

The following policy recommendations have been developed based on the analysis that is aimed at addressing the key challenges in the scrap steel ecosystem and promoting a more sustainable, efficient, and quality-focused steel production framework in India.

Implementation of National Quality Standards for Scrap Steel:

There is a critical need to establish national quality standards for scrap steel to ensure consistent product quality. The chemical and physical composition of scrap steel directly influences the quality of the final steel products. In the absence of standardized guidelines, impurities may persist in the scrap, compromising the mechanical properties and overall usability of the steel. Introducing quality benchmarks will help minimize input variability, enhance recycling efficiency, and ensure that end-use steel products meet required performance standards.

Implementation of Common Platform:

Inconsistent scrap availability and price volatility disrupts the production process and impacts growth of the sector. In this regard, the implementation of common platforms for buyers and sellers of scrap steel may provide a remedy. A nodal agency, such as the Ministry of Steel, Government of India, in coordination with State Governments, can be entrusted with the development and regulation of this common scrap steel platform. Another alternative could be multi-commodity exchanges that are well-versed in platform development and market creation.

Scrap Steel Recycling Zones:

Collection efficiency can be significantly improved through the development of dedicated infrastructure for collection, transportation, and segregation of scrap steel. Establishing specialized scrap steel recycling zones or clusters functioning as regional hubs can help streamline supply and demand across the value chain. As an extension of this approach, setting up vehicular scrappage parks and similar facilities may also be explored to enhance organized scrap recovery and processing.

Improved Data Availability:

Currently, State Pollution Control Boards (SPCBs) have limited data on scrap steel generation and usage, as it is not classified as hazardous waste. Their involvement is primarily focused on regulatory compliance. Moreover, the analysis indicates that middlemen and informal supply chain agents play a significant role in the scrap ecosystem, though they often remain undocumented. Engaging and formalizing these actors could be a crucial step toward enhancing scrap availability and improving overall system efficiency. This can be gleaned from the ***Sampada 4.0*** WSUT model results as well.

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Climate Change, Urbanization and Sustainability (CCUS)

4th Floor, Core 6A, India Habitat Centre, Lodhi Road, New Delhi-110003
The Isher Building, Plot No. 16-17, Pushp Vihar, Institutional Area, Sector 6, New Delhi-110017
E: info@icrier.res.in | W: www.icrier.org | T: +91 11 43112400 | F: +91 11 24620180