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RESOURCE EFFICIENCY IN THE STEEL AND PAPER SECTORS:

Evaluating the Potential for Circular Economy

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Contents

List of Figures

List of Tables

List of Abbreviations

AKD	-	Alkyl Ketene Dimer
BEE	-	Bureau of Energy Efficiency
BF-BOF	-	Blast Furnace-Basic Oxygen Furnace
CAGR	-	Compounded Annual Growth Rate
CBM	-	Carbon-bearing Materials
CCUS	-	Carbon Capture, Utilization and Storage
CII	-	Confederation of Indian Industry
CO_2	-	Carbon dioxide
CT	-	Census Towns
DRI	-	Direct Reduced Iron
EAF	-	Electric Arc Furnace
ECF	-	Elemental Chlorine Free
EOL	-	end-of-life
ETP	-	Effluent Treatment Plant
FTA	-	Free Trade Agreement
GHG	-	Greenhouse Gas
HS	-	Harmonized System
IBM	-	Iron Bearing Material
IF	-	Induction Furnace
IPI	-	Industrial Production Index
IPPU	-	Industrial Processes and Product Use
kcal	-	Kilo calorie
LD	-	Linz Donawitz
MFA	-	Material Flow Analysis
MoEFCC	-	Ministry of Environment, Forest and Climate Change
MT	-	Million ton
$MtCO_2$-eq	-	Million tons carbon dioxide equivalent
mtoe	-	Million ton of oil equivalent
MTPA	-	million ton per annum
NMEEE	-	National Mission for Enhanced Energy Efficiency
PAT	-	Perform, Achieve and Trade
PCI	-	Pulverized Coal Injection
RE	-	Resource Efficiency
RFR	-	Recycled fibre rate
RIR	-	Recycled input rate
SDG	-	Sustainable Development Goals
TCS	-	Ton crude steel
THM	-	Ton hot metal
TOE	-	Oil Equivalent
UNEP	-	United Nations Environment Programme

Executive Summary

Increased global population, urbanization and industrial productivity have led to increased material consumption. The Indian economy grew at a rate of 7.11% (in the period 2003 to 2017): rising populations and urbanization will cause the already high extractive pressure on natural resources to increase and reach unsustainable levels. [1,2,3]

There is need for India to move away from the linear economic model of take-make-dispose, towards a circular economy (CE), a system that is restorative by intention and design. Resource efficiency (RE) and closing of loops (through re-use, re-manufacture, recycle, etc.) form the bedrock of a circular economy.

An established systems-based tool for measuring economy-wide material resource use is Material Flow Analysis (MFA).[4] The current study looks to use this principle for two key sectors of the Indian economy: paper and steel. The steel sector in India contributes to about 4% of GDP while the paper industry provides employment to more than two million people.[5]

Based on micro (entity-level data) and macro parameters (national level production figures) collected by a combination of primary (for micro data) and secondary (for macro data) research, and supplemented by validations through stakeholder consultation, a material flow diagram was developed for both the steel and paper sectors. The MFA quantifies all inputs and outputs from the manufacture of steel and paper across the Indian economy. It helps identify points where material resource-use efficiency can be improved, and CE principles (such as by-product exchange and re-use) can be adopted in longer-term at different parts of the value chain.

In the steel sector, 71% of the iron-bearing material (IBM) required to make crude steel comes from iron ore, suggesting the potential for increasing scrap-use in the value chain. For instance, a 15% increase in overall steel production with increased EAF and IF outputs will increase scrap consumption by 13.4% and lead to savings of 0.8 million tons of iron ore. This reduced extraction of virgin ore will lead to benefits in terms of reduced GHG emissions and improvements in air quality by the avoided processes throughout the life cycle, from extraction to end-of-life. The study recommends a transition towards hydrogen based DRI (H-DRI) technology. A complete transition to it would translate to savings of 17 to 19 MT of coal.

In the pulp and paper industry, the scope for increasing efficiency in mills using recovered paper as the fibre source is significant. The paper industry depends heavily on imported waste paper: estimates from this study suggest that 32% of recovered paper demand are met by importing recovered paper. The study recommends the ensuring of the standardization of quality of imported paper. It is estimated that it could cut the requirement by 0.86 MT (a reduction of 20% from current levels).

The study indicates that application and practice of CE principles has significant potential to reduce virgin material requirement, improve air quality and reduce GHG emissions. There is also evidence that an MFA-based approach to RE (and CE) will allow stakeholders (primarily industry and the government) to take data-driven decisions: for industry, this could be in the form of initiating research and development on certain materials (for instance research on the use of de-inked sludge from recovered paper based mills in cement manufacturing), while, for the government, policy would be better informed (for instance setting-up of industrial parks for steel manufacturing). The approach adopted in the study can be replicated for different sectors at varied scales (unit-level, company-level or sector-level).

1 Growth Rate of GDP. PIB. 2018. Accessed from http://pib.nic.in/newsite/PrintRelease.aspx?relid=186416 on 08 February 2019.

2 Green growth, Resources and Resilience: Environmental Sustainability in Asia and the Pacific, UNESCAP, UNEP and ADB. 2012. Accessed from https://www.zaragoza.es/contenidos/medioambiente/onu/810-eng.pdf on 08 February 2019.

3 Strategy Paper on Resource Efficiency. NITI Aayog. 2017. Accessed from https://niti.gov.in/writereaddata/files/document_publication/Strategy%20Paper%20on%20Resource%20Efficiency.pdf on 10 February 2019.

4 Assessment of resource efficiency indicators and targets: Annexe Report. European Commission. 2012. Accessed from http://ec.europa.eu/environment/enveco/resource_efficiency/pdf/annex_report.pdf on 28 May 2019.

5 An Overview of Steel Sector. Ministry of Steel. 2018. Accessed from https://steel.gov.in/overview-steel-sector on 08 February 2019.

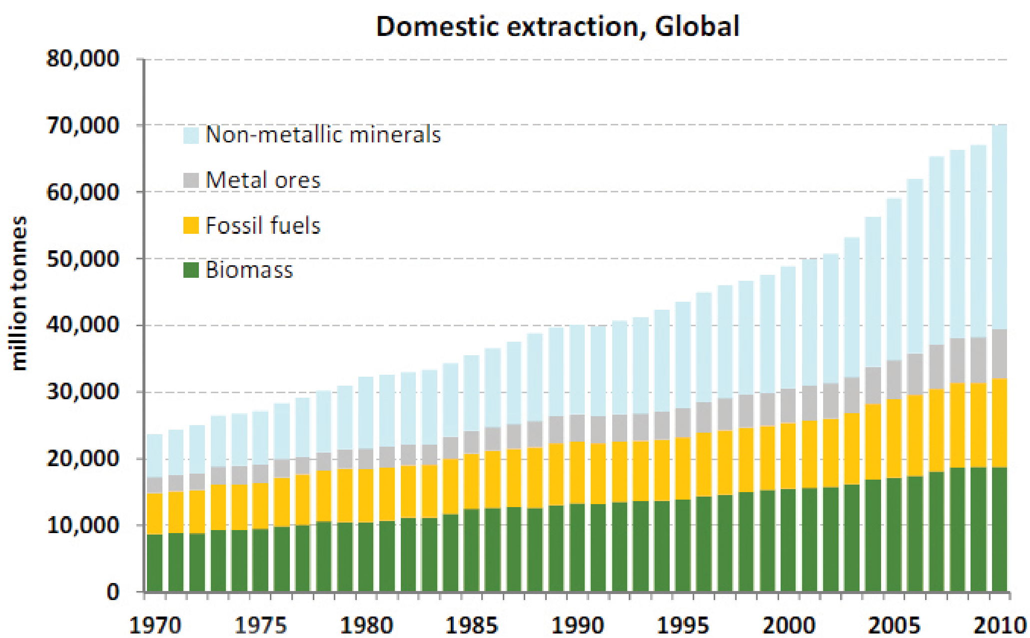
SECTION I:
Introduction

Background

The global population has increased by three times between 1950 and 2017 from 2.5 billion to 7.6 billion.[6] Urban populations have risen from less than a billion in the 1950's to almost 4 billion by the mid-2010s.[7] The value of the global Industrial Production Index (IPI) has doubled in a period of 40 years to over 100 in 2015.[8] All these factors have contributed to significant increases in material consumption.[9]

Material consumption has increased by three times between 1970 and 2010, with a clear increase in the rate after the turn of the century (refer to Figure 1).[10] Growth in construction activities, transportation, communication infrastructure, energy generation capacity, water supply systems, manufacturing infrastructure, etc., rests upon the supply of resources and materials; their availability and supply are associated with risks such as geo-political instability, scarcity due to over extraction and rising prices.

Figure 1: Global material extraction of four material categories between 1970 and 2010[11]



[6] World Population Prospect: key findings and advance tables: 2017 revision. UN. 2017. Accessed from https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf on 22 May 2019.

[7] World Urbanization Prospects [highlights]. UN. 2014 Accessed from https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.pdf on 22 May 2019.

[8] Industrial Production Index, The World Bank. Accessed from https://tcdata360.worldbank.org/indicators/inds.prod.idx?country=BRA&indicator=23&viz=line_chart&years=1919,2017 on 22 May 2019.

[9] Growth in global materials use, GDP and population during the 20th century. Fridolin K., Gingrich S., Eisenmenger N., Erb K.H., Haberl H. and Fischer-Kowalski M. Ecological Economics 68(10), 2696-2705. doi:10.1016/j.ecolecon.2009.05.007. Accessed on 31 May 2019.

[10] Global material flows and resource productivity: forty years of evidence. Schandl et al. Journal of Industrial Ecology, 22 (4), 827-838. 2018.

[11] Global material flows and resource productivity: forty years of evidence. Schandl et al. Journal of Industrial Ecology, 22 (4), 827-838. 2018.

India, like other countries all over the world, faces environmental challenges, as well as challenges on the path to sustainable development. Extractive pressure on natural resources is already high and is clearly unsustainable even as populations continue to grow, industrialize, urbanize and consume.[12,13] In the period 2003 to 2017, India's GDP grew at 7.11%, but the import and the gap between import and export has risen at a much higher CAGR of 13% and 18% respectively. [14,15]

Resource efficiency and circular economy

There is need for India to move away from the linear economic model of take-make-dispose towards a circular economy. In this context, resource efficiency, with respect to the use of four major classes of material resources, fuels, metals, non-metallic minerals and biomass, is of paramount importance.[16]

A circular economy is an industrial system that is restorative by intention and design. Ideally, in a circular economy materials and energy flow in a closed loop within the value chain indefinitely. Resource efficiency and closing of loops form the bedrock of circular economy. In the Indian context, circular economy can cut down greenhouse gas (GHG) emissions by 44 % from current levels, by 2050, and create value to the tune of INR 40 lakh crores by the year 2050, as compared to a business-as-usual scenario.[17]

For over a decade, action has been taken by the Indian government through focused schemes in response to the global imperative to combat climate change: the Perform-Achieve-Trade Scheme of the Bureau of Energy Efficiency, evolved as a tool to promote opportunities for aggressive energy conservation by reducing emissions in energy-intensive industries (some of these were the cement industry, pulp and paper, iron and steel, chlor-alkali, thermal power generators, aluminum, textiles, fertilizers): the savings achieved in this scheme (Phase I) were 8.67 million tons of oil equivalent.

BOX 1: In the cement production case, the resource-use lens can lead to circular models beyond thermal efficiency, focusing on input reduction and reuse. The use of waste materials in cement production can reduce emissions, waste and air pollution impacts. Great potential also lies in recycling, component reuse, maintenance and management of resource efficient consumption, for example through smart infrastructure build-up in cities. Circular models are most beneficial when thought across the value chain and in new business models that delink revenue from material consumption.

Global Resources Outlook, 2019

However, similar attention has not been focused on material resources and the efficiency of their use in Indian industry even though the benefits of improvements to resource efficiency in terms of material conservation, GHG emissions and air quality are well established.[18] In the context of carbon dioxide emissions, the importance of resource efficiency is illustrated well in the cement sector where GHG emissions have been addressed for decades with thermal efficiency approaches (see Boxes 1 and 2). Thermal efficiency has now reached a limit; improvements to it are not able to tackle other impacts such as ecotoxicity and air pollution sufficiently.

[12] Strategy Paper on Resource Efficiency. NITI Aayog. 2017. Accessed from https://niti.gov.in/writereaddata/files/document_publication/Strategy%20Paper%20on%20Resource%20Efficiency.pdf on 10 February 2019.

[13] Green growth, Resources and Resilience: Environmental Sustainability in Asia and the Pacific, UNESCAP, UNEP and ADB. 2012. Accessed from https://www.zaragoza.es/contenidos/medioambiente/onu/810-eng.pdf on 08 February 2019.

[14] Growth Rate of GDP. PIB. 2018. Accessed from http://pib.nic.in/newsite/PrintRelease.aspx?relid=186416 on 08 February 2019.

[15] CII analysis based on import and export data obtained from website of Department of Commerce, Ministry of Commerce and Industry, Government of India at http://commerce-app.gov.in/eidb/default.asp

[16] Economic Survey 2017-18. Ministry of Finance. 2018. Accessed from http://mofapp.nic.in:8080/economicsurvey/pdf/001-031_Chapter_01_ENGLISH_Vol_01_2017-18.pdf on 06 February 2019.

[17] Circular Economy in India: Rethinking Growth for Long-term Prosperity. Ellen Macarthur Foundation. 2016. Accessed from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Circular-economy-in-India_5-Dec_2016.pdf on 10 February 2019.

[18] The Circular Economy – a powerful force for climate mitigation. SITRA, European Climate Foundation, Climate-KIC, Energy Transitions Commission, Ellen Macarthur Foundation, MAVA and Climate Works Foundation. 2018. Accessed from https://media.sitra.fi/2018/06/12132041/the-circular-economy-a-powerful-force-for-climate-mitigation.pdf on 20 May 2019.

> **BOX 2:** The IRP study Re-defining Value: The Manufacturing Revolution shows that manufacturers of industrial printers, vehicle parts and heavy-duty and off-road equipment in the United States of America save 18 to 44 per cent in costs per unit through remanufacturing and comprehensive refurbishment strategies compared to the same product made from new materials. The same measures reduce production waste and GHG emissions by up to 90 per cent (IRP 2018a).
>
> Global Resource Outlook, 2019

Recognizing the need for securing material resources, and in pursuance of environmental policies aimed at preventive and integrated management of pollution – increasingly being adopted over the world – the Indian government is pressing ahead with framing a national policy for resource efficiency. In that context, the Ministry of Environment Forest and Climate Change (MoEFCC) has expressed the need for studies on resource efficiency in different sectors of the economy, which could inform policy-making.

Resource efficiency is also a key element in terms of the Sustainable Development Goals: it is directly reflected in SDG 12: Ensure Responsible Consumption and Production Patterns. Eight other goals (2, 6, 7, 8, 9, 11, 14 and 15) also relate to resource efficiency and circular economy. In today's world with an uncertain geopolitical environment, decoupling growth from resource consumption through strategies of resource efficiency, circularity and sustainable resource management is critical.

The RE Cell of the Ministry of Environment, in mid-2018 had expressed the intention of framing a policy on resource efficiency, supported by first-hand data. Resource consumption for two high-impact sectors, paper and steel, were suggested for an initial study.

Importance of sectors

The steel sector in India contributes about 2% to the GDP, with an annual production of finished steel at 127 million tons in 2017-18.[19] India is also the second largest producer of crude steel in the world with an installed capacity of 138 million tons in 2017-18. India has large deposits of the raw materials used by the industry, but the availability of high-grade iron ore (due to over extraction) and good quality coal (deposits in India have high silica content as compared to imports from Australia and Indonesia) is a growing challenge. The National Steel Policy (2017) envisages growth of crude steel production capacity to 300 million tons per annum by the year 2030.[20] The Policy also sets a goal to increase per capita steel consumption of the country from 61 kg to 160 kg by 2030-31. Another ambitious target is to meet the entire demand for high grade automotive steel, electrical steel, other special steels and alloys for strategic use, domestically.

The pulp and paper industry have a significant impact on socio-economic development. India accounts for about 4.3% of the world's paper production, and provides employment to more than two million people, directly and indirectly. The total installed capacity is 25.55 million tons per annum (MTPA).[21] From 2010 to 2018, exports of paper grew from 0.53 million tons to about 1 million tons: imports rose from 1.78 million tons to 3.17 million tons in the same interval.[22] In the face of recent Free Trade Agreements (FTAs) and paucity of raw materials, especially wood fibre, imports are likely to increase for products made from virgin fibre.

[19] An Overview of Steel Sector. Ministry of Steel. 2018. Accessed from https://steel.gov.in/overview-steel-sector on 08 February 2019.

[20] National Steel Policy 2017. Accessed from https://steel.gov.in/sites/default/files/draft-national-steel-policy-2017.pdf on 08 February 2019.

[21] CPPRI Annual Report 2017-18. CPPRI. 2018 Accessed from http://www.cppri.org.in/sites/default/files/annual%20report%2017%20-%2018.pdf on 10 March 2019.

[22] IPMA Statistics. Accessed from http://ipma.co.in/statistics/ on 11 March 2019.

SECTION II:
Methodology

System Boundary: processes related to manufacturing of paper and steel within factory gates. An illustration of the inclusions and exclusions of the boundary is provided by Figure 2. Further, the sub-categories covered under each sector are:

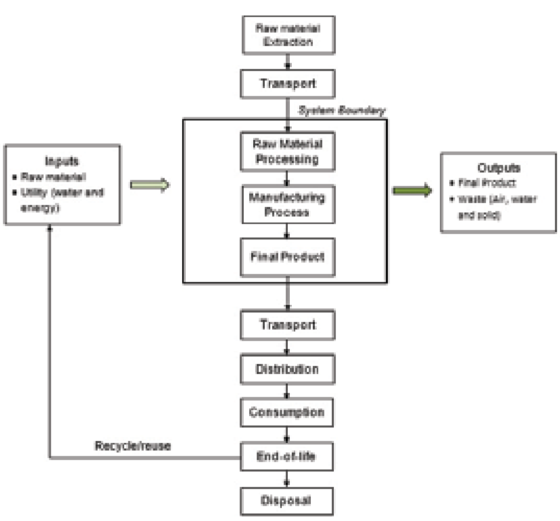
- Pulp and paper industry: manufacture of paper in three categories: newsprint, board, and, writing/printing. The sector is referred to as the 'paper' sector in the report.
- Iron and steel industry: manufacture of iron (for steel manufacturing) and crude steel through BOF, EAF and IF. Iron manufacture in the report covers that which is used in steel manufacturing. The sector is referred to as the 'steel' sector in the report.

Scope of coverage: Within the system boundary, resources (in terms of energy, water and materials) have been accounted for in the following approach:

- energy and water use through a footprint approach
- material use mapped through a process-wide MFA

Data: A combination of primary and secondary data collection methods was used in the study:

Figure 2: Simplified illustration of the system



- Primary data (on material flows at entity level) were collected first hand via interactions with experts and plant personnel in visits to manufacturing units. Data to be collected were decided based on review of existing literature on manufacture of paper and steel and studies based on material flow analysis.
- Secondary data on national level production were obtained from line ministries (such as the Ministry of Steel and the paper desk at Department for Promotion of Industry and Internal Trade) and published data sets (such as those obtained from publications of the Joint Plant Committee and the Central Pulp and Paper Research Institute)

Survey Sample: An analysis of installed capacity data for the two sectors at national level was used to decide the sample size such that the units identified would

- cover the
  - ◊ three prevailing process routes in the steel sector (IF, EAF, BOF)
  - ◊ three raw material streams used to make fibre in the paper sector (agricultural residue, recovered paper and wood)
- cover any variations within manufacturing processes
- provide a representative sample for the ranges of resource consumption across the economy.

Data Validation: At each stage, validations were carried out which are described here:

- While setting the scope and boundary: through interactions with industry association representatives.
- While sampling: through semi-structured interviews with industry association representatives and sector experts
- After data collection: through separate consultations with paper and steel sector stakeholders (association representatives, sector experts and industry personnel).

Assumptions for material flow

Material flow for both paper and steel were developed. The assumptions for the material flow are elaborated in the following sub-section, separately for the steel and paper sector.

Steel sector

Macro level production data of steel was obtained from JPC. The allocation of the production through the three process routes (BOF, EAF and IF) for the year 2017-18 was obtained from Ministry of Steel Annual Reports. Data on internal flows, for instance quantity of raw material input, waste material generated, etc. were based on industry visits and stakeholder consultations.

Crude steel is defined as the intermediate product in the steel manufacturing process (before fabrication to end-products and other value-addition). In the study, crude steel refers to the liquid steel produced in steel converters (before refining, rolling-casting, etc.) Crude, plain carbon steel or unalloyed steel was chosen for the study: a) to bypass the complexity of accounting for thousands of varieties of alloys and, b) because plain carbon steel accounts for 90% of all steel production.[23] The generation of crude steel by BF-BOF, EAF and IF in the year 2017-18 was 44.3 (43%), 30.9 (30%) and 27.8 (27%) MT. This data is used to estimate resource consumption in the three process routes.

The BOF has three inputs: Scrap, hot metal (through BF or COREX process) and flux (limestone and dolomite). The study indicates that total amount of hot metal from the COREX process is 1.6 MTPA. 1,100 kg of iron bearing materials is needed to produce 1 ton of crude steel through BOF. Iron bearing material received through scrap and COREX process is conclusively estimated based on entity level information. It is assumed that the balance of the hot metal requirement is received from BF process route for iron-making. Flux consumption (limestone and dolomite) is estimated based on entity level consumption data.

Data for iron-making through BF and COREX process is presented in Table 2 and Table 3 respectively. Flux can be added in the BF process, or during sintering and pelletization process before the BF iron-making step. For the simplicity of accounting it has been assumed that all fluxes are added directly in BFs. BFs require about 1,700 kg of IBM feed per ton of hot metal.

Table 1: Assumptions for estimation of resource consumption in basic oxygen furnace

Category	Raw material	Unit	Lower bound	Upper bound	Value considered	Justification
IBM	Scrap steel	Percentage	6.4	13	9.7	Average
	Hot metal: COREX	MTPA			1.6	Industry data
Flux	Limestone	kg/TCS	84	96	39	Industry data
	Dolomite	kg/TCS	30	48	40	Industry data
Slag	Slag	kg/TCS			160	Industry data

Table 2: Assumptions for estimation of resource consumption in blast furnace

Category	Material	Unit	Lower bound	Upper bound	Value considered	Justification
Blast furnace (BF) feed	Pellets	Percentage of IBM	20	39	29.5	Average
	Sinters	Percentage of IBM	47	65	56	Average
	Lump ore	Percentage of IBM	14	15	14.5	Average
Carbon Bearing Material	Coke	kg/ton hot metal	252	350	301	Average
	Coal	kg/ton hot metal	162	180	171	Average
Flux	Limestone	kg/ton hot metal	120	165	142.5	Average
	Dolomite	kg/ton hot metal	50	75	62.5	Average
Slag (output)	Slag generation	kg/ton hot metal	310	400	355	Average

[23] Glossary of Terms. Ministry of Steel. Accessed from https://steel.gov.in/glossary-terms-definitions-commonly-used-iron-steel-industry on 30 April 2019.

Pellets and sinters form inputs into the BF and COREX process. The assumptions for these two processes are presented in Table 4 and Table 5.

The shares of production through EAFs and IFs are 30% and 27% respectively. IFs operate on graded scrap. Some IF units have the facility for oxygen blowing and addition of fluxes to refine molten DRI/ pig iron, but the numbers of such IFs are negligible. Therefore, it is assumed that IF input consists of 100% scrap.

The input into EAF units are iron bearing material (DRI, pig iron and scrap), flux (limestone and dolomite) and graphite (electrodes). The data on limestone, dolomite and graphite are presented in Table 6.

It is estimated that 1.27 ton of IBM is required for one ton of crude steel in EAF. However, the data on input of iron bearing material (DRI, pig iron and scrap) vary drastically across the country. A comprehensive figure is not available in the public domain as the ratio of scrap and DRI/pig iron depends heavily on the economies of scale; competitiveness of individual mills, price and availability of these resources. Given the sensitivity of such data, assumptions have been incorporated to refine these ranges. Field visits indicated that the ratio of scrap is higher in regions with a shortage of DRI and pig iron supply in the vicinity. For instance, data from north India suggested scrap input of 50 to 80%. Further, data from south India (where 64% of installed capacity is BOF) indicated a lower scrap charge (6%).

Table 3: Assumptions for estimation of resource consumption in COREX process (in kg/ton hot metal)

Category	Material	Lower bound	Upper bound	Value considered	Justification
Iron bearing material	Iron ore (Pellets)	1,550	1,600	1,575	Industry data
Carbon bearing material	Coal	795	828	811.5	Industry data
	Coke	180	210	195	Industry data
Flux	Limestone	150	180	165	Industry data
	Dolomite	100	140	120	Industry data

Table 4: Assumptions for estimation of resource consumption in sintering (in kg/ton sinter)

Material	Lower bound	Upper bound	Value considered	Justification
IBM (fines)	1,000	1,010	1,005	Average
Coal and coke mix	48	70	64	Average

Table 5: Assumptions for estimation of resource consumption in pelletization (in kg/ton pellet)

Material	Lower bound	Upper bound	Value considered	Justification
IBM (fines)	1,060	1,093	1,076.5	Average
Binder	5.5	7	6.9	Average

Table 6: Assumptions for flux and electrode consumption in Electric Arc Furnaces (in kg/ton crude steel)

Material	Lower bound	Upper bound	Value considered	Justification
Limestone	41	90	65.5	Average
Dolomite	7	43	25	Average
Graphite	1.12	31.2	1.12 to 3.2	Average

Installed capacity data from JPC was analysed. It was noticed that north and west India had no BOF facilities. Thus, it was assumed that mills in these regions dependent heavily on scrap input. For the other regions, a weighted average of the share of EAF capacity to overall steel production installed capacity in the region was used to estimate share of scrap input. The assumptions for scrap input are presented in Table 7.

The remaining charge into EAFs was allocated between DRI and pig iron. Due to the unavailability of the distribution between the two, it was assumed that the share would be of the order of the production of DRI and pig iron. DRI and pig iron production in 2017-18 was 30.51 and 5.73 MT respectively.[25] Thus, the balance charge in each region of the country was allocated as: DRI 84% and pig iron 16%. This has been presented in Table 8.

It was observed that the quantum of slag generation from EAFs was dependent on the charge of IBMs. EAFs using higher amount of DRI and pig iron generate more slag, as they have higher impurities than those relying on higher share of scrap. Data on slag generated in EAF units with higher scrap charge was applied to north and west India. Slag from a unit with higher DRI/pig iron charge in south India was available. This data was refined for east and central India based on the DRI/pig iron charge. These assumptions have been presented in Table 9.

Table 7: Assumptions for scrap input into electric arc furnaces (in percentage of IBM)[24]

Region	Lower bound	Upper bound	Value considered	Justification
North	50	80	65	Average
South	-		6	Industry data
East	-		19	Weighted average
West	50	80	65	Average
Central	-		31	Weighted average

Table 8: Assumptions for DRI and pig iron input in electric arc furnace (in percentage of IBM)[26]

Region	Balance	DRI	Pig Iron
North	35	29.5	5.5
South	94	79.1	14.7
East	81	68.1	12.8
West	35	29.4	5.5
Central	69	58.3	11

Table 9: Assumptions for slag generation from EAFs (in kg/ton crude steel)

Region	Lower bound	Upper bound	Value considered	Justification
North	95	140	117.5	Average
South			320	Industry data
East			276	Weighted Average
West	95	140	117.5	Average
Central			236	Weighted Average

[24] North east is not represented since there are no Electric Arc Furnaces in the region

[25] An overview of the steel sector, Ministry of Steel

[26] North east is not represented since there are no Electric Arc Furnaces in the region

Paper sector

Macro level production based on raw material (wood, agro and recovered paper) and final product (writing and printing, packaging and newsprint) was obtained from CPPRI data.[27] These data were further refined to understand internal flows, for instance quantity of waste material in recovered paper, raw material yield, etc. based on industry visits and stakeholder consultations.

A large amount of recovered paper and pulp is imported in the country. Import data for recovered paper and pulp was obtained from the web portal of Ministry of Commerce. Different HS codes considered for the study have been listed in Annex I. Imported pulp was further categorized as recovered paper pulp, wood mechanical pulp, unbleached pulp and bleached pulp. The HS code allocations are:

- HS Code 47062000 allocated to recovered paper pulp
- HS Code 47010000 allocated to wood mechanical pulp
- HS Code 47031100, 47031900, 47041100, 47041900, 47061000, 47063000, 47069100, 47069200, 47069300 allocated to unbleached pulp
- HS Code 77032100, 47032900, 47042100 and 47042900 allocated to bleached pulp

Imported bleached pulp further allocated between agro and wood on relative share of wood pulp and bleached agro pulp. Imported unbleached pulp allocated equally between agro and wood pulp. Table 10 and Table 11 represent the assumptions mentioned above.

Bleaching is undertaken on pulp through two pathways – Elemental Chlorine Free (ECF) and non ECF (chlorine-based bleaching). The assumptions for bleaching are:

- Writing and printing and newsprint are considered as bleached, irrespective of raw material source.
- Packaging from wood considered as bleached, remaining considered as unbleached.
- Within wood 100% of production considered under ECF bleaching
- 100% of production of bleached pulp from recovered paper considered as non ECF (chlorine based) bleaching

Table 12 presents the allocation of overall paper production to bleached and semi bleached.

Table 10: Allocation of imported pulp

Type	Share of total import (in %)	Quantity (in MT)
Total imported pulp	1	0.552
Wood mechanical pulp	0.004	0.002
Recovered paper pulp	0.001	0.000
Unbleached	0.1	0.034
Bleached	0.9	0.515

Table 11: Allocation of imported bleached and unbleached pulp

Type	Share of total import (in %)	Quantity (in MT)
Wood Chemical Bleached	0.88	0.45
Agro Bleached	0.12	0.06
Wood Chemical Unbleached	0.5	0.0
Agro Unbleached	0.5	0.0

Table 12: Allocation of bleached and unbleached in terms of share of overall production (in %)

Type of raw material	Bleached	Semi-bleached	Unbleached
Wood	23	0.001	0
Agriculture residue	4	0	7
Recycled fibre	13	10	42

[27] Compendium of Census Survey of Indian Paper Industry. CPPRI. 2015

There are two types of major bleaching pathways – ECF and chlorine based. The allocation of bleached pulp to these pathways are presented in Table 13.

Raw material yield is used to estimate the quantity of fibre generated from unit raw material input. Total amount of fibre requirement is estimated as

$$T_{fibre} = T_{production} - FM_i - F_{import}$$

T_{fibre} – Total fibre requirement

$T_{production}$ – Total paper production

FM_i – Filler material requirement

Fimport – Fibre Import, in the form of pulp or recovered paper

The study collected ranges of yield for the three raw material streams. These have been presented in Table 14. The allocation of production capacities within the yield ranges have been undertaken based on industry consultation.

The amount of filler and other materials added in the paper-making process, by the three final product types have been presented in Table 15.

Table 13: Allocation of bleached pulp with respect to bleaching pathways (in %)

Type of raw material	ECF	Chlorine
Wood	100	0
Agriculture residue	20	80
Recycled fibre	0	100

Table 14: Raw material yield in paper sector (in %)

Raw Material	Lower bound	Upper bound	Value considered	Share in respective raw material production	Justification
Wood - Mechanical	90	95	92.5	100%	Median value
Wood - Chemical	38	49			
Average	40	42	41	80%	Median value
Lower			38	9%	Balance amount
Upper			49	11%	Industry data
Agro	35	50	42.5	100%	Median value
Recovered Paper	60	90			
Average	70	75	72.5	80%	Median value
Lower			60	10%	Industry consultation
Upper			90	10%	Industry consultation

Table 15: Amount of filler and other substances in final product (in %)

Final Product	Share in final product	Source
Board	10	Literature
Newsprint	2	Industry
Writing and Printing	21	Industry

Additionally, various waste material streams have been quantified.

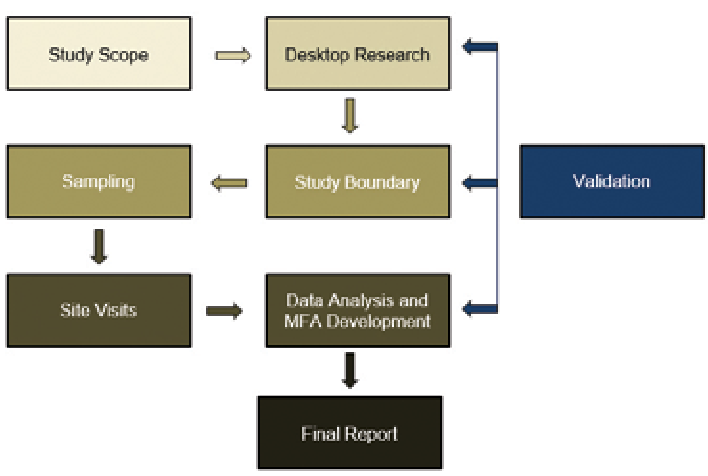
Table 16: Ranges for waste streams generated from paper manufacturing

Wood					
Material	**Unit**	**Lower bound**	**Upper bound**	**Value considered**	**Justification**
Wood Chip	Percentage			5	
Recirculated Fibre (knots and shives)	kg/ton pulp	4	46	25	Average
Fibre collected at ETP	kg/ton pulp	10	25	17.5	Average
Agro					
Material	**Unit**	**Lower bound**	**Upper bound**	**Value considered**	**Justification**
Pith	Percentage	25	30	27.5	Average
Recirculated Fibre (knots and shives)	kg/ton pulp	6	22	14	Average
Fibre collected at ETP	kg/ton pulp	18	25	21.5	Average
Sugar	Percentage			2	Industry value
Other waste	Percentage			1	Industry value
Recovered Paper					
Material	**Unit**	**Lower bound**	**Upper bound**	**Value considered**	**Justification**
High Density Material	kg/ton of raw material	2.86	5.71	4.29	Average
Plastic	kg/ton of raw material	1.61	30	15.8	Average
Sludge	kg/ton of raw material			158	Industry value

Process flow

The process flow for the methodology is represented in the figure below (Figure 3).

Figure 3: Broad schematic of process flow

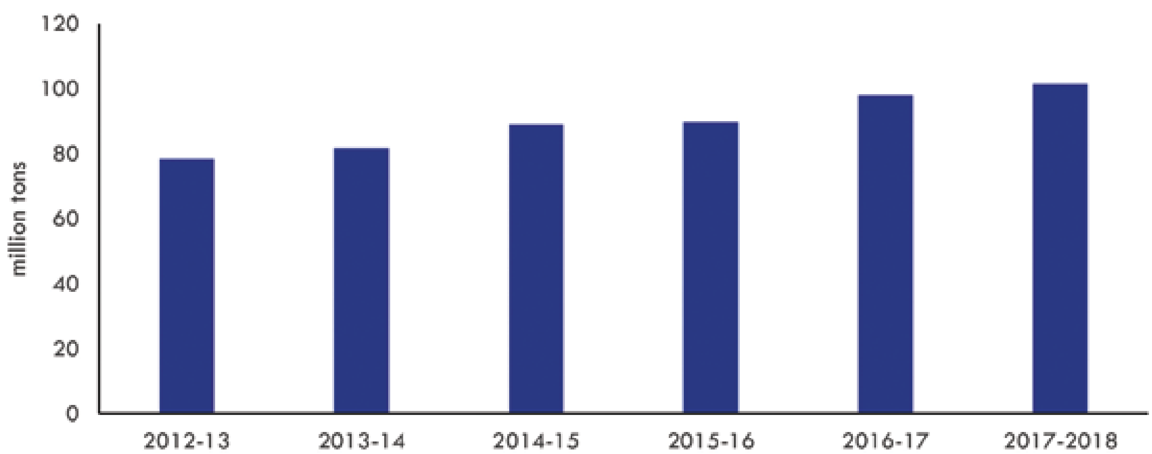


SECTION III:
Steel

Industry characteristics

India is the world's second largest producer of crude steel and the sector contributes about 2% to the country's GDP. The sector comprises facilities that produce steel by all major routes: blast furnace-basic oxygen furnace (BF-BOF), electric arc furnace (EAF) and induction furnace (IF) and rolling/re-rolling units, foundries, forges, casting and fabricating plants that use intermediate steel (crude steel) to make finished products, the mining industry and the scrap processing industry. Currently, India's installed capacity of crude steel is 138 MT and is set to increase to 300 MT.[28, 29] Steel production has grown steadily at a CAGR of 5.6% from 78.4 MT to 103.1 MT between 2012-13 and 2017-18.[30, 31]

Figure 4: Total steel production in India between 2012-13 and 2017-18



The current classification followed by the Ministry of Steel is based on the production route of steel: BF-BOF, EAF, and IF.[32] BF-BOF route units manufacture hot metal from iron ore in blast furnaces and convert it to steel in Basic Oxygen Furnaces. Steel mills using the EAF route use a combination of scrap steel, Direct Reduced Iron (DRI) and pig iron as raw materials. Mills with induction furnaces use only graded scrap steel. The installed capacity and production by the three routes in 2017-18 have been presented in Table 17. As of 2017-18, the number of mills using the BOF, EAF and IF route/process were approximately 18, 50 and 1,000, respectively.

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[28] Joint Plant Committee (2017-18)

[29] National Steel Policy 2017. Accessed from https://steel.gov.in/sites/default/files/draft-national-steel-policy-2017.pdf on 08 February 2019.

[30] Ministry of Steel Annual Report 2017-18

[31] Joint Plant Committee

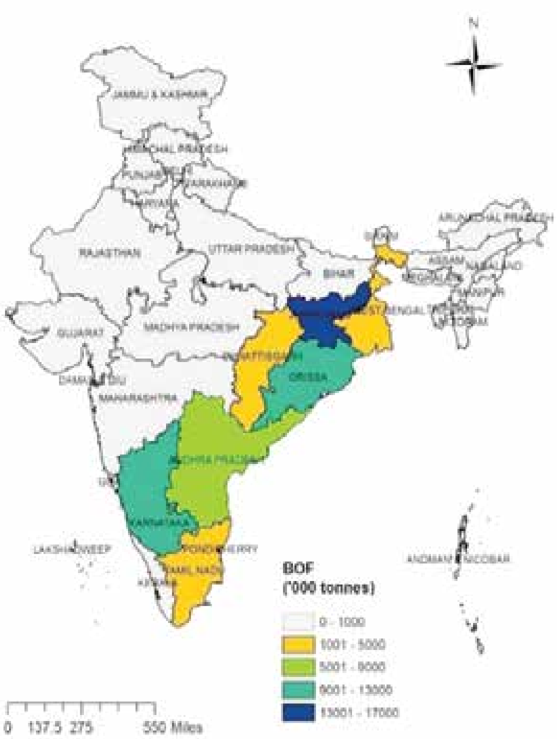
[32] Ministry of Steel. Notification dated 12th May 2016. Available at: http://steel.gov.in/guidelines-classification-steel-plantsproducers-dated-12052016. Accessed on 14 May 2019.

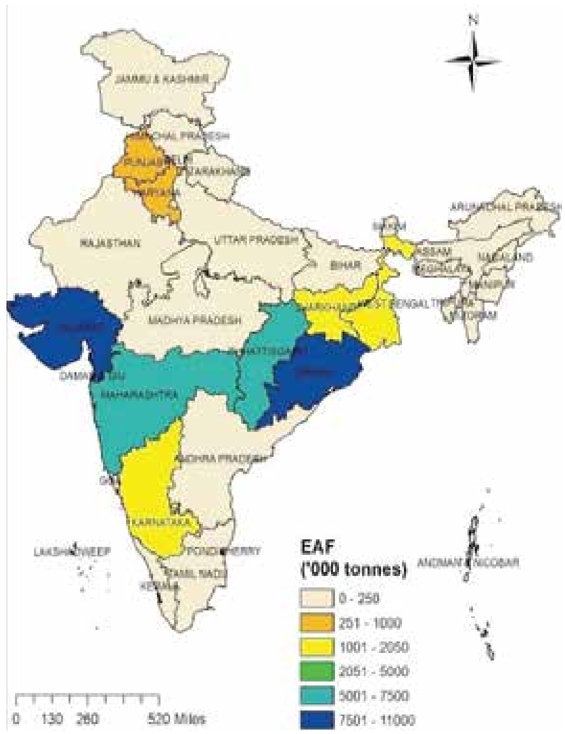
Table 17: Installed capacity and production of steel in India for 2017-18 (in million tons)

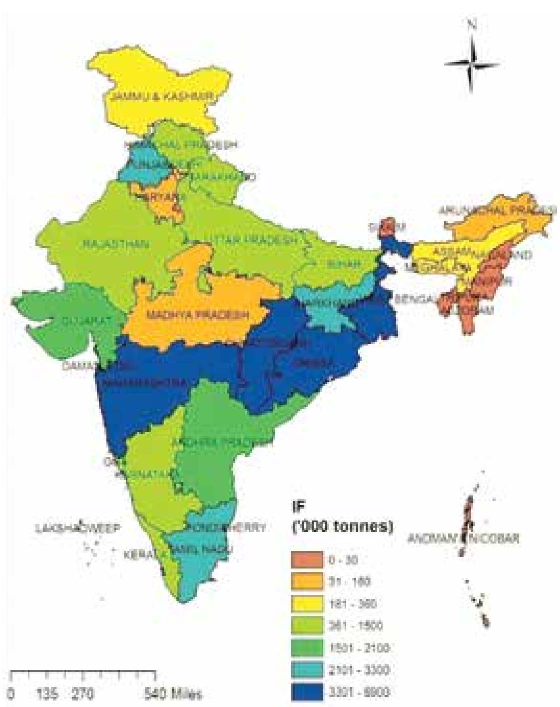
Process route	Installed capacity	Production
BOF	55	44
EAF	40	31
IF	43	28
Total	138	103

Mills following the BF-BOF route/process need a steady supply of virgin iron ore and are hence located in eight states in the east and south of the country. These mills source iron ore from the belt of mines starting from the Chota nagpur plateau region (Jharkhand, Odisha and some parts of West Bengal) to the Bellary-Hospet belt in the South. Mills using the EAF route/process are spread across the country, with significant presence in the states of Gujarat, Maharashtra, Chhattisgarh and Odisha. Punjab and Haryana also have significant production capacity; and cater to the automobile clusters situated in the region. Many units also produce TMT bars, and mild steel. Mills using induction furnaces are located all over the country because of their ease of installation and flexibility in terms of capacity. Figure 5 provides a representation of the spread of all three process routes.

Figure 5: Distribution of installed capacity of steel production by process route







The ferrous raw materials used to make steel can be categorized into virgin sources (iron ore) and recycled sources (iron and steel scrap). Ore used in Indian steel mills is largely of domestic origin. Iron ores are minerals that contain a minimum percentage of elemental iron (Fe) which can be extracted in an economically viable manner. Chemically, iron ores exist as oxides, carbonates, sulphates and silicates. Out of these the most abundant forms of iron ore are two forms of oxides: haematite (Fe_2O_3) and magnetite (Fe_3O_4). India has a total of 33.276 billion tons of magnetite and haematite resources.[33]

Table 18: States with highest reserves of iron ore in India

Ore type	States with reserve
Haematite	Odisha, Jharkhand, Chhattisgarh, Karnataka and Goa
Magnetite	Karnataka, Andhra Pradesh, Kerala, Tamil Nadu and Goa

In 2016-17, total iron ore production in India was about 192 million tons. 36% of this amount was produced by public sectors mines, while the rest was produced by those in the private sector. About 30% of the total production came from captive mines.

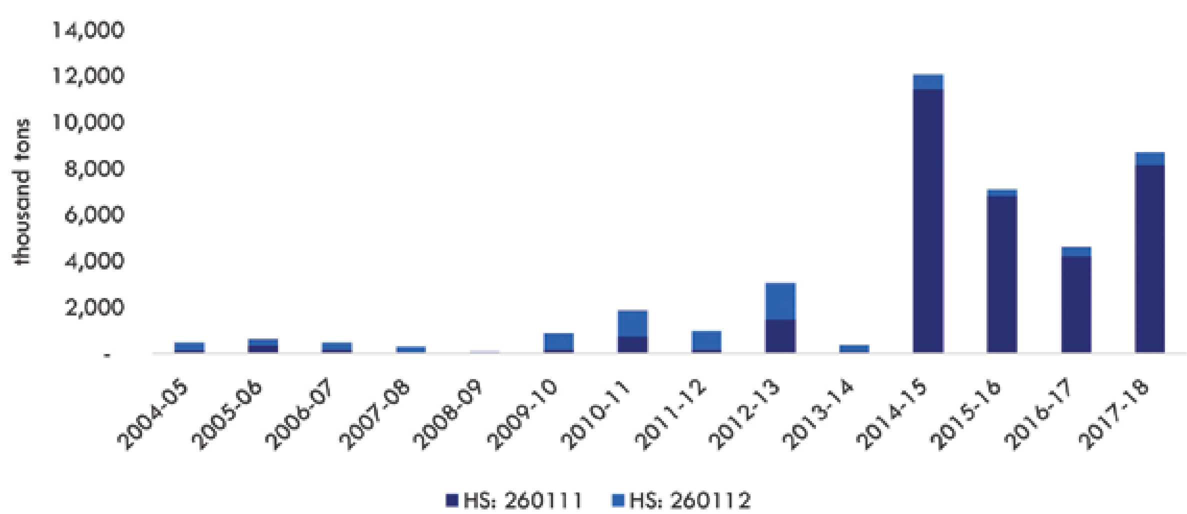
In the past decade, production of iron ore has varied significantly. In the period between 2007 to 2011, production was 210 million tons on an average. Whereas the average production came down below 150 million tons between 2012-13 and 2014-15. In 2016-17, production again picked up to 192 million tons.[5]

Table 19: Iron ore production from public, private and captive mines in 2016-17 (in million tons)

Type of Mine	Production
Public sector	69
Private sector	123

Between 2008 and 2017, imports of iron ore and concentrates too have varied greatly. Imported iron ore (average 4.5 million tons per year) was only a small fraction of the domestic production. Between 2004-05 and 2017-18, import of iron ore grew at a CAGR of 25% from 0.5 million tons to 8.7 million tons. A sharp rise to 12 million tons was observed in 2014-15. This sharp rise can be explained by the slump in domestic ore production due to the ban on mining in Goa over the same period.

Figure 6: Iron ore imports from 2004-05 to 2017-18[34]

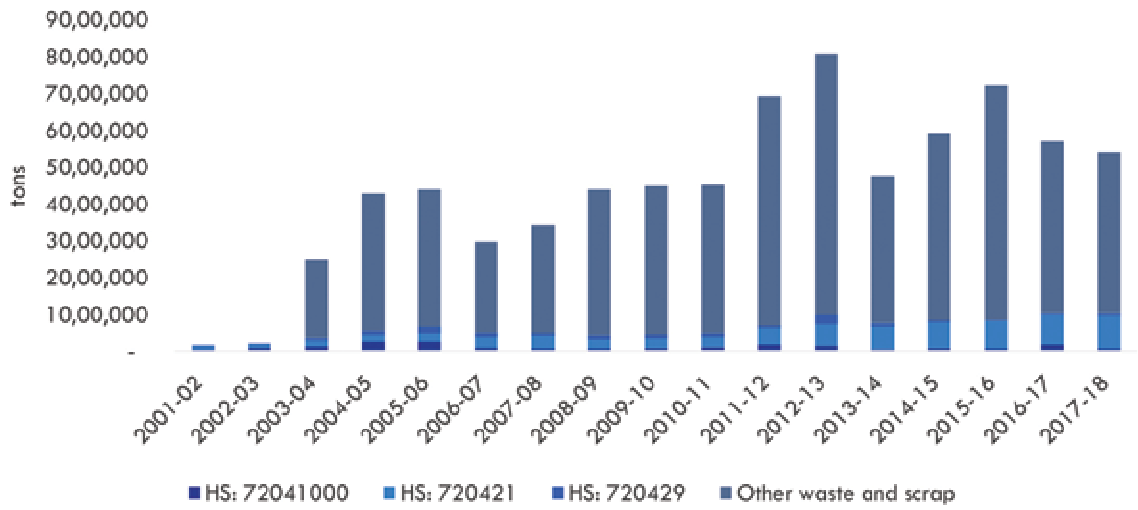


Legend of the graph represents HS codes for various kinds of iron ore imported.
These have been presented in Annex I

[33] Indian Minerals Yearbook 2017. Indian Bureau of Mines. 2018. Accessed from https://ibm.gov.in/index.php?c=pages&m=index&id=1009 on 20 April 2019.

[34] CII analysis based on import data obtained from website of Department of Commerce, Ministry of Commerce and Industry, Government of India at http://commerce-app.gov.in/eidb/default.asp

Figure 7: Scrap (iron and steel) imports from 2001-02 to 2017-18[35]



Legend of the graph represents HS codes for various kinds of scrap imported.
These have been presented in Annex I

Iron and steel scrap constitute a large chunk of iron bearing materials used for steelmaking. It is used as the primary raw material in IFs and EAFs. Scrap is generated by industries including ship-breaking units, automobiles, railways and engineering workshops. Currently, there is no robust system of scrap collection and sorting in India, forcing producers to import scrap to meet their requirements. The study estimates that 11% of scrap demand is met by imports. Imports of scrap have grown at a CAGR of 5% from 2.12 million tons in 2003-04 to 4.29 million tons in 2017-18.

Coal, coke and natural gas are materials used at various stages of steelmaking, both as fuels and reducing agents. India has about 315 billion tons of coal reserves; in 2017-18 coal production was estimated at 700 million tons.[36]

During the iron-making and steel-making process fluxes such as limestone and dolomite are used to remove gangue minerals (such as silica, alumina, sulphur, phosphorus) in the form of slag. Steel-grade limestone (low silica content) is imported, as domestic production is not enough to meet demand.

Results and discussions

Overview of process

Based on information gathered during site visits and stakeholder consultations a process flow (Figure 8) for manufacturing of steel was developed.

While arriving at the process flow diagram and in subsequent analyses, the system boundary was taken as the walls of the manufacturing unit. All inputs have been kept on the left, primary output on the right and waste streams at the top. The rectangles represent processes; dashed rectangles represent equipment and the rounded rectangles represent materials.

The entire process of steel manufacturing can be divided into iron-making and steel-making. Iron-making involves extracting iron from its ore by reduction; the molten metal is converted into steel in furnaces (BOF and EAF) where the composition of the hot metal is adjusted to achieve the desired carbon content, remove impurities, and add elements depending on the final product specifications.

[35] CII analysis based on import data obtained from website of Department of Commerce, Ministry of Commerce and Industry, Government of India at http://commerce-app.gov.in/eidb/default.asp

[36] IIM Metal News: February 2019. Indian Institute of Metals 22(2). Accessed from http://www.iim-india.net/metal-news/category/19/metal-news/february-2019 on 01 March 2019.

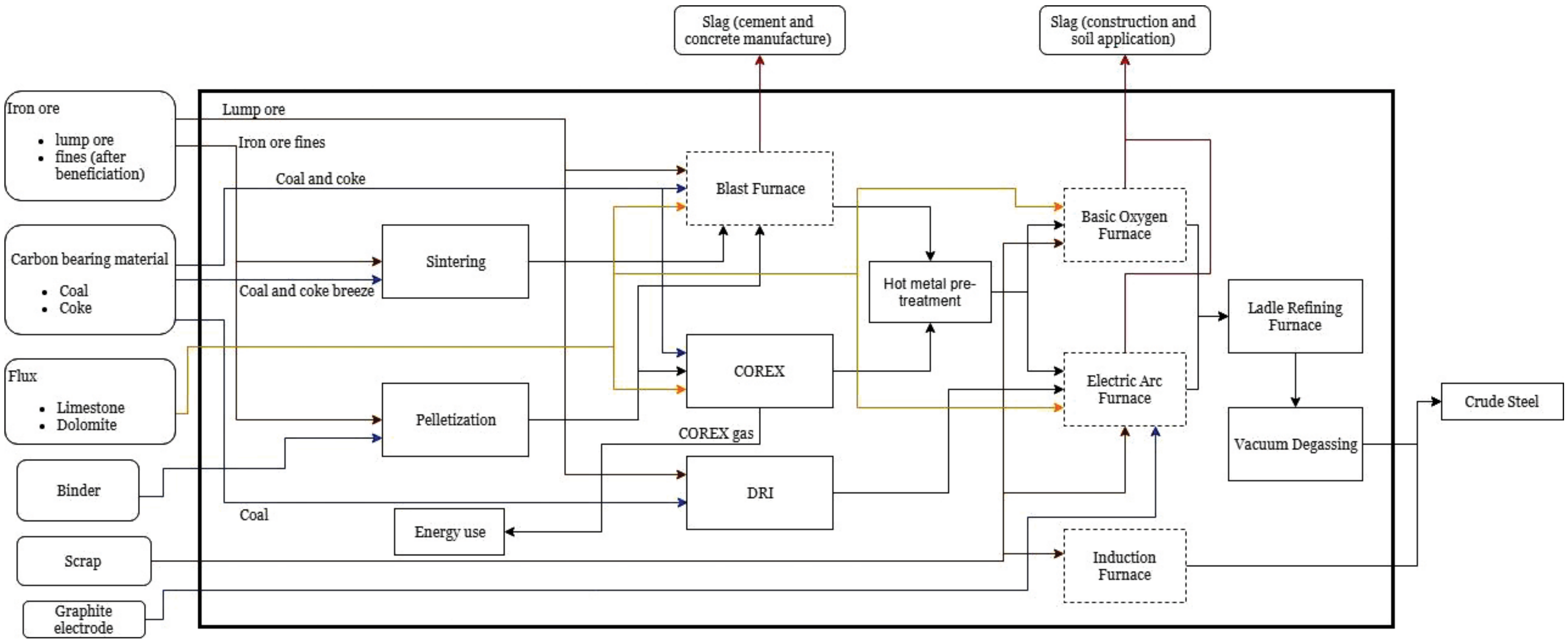


Figure 8: Schematic of steel manufacturing process

Iron-making

In the iron-making process, iron ores are reduced in one of three possible routes using agents such as coal, coke, hydrogen and natural gas to produce elemental iron. Gangue minerals such as silica and alumina along with other impurities such as sulphur and phosphorus are removed/reduced in the form of slag, a by-product. Iron-making can take place in a blast furnace, by the COREX process, and via the DRI route. In a blast furnace and the COREX process, iron ore is melted and treated to achieve the required percentage of elemental Fe; the DRI route involves reducing ore without melting using coal or reformed natural gas.

For iron ore to be charged into a blast furnace, the iron content must be brought up to 62-64% through a combination of physical and chemical separation techniques. Lump ore (36 to 40 mm in size) can be charged directly while fines (<10 mm) must be agglomerated as sinters or pellets. Sinters and pellets make up a higher percentage of the raw material mix as they provide better packing efficiency and permeability. Many operators add fluxes (calcite, dolomite, etc.) at the sintering and pelletization stage. Iron produced by the blast furnace is called pig iron while the product of the DRI process is called sponge iron.

In the blast furnace process a mix of iron ore (lumps), sinters, pellets, coke, coal and flux are charged into the furnace from the top and a hot blast of air injected at a lower level through tuyeres. Iron ore is reduced by the carbon in the furnace, to form elemental iron. The added fluxes, limestone and dolomite, break down into CaO and MgO, respectively, which form complexes – slag – with gangue minerals such as silica and alumina. A coke bed forms at the bottom of the furnace, which supports the molten metal and slag which are tapped separately. Slag, being lighter than molten Fe, floats as a separate layer.

DRI is produced by two routes: gas-based and coal based. In the gas-based process, reduction of sized iron ore (lumps) or pellets is achieved in a series of reactors by passing reformed natural gas (14% CO, 75% H_2, rest is CO_2 and CH_4) through a static bed of charge; iron oxides are reduced to metallic Fe. In coal-based DRI, coal is used to reduce iron ore. In DRI ironmaking, since the process occurs in solid state (ore) and there is no provision for adding flux, the output is a mixture of iron oxides, elemental iron and gangue minerals present in the ore. DRI processes are useful in regions where coking coal is not readily available.

In the COREX process, coal is used as a reducing agent and fuel. Coal is gasified in a rector in presence of oxygen and carbon monoxide (CO) is generated. The coal gas (85% CO) and iron ore pellets move in counter-clockwise direction and the pellets undergo partial reduction (called pre-reduction). Pre-reduced iron ore then enters the melter-gasifier chamber where hot metal is produced after final reduction.

Steel-making

In steel-making excess carbon and other impurities in molten iron are removed by oxidation. Iron-bearing material (DRI, pig iron and scrap) is converted to steel by melting in a furnace (EAF and BOF) and then processing the molten metal further. Hot metal (from the iron-making process) is pre-treated to reduce sulphur content by adding calcium carbonate, lime, calcium carbide, etc., which form slag; excess carbon and other impurities are then removed by oxidation in a steel converter by blowing oxygen through lances.

Final refining takes place in the Ladle Refining Furnace (LRF) where crude steel is subjected to an electric arc; finer refining and alloying are carried out by adding fluxes and metals based on the end-product. This is followed by vacuum degassing to reduce the content of gases such as hydrogen, oxygen and nitrogen in the refined steel to a degree determined by the end-product's specifications. The molten, degassed steel is then cast and rolled into ingots, bars, slabs, billets, etc.

Three types of furnaces are used for steel manufacturing: basic oxygen furnace (BOF), electric arc furnace (EAF) and induction furnace (IF). In the BOF process, oxygen is blown into a vessel containing molten hot metal (pig iron) to reduce the carbon content. The refractory lining is basic. The most commonly used basic oxygen furnace is the modified LD Converter (Linz Donawitz Converter). Modern converters use a lance covered with refractory material that is lowered into the molten bath to blow oxygen from the bottom. The conversion process is exothermic and hence self-sustaining: excess heat is absorbed by charging cold scrap (about 15% of total ferrous charge) and when conversion is complete, the vessel is tilted to tap out the molten steel.

In an EAF the temperature is maintained by an electric arc struck between three graphite electrodes and the metallic charge (DRI, pig iron and scrap). Flux (dolomite and limestone) are added to remove gangue materials. Oxygen charging is available in modern EAFs and it reacts with the excess carbon, silicon, and some portion of Fe exothermically, providing additional energy, which helps reduce net energy consumption.

IFs operate on induced heating produced by a high-frequency alternating current passed through copper tubing. IFs are mainly used as melting pots, where graded steel scrap is charged into the furnace—light scrap is charged first, forming the bottom layer, while heavy scrap is charged on top, to minimize oxidation of scrap due to contact with the atmosphere. A thin layer of slag is maintained at the top, which prevents further oxidation.

Resource consumption data

Data collected in the study are presented in Table 20 to Table 27. These tables cover water consumption (Table 20); iron making in a blast furnace (Table 21); COREX process (Table 22) and DRI (Table 23); steel-making through BOF (Table 24) and EAF process (Table 25); and agglomeration of iron ore through sintering (Table 26) and pelletization (Table 27).

Table 20: Water consumption in steel sector (in m^3/ton steel)

Route	World Steel survey	Observed range in India
EAF/IF	1.6	0.9 to 2.75
Integrated producers	3.3	2.64 to 4.7

Material consumption in the steel manufacturing process takes place in two stages: iron-making and steel-making. There are three separate pathways for iron making: blast furnace, COREX and DRI. Table 21 represents information of inputs and outputs from blast furnaces. Approximately 1.6 to 1.8 tons of iron ore/iron bearing materials (IBM) are required to produce one ton of hot metal. This amount may vary according to the grade of ore used.

It was observed that two mills in India use the COREX process for iron-making. Data collected from one of these has been presented in Table 22.

DRI is suitable for areas lacking coking coal and these units are easier to set up and maintain. India is the largest DRI producer in the world. Table 23 presents data collected for the DRI process.

After hot metal (iron) is made, it is sent for conversion to steel. This is undertaken through three pathways/processes (BOF, EAF and IF). Table 24 presents data for the BOF process.

Table 21: Resource consumption data for iron-making in a blast furnace

Category	Material	Unit	Value
Blast furnace (BF) feed	Pellets	Percentage of IBM	20 to 39
	Sinters	Percentage of IBM	47 to 65
	Lump ore	Percentage of IBM	14 to 15
	BF yield	Percentage	57 to 59
Carbon Bearing Material	Coke	kg/ton hot metal	252 to 350
	Coal	kg/ton hot metal	162 to 180
Flux	Limestone	kg/ton hot metal	120 to 165
	Dolomite	kg/ton hot metal	50 to 75
Slag (output)	Slag generation	kg/ton hot metal	310 to 400

Table 22: Resource consumption for iron-making through COREX process (in kg/ton hot metal)

Category	Material	Value
Iron bearing material	Iron ore (Pellets)	1,550 to 1,600
Carbon bearing material	Coal	795 to 828
	Coke	180 to 210
Flux	Limestone	150 to 180
	Dolomite	100 to 140

Table 23: Resource consumption for iron-making through DRI process (in kg/ton DRI)

Category	Material	Value
Iron bearing material	Iron ore (Lumps)	1,800 to 1,900
Carbon bearing material	Coal	900 to 1,000

Table 24: Resource consumption in Basic Oxygen Furnace (in kg/ton crude steel)

Material	Value
Hot metal	1,000
Scrap	64 to 130
Limestone[37]	84 to 96
Dolomite[37]	30 to 48
Slag (output)	160

[37] Consumption of calcined limestone and calcined dolomite was collected. This was multiplied by a factor of 1.2 to obtain limestone and dolomite consumption

Table 25 presents data collected for the EAF process. Approximately 1.27 tons of iron-bearing materials are required to produce one ton of crude steel through this process route.

Table 25: Resource consumption in Electric Arc Furnace

Material	Unit	Value
Pig iron/hot metal + DRI	Percentage of IBM	20 to 94
Scrap	Percentage of IBM	6 to 80
Limestone	kg/ton crude steel	41 to 90
Dolomite	kg/ton crude steel	7 to 43
Graphite	kg/ton crude steel	1.12 to 3.2
Slag (output)	kg/ton crude steel	95 to 320

The iron ore production and beneficiation process create iron ore fines (less than 10 mm). To economically use these fines, these are agglomerated through the process of sintering and pelletization. Table 26 and Table 27 below capture the data for resource consumption in these two processes.

Table 26: Resource consumption in sintering (in kg/ton sinter)

Material	Value
IBM (fines)	1,000 to 1,010
Coal and coke mix	58 to 70

Table 27: Resource consumption in pelletization (in kg/ton pellet)

Material	Value
IBM (fines)	1,060 to 1,093
Binder	5.5 to 7

All the resources in Table 21 to Table 27 were summed and multiplied by production data to arrive at resource consumption at the national level. The following tables (Table 28 and Table 29) indicate the quantity of materials consumed by the steel sector in India.

Table 28: Economy-wide resource demand/ consumption (in million ton)

Material	Lower bound	Upper bound
Iron bearing material (fines)	56.64	88.54
Iron bearing material (lump ore)	45.94	48.67
Ferrous scrap	48.48	
Coal	26.24	26.24
Coke	12.03	12.03
Coal & coke mix (for sintering)	2.16	2.16
Graphite	0.03	0.03
Limestone	10.78	10.78
Dolomite	4.03	4.03
Binder	0.10	0.10

Table 29: Process-wise resource consumption (in million ton)

Process	Material	Lower bound	Upper bound
Induction Furnace	Scrap	27.85	
Electric Arc Furnace	Scrap	16.59	
	DRI	19.11	
	Pig iron	3.59	
	Limestone	1.23	2.69
	Dolomite	0.21	1.29
	Graphite	0.33	0.096
Basic Oxygen Furnace	Hot metal (from BF)	43	
	Hot metal (from COREX)	1.6	
	Scrap	4.05	
	DRI	0.25	
	Limestone	3.73	4.26
	Dolomite	1.33	2.13
Blast Furnace	Pellets	15.84	30.89
	Sinters	37.22	51.48
	Lump ore	11.09	11.88
	Coke	11.74	16.31
	Coal	7.55	8.39
	Limestone	5.59	7.69
	Dolomite	2.33	3.49
COREX	Iron ore (Pellets)	2.48	2.56
	Coal	1.27	1.32
	Coke	0.29	0.34
	Limestone	0.24	0.29
	Dolomite	0.16	0.22
DRI	Iron ore (lumps)	34.85	36.79
	Coal	17.43	19.36
Pelletization	IBM (fines)	19.42	36.55
	Binder	0.10	0.25
Sintering	IBM (fines)	37.22	51.99
	Coal & coke mix	2.16	3.60

National level estimate of slag generated is presented in Table 30.

Table 30: Estimate of slag generation for the year 2017-18 in the iron and steel making process (in million ton)

Type of Slag	Value
BF Slag	16.54
COREX Slag	0.68
BOF Slag	7.1
EAF Slag	6.05

Material flow in steel sector

Based on an understanding of the process flow and data on resource consumption, an economy-wide material flow for the steel sector has been developed. Figure 9 shows the Sankey diagram of the economy-wide steel flow in India. The figure represents the flow of materials from raw material (left) for all three input streams, including imported scrap to the final product (crude steel) and by-products (right) generated during the steel manufacturing process.

The flow width is proportional to the quantity of the resource represented. The left side of the figure shows all inputs: iron bearing material (lumps, fines, scrap: domestic and imported), fluxes (dolomite and limestone) and carbon bearing material (coal and coke). The right side of the figure shows the outputs: crude steel (through BOF, EAF and IF process route) and by-products. The by-products have been categorized into two, gaseous (in grey), and solids (in purple). This second category of waste identifies the current situation with respect to potential for use of by-products.

Air Quality and GHGs

The study looks to estimate Industrial Processes and Product Use (IPPU) emissions from the iron and steel industry. IPPU emissions cover greenhouse gas emissions occurring from industrial processes, from the use of greenhouse gases in products, and from non-energy uses of fossil fuel carbon.

Major IPPU emissions in iron and steel manufacturing occur due to the use of carbon bearing material (coal and coke) and fluxes (limestone and dolomite) in the process. Minor emissions occur due to the use of graphite electrodes in EAF.

Table 31 presents the lower and upper range of emissions. The wide range of the total emissions is due to the uncertainty in the consumption of resources that cause the emissions.

Table 31: Carbon dioxide emissions from IPPU sector (million tons CO_2 per year)

Process Route	Lower bound	Upper bound
BF-BOF	49.6	69.7
EAF	36.7	49.7

Discussion

Significant efforts have been taken in the iron and steel sector to combat energy and water-use efficiency. The International Energy Association reports that energy intensity of the global steel sector had peaked in 2009, and then declined annually at a rate of 0.8%. In India, various initiatives have been implemented to improve energy efficiency. The Government of India launched the PAT Scheme (Perform, Achieve and Trade) for improving energy efficiency, under the National Mission on Enhanced Energy Efficiency. Under the aegis of this scheme benchmarks were created for the sector. In the PAT-I cycle (ended 2015), against a target to reduce specific energy consumption by 1.486 million toe (Total Oil Equivalent), total savings of 2.1 million toe was achieved.[39]

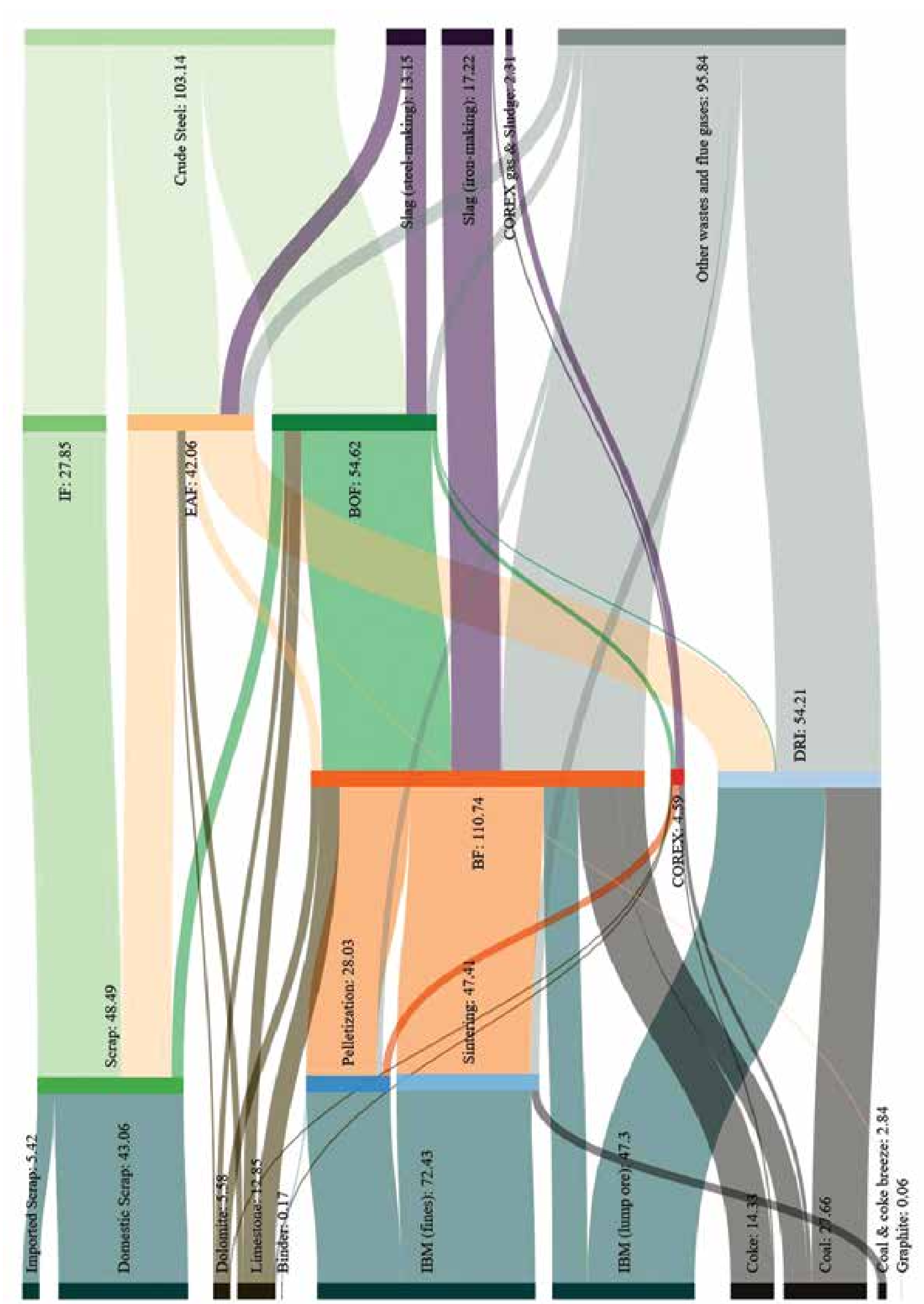
Water plays an important role in the steel sector. It is used for raw material preparation, dust suppression, a coolant, as well as in power generation. It is estimated that by 2030, Indian steel industry will require 1,500 million cubic metre of water annually.[40] The study indicates that steel mills in India perform at par with global standards on water consumption.

It was evident during the study that larger mills perform better in terms of resource efficiency as compared to standalone units that re-melt DRI/Pig iron to produce steel. Cost of equipment and quality and type of raw materials often decide the level of efficiency in resource consumption.

[39] Achievements under Perform, Achieve and Trade (PAT). BEE. 2017. Accessed from https://beeindia.gov.in/sites/default/files/Booklet_Achievements%20under%20PAT_May%202017.pdf on on 22 April 2019.

[40] National Steel Policy 2017. Accessed from https://steel.gov.in/sites/default/files/draft-national-steel-policy-2017.pdf on 08 February 2019.

Figure 9: Material flow of the steel sector in India[38]



[38] All values in million tons

The material flow in Figure 9 is a representation of the relative importance of resource streams generated across the Indian economy through the manufacture of steel. These have been discussed separately for the different processes in the subsequent section.

Iron-making

A significant portion of by-product generation in the sector happens at the iron-making stage. Iron-making is undertaken through three process routes: BF, COREX and DRI. The waste generated are gaseous and solid (slag). The study estimates 17.13 MT of slag generated from BF and COREX process. BF slag forms a major share (96%) of this due to the larger installed capacity of BF iron-making in India. The amount of gangue material in the ore, after beneficiation, determines the amount of flux needed in the process and the amount of slag generated. Approximately 320 to 400 kg of slag are generated per ton of hot metal (THM), depending upon Fe percentage in ore feed: the higher the Fe content, the less the slag generated. Blast furnace slag is either air-cooled (which results in crystalline, rock-like structures) or water cooled (results in granulated slag). Air-cooled slag is used as aggregates, whereas granulated slag can be used in the manufacture of cement and concrete.[41]

Another by-product of the process is the gaseous emissions. It is estimated that 88 MT of gaseous waste is emitted. BF (54%) and DRI (44%) emissions form the major component of these emissions. BF emissions are rich in carbon monoxide and can serve as a fuel for other processes. Some manufacturers use it for in-house power generation, thus reducing power intake from the grid. Similarly, the COREX process produces about 1,600 kg of gas per ton of hot metal, known as COREX gas. The composition of the gas is: CO (45%), CO_2 (35%), H_2 (10%) and CH_4 (2.5%). COREX gas has a high calorific value and is used to pre-heat materials in the blast furnace and coke oven.

Coke forms an indispensable part of the ironmaking process. Given its mechanical properties, it supports the raw material burden inside the blast furnace, apart from reducing iron ore. India is deficient in coke and relies significantly on imports to meet demand. Part of the coke demand can be offset by pulverized coal injection (PCI) in the blast furnace; however, a high rate of PCI can be maintained only if slag rate is low, i.e. iron ore charged into the blast furnace is of high grade/sufficiently beneficiated. This requires a supply of uniform grade ore. However, the study indicates that steelmakers without access to captive mines often deal with erratic quality of iron ore, and hence their slag generation rate varies.

Steel-making

Basic oxygen furnaces (BOFs) have the largest contribution to steelmaking and will constitute a large portion of India's projected steelmaking capacity by 2030. At a sectoral level the study estimates that the steel-making process generates 30% less slag (13.15 MT) than the iron-making process. The slag generation from steel-making process is almost equal from BOF (54%) and EAF (46%). This slag is alkaline in nature and can be used for soil applications (to manage pH), road construction, railway ballast etc. The feasibility of using steel slag for manufacturing of bricks is also being explored.[42] Many mills also use slag to repair the refractory lining in steel converters.[43] Steel slag must be weathered to reduce lime content before it is used as construction material; presence of lime causes volumetric instability in steel slag when in contact with water.

Scrap material forms an integral part of the steel-making process. This includes both internal scrap (generated from conversion of crude steel to end-products) and external scrap (purchased scrap: both domestic and imported). The current study estimates that the overall scrap demand is 48.74 MT. There has been a steady increase of imported scrap in India, the study estimates 11% of the total scrap demand is met by imports. This value is an under-estimation since it includes internal scrap used within the manufacturing units. The Government of India's proposed Vehicle Scrapping Policy can provide a formal channel for re-

[41] Strategy Paper on Resource Efficiency in Steel Sector through Recycling of Scrap and Slag. NITI Aayog and Ministry of Steel. 2018. Accessed from https://niti.gov.in/writereaddata/files/RE_Steel_Scrap_Slag-FinalR4-28092018.pdf on 17 April 2019.

[42] Characteristics of bricks made from waste steel slag. Shih, P.H., Wu, Z.Z. and Chiang, H.L. Waste management, 24(10), pp.1043-1047. 2014. Accessed from http://europepmc.org/abstract/med/15567669 on 29 March 2019.

[43] Strategy Paper on Resource Efficiency in Steel Sector through Recycling of Scrap and Slag. NITI Aayog and Ministry of Steel. 2018. Accessed from https://niti.gov.in/writereaddata/files/RE_Steel_Scrap_Slag-FinalR4-28092018.pdf on 17 April 2019.

use of scrap within the economy.[44] Studies indicate ELV (end of life vehicles) scrap generation will be at 3.5 MTPA by 2030.[45] However, refurbishment and remanufacture should be prioritized above scrapping.

India is still going through a process of massive infrastructure development; studies indicate that a significant share (70%) of buildings that will exist in 2030 are yet to be built.[46] Thus, the demand for crude steel is bound to grow. Thus, a holistic effort must be made to assure the supply of iron bearing materials to the industry through scrap and/or sustainable production of pig iron and DRI.

Air Quality and GHGs

A significant portion of IPPU emissions occur during the iron-making stage. The International Energy Agency (IEA) prescribes uptake of scrap-based EAF production to reduce GHG emissions in the short term while, for long term reductions, it proposes following courses of action: a) adoption of new direct reduced iron and smelting reduction technologies run on low-carbon electricity, b) adoption of CCUS (carbon capture, utilization, and storage), and c) adoption of material efficiency strategies to optimize use of steel.[47]

Sponge iron or DRI production in India is either coal-based or gas-based. While both processes are intensive in terms of GHG emissions, coal-based process adds to deterioration of air quality as well.[48] A possible alternative is to promote H-DRI or hydrogen based direct reduction of iron. The technology will replace the natural gas consumed in DRI with hydrogen and reduce the carbon footprint of the process.[49]

[44] Consultation note on scrapping of commercial vehicles. Ministry of Road Transport and Highways. 2019. Accessed from http://jhtransport.gov.in/pdf/Morth_Scrapping%20of%20Older%20Vehicle.pdf on 17 April 2019.

[45] Indian scrap imports to keep rising despite launch of local shredding operations. Accessed from https://www.metalbulletin.com/Article/3828265/Indian-scrap-imports-to-keep-rising-despite-launch-of-local-shredding-operations.html on 17 May 2019.

[46] Circular Economy in India: Rethinking Growth for Long-term Prosperity. Ellen Macarthur Foundation. 2016. Accessed from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Circular-economy-in-India_5-Dec_2016.pdf on 10 February 2019.

[47] Iron and Steel: Tracking Clean Energy Progress. International Energy Agency. Accessed from https://www.iea.org/tcep/industry/steel/ on 29 March 2019.

[48] Reference Report for National Resource Efficiency Policy for India. TERI. 2019. Accessed from https://www.teriin.org/sites/default/files/2019-04/National-Policy-Report.pdf on 01 May 2019.

[49] Assessment of hydrogen direct reduction for fossil-free steelmaking. Vogl, V., Åhman, M. and Nilsson, L.J. Journal of Cleaner Production, 203, pp.736-745. 2018. Accessed from https://www.sciencedirect.com/science/article/pii/S0959652618326301 on 01 May 2019.

SECTION IV:

Paper

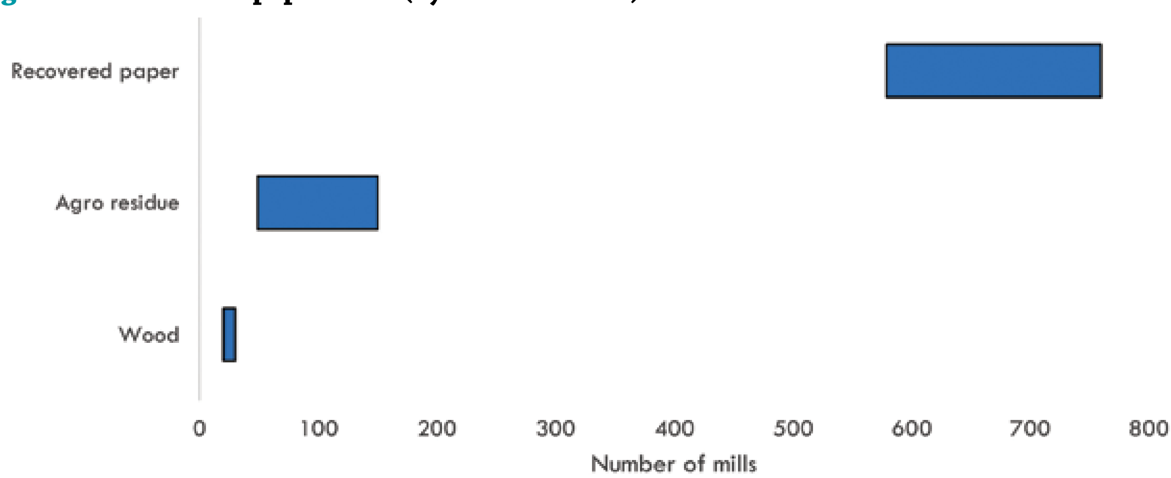
Industry characteristics

The paper industry in India accounts for 3.7% of the global paper production and is growing at the rate of 6 to 7%.[50, 51] The fibre used to make paper (pulp) is derived from broadly three sources:

- Wood: from trees such as bamboo, eucalyptus, casuarina and subabul
- Agricultural residue: such as bagasse, rice and wheat straw
- Recovered (or waste) paper

None of the print sources consulted agreed about the number of mills and the share of production from the various fibre sources. In the subsequent section CII has attempted to consolidate these figures to provide a range and justified the figures used in the current study. The total number of mills in India ranges between 653 and 850.[52] It is also known that the majority of mills use recovered paper as fibre source (579 to 760) followed by those using agricultural residue (49 to 150); 20 to 30 mills in the country use wood as the source of fibre. Figure 10 provides an overview of the segregation of the total number of mills.

Figure 10: Number of paper mills (by source of fibre) in India[52]



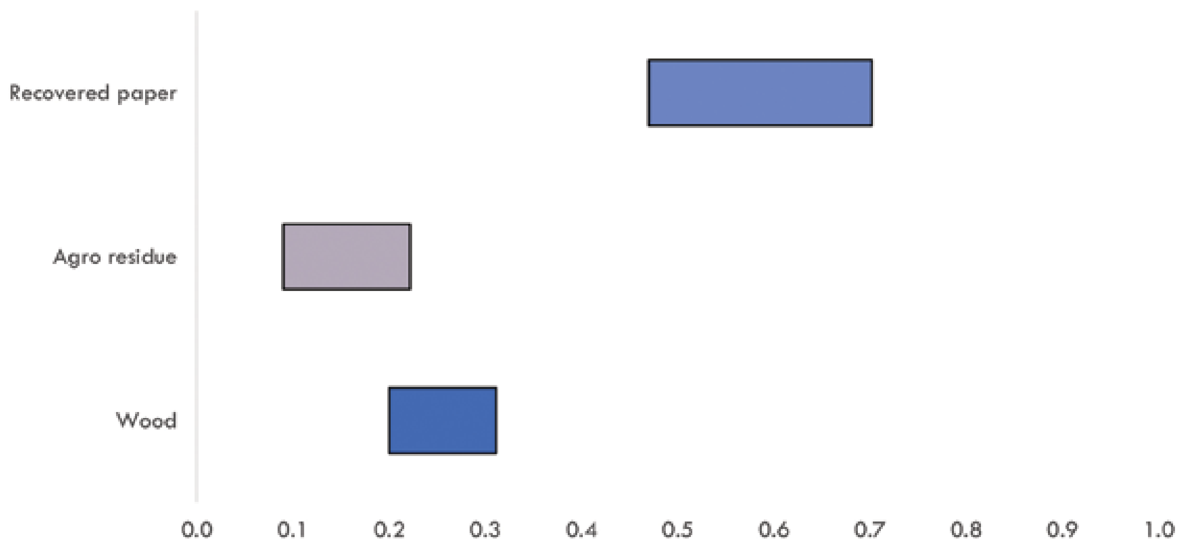
[50] IPMA website. Accessed from http://ipma.co.in/overview/ on 26 February 2019.

[51] Indian paper industry growing at 6-7%, says industry official, The Economic Times. 2018. Accessed from https://economictimes.indiatimes.com/industry/indl-goods/svs/paper-/-wood-/-glass/-plastic/-marbles/indian-paper-industry-growing-at-6-7-says-industry-official/articleshow/65744949.cms on 08 March 2019.

[52] CII Analysis based on secondary sources.

- A Report on Opportunities for Green Chemistry Initiatives: Pulp and Paper Industry. Office of the Principal Scientific Officer, GoI. 2014. Accessed from http://www.gcpcenvis.nic.in/Thesis/Report_on_Opportunities_for_Green_Chemistry_Initiatives_in_Pulp_Paper_Industry_India.pdf on 08 March 2019;
- Indian Agro and Recycled Paper Mills Association. Accessed from http://www.iarpma.org/indian-paper-industry.asp on 08 March 2019;
- Annual Report 2016-17. CPPRI. 2017. Accessed from http://www.cppri.org.in/sites/default/files/annual-report16-17.pdf on 08 March 2019;
- Normalization Document and Monitoring and Verification Guidelines – Pulp and Paper Sector, Ministry of Power. GoI. 2015. Accessed from https://beeindia.gov.in/sites/default/files/Pulp-and-Paper-1-44.pdf on 08 March 2019; and
- Technology Compendium on Energy Saving Opportunities – Pulp and Paper Sector. BEE and CII. Accessed from http://www.indiaenvironmentportal.org.in/files/file/pulp_paper.pdf on 08 March 2019.

Figure 11: Share of production of paper in India by fibre source[55]



All the wood-based mills are of large sizes (>400 TPD), while agro mills are in the category of small and medium (50 to 400 TPD). Recovered paper mills are mostly small in size (<50 TPD). The estimated total production in the year 2017-18 was 17 million tons.[53] Of the total production, the share of wood based unit range between 20% and 31%. Agriculture residue based (rice husk, bagasse, wheat straw, etc.) unit comprises 9% to 22% of the total production. The remaining, amounting between 47% and 70%, are from recovered paper based units. Figure 11 represents the share of production from units based on the different raw material used.[54]

Paper production can be further segregated by the type of final product: newsprint, writing/printing and board. The growth rate of the market for these categories are 2.6%, 4.86% and 8.37% respectively.[56] Owing to large variation in the classification of mills and the raw material streams that are utilized, the current study uses the production value of 2017-18 (17 million tons) and the share of internal segregation based on CPPRI data (Table 32).

Table 32: Fibre source used for different paper grades[57]

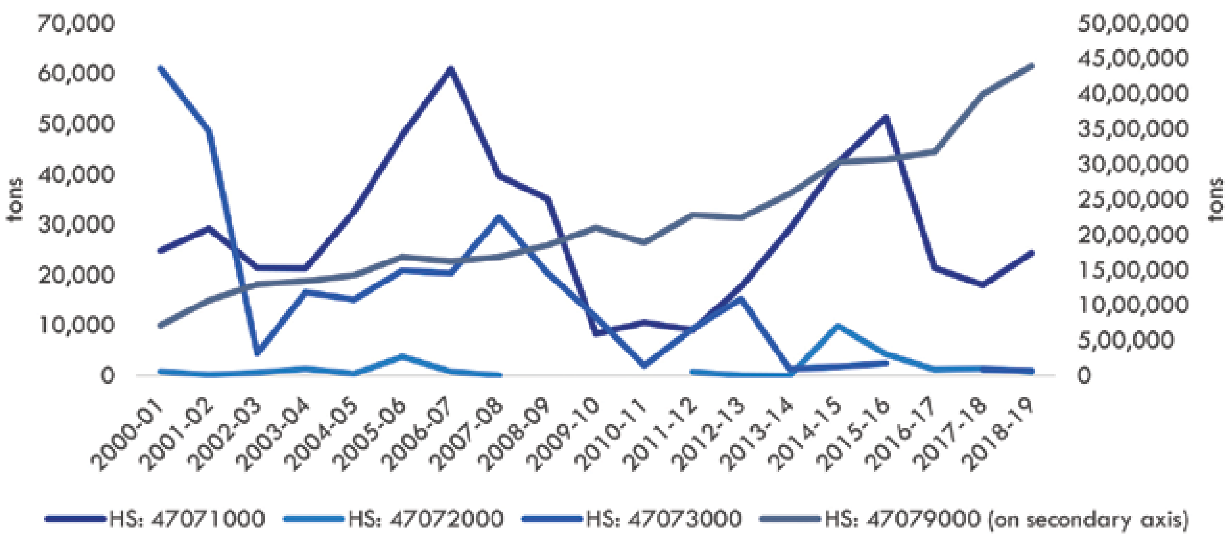
Paper grade	Raw material	Share in grade	Share in overall
Writing printing grade	Wood	0.51	0.35
	Agriculture residue	0.10	
	Recycled fibre	0.38	
Packaging grade	Wood	0.10	0.55
	Agriculture residue	0.13	
	Recycled fibre	0.77	
Newsprint grade	Wood	0.01	0.10
	Agriculture residue	0.00	
	Recycled fibre	0.99	

[53] IPMA website. Accessed from http://ipma.co.in/overview/ on 26 February 2019.
[54] The numbers do not add up to 100 since the range is compiled from different sources.
[55] Based on secondary desktop review and stakeholder interactions
- Annual Report 2016-17. CPPRI. 2017. Accessed from http://www.cppri.org.in/sites/default/files/annual-report16-17.pdf on 20 January 2019;
- IPMA website. Accessed from http://ipma.co.in/overview/ on 20 Jan 2019;
- A Report on Opportunities for Green Chemistry Initiatives: Pulp and Paper Industry. Office of the Principal Scientific Officer, GoI. 2014 Accessed from http://www.gcpcenvis.nic.in/Thesis/Report_on_Opportunities_for_Green_Chemistry_Initiatives_in_Pulp_Paper_Industry_India.pdf on 20 January 2019; and
- stakeholder interactions

[56] IPMA website. Accessed from http://ipma.co.in/overview/ on 26 February 2019.
[57] Compendium of Census Survey of Indian Paper Industry. CPPRI. 2015

The geographical location of the mill often determines the type of raw material used for paper manufacturing. About half of the total number of paper mills in the country are in the states of Gujarat, Maharashtra, Uttar Pradesh and Punjab. Most mills in the northern and western regions of India use agricultural residue and recovered paper as the fibre source while southern and eastern regions use wood and bamboo as raw materials. Mills located in the southern and eastern areas are located in areas where agro-forestry practices are prevalent. More than 50 per cent of the total paper produced from recovered paper is made in western India with easy access to the coast and ports. Recovered (waste) paper import into the country has grown by 514% between 2000-01 and 2018-19, from 8,01,729 to 44,19,507 tons (Figure 12).[58] The figure displays the Harmonised System Code classification to identify the material being imported accurately (Annex I). The CAGR and average annual increase in quantum of import over the last two decades were 9.4% and 2,00,988 tons. It is estimated that in 2017-18, approximately 32% of recovered paper demand as fibre source was met by importing recovered paper.[59]

Figure 12: Recovered (waste) paper imports from 2000-01 to 2018-19 [58,60]



Legend of the graph represents HS codes for various kinds of waste paper imported.
These have been presented in Annex I

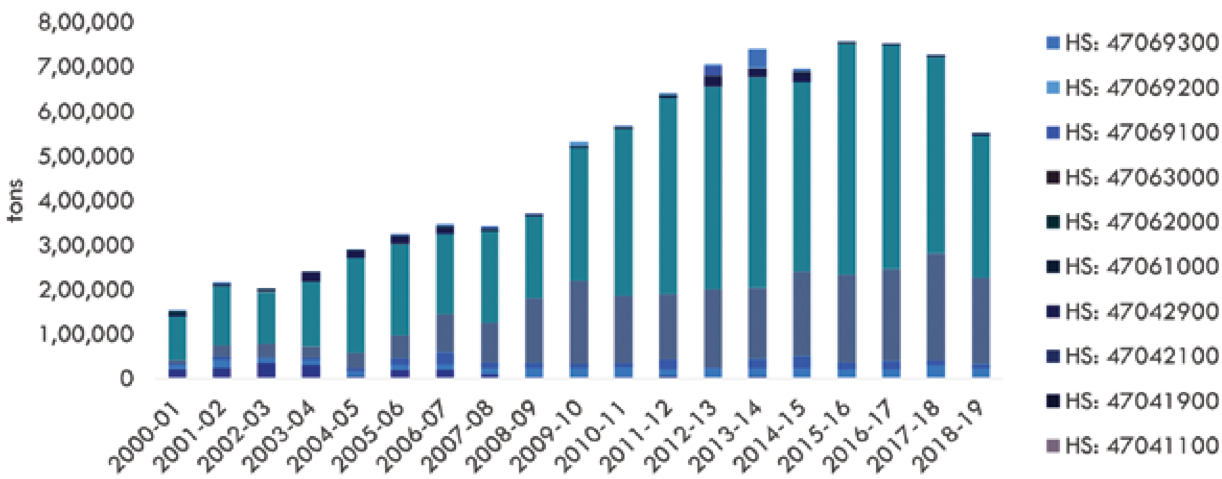
Importing softwood pulp (which is not available in India) is necessary for economic reasons and the quality of a particular paper grade. The amount of pulp imported has been increasing steadily at the rate of 10% CAGR from 1,30,167 tons in 2000-01 to 7,25,205 tons in 2017-18.[61] The major portion (81% to 93% over the time frame) of the imports falls into one of two categories: bleached or semi-bleached coniferous chemical wood pulp sulphate and bleached or semi-bleached non-coniferous chemical wood pulp sulphate. Figure 13 below shows the trend followed by pulp imports between the years 2000-01 and 2018-19.

[58] CII Analysis based on import data obtained from website of Department of Commerce, Ministry of Commerce and Industry, Government of India at http://commerce-app.gov.in/eidb/default.asp

[59] Based on estimates from current study. The estimations have been elaborated in the subsequent sections

[60] Data for 2018-19 is for the period April to December 2018

Figure 13: Pulp imports between 2000-01 and 2018-19 [61, 62]



Legend of the graph represents HS codes for various kinds of pulps imported.
These have been presented in Annex I

Results and discussion

Overview of process

Based on information gathered during site visits and stakeholder consultations a process flow (Figure 14) for manufacture of paper was developed.

The manufacturing process for all three sources of fibre (wood, agricultural residue and recovered paper) was studied a simplified schematic, combining the three pathways was drawn up. It is useful to note that while the processes are broadly similar, some parts of it are different for recovered paper.

While arriving at the process flow diagram and in subsequent analyses, the system boundary was taken as the walls of the manufacturing unit. The blue arrows represent material input from outside the factory; green arrows represent material re-use within the mills; and red arrows represent waste material sent outside the unit. The rectangles represent processes; dashed rectangles represent equipment and the rounded rectangles represent materials.

The manufacture of paper can be broken down into three steps: raw material processing, pulping (including chemical treatment/digestion) and paper-making (essentially, removing moisture to form a sheet).

In the context of resource efficiency, it is important to note that the need to conserve resources in the form of chemicals used in digestion, and reduce effluents from the pulping/cooking process, is greater than ever now. Regenerating and recirculating chemicals to minimize losses is thus an extremely important part of a pulp and paper mill's process.

During the processing of raw material, wood and agricultural residue are chipped/broken into smaller pieces to increase digestion efficiency generating wood dust and pith (sent to the boilers to be used as fuel). When recovered paper is the raw material, plastic, pins, staples and other high-density material are separated and sent to formal/informal recyclers.

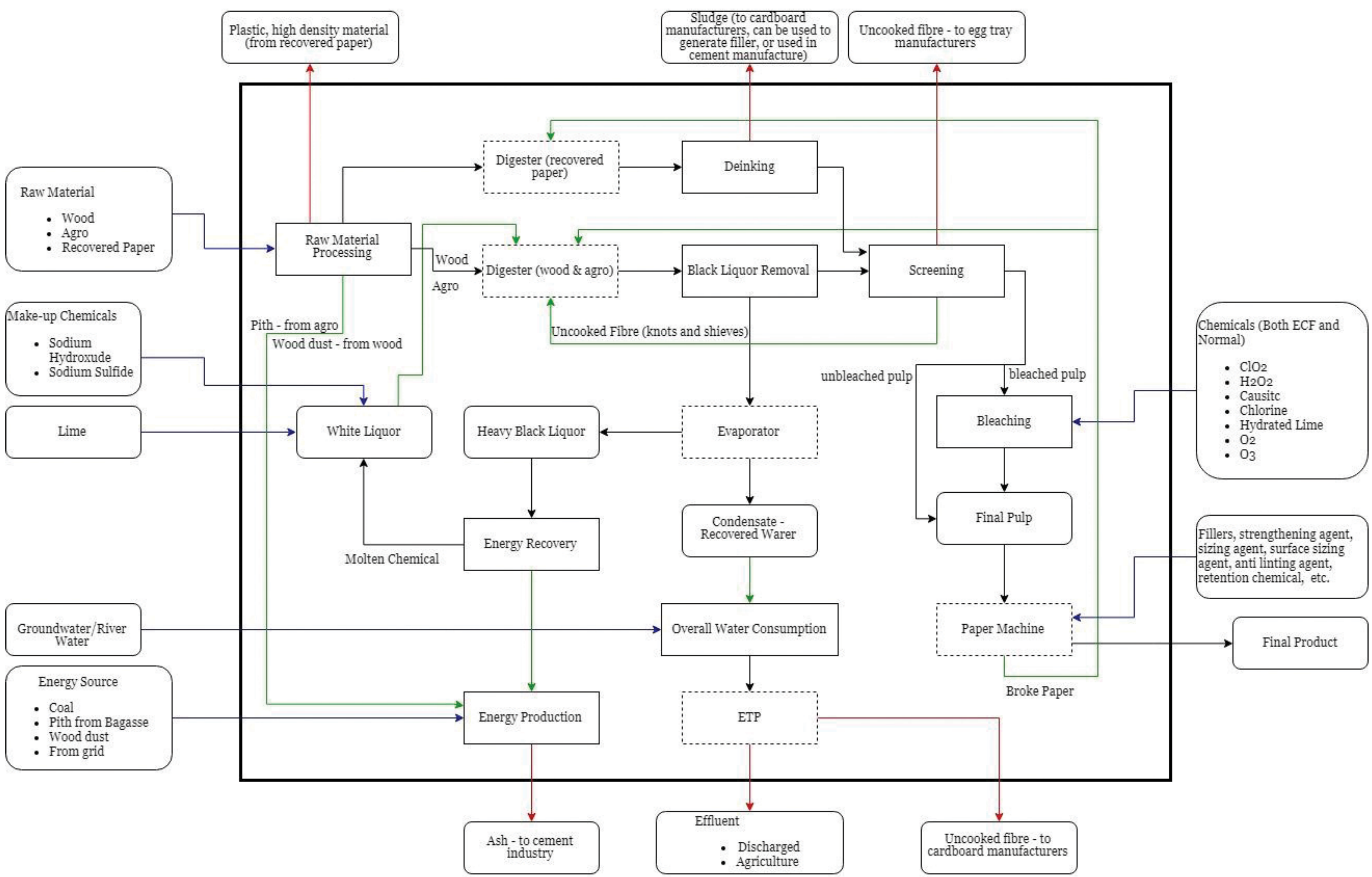
After the processing of raw materials (whether it is of plant origin such as wood, agricultural residue, or recovered paper), pulping is undertaken. During the pulping process, when wood or agricultural residue are the fibre source, cellulose fibres are separated either chemically or mechanically, in a 'digestion' process. When recovered paper is the source of fibre, some chemicals are be used for treatment along with water.

During the digestion process (for wood and agricultural residue), the pulp is cooked in steam with

[61] CII analysis based on import data obtained from website of Department of Commerce, Ministry of Commerce and Industry, Government of India at http://commerce-app.gov.in/eidb/default.asp

[62] Data for 2018-19 is for the period April to December

Figure 14: Schematic of paper manufacturing process



a mixture of sodium hydroxide (NaOH) and sodium sulphide (Na_2S) known as white liquor. After several hours, a dark coloured mixture of broken-down plant material and spent cooking chemicals (also containing lignin and called black liquor) are separated through a cross-flow washing process. The pulp is passed through a series of screens to filter out any uncooked fibres that are then recirculated in the digester. The resulting pulp is then sent for bleaching (if the final product requires it).

When recovered paper is used as the source of fibre, digestion involves mixing recovered paper with water and sodium hydroxide in a digestor, followed by deinking (particularly when the product is newsprint). Deinking removes materials such as fillers, brightening agents, ink, and the resulting sludge contains a small percentage of lost fibre and calcium carbonate (filler). The sludge is sent to cardboard manufacture units.

In the next step, pulp is sent to the paper machine, where the final product is made by adding fillers, strengthening agents, coating chemicals, anti-linting agents, brighteners etc., and adjusting the moisture content to desired levels.

Chemical recovery is an intrinsic part of mills using plant-based raw material and consists of four key stages: (1) black liquor concentration, (2) black liquor combustion (recovery boiler), (3) recausticizing, and (4) calcining (lime burning).

When black liquor is first separated from pulp it is relatively dilute and is called weak black liquor. It is sent to multiple evaporators where the concentration of black liquor solids gradually increases, and any condensate recovered is recirculated. The now concentrated black liquor (known as heavy black liquor) has a relatively high calorific value (2,600-3,200 kcal/kg DCS) owing to the presence of organic matter and lignin and is fired in a recovery boiler generating steam that is used within the entity.

During combustion, the inorganic process chemicals are reduced to a molten smelt, which is removed from the bottom of the boiler and is further refined in subsequent steps.[63] In order to reconstitute the cooking solution (white liquor), the smelt from the recovery boiler is first mixed with weak white liquor solution, forming green liquor. Recausticization of green liquor then takes place with the addition of calcium hyrdroxide ($Ca(OH)_2$). The calcium carbonate ($CaCO_3$) formed during recausticizing is removed as lime mud leaving behind a white liquor that can be reused in the cooking process. The lime mud is sent to a lime kiln to be calcined. The resulting lime (CaO) is dissolved in water to produce calcium hydroxide.[63]

Resource consumption data

Data collected in the study are presented in Table 33 to Table 37. These tables cover energy and water consumption (Table 33); raw material yield (Table 34); chemicals consumed during cooking, bleaching and recovery (as also indicators of chemical recovery) for wood and agriculture residue mills (Table 35) and chemicals consumed in mills using recovered paper as fibre source (Table 36). Differences in process and paper grade result in a spread of data and therefore ranges have been presented in these tables. Wherever possible, the qualitative distribution of the ranges has also been described.

In Table 34, raw material yield is defined as the amount of raw material required to produce one ton of bone dry pulp. Yield is dependent on the paper grade that is being produced and can vary significantly with raw material type and the process (details of yield by fibre source are shown in Table 14 in the methodology section).

Table 33: Energy and water consumption

Indicator	Unit	Wood	Agriculture residue	Recovered paper
Energy	kWh/ton of final product	1,050 to 1,350	1,000 to 1,100	400 to 800
Share of energy produced by recovery boiler	Percentage	21 to 60	16 to 23	NA
Water	m^3/ton of final product	30 to 70	50 to 80	8 to 12

[63] An Energy Star® Guide for Energy and Plant Managers. Klaas Jan Kramer, Eric Masanet, Tengfang Xu, and Ernst Worrell. Energy Analysis Department, Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory. 2009.

Table 34: Raw material yield (in %)

Raw material	Lower bound	Upper bound
Wood: mechanical[64]	90	95
Wood: chemical	38	49
Agricultural residue	35	50
Recovered paper	60	90

Table 35: Chemical consumption (at pulping and bleaching stage) and indicators of chemical recovery (wood and agriculture residue)

Process	Indicator	Unit	Wood	Agriculture residue
Cooking	Sulfidity through sodium sulphate and sodium hydroxide[65]	kg/ton of pulp	20 to 40	25 to 35
	Uncooked fibre (for recirculation) knots and shives	kg/ton of pulp	4 to 46	6 to 22
Bleaching: Chlorine based	Chlorine	kg/ton pulp	NA. All wood-based plants use elemental chlorine free bleaching	48 to 53
	Sodium hydroxide	kg/ton pulp		10 to 23
	Hydrated lime	kg/ton pulp		26 to 30
Bleaching: Elemental chlorine free	Chlorine dioxide	kg/ton pulp	15 to 35	15 to 20
	Hydrogen peroxide	kg/ton pulp	6 to 29	5 to 17
	Oxygen	kg/ton pulp	5 to 6	3 to 5
	Caustic soda (sodium hydroxide)	kg/ton pulp	10 to 20	5 to 10
Recovery boiler	Black liquor generation	m^3/ton of pulp	8 to 12	8 to 12
	Recovery efficiency	Percentage	96 to 97	94 to 96
	Total lime requirement	kg/ton of white liquor	700 to 1,200	700 to 1,200
	Lime from external source	kg/ton of white liquor	16 to 76	NA. No lime kilns in plants of this category[66]

Table 36: Chemicals consumed (recovered paper) (in kg/ton of pulp)

Process	Indicator	Range of values
Cooking	Caustic soda (sodium hydroxide)	2 to 8
De-inking/bleaching	Hydrogen peroxide	20 to 30
	Hydro sulphite	4 to 8
	Hydro-bisulphite	25 to 30

[64] Only one paper mill in India uses mechanical pulping
[65] Through make-up chemicals
[66] Except in TNPL, Tamil Nadu. However, at TNPL all three fibre sources are used: agricultural residue, wood and recovered paper.

All the resources in Table 34 to Table 37 were summed and multiplied by production data to arrive at resource consumption at the national level. Raw material consumption has been estimated based on the distribution of yield (in Table 34) a cross the production capacity. This distribution has been described in in Table 14 in the methodology section.

Since pulp is bleached via two pathways (elemental chlorine-free (ECF), and non-ECF or chlorine-based bleaching), calculating the consumption of bleaching chemical, involved allocation of pulp quantities (bleached, semi-bleached and unbleached pulp) to the two possible pathways was used. Table 12 and Table 13 show the economy-wide assumptions used to quantity amount of pulp bleached Quantification of the chemicals consumed in the paper machine stage is based on the overall production of different grades of paper. Table 38 below presents economy-wide resource demand/consumption figures.

Table 37: Chemicals used in paper machine (by paper grade) (in kg/ton final product)

Function	Chemical	Writing and printing	Newsprint	Board[67]
Filler	Calcium carbonate	155	0.2	139
Sizing agent	Alkyl ketene dimer (AKD)	15	8	13
Optical Brightening Agent (OBA)	OBA (generic name)	7	2.4	6
Strengthening	Cationic starch, surface starch	28	6	25.1
Other	ALA, PAC, CPAM, APAM, dyes, etc.	0.8	0.4	0.7

Table 38: Economy-wide resource demand/consumption

Category	Aspect	Unit	Lower bound	Upper bound
Fibre source	Wood	million tons	6.7	
	Agriculture residue[68]	million tons	3	4.3
	Recovered paper	million tons	13.7 (4.42 imported)	
Bleaching[69]	Chlorine dioxide	kilo tons	44	101
	Hydrogen peroxide[70]	kilo tons	86	187
	Oxygen	kilo tons	14	17
	Caustic soda[71]	kilo tons	32	66
	Hydro sulphite	kilo tons	14	28
	Hydro bi-sulphite	kilo tons	86	103
	Chlorine	kilo tons	17	18
	Hydrated lime	kilo tons	9	10
Chemicals consumed in recovery	Sulfidity chemicals (NaOH + Na2S)	kilo tons	132	234
	Lime[72]	kilo tons	337	693
Paper Machine	Calcium Carbonate (filler)	kilo tons	1,736	
	AKD (sizing agent)	kilo tons	176	
	OBA (Optical Brightening Agent)	kilo tons	82	
	Starch (surface and cationic for strengthening)	kilo tons	315	
	Dry strength resin (DSR) (strengthening)	kilo tons	7	
	Other	kilo tons	10	

[67] Assumed to be 10% of final product (based on literature). Accordingly, allocation made from writing and printing data

[68] For mills using agricultural residue as fibre source, the understanding of distribution of raw material yield across the production is lacking, hence the figures for lower and upper value of yield have been used to determine resource consumption.

[69] Refer to methodology section for allocation of production to both types of bleaching

[70] Includes both, ECF and chlorine-based bleaching

[71] Includes both, ECF and chlorine-based bleaching

[72] Here it is assumed that all wood-based units have kilns for lime recovery from sludge.

Material flow in paper sector

Based on an understanding of the process flow and data on resource consumption, an economy-wide material flow for the paper sector has been developed. Figure 15 shows the Sankey diagram of the economy-wide paper flow in India. The figure represents the flow of materials from raw material demand (left) for all three input streams, including imported recovered paper and pulp, to the final product and by-products (right) generated during the paper manufacturing process.

The flow width is proportional to the quantity of the resource represented. The left side of the figure shows all inputs: fibre source (recovered paper, wood and agricultural residue), filler materials and imports (pulp and recovered paper). The right side of the figure shows the outputs: final product (newsprint, packaging board, writing and printing paper) and by-products. The by-products have been categorized into two, those used for energy co-generation (in red), and, those disposed outside the factory boundaries in landfills or by selling to other users (in purple). This second category of waste identifies the current situation with respect to of the use of by-products and represents the present situation of circular economy in the sector.

Air quality and GHGs

The study looks to estimate Industrial Processes and Product Use (IPPU) emissions from the pulp and paper industry. IPPU emissions cover greenhouse gas emissions occurring from industrial processes, from the use of greenhouse gases in products, and from non-energy uses of fossil fuel carbon. The GHG emitted is carbon dioxide.

Emissions occur during the make-up of carbonates in the recovery process (through addition of lime/limestone and sodium carbonate). Emissions from limestone occur in wood based mills where make-up limestone is added in kilns to produce lime. In agricultural residue based mills lime is bought from market and hence emissions due to conversion of limestone to lime are undertaken outside the scope of the study.

Table 39: Carbon dioxide emissions from IPPU sector (kilotons CO_2 per year)

Input	Lower bound	Upper bound
Limestone	22	106
Sulphidity chemicals	55	97
Total	77	203

Table 39 presents the lower and upper range of emissions. The wide range of the total emissions is due to the uncertainty in the consumption of the chemicals that cause the emissions.

Discussion

While resource efficiency is generally understood in terms of three kinds of resources, materials, energy and water, this study focuses on material resources alone for the following reasons: in India, energy and water consumption have been given much attention in the pulp and paper industry over the last two decades.[74] Thirty-one pulp and paper units were named Designated Consumers in the Perform, Achieve and Trade (PAT) Cycle 1 scheme of the National Mission for Enhanced Energy Efficiency (NMEEE), implemented by the Bureau of Energy Efficiency (BEE), Ministry of Power. It resulted in energy savings of 0.289 Mtoe and GHG reductions of 1.24 $MtCO_2$-eq.[75]

Numerous initiatives on water conservation have been implemented by industry in India in response to societal and policy pressures; the water consumption in Indian mills has significantly reduced over the last two decades.[76] Material flows at the level of a factory do not usually account for water because of the significant weight associated with its use in industrial processes: including water completely mask the flows of other materials.[77]

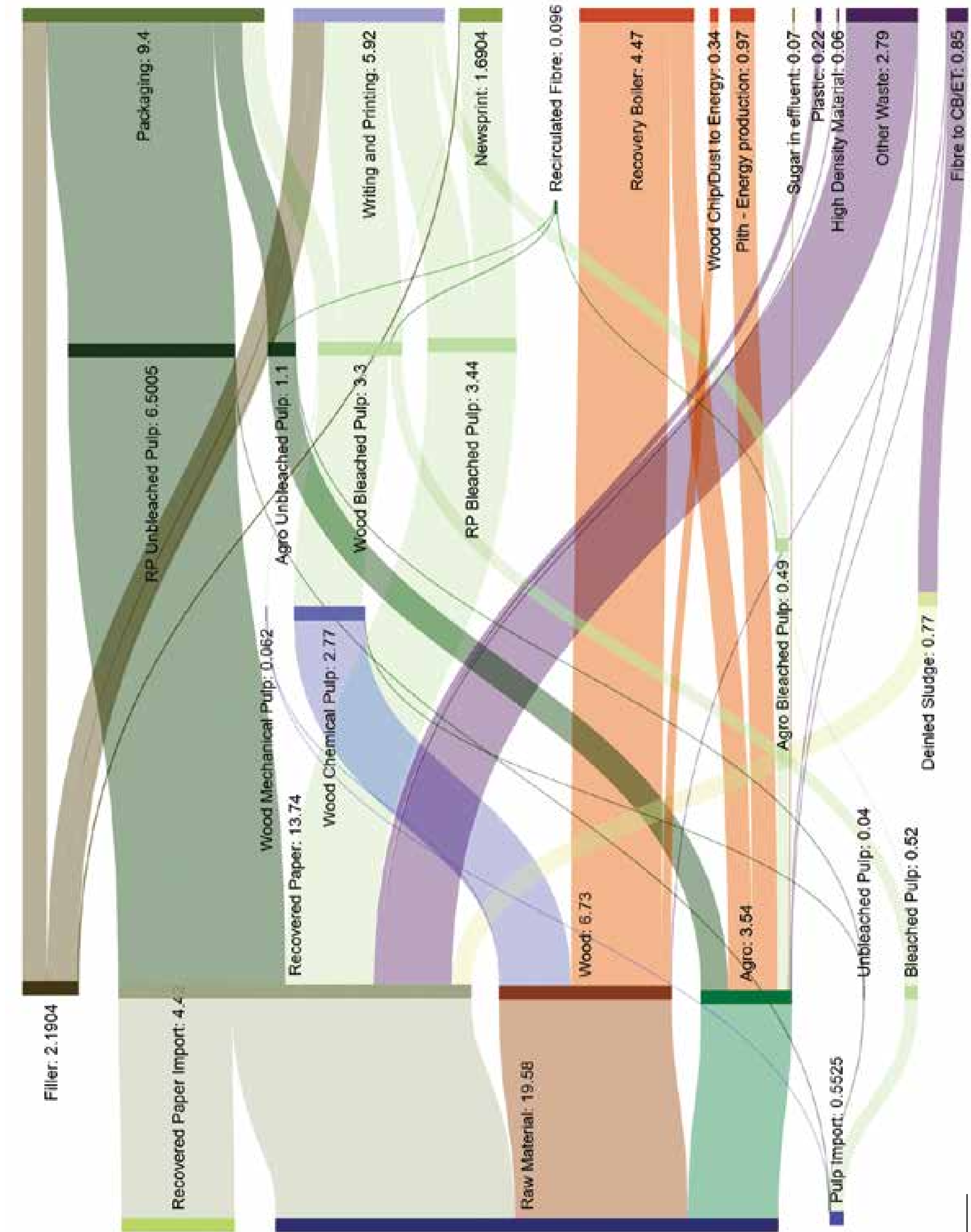
[74] Analysing Resource Efficiency Transitions in Asia and the Pacific. UNESCAP. 2017. Accessed from https://www.unescap.org/sites/default/files/publications/Analysing%20Resource%20Efficiency%20Transitions_arunjacob_13_3_2018.pdf on 01 May 2019.

[75] Pulp and Paper Sector. BEE. Accessed form https://www.keralaenergy.gov.in/files/Resources/Pulp__Paper_Sector_Report.pdf on 25 April 2019

[76] Report on Water Conservation in Pulp and Paper Industry. CPPRI. 2008. Accessed from http://www.dcpulppaper.org/gifs/report17.pdf on 01 May 2019.

[77] Measuring Material Flows and Resource Productivity: Volume I: The OECD Guide. OECD. 2008. Accessed from https://www.oecd.org/environment/indicators-modelling-outlooks/MFA-Guide.pdf on 30 April 2019.

Figure 15: Material flow of the paper sector in India[73]



[73] All values in million tons

Therefore in the current study, only footprints of energy and water in pulp and paper manufacturing are reported.

The material flow in Figure 15 is a representation of the relative importance of resource streams generated across the Indian economy through the manufacture of pulp and paper. These have been discussed separately for the three fibre sources (raw material streams) in the subsequent section.

Recovered Paper

Over half of paper produced in India (66%) is made in mills using recovered paper as fibre source which would imply that the wastes from this raw material stream form a significant component of the waste generated throughout the country. Recovered paper is the fibre source and the sector depends on imported recovered paper: estimates from this study suggest that about one-third (32%) of the recovered paper demand is met by imports (refer to Figure 12 for time series data on recovered paper import to India). However, the quality of imported recovered paper is not uniform, and a substantial portion of the imports consists of unsorted scrap paper. On account of the low quality (poor segregation) of imported recovered paper, the overall yield of recovered paper units is also low. Poorly segregated recovered paper is associated with a larger proportion of by-products such as plastics, high density materials, packaging waste, deinked sludge, etc.

De-inked sludge generated during the production of newsprint and writing/printing paper from recovered paper forms a major part (0.77 MT) of the waste generated in mills using recovered paper as raw material. The sludge is made up of a small fraction of fibre and filler material (usually calcium carbonate) and is sold to cardboard and egg-tray manufacturers. Since, it contains calcium carbonate, it can also be used in cement manufacturing and to make filler material used in the paper machine. Even though the amount of sludge generated by individual units is insignificant, (since most mills in this class are small-scale units) they are often located in clusters, and the cumulative sludge generated is significant and merit policy attention.

Due to the large variation (60% to 90%) in the yield of such mills, there is uncertainty in the total allocation of wastes generated by them in the material flow diagram. A small component of the raw material stream is composed of plastics (0.22 MT) and high-density materials (0.06 MT). These are sold to recyclers through formal or informal channels. To balance the material flow in the analysis and account for the uncertainty in yield, a portion of the waste (2.75 MT) generated by such mills (Figure 15) is classified as "other waste" and includes waste streams shown in the diagram (plastics, deinked sludge and high-density materials) along with the packaging material used during the transportation of recovered paper.

In the larger wood and agricultural residue-based mills the larger scale of operations allow better practices in the form of process upgrades and attention to the quality of the fibre source.

Wood

Pulping (when wood is the fibre source) involves the separation of cellulose (fibre) from non-cellulose material (mostly lignin and hemicellulose) in the raw material. Hardwood species that are used in India have a fibre content of 45 to 48%; globally, hardwood species with a higher fibre content (51 to 53%) are used. The large scale of operations in wood-based mills compared to mills using recovered paper and agricultural residue) translates into good operating practices, better process technologies and efficient raw material consumption.

In mills using wood 2-5% of raw material in the form of wood dust is generated when the wood is chipped, which is sent to the unit's cogeneration facility (the boilers here are known as 'green' boilers). The lignin and other non-fibrous components of wood (separated from pulp after the digesting process) are sent to recovery boilers for steam cogeneration. A fibre loss of 2% (0.05 MT) is noticed across the manufacturing process and is recovered in ETPs to be sold to cardboard and egg-tray manufacturers. According to estimates from this study, all these together (wood chip dust, lignin, fibre loss collected at ETP) amount to 56 to 58% of the raw material input.

Agricultural residue

The residue used to make paper is composed of pith, fibre and non-fibrous material. In mills using agricultural residue as fibre source, 27.5% of the residue (mostly pith) is sent to boilers, while 18% of the raw material (non-fibrous material) is used in recovery boilers for steam cogeneration. It is estimated 6% (0.03 MT) of fibre is lost in the manufacturing process is recovered in ETPs and sold to cardboard and egg-tray manufacturers.

Water is sprinkled on agricultural residue stored in the mills' yards to prevent it getting blown away. Sugar residue from bagasse (the residue used in one mill visited) dissolves into the water and leaches out. This leachate was collected and used to generate biogas and supplement energy generation within the mill.

Producing goods using recycled materials is less energy intensive than manufacturing goods from virgin materials. Recycling can thus reduce production costs and carbon emissions. Recycling has a great potential to improve resource efficiency.

Recycling Metrics

Recycling is commonly calculated by dividing the demand of recovered paper by the total production of paper.[78] Based on our estimates, for the Indian economy this is at 81%, but the basis for calculation would appear to be erroneous. This is because a quantity at the pulping stage (demand of recovered paper) is compared with a quantity at the paper-making stage (final production) omitting losses that might occur between the two stages. A more consistent and meaningful metric is the recycled input rate (RIR) which compares recovered paper input with total inputs (fibre source: wood, agricultural residue and recovered paper).[79] The RIR is computed at 57%. Another similar metric is the recycled fibre rate (RFR) which compares fibre from recovered paper to total fibre requirement.[80] The value of RFR based on the study is estimated at 67%.

Table 40: Value of various recycling metrics[81]

Metric	Metric
Recycling	81%
Recycled input rate (RIR)	57%
Recycled fibre rate (RFR)	67%

While these metrics suggest that 100% recycled paper is technically possible, in practice, a lot depends on the desired quality and properties of the final products.

The final product defines the technical limit up to which recycled fibre can be substituted for virgin fibre. Improving the yield of mills using recovered paper as fibre source by improving the quality of the input recovered paper would reduce the demand for recovered paper, and hence reduce the value of RIR. Thus, these metrics should be interpreted with some knowledge of the assumptions and calculations.

Air quality and GHG benefits

Greenhouse gases are emitted at various stages of the pulp and paper making process. However, the current study limits the scope of emissions to the IPPU sector. Emissions are estimated to range between 77 and 203 kilotons of CO_2. Major emissions occur due to the burning of limestone in kilns for production of lime. If agriculture residue based mills were to use lime kilns with recovery rates in the lime cycle similar to wood based mills, the overall IPPU emissions would increase by 10 to 20%.

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[78] A global, comprehensive review of literature related to paper recycling: A pressing need for a uniform system of terms and definitions. Ervasti, I., Miranda, R. and Kauranen, I. Waste Management 48, pp. 64-71. 2016. Accessed from https://www.sciencedirect.com/science/article/pii/S0956053X1530204X?via%3Dihub on 29 April 2019.

[79] What do we know about metal recycling rates? Graedel, T. E., J. Allwood, J. P. Birat, M. Buchert, C. Hagelüken, B. K. Reck, S. F. Sibley, and G. Sonnemann. Journal of Industrial Ecology 15(3): 355–366. 2011. Accessed from https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1530-9290.2011.00342.x on 29 April 2019.

[80] Fibre requirement is the difference of total paper production and total amount of filler and other materials

[81] Based on estimates from current study.

SECTION V:
Summary and Recommendations

The study identifies few areas of intervention for both government and businesses that can assist in reducing emissions, improving air quality and reduce pressures on raw material extraction. These are listed below for both the steel and paper sector.

Steel sector

- Government
  - ◊ Government explore possibility of setting-up hubs for raw material stocking and procurement (iron-bearing materials such as scrap, DRI and pig iron), thus discouraging the procurement of iron-bearing material from larger distances (including imported scrap).
    - ▪ It became evident during the study that iron-bearing materials are often transported across large distances across the country. There is scope to reduce emissions from transport of IBMs.
    - ▪ The study corroborates the recommendation of Niti Aayog's Strategy Paper on Resource Efficiency in Steel Sector Through Recycling of Scrap & Slag for the setting-up of scrap processing units near the centers/clusters of scrap consumers.
  - ◊ Government explore possibility of setting-up industrial parks for steel manufacturing
    - ▪ Industrial parks would promote setting-up common facilities for ore beneficiation, sintering and pelletization, since all three lead to large improvements in yield.
    - ▪ Conversion and end-use manufacturing plants can be set up close by to reduce transport costs and corresponding emissions.
- Businesses
  - ◊ Businesses to look at use of hydrogen-based DRI (H-DRI) technology.
    - ▪ A substantial part of emissions (86%) in the iron and steel-making processes occurs during the iron-making stage (refer to Figure 9 for MFA of steel sector).
    - ▪ Of the two process routes, the DRI process is more polluting than the BF process.
    - ▪ Using H-DRI can help reduce emissions associated with burning of coal (used as a reducing agent). The specific energy consumption of the H-DRI process is 5% less than that of the BF process.[82]
    - ▪ Complete transition to H-DRI technology can help reduce coal consumption in DRI making to zero (estimated current coal consumption through coal based DRI is 17 to 19 million tons)
    - ▪ Transition towards H-DRI will lead to an increase in electricity consumption (since such units run on electricity). However, with the construction of more super critical thermal power plants and increased contribution of renewable power to the grid, the overall environmental impact of the transition would be lower than in the current scenario.
  - ◊ Businesses to look at setting up shared services.
    - ▪ Mills located in clusters or ones located in industrial parks can set up common facilities for ore beneficiation, sintering and pelletization, since all three lead to large improvements in yield.

[82] Assessment of hydrogen direct reduction for fossil-free steelmaking. Vogl, V., Åhman, M. and Nilsson, L.J. Journal of Cleaner Production Volume 203, pp. 736-745. 2018.

- Small-scale mines located close together can set up ore blending and beneficiation facilities on a shared basis.
- Small-scale steel manufacturers (less than 1 MTPA) can examine the possibility of resource-sharing, especially for sintering and pelletization, both of which improve yields.

Paper sector

- Government
  - ◊ Government (through the Ministry of Commerce, Customs, Department for Promotion of Industry and Internal Trade, Bureau of Indian Standards etc.) develop standards for quality of recovered paper import and establish monitoring mechanism.
    - Currently, imported recovered paper meets nearly one-third of the country's requirement. Poorly segregated recovered paper in the country of origin, leads to reduced yield in mills using this as fibre source. The study found lower yields in mills dependent on imported paper.
    - Imports meeting a specified quality standard could cut the requirement by 0.86 MT (a reduction of 20% from current levels).
    - Such a standardization would go a long way in reducing Scope III emissions (from transport of imported paper from the country of origin to ports to manufacturing units).
  - ◊ Government (through Ministry of Heavy Industries, Ministry of Environment, Forest and Climate Change, etc) mandate setting of RE target for replacement of virgin limestone in cement manufacturing.
    - To this effect the following waste utilizations from the paper industry can be investigated further:
      - Lime sludge from agro-based paper industries
        - ◊ Lime sludge in such mills has a high silica content (compared to wood based mills): sludge from the first stage of the causticizer can be used in the cement industry.
        - ◊ One of the companies studied (with a cement manufacturing unit located close by) substituted 24,545 tons of virgin limestone year with 44,528 tons of lime sludge from the paper mill.
        - ◊ This would also reduce emissions associated with the extraction, processing and transport of limestone.
      - Deinked sludge from recovered paper units in the clinker manufacturing process.
        - ◊ Some recovered paper-based plants were sending their deinked sludge to cement manufacturing units in the vicinity. Annually, 0.77 MT (estimated in our study for 2017-18) of deinked sludge (containing mostly filler material, calcium carbonate, and uncooked fibre), is generated across the country. This is a useful input particularly for mini-cement plants and can reduce the pressure on virgin raw material extraction and its associated emissions.
- Businesses
  - ◊ Companies (through their operations or research and development departments) examine possibility of using leachate generated from storage of agricultural residue (especially bagasse), for biogas-based energy generation.
    - One of the companies visited in the study reported an annual generation of 6.3 million m^3 of biogas, resulting in savings of 3,724 KL of furnace oil, 319 MT of imported coal and 83,314 tCO_2-eq of GHG emissions by using leachate to generate energy.
    - Extrapolating the value for biogas generation from agricultural residue leachate, there is a potential for generation of about 30 million m^3 of biogas.
  - ◊ Private sector, Department for Promotion of Industry and Internal Trade (DPIIT) and research institutions can examine the scope of research and development for regenerating filler material from deinked sludge.
    - Deinked sludge has a high percentage (almost 65%) of calcium carbonate, which forms a filler in the paper-making stage. There is potentially a scope for exploring utilization of this waste stream for regeneration of filler. 0.77 MT of deinked sludge is generated across the country
  - ◊ Companies (through their raw material procurement departments) recommended debarking wood to reduce gross material entering the process and improve efficiency/yield.

SECTION VI:
Future Work

Several areas with scope for future work emerged as the study unfolded: the use of material flow analysis as a tool and its visual representation allowed a direct understanding of the magnitude of resource flows at national level.

For example, it is immediately evident from the steel MFA that the bulk of emissions in that sector is associated with iron-making process. In the paper sector study, also, the width of the inflow for paper imports shows that it is a significant contributor to raw material demand; the points where action can be taken are immediately evident. Such MFAs can be drawn up for a large number of materials and sectors critical to the country's economy and industry.

Across the study there were pointers to the potential for reducing Scope 3 emissions. There were several examples of good practices and the use of one unit's waste as inputs into another's, either within that unit or outside, illustrating the practice of industrial symbiosis. These practices, if documented and mainstreamed would lead to savings in resource use throughout industry.

Although this was a scoping study and limited to the gates of the factory, there were enough indications of the potential to reduce air pollution, GHG emissions and increase resource-use efficiency that also lay outside the factory walls. Expanding the boundaries in future work would lead to the identification and quantification of all such points of potential, and a description of how circular economy principles would apply to sectors.

The study also throws up avenues for future work that would help refine the findings of the current study. Some of these are:

- Increase the scope of MFA to include end-of-life to improve understanding and estimation of the overall recycling potential of scrap metal and recovered paper.
- MFA for steel products to cover rolling, casting, and fabrication.
- Quantify environmental, social and economic cost-benefit to support the case for improved resource efficiency.
- MFA-based studies in other resource-intensive sectors such as cement and for other construction materials, sand, soil and stone, aluminum and plastics.
- Resource efficiency linked performance indicators for India and develop a monitoring mechanism for government.

ANNEX I

Table 41: **List of HS codes and their description**

HS Code	Description
47071000	Waste and scrap of unbleached kraft paper or paperboard or corrugated paper/paperboard
47072000	Waste and scrap of other paper/paperboard made of bleached chem pulp not colored
47073000	Waste and scrap of other paper/paperboard made of mechanical pulp (e.g. newspaper journals etc.)
47079000	Other incl unsorted waste and scrap
47031100	Chemical wood pulp unbleached conifers, sulphate
47031900	Chemical wood pulp unbleached n-conifers, sulphate
47032100	Bleached or semi-bleached coniferous chemical wood pulp sulphate
47032900	Bleached or semi-bleached non-coniferous chemical wood pulp sulphate
47041100	Unbleached conifers chemical wood pulp sulphite
47041900	Unbleached n-conifers chemical wood pulp sulphit
47042100	Semi-bleached/bleached coniferous chemical wood pulp sulphite
47042900	Semi-bleached/bleached non-coniferous chemical wood pulp sulphite
47061000	Cotton linters pulp
47062000	Pulps of fibres derived from recovered (waste and scrap) paper and paperboard
47063000	Other, of bamboo
47069100	Other mechanical pulp
47069200	Other chemical pulps
47069300	Other semi-chemical pulp
47010000	Mechanical pulp
7204	Ferrous waste and scrap; remelting scrap ingots of iron or steel
72041000	Waste and scrap of cast iron
720421	Waste and scrap of stainless steel
720429	Waste and scrap of other alloy steels
72044100	Turnings, shavings, chips, milling waste, saw dust, fillings, trimmings and stampings, whether or not in bundles
72044900	Other
72045000	Remelting scrap ingots
2601	Iron ores and concentrates including roasted iron pyrites
260111	Non-agglomerated
260112	Agglomerated

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