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Material Consumption Patterns in India

A Baseline Study of the Automotive and Construction Sectors

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March 2016

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List of Abbreviations

ABS	Antilock Brake System
ABS	Acrylonitrile Butadiene Styrene
ACMA	Automotive Component Manufacturers Association of India
AMD	Acid Mine Drainage
ARAI	Automotive Research Association of India
ASA	Acrylonitrile Styrene Acrylate
ASR	Auto Shredder Residue
BIS	Bureau of Indian Standards
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BOF	Basic Oxygen Furnace
BRIC	Brazil-Russia-India-China
BTU	British Thermal Unit
C&D	Construction and Demolition
CAGR	Compound Annual Growth Rate
CCR	Continuous Casting and Rolling
CDM	Clean Development Mechanism
CEN	European Committee for Standardisation
CFRP	Carbon Fibre Reinforced Plastic
CPCB	Central Pollution Control Board
CRRI	Central Road Research Institute
CRZ	Coastal Regulation Zone
CSE	Centre for Science and Environment
CSR	Corporate Social Responsibility
Cu	Copper
DE	Domestic Extraction
DfR	Design for Recycling
DM	De-Mineralisation
DMC	Domestic Material Consumption
DMI	Direct Material Input

DMO	Direct Material Output
DPO	Domestic Processed Output
EEA	European Environment Agency
EC	Electrical Conductivity
ELV	End-of-life Vehicle
ESP	Electrostatic Precipitator
ETP	Effluent Treatment Plant
EU	European Union
FIMI	Federation of Indian Mineral Industries
FSV	Future Steel Vehicle
GARC	Global Auto Research Centre
Gcal	Giga Calorie
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft fur Internationale Zusammenarbeit GmbH
GJ	Giga Joule
GoI	Government of India
GRIHA	Green Rating for Integrated Habitat Assessment
GSB	Granular Sub Base
GSI	Geological Survey of India
GWP	Global Warming Potential
HCL	Hindustan Copper Limited
IBM	Indian Bureau of Mines
ICE	Internal Combustion Engine
IGBC	Indian Green Building Council
INDC	Intended Nationally Determined Contributions
INR	Indian Rupee
ISO	International Organisation for Standardisation
KIOCL	Kudremukh Iron Ore Company Limited
kWh	Kilo Watt-hour
LC^3	Limestone Calcined Clay Cement
LEED	Leadership in Energy and Environmental Design

MAV	Multi-Activity Vehicle
MFA	Material Flow Analysis/Accounting
MJ	Mega Joule
MMDR	Mines and Minerals Development and Regulation Act (Government of India, 1957)
MNRE	Ministry of New and Renewable Energy (Government of India)
MoCF	Ministry of Chemicals and Fertilizers (Government of India)
MoCI	Ministry of Commerce and Industry (Government of India)
MoEF&CC	Ministry of Environment, Forest and Climate Change (Government of India)
MoHI	Ministry of Heavy Industries and Public Enterprises (Government of India)
M-sand	Manufactured Sand
MWh	Mega Watt-hour
NAS	Net Additions to Stock
NATRiP	National Automotive Testing and R&D Infrastructure Project
NEDO	New Energy and Industrial Technology Development Organisation
NGO	Non-Governmental Organisation
NGT	National Green Tribunal
NiMH	Nickel Metal Hydride
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OES	Original Equipment Supplier
PAT	Perform Achieve and Trade
PBT	Polybutylene Terephthalate
PE	Polyethylene
PET	Polyethylene Teraphthalate
PGM	Platinum Group Metals
PMMA	Polymethyl Methacrylate
POM	Polyoxymethylene
PP	Polypropylene
PPP	Purchasing Power Parity
PPP	Public Private Partnership
ProgRess	Resource Efficiency Programme (German Federal government)

PSU	Public Sector Undertaking
PTB	Physical Trade Balance
PVC	Poly Vinyl Chloride
PWD	Public Works Department
R&D	Research and Development
RCC	Reinforced Concrete Cement
RMC	Raw Material Consumption
RMC	Ready Mix Concrete
RME	Raw Material Equivalent
RMI	Raw Material Input
RWA	Residents Welfare Association
SAIL	Steel Authority of India Limited
SEC	Specific Energy Consumption
SEEA	System of Integrated Environmental and Economic Accounting
SEIAA	State Environmental Impact Assessment Authority
SIAM	Society of Indian Automobile Manufacturers
SIIL	Sterlite Industries (India) Limited
SME	Small and Medium Enterprises
SPCB	State Pollution Control Board
SPM	Suspended Particulate Matter
TCS	Tonne of Crude Steel
TDO	Total Domestic Output
TDS	Total Dissolved Solids
TERI	The Energy and Resources Institute
TIFAC	Technology Information Forecasting and Assessment Council (Government of India)
TMC	Total Material Consumption
TMI	Total Material Input
TMO	Total Material Output
TMR	Total Material Requirement
TOE	Tonne of Oil Equivalent
UAE	United Arab Emirates

ULB	Urban Local Body
UN	United Nations
UNEP	United Nations Environment Programme
UNFC	United Nations Framework Classification for Mineral Resources
UNIDO	United Nations Industrial Development Organisation
USD	United States Dollar
USEPA	United States Environmental Protection Agency
UT	Union Territory
UV	Ultra Violet
WPI	Wholesale Price Index

Chapter 1: Introduction

All societies need natural resources for their economic and social well-being, be it metals, non-metallic minerals, fossil fuels, water or biomass. Owing to rapid economic and population growth throughout the 20th century, concerns about resource depletion have become more acute in the last few decades. Resource supply constraints and price shocks can not only produce potentially severe economic and social consequences, but can also engender political conflict when vital resources are unequally distributed. In addition, resource extraction, utilisation and disposal also typically impose significant environmental burdens, many of which, particularly climate change caused by GHG emissions from fossil fuel use, are becoming acute in the 21st century. Therefore, judicious use of resources is in every society's interest through a combination of conservation and efficiency measures for economic, social and environmental sustainability.

As the global economy grows, more integrated, coordinated and collaborative efforts are required to ensure both availability and conservation of resources to reconcile increasing demand with finite supply. Industrialised countries need to demonstrate how they intend to maintain a high quality of life while consuming fewer resources, whereas developing countries need to determine how their economies can continue growing through the most efficient use of scarce resources. While the European Union in general, Germany in particular, have adopted resource efficiency as a priority in their policy agenda and are taking consistent steps in that direction, it is also important for India to initiate discussion on resource use and to identify its own areas for action. In a resource constrained world, India cannot afford to ignore this issue since it can potentially jeopardise its development plans, not to mention the enormous social benefits that can accrue from reduced environmental burdens. In addition, GHG emissions reductions accruing from resource efficiency measures will help India to meet its climate change commitments under the Paris global accords, 2015.

1.1 Aims and Scope of this Study

The German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), under its International Climate Initiative, has launched a bilateral cooperation project with the Indian Ministry of Environment, Forests and Climate Change (MoEF&CC) titled Resource Efficiency and Sustainable Management of Secondary Raw Materials (in short "Resource Efficiency"). The project is being implemented by GIZ-India, in cooperation with German and Indian knowledge partners. The project aims to enable Indian key institutions responsible for the formulation of environment, climate, industry, and resource policy to aid and establish institutional frameworks that improve resource efficiency.

The project has three interrelated action plans (work packages). First, material flows in key selected sectors of the Indian economy will be mapped to identify gaps, barriers and areas of intervention. Second, options for improving resource efficiency and enhancing the use of secondary raw materials will be demonstrated on a pilot basis for selected industry sectors. Third, a high-level Indian Resource Panel will be set up with renowned experts who will provide recommendations to the Government of India based on the learnings from the project. This study is part of the first action plan (work package). A detailed analysis of material flows, resource needs, utilisation and trends in selected sectors will help achieve a better understanding of these sectors and identify gaps and barriers for resource efficiency and potential areas of intervention. These findings will inform both the selection of pilot demonstration projects as well as the deliberations of the Indian Resource Panel. Pilot projects will demonstrate reductions in material use, energy use and GHG emissions, and policy recommendations by the Indian Resource Panel will aim to upscale such improvements economy wide.

The automotive and construction sectors have been chosen due to their importance in the Indian economy, as outlined in section 1.3. Chapter 2 will discuss methodological approaches related to accounting of material flows. Chapter 3 will offer a detailed analysis of material flows, resource needs, utilisation and trends in the Indian automotive and construction sectors. Chapter 4 will survey best practices in resource efficiency in the respective sectors in India as well as internationally and outline improvement potential. Finally, Chapter 5 will draw upon these findings to recommend future courses of action for improvements in resource efficiency.

1.2 Context of Resource Efficiency in India

India is witnessing dynamic transformation due to its rapid economic growth, which is driven by five main interlinked factors that have a strong impact on resource consumption (IGEP, 2013):

Growing population

India has the second largest population in the world at 1.25 billion (UN, 2015). It has the highest population growth rate among the BRIC nations and also in contrast to many Western countries that are currently experiencing negative population growth rates. Projections show that India will overtake China and become the most populous country by 2030 and its growth rate will remain positive past 2050 (UN, 2015).

Expanding industrial and service-related production

Although the agricultural sector is still dominant in terms of employment, the industrial and in particular the service sectors are increasingly contributing higher shares to employment and GDP. While in 2000, the agricultural sector still contributed nearly one-fourth of GDP, its share fell to 15% by 2011. In contrast, the service sector accounted for 58% of GDP in 2011 (Government of India, 2015a). Some Indian companies in the IT sector are among the world's leading companies. These companies are contributing increasingly to rising income and employment.

Rising (average) income

With an average GDP growth rate of 8% in the period from 2004-05 to 2011-12, India has been considered an emerging economy. India has demonstrated faster and more stable growth than most other emerging economies in the period 2006-2011 (IMF, 2012). By 2010, India's GDP ranked fourth in the world after USA, China and Japan (World Bank, 2015). While per capita income at USD 1,596 (current USD) is still low by international standards, it increased by a remarkable 400% between 1991 and 2014 (World Bank, 2015).

Growing middle class

With rising incomes, the middle class engages in aspirational consumer behavior accompanied by high resource consumption. A 2010 survey by the National Council of Applied Economic Research found that the Indian "middle class" doubled in size over the decade 2001-2010, growing from 5.7% of all Indian households to 12.8%. This was equivalent to 28.4 million households representing a population of 153 million people (Shukla, 2010). In terms of middle-class consumption expenditure, India is currently ranked 12th in the world; however by 2020 it is expected to be 3rd with a share of 13% of world's consumption, and the largest consumer by 2030, with a share of 23% of world consumption. By 2050, India will have the largest middle class in the world (Kerschner & Huq, 2011).

Increasing urbanisation

Like other emerging economies, India is also facing increased urbanisation, concomitant with a growing population. Indian cities are already home to about 350 million people, and by 2030, there will be an estimated 590 million people living in cities. Cities, which accounted for around 58% of India's GDP in 2008, will account for nearly 70% of GDP by 2030. However, compared to other BRIC nations, India had a relatively low urban population (31%) in 2010; and is therefore witnessing a much faster rate of urbanisation that is expected to continue till 2050 by which time a majority of India's population is expected to live in cities (McKinsey Global Institute, 2010). Increasing urbanisation creates huge demand for housing, infrastructure and other goods and services.

Per capita consumption of materials in India is still low compared to the rest of the world. With an average of 4.2 tonnes per capita, India ranked 151 out of 193 countries in the world in 2009, consuming less than half of the global average of around 10 tonnes. In comparison, in the same year, average resource consumption per capita in OECD countries was about 15.7 tonnes, while it was around 3.5 tonnes in the least developed countries (Dittrich, 2012). However, due to its large population, India's resource consumption is quite high in absolute terms. It also means that at the current rates of economic growth, India's resource demand is likely to increase very rapidly, and meeting that demand may be challenging.

In absolute terms, India's material consumption amounted to 4.83 billion tonnes in 2009, compared to 1.7 billion tonnes in 1980 (an increase of 184%) as depicted in Figure 1.1.

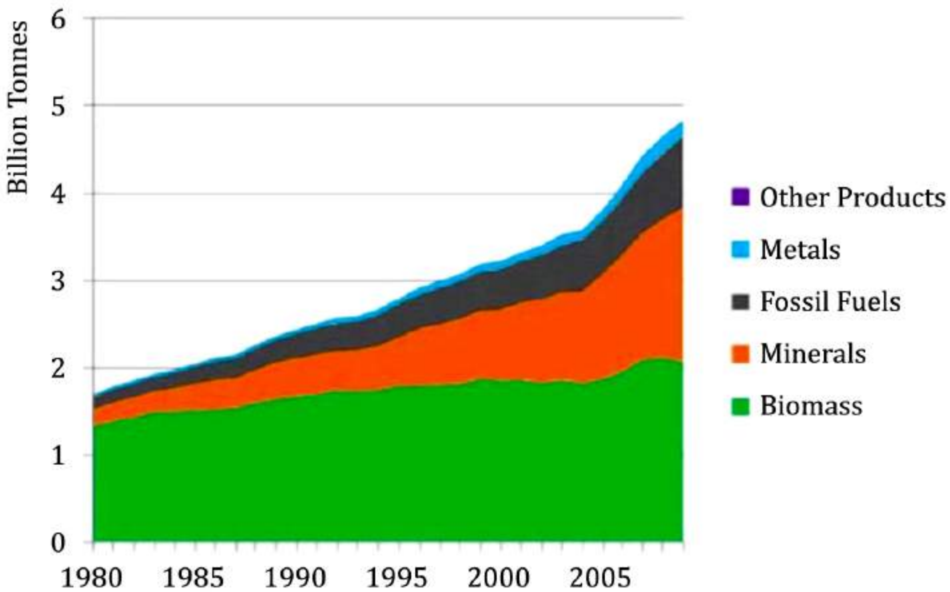


Figure 1.1: Absolute consumption of materials in India, 1980-2009

(Source: IGEP, 2013; p. 17)

In 2009, India was the third largest consumer of materials in the world after China (with 21.5 billion tonnes) and the USA (with 6.1 billion tonnes). In that year, India accounted for 7.1% of global material consumption while hosting 17% of global population (Dittrich, 2012). India's material consumption in the past few decades exhibits a pattern typical of countries making a transition from an agrarian society to an industrial society, where the consumption of non-renewable materials increases, in particular minerals and metals required for building infrastructure and fossil fuels for energy supply. This is clearly evident from Figure 1.1; the absolute consumption of biomass has almost stagnated while the share of renewable resources has declined from 79% in 1980 to 43% in 2009.

If current economic trends persist and population grows according to the medium UN scenario, India's material requirements are projected to be nearly 15 billion tonnes by 2030 and little above 25 billion tonnes by 2050 (Dittrich, 2012), with the biggest shares in fossil fuels and non-metallic minerals, as depicted in Figure 1.2. According to this projection, by 2030, India will consume as much materials as all the OECD countries combined consume today.

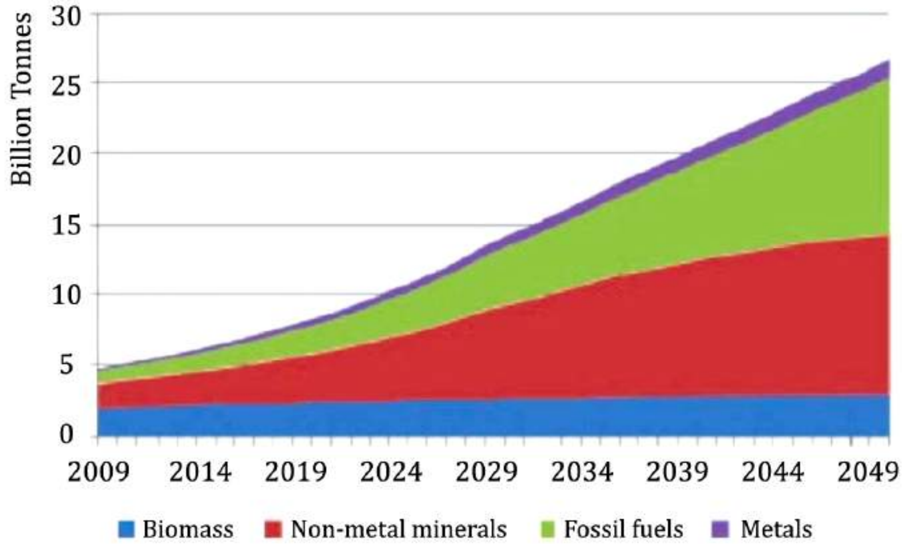


Figure 1.2: Future material consumption in India by category in scenario continuing current dynamic

(Source: IGEP, 2013; p. 21)

Like many countries, India meets most of its material requirements domestically, and increased domestic resource extraction is likely in response to the massive increase in future resource demand. While insufficient exploration and technological constraints may be one set of factors hindering effective utilisation of domestic mineral resources, environmental and social issues associated with mining are the bigger problems in India. Extraction per area in India, which could be used as a rough estimate of environmental pressure, is already the highest in the world, at 1,579 tonnes per km^2 land area compared to the global average of 454 tonnes per km^2 (Dittrich, 2012). Many mineral reserves are located in biodiverse forests, vital watersheds and lands inhabited by indigenous people. Environmental degradation, displacement and loss of livelihood associated with mining expansion has resulted in serious strife and conflict in many parts of India, and may be exacerbated with expanded mining (CSE, 2008). Further, since mining is an energy intensive industry, increased mining in forest areas would conflict with India's National Action Plan on Climate Change (IGEP, 2013). India has pledged to reduce its carbon intensity by 33-35% by 2030, from 2005 levels, under its Intended Nationally Determined Contribution (INDC) plan. Between 2000 and 2014, its carbon intensity has been falling by 1.4% annually, but this rate is insufficient to meet the declared target (PWC, 2015). Being the 4^{th} largest emitter of GHG and expected to be the world's fastest growing major economy, India's carbon intensity management will likely play an important role in determining the world's ability to limit global temperature rise to $2^{o}C$ by 2010. As with other sectors, GHG reductions through resource efficiency must make a significant contribution towards India's carbon intensity reduction target.

At present, around 97% of all materials consumed are extracted within India, while only 3% are net imports (Dittrich, 2012). While this aggregate figure may create the appearance of self-sufficiency, several considerations are necessary. Net imports have increased substantially over the past few decades, at a faster rate than that of domestic extraction; in 1980, India imported less than 0.8% of its material requirements. As a net importing country, India had a negative trade balance of USD 161 billion in 2011 (IGEP, 2013); improving or not worsening it is likely to be an important macroeconomic goal for policy makers. While the aggregate 3% figure appears small, India is already extremely import dependent for several vital minerals including 95% of copper, and 100% each for cobalt and nickel (IGEP, 2013). Mineral import dependent countries are likely to be exposed to several risks in the 21st century. Commodity price spikes due to demand-supply mismatch have wreaked havoc on many importing countries in recent years. This is further worsened by monopoly behavior on the part of exporting companies or countries. Some countries have even resorted to export restrictions to fulfill their strategic aims. And finally, several mineral rich countries have been affected by instability and conflict often leading to supply disruptions (IGEP, 2013). Therefore, high import dependence is a risky strategy for any country going forward.

Since over-extraction and over-dependence on imports both have significant associated risks, using resources more efficiently needs to be a major part of India's economic strategy. In 2009, India gained 716 USD (PPP in constant 2005 USD terms) per tonne of used material, while the global average was much higher at 953 USD, and the OECD average was 1,768 USD (Dittrich, 2012). While India currently lags significantly behind in terms of resource productivity, it has made significant improvements in recent decades. Between 1980 and 2009, India's resource productivity increased more than three times the global average (98% for India versus 27% for global average). However, India's improvements were lower than those of China (118%) and Germany (139%). If India continues to make improvements in resource productivity at the present rate, it could gain around 1,306 USD per tonne of materials by 2030 (Dittrich, 2012); a much higher level could be achieved with a stronger commitment to resource efficiency.

1.3 Rationale for the Choice of Sectors in this Study

The automotive and construction sectors were chosen for analysis in this study due to their economic importance as well as their considerable material requirements.

Automotive Sector

Mobility is vital for economic development and provision of essential services in any country, but the transportation sector is associated with many negative impacts – it is resource and energy intensive, and is often one of the highest contributors to pollution, including GHG emissions. India being a developing country, public transport still enjoys a high share in terms of transport mode. In 2010, less than a quarter of motorised trips were completed in personal vehicles (2 and 4 wheelers) while in Germany the same figure was just above 80% (IGEP, 2013). But car ownership is increasing rapidly and this trend is expected to continue due to rising incomes and an expanding middle class. The Indian automotive sector has enjoyed annual growth rates of 14.4% over the past decade. Currently, it employs 13 million people (about 1% of India's population), directly and indirectly, and contributes nearly 7% to India's GDP. India's auto production amounts to nearly 5% of world production, placing it 6th in the world (GIZ, 2015a). This is a key priority sector for the government that has future plans to transform India into a regional export hub catering to the Asia Pacific region.

Vehicle manufacturing requires different metals such as steel, aluminium, copper, lead, chromium, nickel and zinc, as well as significant amounts of plastic, glass, rubber and fabric. Analysing the direct and indirect raw material requirements in the Indian automotive sector and comparing them from 1997 and 2007, it was found that the material requirement of the sector doubled in a period of 10 years (IGEP, 2013) as shown in Figure 1.3.

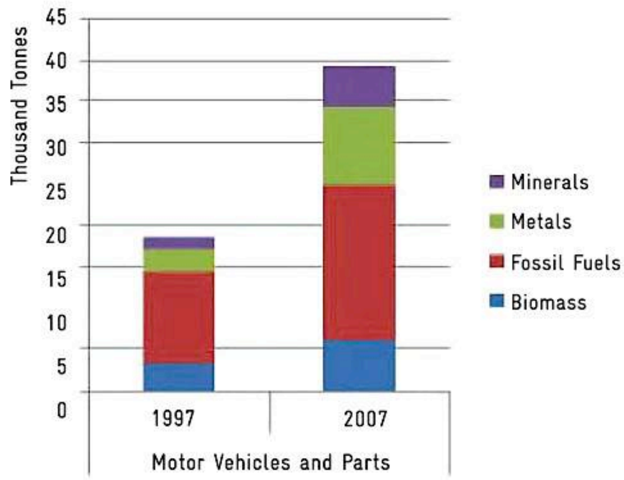


Figure 1.3: Raw material requirement of the Indian automotive sector (1997 and 2007)

(Source: IGEP, 2013; p. 49)

If current growth trends continue, the total number of registered cars could exceed 100 million by 2030, with a concomitant rise in material requirements.

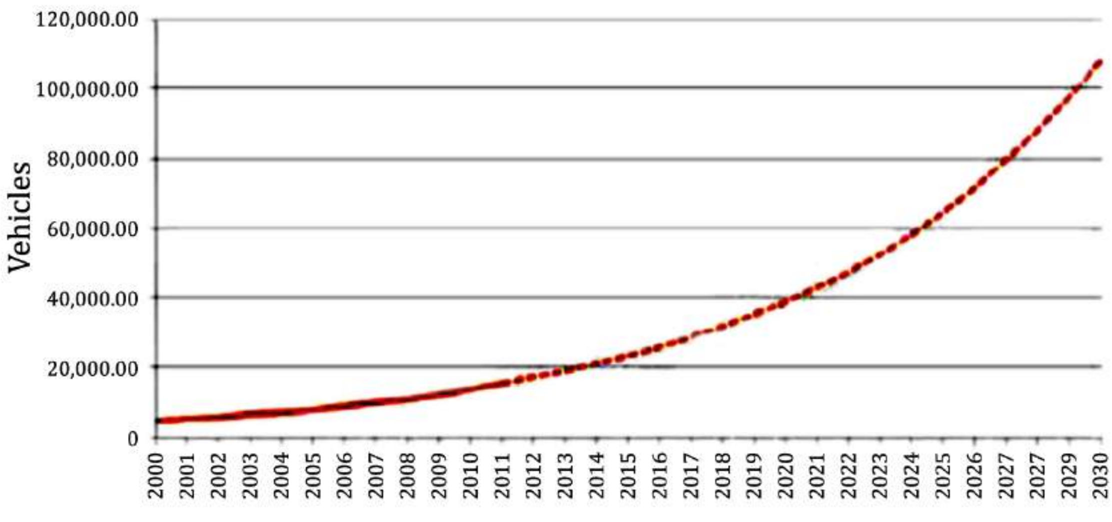


Figure 1.4: Growth in total number of registered cars in India*

* commercial vehicles not included; projected annual growth rate of 10.8% (2011-2030)

(Source: IGEP, 2013; p. 52)

The future distribution of different modes of transport – the modal split – has a significant influence on future resource demand. Heavy reliance on private vehicles would naturally mean much higher levels of resource requirements compared to reliance on public transport options.

Construction Sector

Housing and associated infrastructure are essential for economic and social well-being, but the construction sector is one of the largest consumers of material resources in any country. Provision of housing and related infrastructure plays a crucial role in countries undergoing rapid development and urbanisation. Housing and infrastructure investments are typically made for decades; therefore choices about design, location, building materials, etc. have long term implications with respect to resource and energy use.

The share of the real estate segment accounts for about half of the construction sector, while the other half is contributed by infrastructure. In the last few decades, India has increased its housing stock to a remarkable degree. According to the 2011 census, India's housing stock amounted to more than 330 million units, of which roughly 2/3 were in rural areas and 1/3 in urban areas; a significant increase compared to 250 million units in 2001 (Government of India, 2012). The Indian construction sector has been growing at an average annual growth rate of 10% over the last decade, with its contribution to GDP increasing from INR 1.5 trillion (USD 23 billion) in 2001-02 to INR 4 trillion (USD 62 billion) in 2011-12, equivalent to 8% of the nation's GDP. The construction sector forms the second largest segment in India's economy in terms of employment, after agriculture, providing employment to about 35 million people (Planning Commission, 2011).

While domestic production for domestic consumption has been the predominant feature of construction materials in India, recent demand growth is bringing about changes. In recent years, net imports of limestone and gypsum have increased in particular, while net exports of building stones and mineral products such as cement have decreased (IGEP, 2013).

Given the strong demand drivers – population, urbanisation and income growth – the under supply of housing is becoming acute, especially in cities (IBEF, 2011), and the built up area in India is expected to increase exponentially. According to NRDC-ASCI (2012), at current rates, about 70% of the buildings that will exist in 2030 are yet to be built. Considering the current housing stock of 330 million units, this means that 770 million housing units will be built by 2030. CSE predicts that the overall constructed area will swell to around five times the current size, reaching approximately 9.6 billion m^2 by 2030 (CSE, 2011).

In India, the construction sector was the second largest sector with regard to material consumption in 2007, accounting for around 20% of all material demand (Dittrich, 2012). Further, the construction sector was the fastest growing sector with regard to increases in absolute material consumption: between 1997 and 2007, material consumption grew by more than one billion tonnes. If such growth rates continue, the construction sector will surpass the agricultural sector before 2020 and become the sector with the highest material consumption in India (Dittrich, 2012).

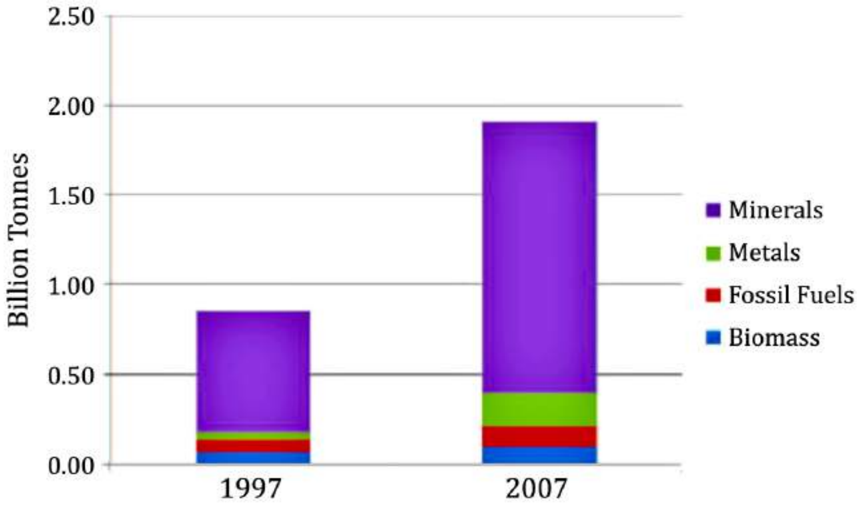


Figure 1.5: Raw material consumption in the Indian construction sector by main aggregates, 1997 and 2007

(Source: IGEP, 2013; p. 63)

The predominant materials used in the construction sector are sand, gravel, soil (for bricks) and limestone (for cement). Notably, the share of metals increased around 400% between 1997 and 2007, reflecting the more intensive use of structural metal elements in construction. The cement industry is one of the largest emitters of CO_2; in India it accounts for approximately 7% of the country's total CO_2 emissions (WBCSD & IEA, 2013). India is currently the second largest producer of cement in the world, producing 210 million tonnes in 2010, which was 6.3% of global production. India nearly quadrupled cement production between 1996 and 2010 (WBCSD & IEA, 2013). In India, per capita consumption of cement is still low at less than 200 kg per person relative to developed countries, but at current growth rates, Indian cement production may increase 4-7 times by 2050 (WBCSD & IEA, 2013). While India has considerable limestone reserves, they may run out by 2030 under the assumptions of the above scenarios (IGEP, 2013).

It is clear even from preliminary surveys that the Indian construction industry is likely to face serious material supply problems if predicted growth in demand continues. Supply bottlenecks are already starting to affect prices and construction schedules in some parts of the country. The construction sector is particularly vulnerable to price shocks since material costs account for roughly 2/3 of the total cost of a typical building (IGEP, 2013). Therefore, a strong emphasis on resource efficiency and use of secondary and alternate materials is essential for the Indian construction industry going forward.

Chapter 2: Conceptual Framework for Measuring Resource Use and Efficiency

2.1 Background

Making comprehensive assessments of a country's resource requirements is a challenging task. The methodological framework for Material Flow Accounting (MFA) was developed in response to the understanding that many of the most pressing environmental problems were strongly related to the overall scale of resource extraction and use. Economy wide MFAs and balances, and the indicators derived from them are descriptive tools aiming to provide information on the quantum of materials coming into and leaving a society/economy. They are conceptually based on a simple environment-economy model where the economy is embedded in the surrounding environment and connected through material and energy flows. Terms such as "industrial metabolism" or "societal metabolism" (Ayres 1989; Fischer-Kowalski & Haberl, 1993) have been used to illustrate such flows, and the scale of impact on the environment can be indicated by the size of the "metabolic throughput" (i.e. the amount of materials appropriated from the environment and returned back to it in altered form) (Daly, 1992). The material balance principle provides a logical basis for the physical book-keeping of the economy-environment relationship and for the consistent and comprehensive recording of inputs, outputs and material accumulation.

The basic principles and statistical approaches towards material flow accounts and material balances have been formulated in the 1970s (see for e.g. United Nations, 1976). In the 1990s, the applications were revitalised and put into statistical practice in several EU member states (Steurer, 1992; Schutz & Bringezu, 1993; German Federal Statistical Office, 1995; Eurostat, 1997), as well as in Japan (Japanese Environmental Agency, 1992) and the USA (Wernik et al., 1996). Research has advanced over the years, as have efforts to standardise approaches and formats. The publication of the reports: *"Resource Flows: The Material Basis of Industrial Economies"* (Adriaanse et al., 1997) and *"The Weight of Nations: Material Outflows from Industrial Economies"* (WRI, 2000) were important steps towards internationally comparable data based on harmonised approaches. Indicators for materials flows through the economy feature prominently on the political agenda in the context of concepts such as "factor 10" (Schmidt-Bleek, 1994) or "eco-efficiency". The EU Environmental Headline Indicators as well as the United Nations Indicators for Sustainable Development include a resource use or material consumption indicator based on a materials balance approach. The European Environment Agency (EEA), in its *"Environmental Signals 2000"* report included a first experimental estimate of Total Material Requirement (TMR) for the EU (EEA, 2000). The OECD as well as the UNEP have created programs and panels on materials flows and resource productivity within the last decade. The European Commission's Directorate General for the Environment collaborates with Eurostat and the EEA to compile and update standardised methodologies and develop environmental headline indicators one of which is based on materials balance (Eurostat, 2001). A major step towards methodological harmonisation was the publication of *Economy-wide Material Flow Accounts and Derived Indicators: A Methodological Guide* (Eurostat, 2001). The report *Materials Use in the EU-15: Indicators and Analysis* (Eurostat 2002), presented the first official MFA dataset for the EU-15 and provided detailed information on accounting methods. Standardised methodologies are updated at regular intervals and guides are made publicly available for practitioners and researchers (for example, see, Eurostat, 2009; 2013; and OECD, 2007). In recent years, this methodology has been used to conduct some initial assessments of material use in several Asian countries including India (see, UNIDO, 2010; 2011; Singh et al. 2012; IGEP, 2013).

MFAs are a part of environmental and natural resource accounting. They are integral to the world-wide System of Integrated Environmental and Economic Accounting (SEEA). The benefits of economy-wide MFA and materials balance accounts include (Eurostat, 2001):

- They provide insights into the structure and change over time of the physical metabolism of economies;
- They permit analytical uses, including estimation of material flows and land use induced by imports and exports;
- Useful indicators on resource use, resource productivity, eco-efficiency, material intensity, etc. can be derived;
- Through their underlying data structure, they can be integrated into existing national accounts for complementing macroeconomic analysis;
- They can be used to react flexibly and quickly to new policy demands (e.g., related to specific materials/sectors).

2.2 Key Concepts

Economy-wide MFA and balances provide an aggregate overview, in tonnes, of annual material inputs and outputs of an economy including inputs from and outputs to the environment and the physical amounts of imports and exports, as well as embodied/upstream flows associated with imports/exports. The net stock change (net accumulation) is equal to the difference between inputs and outputs. Economy-wide MFA and balances constitute the basis from which a variety of material flow based indicators can be derived. A complete material balance for an economy is statistically difficult to achieve since not all material input and output flows are observed in a systematic way; some material flow categories must be estimated. This method can be used to calculate the physical flows of an economy, or just be restricted to certain categories of flows, as desired by user/s. In this report, Eurostat methodology guidelines have been followed as much as possible.

Two types of system boundaries are recognised: one between the national economy and the natural environment, the other between the national economy and the rest of the world economy. Extraction of primary materials from and discharge of materials to the national environment are covered, as are material flows to and from the rest of the world (imports and exports). Natural flows into and out of a geographical territory, such as air and precipitation, are excluded. Material flows within the economy are not analysed in economy-wide MFA; however, they can be calculated in parallel if, say, analysis of a specific industry sector is required. Direct material inputs are defined as all materials[1] that enter the economy for further use in production or consumption processes. The two main categories of raw materials are those that are domestically extracted and those that are imported. Similarly, outputs include outputs to nature/environment and exports. Outputs to the environment are defined as all material flows entering the natural environment, either during or after production or consumption processes. Such outputs include emissions to air and water, waste landfilled, disposal of unused domestic extraction, as well as materials dissipatively used (e.g., fertiliser). The simplified scope of economy-wide MFA is depicted as follows in Figure 2.1; the more complete version including missing aspects follows subsequently.

[1] Experience shows that water flows are orders of magnitude higher than that of other materials, and hence are usually tabulated separately.

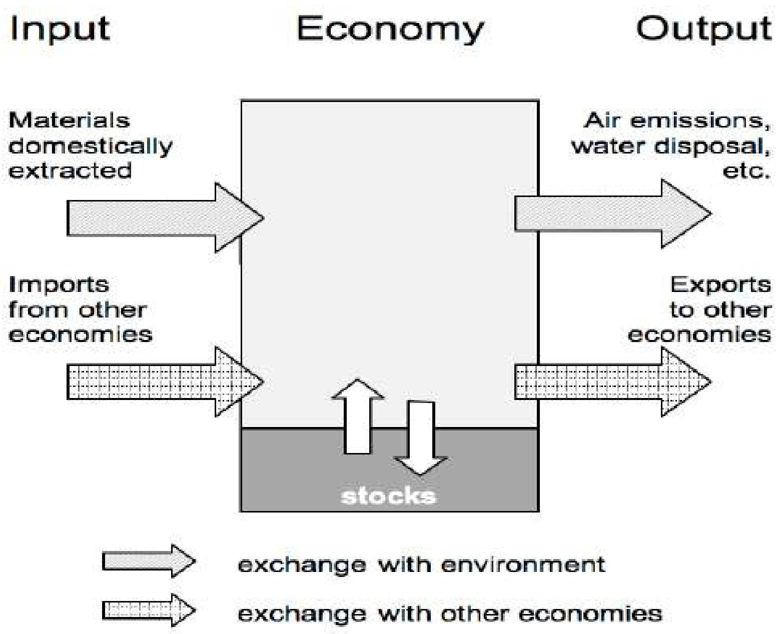


Figure 2.1: Simplified scope of economy-wide MFA

(Source: Eurostat 2009, p. 8)

In economy-wide MFA and material balance calculations, "hidden" flows are often captured by distinguishing between used and unused extraction. Materials that are extracted but not actually used by the economy may include mining overburden or soil excavation during construction. Such domestic hidden flows are termed "domestic unused extraction". Similarly, researchers may choose to account for unused extraction associated with imports occurring in foreign countries.

It is important to note that MFA is a flow concept, measuring flows of material inputs, outputs and stock changes within the national economy per year. This means that in MFA, stock changes are accounted for but not the quantity of the socio-economic stock itself. Again, individual studies focusing on, say a particular industry or sector, can choose to analyse that sector's stock depending on the scope of the study.

A schematic representation of economy-wide MFA is depicted in Figure 2.2. The figure includes input and output flows, including unused extraction, as well as the stock. Input materials, whether domestically extracted (DE) or imported, can be further disaggregated into, e.g., fossil fuels, metal ores, industrial minerals, construction minerals and biomass. Each of these broad material groups can be further broken down, e.g., fossil fuels into fuel types, biomass into timber, agricultural harvest, fish catch, etc. Output includes exports as well as domestic processed output (DPO) which includes materials flowing to the environment after being used in the domestic economy.

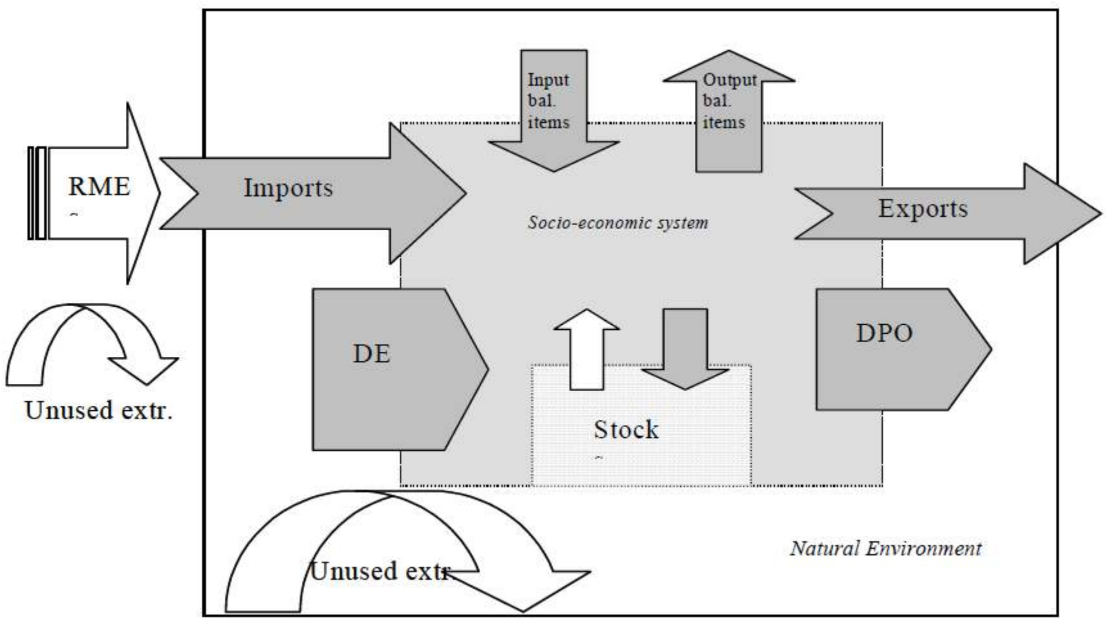


Figure 2.2: Schematic representation of economy-wide MFA

(Source: Eurostat 2009, p. 15)

2.3 Indicators Derived from MFA

A set of important indicators can be derived from the MFAs that provide an aggregate picture of the "industrial metabolism" of the economy. These indicators can be grouped into input, consumption and output indicators. The choice of the most relevant indicators for any particular project depends on the policy focus and goals of the project. Along the same vein, countries can choose to focus on certain indicators more than others depending on the focus and political goals of the country.

Input Indicators

Direct Material Input (DMI): measures the direct input of materials for use into the economy, i.e. all materials which are of economic value and are used in production and consumption activities. DMI equals domestic (used) extraction plus imports.

Total Material Input (TMI): includes, in addition to DMI, unused domestic extraction, i.e. materials that are moved by economic activities but that do not serve as input for production or consumption activities.

Total Material Requirement (TMR): includes, in addition to TMI, the (indirect) material flows that are associated to imports but that take place in other countries. It measures the total "material base" of an economy. Adding indirect flows converts imports into their "primary resource extraction equivalent".

Consumption Indicators

Domestic Material Consumption (DMC): measures the total amount of material directly used in an economy (i.e. excluding indirect flows). DMC equals DMI minus exports.

Total Material Consumption (TMC): measures the total material use associated with domestic production and consumption activities, including indirect flows imported but less exports and associated indirect flows of exports. TMC equals TMR minus exports and their indirect flows.

Net Additions to Stock (NAS): measures the "physical growth of the economy", i.e. the quantity (weight) of new construction materials used in buildings and infrastructure, and materials incorporated into new durable goods such as cars, machinery and household appliances. Materials are added to the economy's stock each year (gross additions), and old materials are removed from stock as buildings are demolished, and durable goods disposed of (removals).

Physical Trade Balance (PTB): measures the physical trade surplus or deficit of an economy. PTB equals imports minus exports. Physical trade balances may also be included for indirect flows associated to imports and exports.

Output Indicators

Domestic Processed Output (DPO): the total weight of materials, extracted from the domestic environment or imported, which have been used in the domestic economy, before flowing to the environment. These flows occur at the processing, manufacturing, use, and final disposal stages of the production-consumption chain. Included in DPO are emissions to air, industrial and household wastes deposited in landfills, material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows). Recycled material flows in the economy are not included in DPO.

Total Domestic Output (TDO): the sum of DPO, and disposal of unused extraction. This indicator represents the total quantity of material outputs to the environment caused by economic activity.

Direct Material Output (DMO): the sum of DPO and exports. This indicator represents the total quantity of material leaving the economy after use either towards the environment or towards the rest of the world.

Total Material Output (TMO): measures the total quantity of material leaving the economy. TMO equals TDO plus exports.

Efficiency Indicators

Material Intensity is defined as the DMC to GDP ratio.

Material Productivity is the inverse of material intensity, thus the GDP to DMC ratio.

Area Intensity: DE or DMC to total land area ratio: The ratio between material flows and total land area indicates the scale of the physical economy vis-à-vis its natural environment.

DE/DMC: The ratio of domestic extraction to domestic material consumption indicates the dependence of the physical economy on domestic raw material supply. Therefore, the DE to DMC ratio represents "domestic resource dependency" (see Weisz et al., 2006).

Use of New Indicators

While the economic system and traditional indicators are concerned with materials directly used, imported or exported, an increased focus on resource efficiency has elevated the importance of indirect flows such as unused extraction that do not end up as part of products traded or consumed in the economy. Capturing indirect flows with consistent empirical data is extremely challenging. Raw Material Equivalents (RMEs) are increasingly used to count trade flows within the system boundaries of domestic extraction used. All materials, used to produce the export within the boundaries of domestic extraction used are included in RME calculations. By doing this, the system boundaries are nearly the same as system boundaries of economic accounting. Consequently, the following indicators are now considered more useful for material flow accounting (Eurostat, 2014):

Raw Material Input (RMI) in place of DMI: includes domestic extraction and imports plus raw material equivalents of materials associated with the given imports within the system boundaries of domestic extraction used.

Raw Material Consumption (RMC) in place of DMC: similar to DMC but counts imports and exports in raw material equivalents.

2.4 Applications of MFA and Derived Indicators

MFA has been used extensively in several countries, most prominently in the EU nations. A few examples discussed below demonstrate their applications and usefulness.

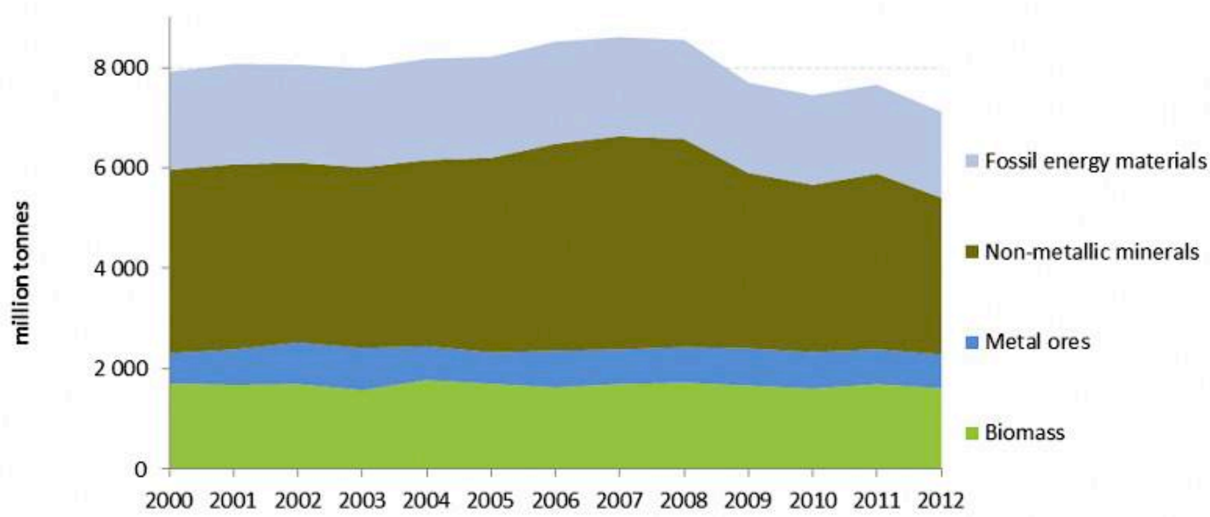


Figure 2.3: RMC broken down by material categories, EU-27, 2000-2012 (million tonnes)

(Source: Eurostat, 2014)

RMC is one of the central indictors in EU-27 for measuring material use and productivity. Figure 2.3 shows that RMC has gone down slightly in the EU over the last decade. Also, it is worth noting that non-metallic minerals account for a much higher share compared to other categories in overall material consumption.

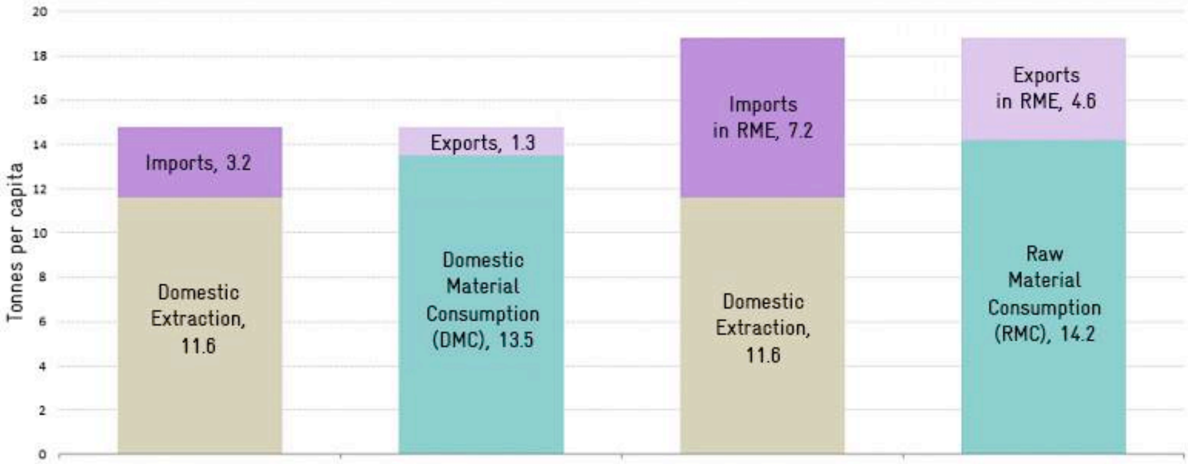


Figure 2.4: Comparison of actual material flow indicators with material flow indicators expressed in raw material equivalents (RME), EU-27, 2012 (tonnes per capita)

(Source: Eurostat, 2014)

Figure 2.4 clearly shows that imports and exports measured in RME for the EU nations is higher than the direct imports and exports. The imports measured in RME is higher than the exports measured in RME.

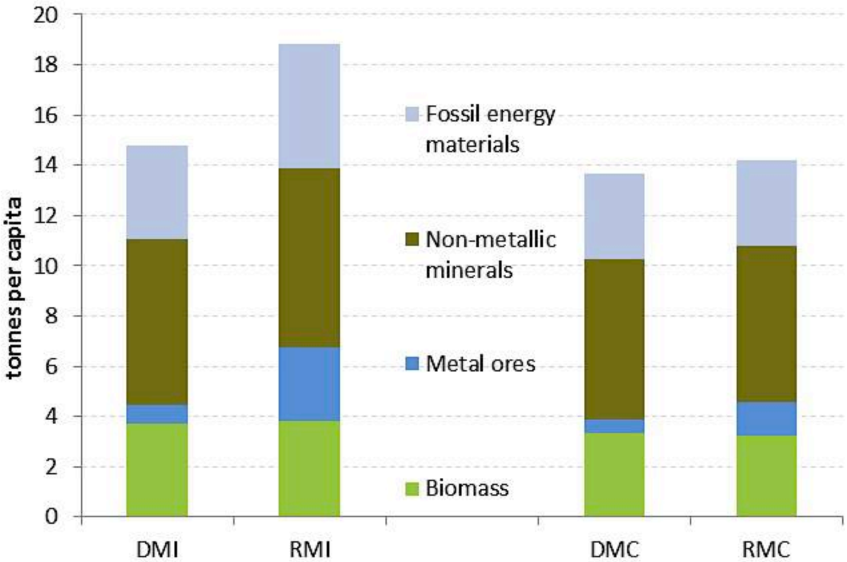


Figure 2.5: Comparison of DMI with RMI and DMC with RMC, EU-27, 2012 (tonnes per capita)

(Source: Eurostat, 2014)

From Figure 2.5, it is clear that the input indicators are greater in magnitude than the consumption indicators because consumption indicators deduct materials that are ultimately exported. It is once again evident, that the RME for metals ores are proportionally much greater than their DMI or DMC counterparts when compared to other categories (for the same reasons mentioned in Figure 2.4).

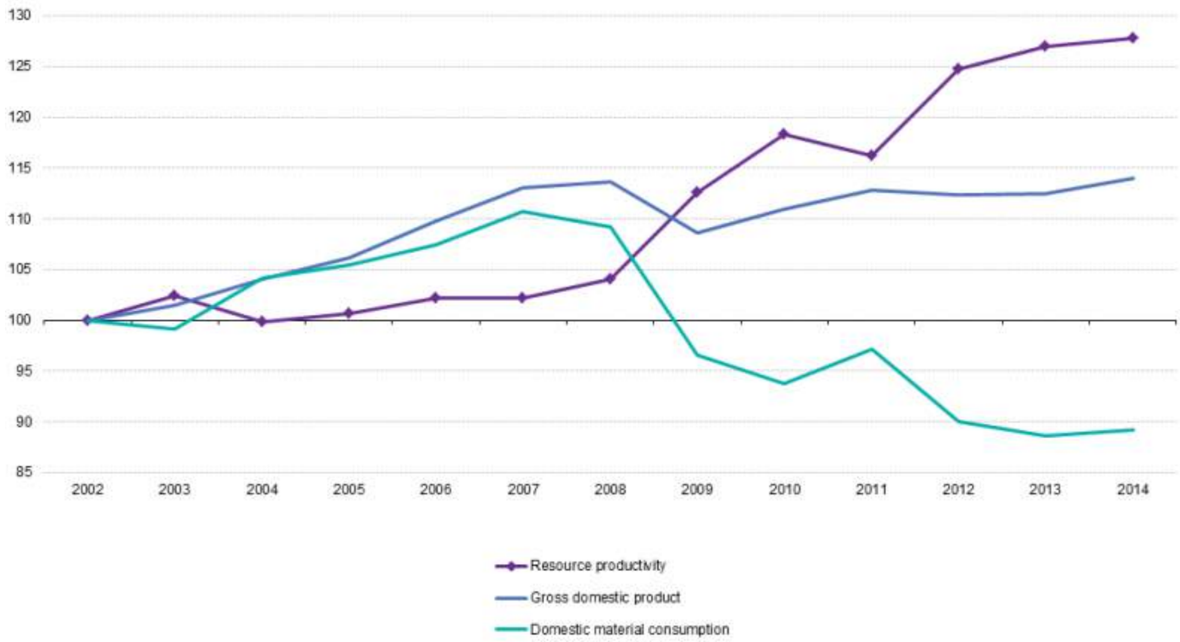


Figure 2.6: Change in resource productivity in comparison with GDP and DMC, EU-28, 2002-2014 (2002=100)

(Source: Eurostat, 2015)

Figure 2.6 shows a significant increase in resource productivity in the EU (as measured by the ratio of GDP and domestic material consumption), especially over the last 5 years.

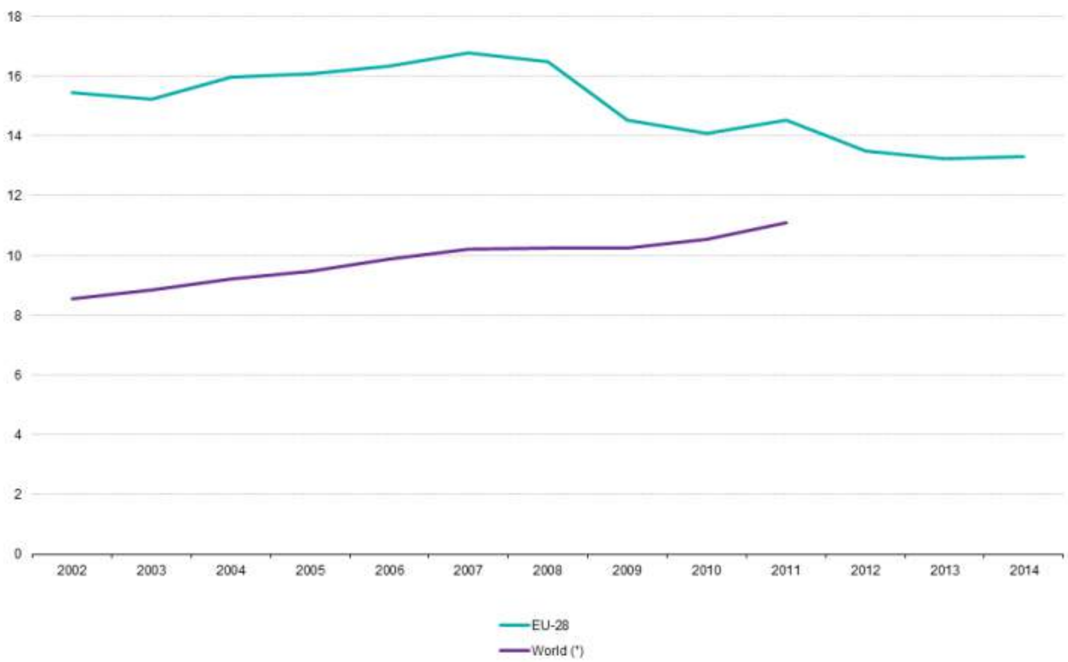


Figure 2.7: Trends in material consumption, EU vs. rest of the world (tonnes per capita)

(Source: Eurostat, 2015)

Figure 2.7 shows that per capita material consumption in the EU is declining gradually even though it is still significantly higher than the average for the rest of the world. However, the rest of the world is on an upward trajectory and is likely to catch up with the EU in the foreseeable future, driven by rapid industrialisation in many developing countries.

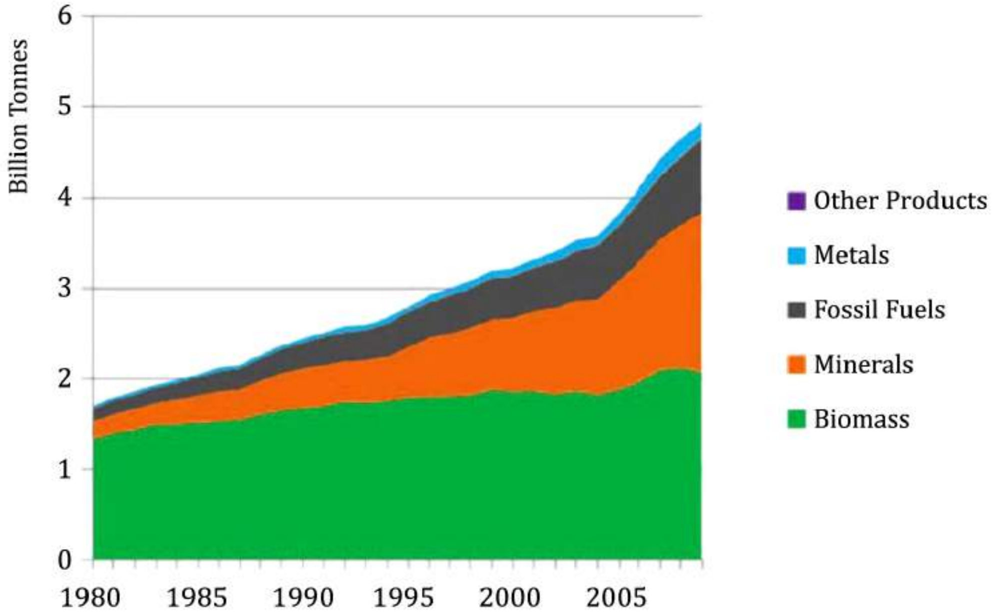


Figure 2.8: Material consumption in India by category, 1980-2009

(Source: IGEP, 2013; p. 17)

From Figure 2.8, several trends are noticeable. Firstly, biomass is the dominant material category, which is the trend in countries in their early stages of industrial development. However, in recent years, the share of biomass has stagnated while that of metals, minerals and fossil fuels has increased sharply, consistent with rapid industrialisation. Like other countries, non-metal minerals occupy a much bigger share compared to metals. Finally, the overall total material consumption has been increasing steadily, as one would expect from a country undergoing significant economic growth.

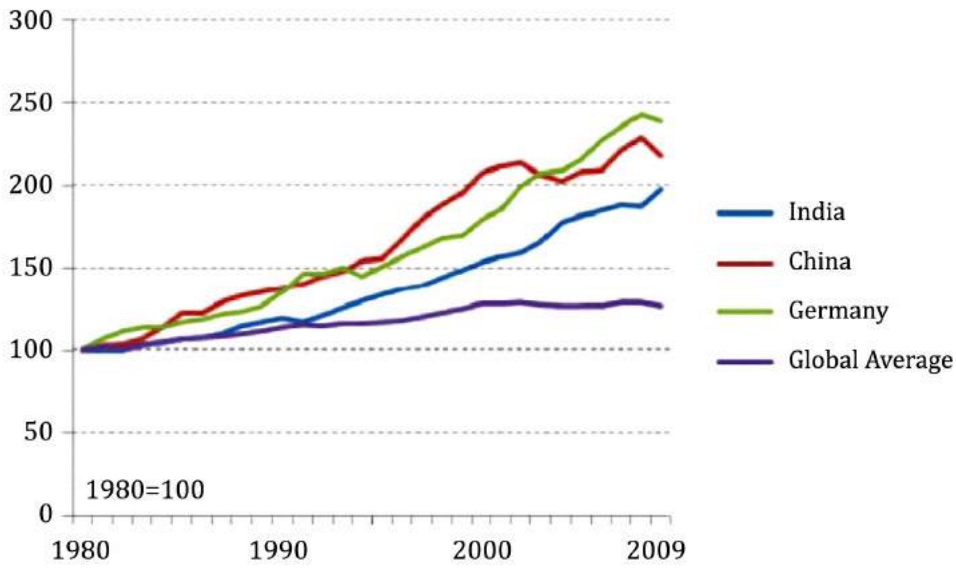


Figure 2.9: Improvements in resource productivity in India, China and Germany compared to global average between 1980 and 2008

(Source: IGEP, 2013; p. 28)

As shown in Figure 2.9, global improvements in resource productivity were around 27% between 1980 and 2009. During the same period, India showed an improvement more than three times the world average at 98%, but lower than that in China (at 118%) and Germany (at 139%).

2.5 Analytical Framework for this Study

From the previous discussion it is clear that the choice of methodology and indicators depends on the goals of any particular study. While economy-wide MFA is useful for measuring the overall material flow in an economy, analysis of particular sectors requires a more targeted approach. In this study, the focus is on two sectors of the Indian economy – construction and automotive; the rationale for focusing on these sectors was explained in Section 1.3.

In each of these two sectors, a shortlist of "priority" materials were identified based on their importance to the resource efficiency debate in India, as explained in the following section. For each identified material, the flows into/out of the economy, domestic extraction, as well as flows within the economy (for different sectors and applications) were analysed.

Automotive Sector

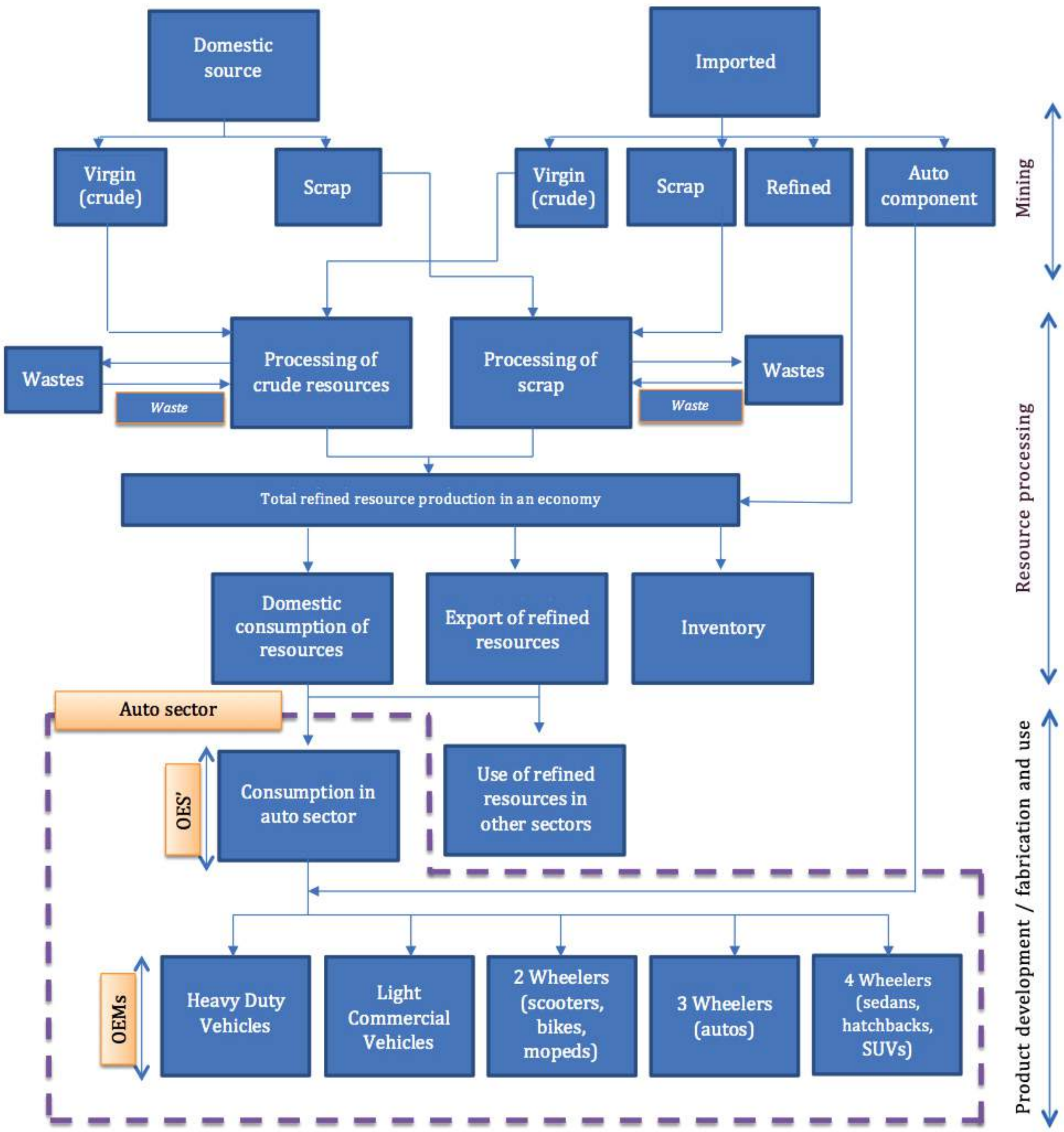
For this study, the analysis of the automotive sector was limited to 5 important materials used in the sector based on their economic importance and supply risk. The economic importance of a material is determined on the basis of its application in the automobile sector and the extent of its substitutability by other metals or materials. The economic importance of a material in this sector was derived by analysing the composition of the most sold/used auto components in the market. The supply risk was determined by: limited geological potential, limited geological availability due to inadequate exploration, production in the nature of by-products, techno-economic constraints, socio-environmental constraints, high import dependency, and geopolitical and geo-economic constraints.

The five materials thus identified for analysis were:

- Iron and Steel
- Copper
- Aluminium
- Zinc and Nickel
- Plastics and Composites

Figure 2.10 depicts the schematic representation of the material flow analysis for the automotive sector used in this study. The steps covered include domestic extraction and imports of raw materials, processing and intermediate conversion to crude metal, further use in auto component manufacturing and the final use by original equipment manufacturers, as well as recycling of wastes.

Figure 2.10: Material flow in the automotive sector



Construction Sector

Similarly, in the construction sector, 5 materials were identified for analysis based on their criticality. In order to assess the criticality of the resources, a framework was developed and applied to the above resources. Criticality was assessed on the basis of:

- Scarcity of the resource, both physical and economic
- Cost of the material and the transit / carriage
- Environmental impact due to extraction and production
- Embodied energy, i.e. energy consumed while extraction, production and transport
- Supply risk, i.e. political, physical, cultural, legal, etc.
- Reuse and recyclability potential; secondary uses

The five materials thus identified for analysis are as depicted in Table 2.1:
• Sand
• Soil
• Stone (aggregates)
• Limestone
• Iron and Steel

Table 2.1: Criticality framework for materials in the construction sector

Parameters → Resource ↓	Scarcity	Cost	Environmental Impact	Embodied Energy	Supply Risk	Lack of Recycl-ability	Opportunity Cost / Conflict of Use
Soil	**	*	***	***	**	***	***
Iron	*	**	***	***	*	*	*
Limestone	*	*	***	***	*	***	**
Sand	***	***	***	***	***	***	***
Stone (Aggregate)	**	*	***	**	**	***	***
Marble / Granite	*	*	***	**	*	***	**
Copper	*	**	***	***	*	*	*
Bauxite (Aluminium)	*	**	***	***	*	*	*
Petroleum (PVC)	*	*	***	**	*	*	*
Silica (Glass)	*	**	***	**	*	*	*
Wood	**	**	***	**	**	**	*

Sand, soil, stone and limestone were shortlisted due to the associated scarcity of the resource as against the projected demand, thus enhancing their supply risk. Another key distinguishing factor was the lack of reuse/recyclability potential, especially compared to metals. On the other hand, iron, though recyclable, was shortlisted due to its growing importance in construction, as well as social, economic and environmental problems associated with extraction and supply.

Chapter 3: Material Flow Analysis

3.1 Automotive Sector

3.1.1 Introduction

In the context of addressing the broader sustainability related challenges of an economy, mobility has a very important role to play, and India is no exception in this context. With growing population, migration and rapid urbanisation, demand for mobility has experienced phenomenal growth over the past few decades, accompanied by substantial transformation, particularly in urban mobility practices. Railways has remained the most important mode of transport for long distance travel, although recent trends have indicated increased reliance on air travel for the urban middle classes. The road transport system, that used to be dominated by bicycles and auto-rickshaws, and public transport modes like buses, are experiencing substantial change in major urban centres in the country, where there is a growing preference for personalised transportation due to growing affluence. Increased personal ownership of two wheelers and cars has resulted in severe traffic congestion, high levels of air pollution and other challenges.

The automotive industry plays a very important role in providing options through different types of vehicles like passenger cars, light, medium and heavy commercial vehicles, multi-utility vehicles such as jeeps, scooters, motorcycles, mopeds, three wheelers, tractors, etc., to support the mobility needs of the people. It is a strong pillar of the global economy and a main driver of macroeconomic growth and technological advancement in both developed and developing countries. This industry in India, comprising of the automobile and auto component manufacturers, is one of the key segments of the economy, having extensive forward and backward linkages with other segments of the economy. It has grown 14.4% over the past decade, making India the world's sixth largest producer of automobiles in terms of volume and value. With more than 35 automobile companies manufacturing in the country, the industry contributes 7% to India's GDP and accounts for 7-8% of India's total employed population (GIZ, 2015a).

Today, India has become the outsourcing hub for several global automobile manufacturers, not just for low-cost manufacturing, but increasingly as a source of higher value innovation. India has a well-developed, globally competitive auto ancillary industry for auto component parts and has established automobile testing and R&D centres.

The automobile sector in India is engaged in manufacturing passenger motor vehicles (Passenger Cars, Utility Vehicles and Multi-Purpose Vehicles), commercial vehicles (Medium, Heavy and Light Commercial Vehicles), two wheelers, and three wheelers. The Indian automotive industry has attained a turnover of INR 1.6 trillion (equivalent to about USD 34 billion) and has provided direct and indirect employment to 13.1 billion people in the country (GIZ, 2015a). The trends in domestic sales and export segment are given in Tables 3.1 and 3.2.

Table 3.1: Automobile domestic sales trends in India (number of vehicles in millions)

Category	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Passenger Vehicles	0.15	1.95	2.50	2.62	2.66	2.50
Commercial Vehicles	0.38	0.53	0.68	0.80	0.79	0.63
Three Wheelers	0.34	0.44	0.52	0.51	0.53	0.47
Two Wheelers	7.43	9.37	11.76	13.40	13.79	14.80
Grand Total	9.72	12.29	15.48	17.36	17.79	18.42

(Source: Government of India, 2015b)

Table 3.2: Automobile exports trends from India (number of vehicles in millions)

Category	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Passenger Vehicles	0.33	0.44	0.44	0.50	0.55	0.59
Commercial Vehicles	0.04	0.04	0.07	0.09	0.08	0.07
Three Wheelers	0.14	0.17	0.26	0.36	0.30	0.35
Two Wheelers	1.00	1.14	1.53	1.97	1.95	2.08
Grand Total	1.53	1.80	2.31	2.93	2.89	3.10

(Source: Government of India, 2015b)

While the motorisation rate in India, the number of passenger cars per 1,000 inhabitants, is lower than many developing countries – both in absolute terms and relative to size of the population, over the last decade, India has been experiencing one of the highest motorisation growth rates in the world.

The percentage share of different types of vehicles across time is given in Figure 3.1. Though the percentage share of Cars, Jeeps and Taxis has decreased over time, it is extremely important to note that the absolute numbers of these have increased significantly in the context of the overall growth of the automobile sector.

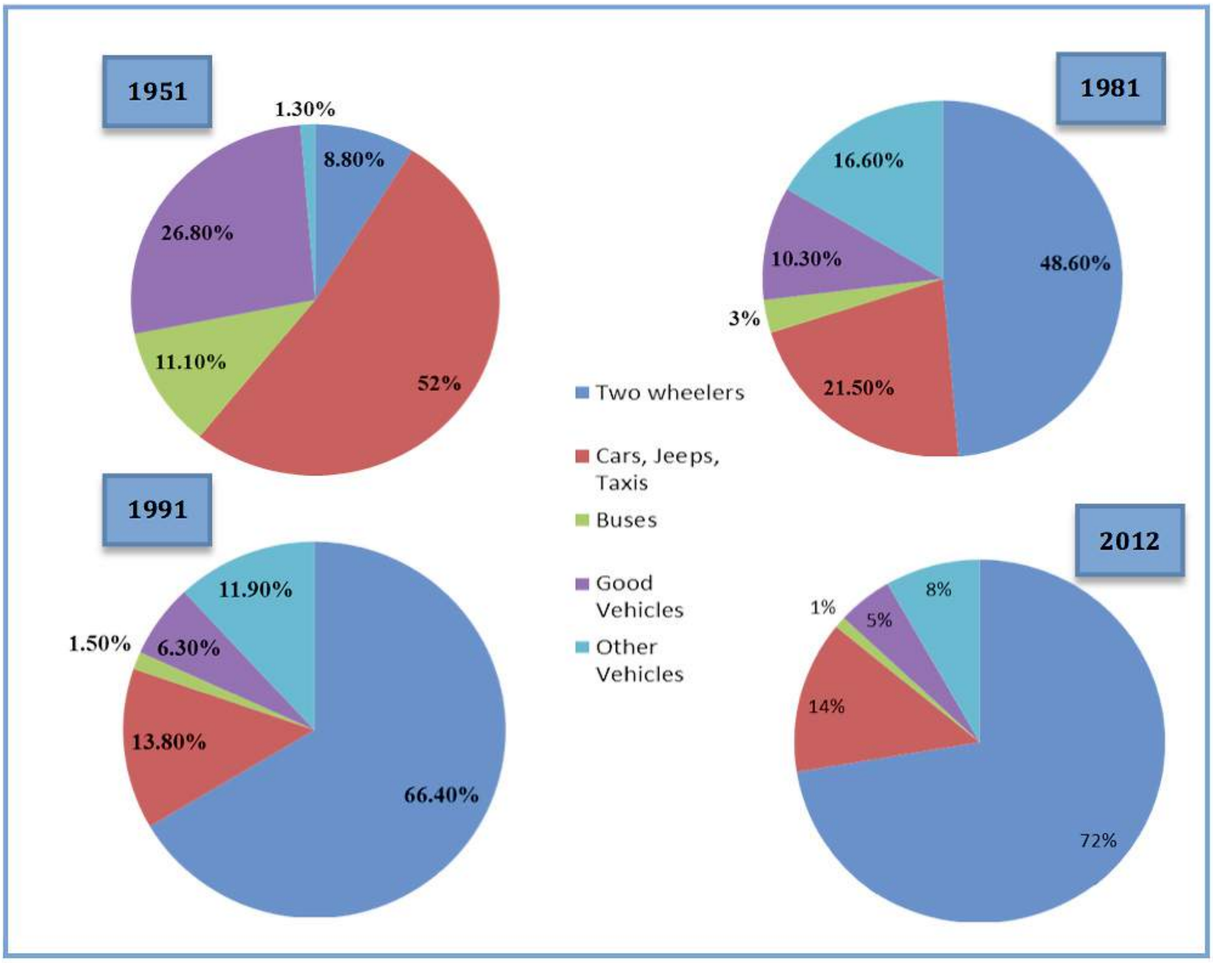


Figure 3.1: Share of different categories of motorised vehicles in different years in India

(Source: MoRTH, 2012)

An automobile is composed of various material components which are produced by utilising a wide variety of technologies to satisfy customer needs, safety and environmental norms. These include conventional steel, high strength steel, stainless steel, other steels, iron, aluminium, rubber, plastics/composites, glass , copper and brass , zinc die castings, powder metal parts, fluids and lubricants, and other materials.

In the past, automobiles have been composed primarily of iron and steel. Steel has remained a major automotive component because of its structural integrity and ability to maintain dimensional geometry throughout the manufacturing process. In response to increasing demands for more fuel efficient cars, the past ten years have seen changes in the composition of materials used in automobiles. Iron and steel use has steadily decreased, while plastics and aluminium have steadily increased. The decline in steel used in automobiles is partly due to the use of better and more compact steel components in recent years, particularly the use of high strength steel plate (High-Tensile Steel). Its use is rapidly increasing as a means to reduce car body weight; in some types of automobiles, it is used for more than 50% of the car body. Aluminium and plastics are valuable car components not only for their lighter weight, but also because of their inherent corrosion resistance (GIZ, 2015a).

The manufacturing processes used to produce the thousands of discrete parts and accessories vary depending on the end product and materials used. Different processes are employed for the production of metal components versus the production of plastic components. Most processes however, typically include casting, forging, moulding, extrusion, stamping, and welding.

The component industry in India, which is an important part of the automotive sector, comprises about 500 firms in the organised sector and more than 10,000 firms in the unorganised sector (GIZ, 2015a). The auto component industry has been one of the fastest growing segments of Indian manufacturing and one of the few sectors in the economy that has a distinct global competitive advantage in terms of cost and quality. The advantages of sourcing auto components from India includes low labour cost, raw material availability, technically skilled manpower and quality assurance. An average cost reduction of nearly 15-20% has attracted several global automobile manufacturers to set up base in India since 1991. India's process-engineering skills, applied to re-designing of production processes, have enabled reduction in manufacturing costs of components. In the coming years, innovation and cost pruning hold the key to meeting the global challenge of rising demand from developed countries and competition from other emerging economies. Several large Indian auto component manufacturers are already gearing up to this new reality and are in the process of substantially investing in capacity expansion, establishing partnerships in India and abroad, acquiring companies overseas and setting up greenfield ventures, R&D facilities and design capabilities (GIZ, 2015a).

According to industry statistics compiled by the Automotive Component Manufacturers Association of India (ACMA), engine parts form the largest segment (31%) of the auto components industry followed by drive transmission and steering parts (19%). Suspension and braking parts, and body and chassis account for 12% each in the entire product range, followed by equipments accounting for 10% (Figure 3.2).

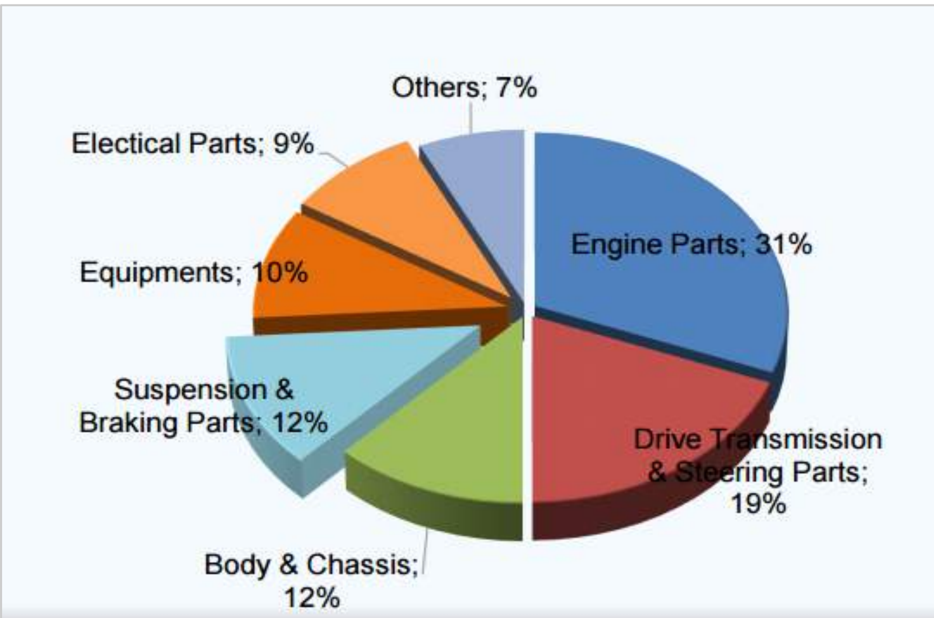


Figure 3.2: Major auto-components/product groups

(Source: ACMA, 2015)

The top components identified by resource intensity and corresponding raw material in making an automobile are - Frame, Axle, Cylinder Block, Gearbox, Flywheel, Wheel Rims, Disc Brake, Clutch, Connecting Rod, Piston (GIZ, 2015a).

3.1.2 Material Flow Analysis

To make an assessment of material use in the mobility sector in India, particularly for the automobile segment, and estimate India's future resource demand in detail, a partial MFA approach has been used, as explained in Section 2.5.

The Planning Commission (2007) has classified non-fuel minerals in India into four categories as listed in Table 3.3.

Table 3.3: Availability of non-fuel minerals in India

Minerals	Abundant	Adequate	Deficit	Scarce
Metallic	Iron ore, Bauxite, Titanium minerals	Manganese, Chromite	Copper, Lead, Zinc, Pyrite	Gold, Silver, Gallium, PGM, Antimony, Molybdenum, Nickel, Tin, Tungsten, Vanadium, Cobalt
Non-metallic	Limestone, Dolomite, Barytes, Bentonite, Fireclay, Fuller's Earth, Kaolin, Magnesite, Sillimanite, Silica sand & Quartz, Quartzite, Garnet, Calcite, Felspar	Ball clay, Mica, Gypsum, Graphite, Stealite, Wollastonite, Ochre, Vermiculite, Pyrophyllite, Salt rock	Apatite, Rock phosphate, Asbestos, Fluorite, Kyanite	Diamond, Potash, Sulphur, Borax
Minor[2]	Marble, Granite, Slate			

(Source: Planning Commission, 2007)

For this study, the analysis for the automobile industry was limited to 5 important materials used in the industry (which includes two materials – *copper* and *zinc* from the "deficit" and "scarce" categories in Table 3.3 above) based on their economic importance and supply risk, with an idea to study materials that could be illustrative of the different issues and challenges associated with these materials in this sector.

One important set of data that is required to estimate the usage of the different materials is the average kerb weight of a representative vehicle by segment. The indicative kerb weights used in this study based on different data sources (as listed in Column 3) are given in Table 3.4.

[2] Minor minerals are defined under the MMDR Act, 1957 and typically include all the minerals used in construction such as sand, stone, etc.

Table 3.4: Indicative kerb weight for different segments of vehicles

Vehicle Type	Weight of the vehicle (in kg)	Source
Trucks 	6,980	"3116 (8x2)MAV Fuel Saver " http://international.ashokleyland.com/3116.php
Buses 	5,050	"Starbus 32" http://www.buses.tatamotors.com/products/City-Bus/starbus-32-bs4.aspx?comefrom=fbb
Four Wheelers 	1,100	"Maruti Swift Hatch back" http://www.indianauto.com/cars-in-india/maruti/maruti-swift.html "Maruti SX4" http://www.indianauto.com/cars-in-india/maruti/maruti-swift.html
Three Wheelers 	371	"Diesel Fuel Optima" http://www.bajajauto.com/bajajre/diesel-optima-tech-specs.html
Two Wheelers 	103	"Honda Activa" http://www.honda2wheelersindia.com/activai/specifications/

There is very limited information available on the material composition of vehicles in India. Results from one study (Ducker Worldwide, 2009), where the percentage composition of different materials in light vehicles (those having kerb weight of 1,306 kg or less) in India and other Asian countries is broken down, is depicted in Figure 3.3.

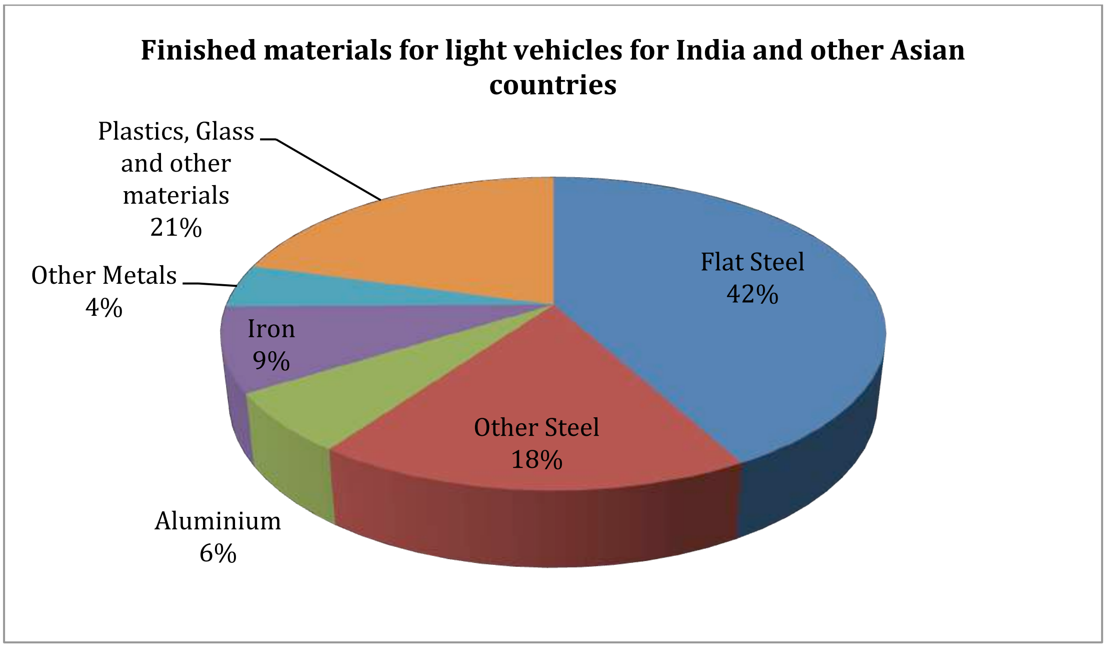


Figure 3.3: Material composition of light vehicles in India and other Asian countries

(Source: Ducker Worldwide, 2009)

As part of the study, different stakeholders were also consulted to understand the material composition of vehicles across segments. Based on limited availability of secondary information and stakeholder consultations[3], the material composition across various types of automobiles (except that of two wheelers) was taken to be 64% iron and steel (57% steel and 7% iron), 8% aluminium, 1.36% copper, 8% plastics, 5% nickel and zinc, and the rest being accounted for by other materials including rubber, glass, textiles, etc. (Kanari, Pinau & Shallari, 2003; Bhaskar, 2013). For two wheelers, based on data available from a recent market analysis study (Sabu, 2015) and validated through stakeholder consultations, the material composition is taken as 66% iron and steel, 15% aluminium, 5% copper, 7% plastics, 5% zinc and nickel, and the rest being other materials. The demand for steel was estimated across the five broad segments of vehicles:

- Trucks (Medium and Heavy Commercial Vehicles);
- Buses and Trucks (Light to Medium Commercial Vehicles);
- Cars and Multi Activity Vehicle (MAV);
- Three wheelers; and
- Two wheelers.

To fulfil fuel economy targets, it is necessary to reduce vehicle body weight while also improving engine and rolling energy losses. These improvements are being achieved mostly through changes in

[3] We consulted various stakeholders including ARAI, NATRiP, and Ministry of Heavy Industries to understand the composition of materials in different types of vehicles. Their general view was that there is not much difference in the percentage composition and we could assume similar composition for the different segments of vehicles, at least for the baseline assessment. Further consultations with OEMs particularly could be explored to get better estimates of the actual composition of materials across segments of vehicles.

material composition, such as through the use of high strength steel sheets and/or in conjunction with even greater increased usage of aluminium, magnesium and titanium alloys having lower specific weights compared with iron and steel. This is expected to change the material composition of vehicles in the coming years.

3.1.2.1 Iron and Steel

Uses of iron and steel

Iron and steel are key materials for the global economy. Iron is the fourth most common element in the earth's crust (Woodford, 2015). Its high strength and relatively low cost accounts for valued use in many industries and provides the necessary raw material for extensive industrial supply chains. It provides the foundation for construction (bridges, buildings), transportation systems (railroads, cars, trucks, ships), utility systems (municipal water systems, power systems), as well as other diverse applications including military equipment, food storage, appliances and tools. Iron is not used directly because of its softness, but is combined with carbon, which then results into a tougher and more usable material – steel. The sector wise use of steel in India is depicted in Figure 3.4; construction is seen to account for the biggest share (61%), followed by the automotive sector (8%).

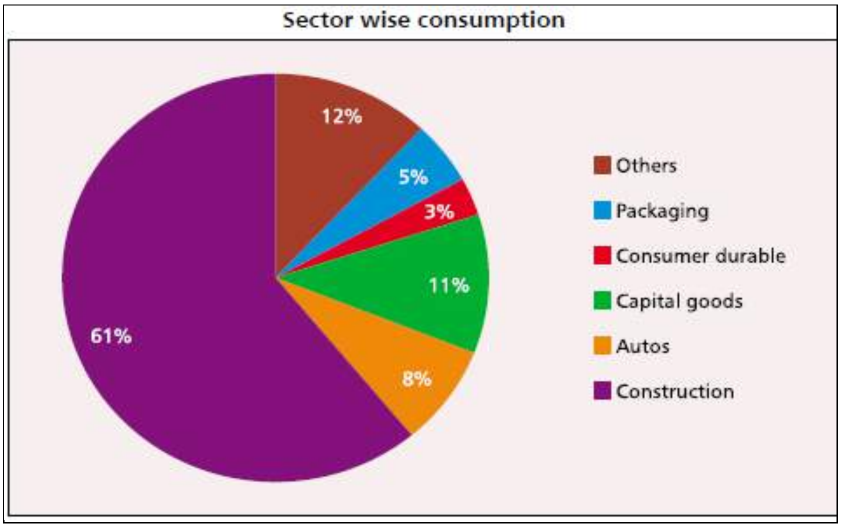


Figure 3.4: Sectoral usage of steel in India

(Source: Dun & Bradstreet India, 2011)

Use of iron and steel in the automotive sector

According to the World Steel Association, out of the total global steel consumption, 12% is accounted for in the automotive sector (Forbes, 2015), whereas in India, it is 8% (Dun & Bradstreet India, 2011) (Figure 3.4). Steel is the most dominant metal in automobile production (Bhaskar, 2013). Currently, steel content is around 57% of the raw material constituent of an average small car by weight, whereas iron is around 7% of the same (ICRA, 2011). Thus, the total iron and steel component in the weight of a car combines to around 64%. Similarly, in light duty vehicles, the iron content is 10% and steel is 54% of the total kerb weight (Sullivan, Burnham & Wang, 2010).

This heavy reliance on iron and steel implies that there is a high potential for resource efficiency improvements for these materials.

Taking an ore-to-metal conversion ratio of 1:1.6 (OECD, 2012), the amount of iron ore required for production of vehicles in India is projected to increase to 129 million tonnes by 2030[4] if the automotive sector does not engage in improvements in efficient manufacturing and waste reduction.

Availability and prices

The production of iron ore in India was around 136,000 tonnes in 2013 (WSA, 2014a), accounting for 7% of global production (Figure 3.5). India is a major exporter of iron ore and imports are only a small fraction of total exports. But since 2011, there has been a steep decline in exports to meet increasing domestic demand (Figure 3.6).

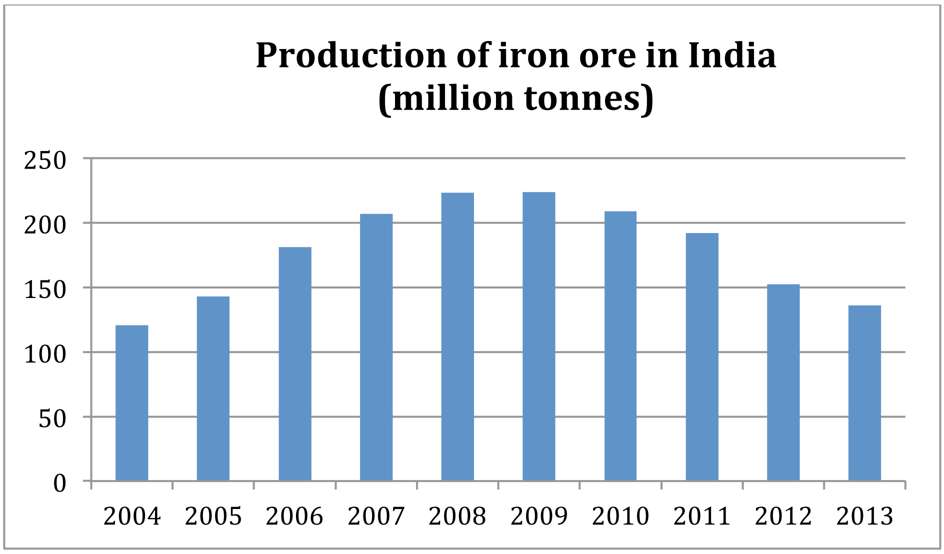


Figure 3.5: Production of iron ore in India

(Source: WSA, 2014a)

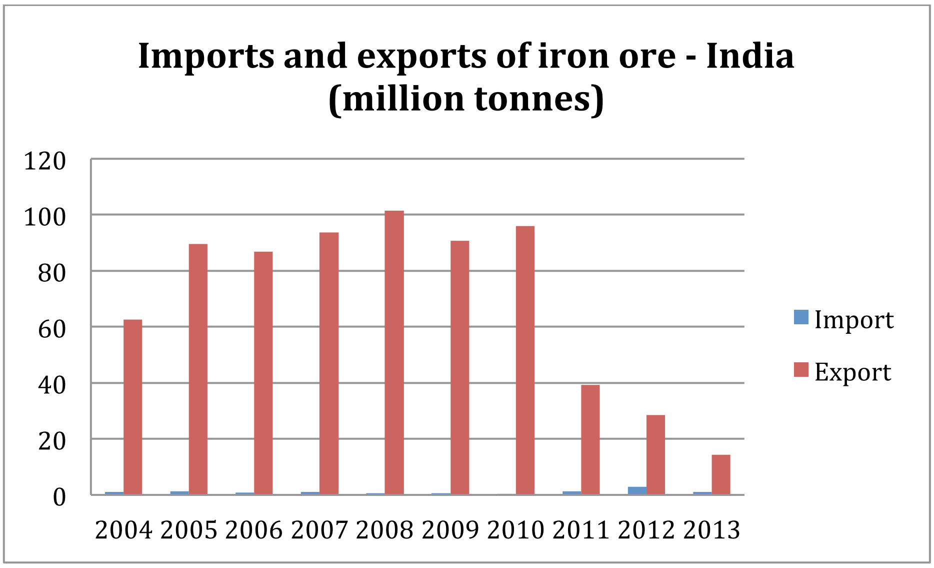


Figure 3.6: Imports and exports of iron ore - India

(Source: WSA, 2014a)

[4] Authors' calculations based on current demand and future growth projections of automotive sector.

India has been steadily increasing its steel production since 2004, and is currently the third-largest steel producer in the world (Figure 3.7). In the year 2014-15, it produced 91.46 million tonnes of finished steel (Ministry of Steel, 2015a). Total finished steel production in the country increased at a Compound Annual Growth Rate (CAGR) of 7.45% during the fiscal year 2011–12 to 2014-15 (IBEF, 2015). From the period of 2001-02 to 2006-07, India was a net exporter of finished steel. The position switched after the global economic crisis in 2008 and exports started to fall. After 2010-11, there has been a steady rise in steel exports and India's export surpassed its import in the year 2013-14 (Figure 3.8).

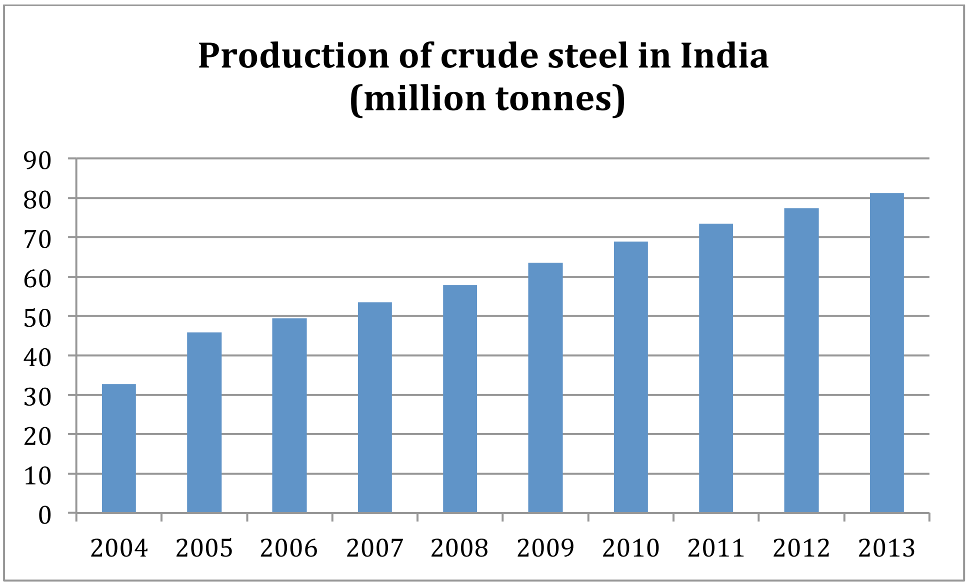


Figure 3.7: Production of crude steel in India

(Source: WSA, 2014a)

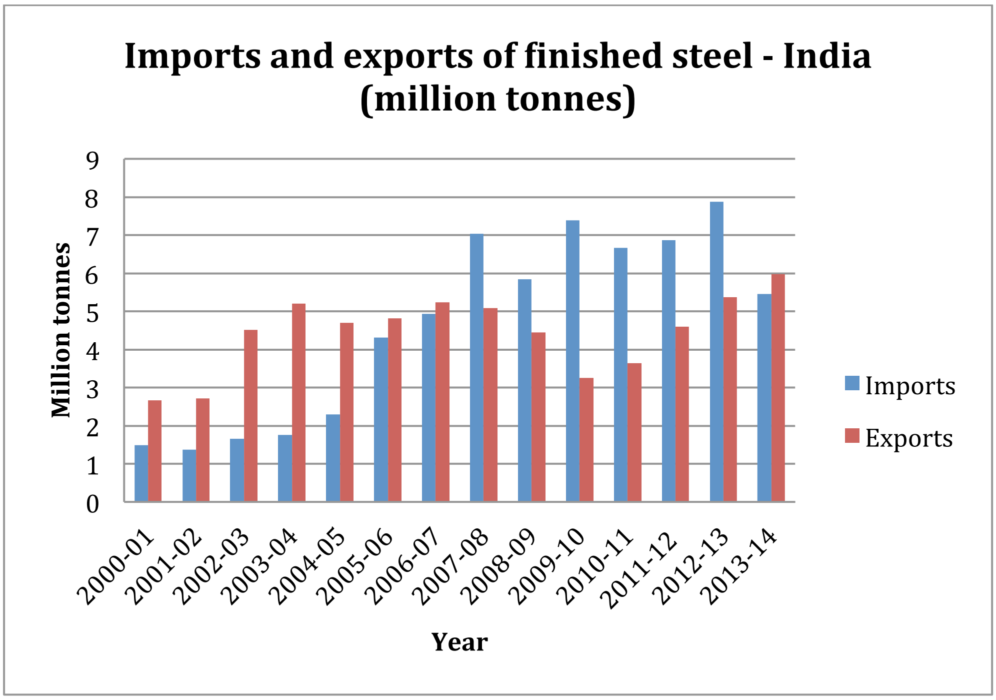


Figure 3.8: Import and export of finished steel – India

(Source: Indiastat.com)

As the demand for steel has been rising over the years, there have been fluctuations in steel prices as well. Figure 3.9 depicts these fluctuations in prices for steel using the example of the Delhi Retail Market during the period of January, 2008 – March, 2013. The plunge in prices from September 2008 to around January 2010 can be attributed to the decline in global stock markets. With projected increase in demand and in absence of technological changes, these prices are expected to escalate in the future (Baksi & Biswas, 2009).

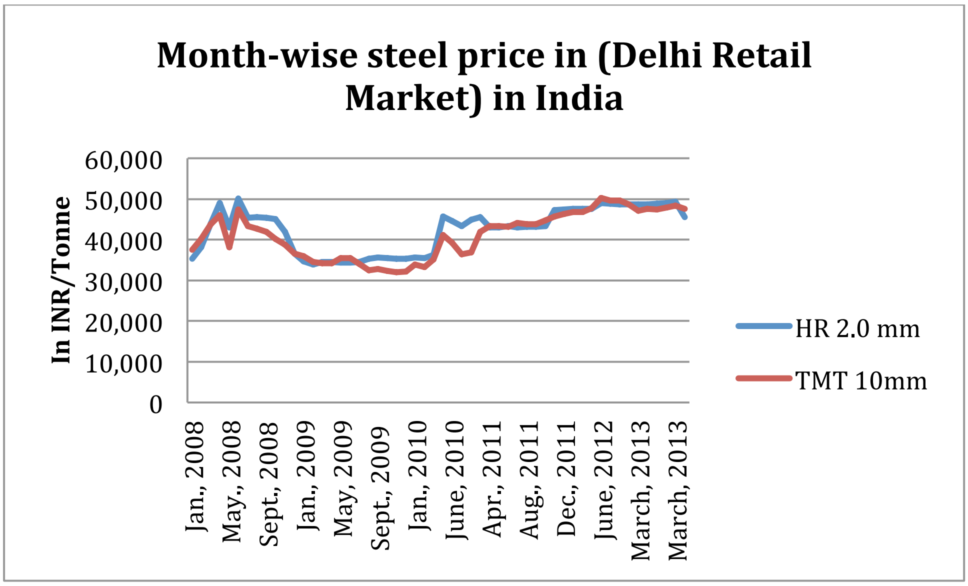


Figure 3.9: Month-wise steel price in (Delhi retail market) in India

(Source: Indiastat.com)

Environmental and social impacts of iron and steel

The production of iron and steel can be divided into five different steps namely: treatment of raw materials; iron making; steel making; casting and rolling; and finishing. Steel production is highly energy intensive and involves melting of iron ore at high temperatures which leads to emission of greenhouse gases (primarily CO_2 along with other gases like CH_4 and N_2O). Various factors are responsible for emissions such as combustion of fossil fuels, use of electricity, and use of coal and lime as feedstock. One tonne of steel produced in a Basic Oxygen Furnace (BOF) requires 1.6 tonnes of iron ore, 0.6 tonnes of coking coal and 0.21 tonnes of steel scrap. Extraction of iron from its ore is resource intensive and estimates suggest that production of 1 tonne of iron requires 1.4 tonnes of ore, 0.5-0.65 tonnes of coke, 0.25 tonnes of limestone or dolomite, and 1.8-2 tonnes of air (OECD, 2012; OECD & IEA, 2001).

Mining of iron ore rock releases dust particles in the air which leads to health hazards such as transient irritation, lung fibrosis, carcinoma, bronchitis, asthma and other lung diseases. Mining workers are exposed to iron dust particulates for long periods and thus have a higher probability of suffering from lung cancer in the long run (PLRARA, 2015).

Iron mining is generally carried out by the open cast process which involves operations such as excavation, loading, sizing, crushing and screening, and transportation. These operations generate emission from ore bodies, drilling, blasting and transportation, which deteriorates the ambient air quality within the range of the mining site and surrounding areas.

The Odisha State Pollution Control Board (OSPCB) highlighted the negative effects associated with iron mining which included altered land use patterns and degradation of the environment, mineral loss due to acidic rain, increased accumulation of waste, and deterioration of water quality due to run off from the dump and mining areas. Noise pollution is also caused due to mining operations such as excavation, drilling, blasting, handling and transportation of ore. In Odisha, the solid waste generated during 2013-14 because of iron mining activity was estimated to be 626,500 m^3 from six sites (Pradhan, 2015).

To mitigate or reduce the negative impacts associated with iron mining, the Odisha SPCB suggested several measures. For mitigating air pollution, the board suggested regular water spraying on service roads, provision of dust collector, controlled blasting, plantation of wide leaf trees, and limiting speed of vehicles within 20 km/h near the mining site. For controlling water pollution, the board suggested actions like construction of check dams, disposal of sewage waste using septic tanks, and minimising use of ground water for mining operations. Measures like modifying older equipment or selecting low-noise equipment, adopting controlled blasting techniques, and providing protective equipment to employees were suggested to control noise pollution in and around mining sites (Pradhan, 2015).

Steel production is a complex process that is energy driven and resource intensive, which creates many environmental challenges. Steel production from an integrated steel mill is much more energy intensive and emits higher GHG emissions as compared to steel production from mini-mills (OECD & IEA, 2001). The Steel Authority of India Limited (SAIL), one of the leading steel producers in India, has adopted some best practices such as maintenance and consistent operation of pollution control systems, effluent treatment plants, recycling of solid wastes and adoption of cleaner and environmental friendly technologies.

The Ministry of Steel, Government of India has promoted various initiatives and schemes for reducing energy consumption and emissions of environment pollution in steel plants in India. Some of the initiatives are Charter on Corporate Responsibility for Environmental Protection, National Clean Development Mechanism Authority, National Action Plan on Climate Change, Promotion of Energy Efficiency in Small Medium Enterprises (SME) sector, and NEDO Model Projects for Energy Efficiency Improvements (Ministry of Steel, 2015b).

The steel sector contributes almost 2% to the country's GDP and currently employs nearly 0.6 million people. Most steel plants are situated in economically and socially remote regions of the country and since labour recruitment is carried out locally, a large number of socially disadvantaged groups get employed in the steel industry (especially SAIL). Therefore, the iron and steel companies have been a major contributor in the development of structurally weak regions by providing them with basic civic services such as medical, educational, health care and other facilities. The Public Sector Undertakings (PSUs) under the Ministry of Steel, Government of India are progressively contributing their bit for improving society and environment by investing in Corporate Social Responsibility (CSR) activities through projects related to water supply, irrigation facilities, health and family welfare, cleanliness, education, solar energy and relief fund for natural calamities (Ministry of Steel, 2015b).

Recycling iron and steel

Recycling iron and steel has many financial, economic and environmental benefits as it reduces landfill disposal of waste, reduces the need to extract and manufacture raw materials, as well as contributes to the reduction of pollution and GHG emissions. Recycled steel uses 75% less energy than steel made from virgin raw materials (Hyder Consulting, 2009). All types of steel are 100% recyclable and can be recycled infinitely without a loss in quality. Recovery of 1 tonne of steel scrap conserves an estimated 1,030 kg of iron ore, 580 kg of coal and 50 kg of limestone (Fenton, 1998).

According to the Institute of Scrap Recycling Industries, recycling one car can save around 1,000 kg of iron ore, 560 kg of coal and 48 kg of limestone. In 2012, the USA recycled nearly 11.8 million cars, achieving a recycling rate of 93%. Other recycling rates related to iron and steel in the USA for the year 2012 was 98% for structural steel, 90% for electronic appliances, and 71% for steel cans (ISRI, 2014).

According to a US-based study, vehicles in North America are composed of approximately 20% post-consumer recycled material by weight (ARA & ISRI, undated). Even though steel is the most used raw material, GHG reductions per vehicle recycled were most for aluminium, followed by steel (Figures 3.10 and 3.11).

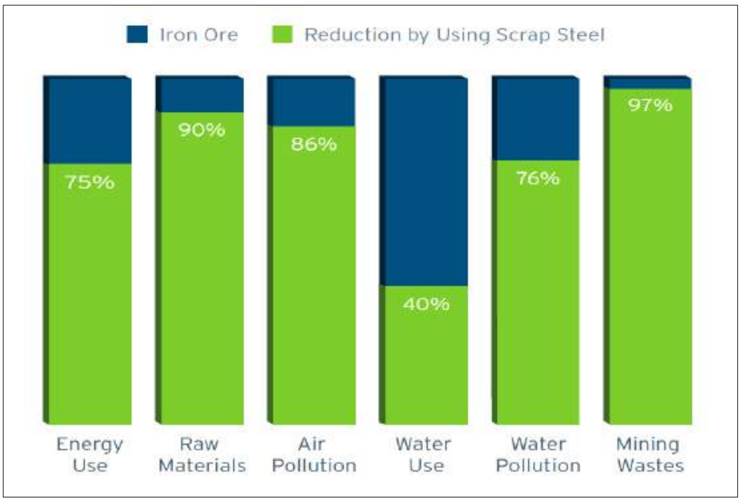


Figure 3.10: Benefits of using scrap steel vs iron ore

(Source: ARA & ISRI, undated)

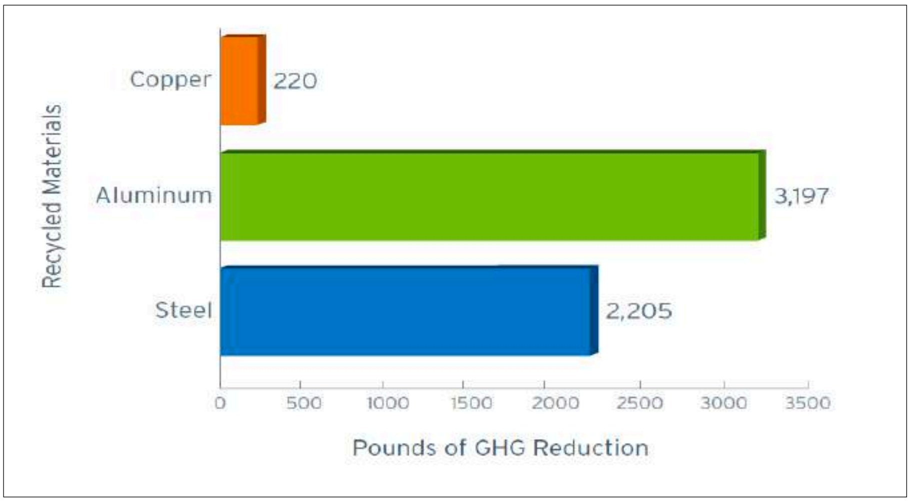


Figure 3.11: Estimated GHG reductions per vehicle recycled

(Source: ARA & ISRI, undated)

In automotive industries, a lot of scrap and waste is generated. The average material losses in component manufacturing (percentage to net material used in a vehicle) as per our estimates are around 25%. There are also huge variations in net metal usage depending on the sub-category of a vehicle. For instance, in 2010, on average, Tata Motors used 0.28 tonnes of steel to produce each vehicle, while BMW used 1.19 tonnes of steel per vehicle, which is higher by more than a factor of 3

(Baldock, undated). Considering BMW manufactures its luxury cars to meet high European safety and convenience standards, more steel-intensive vehicles raise the importance of recycling to use raw materials more efficiently. The kerb weight of a luxury car is usually 2 to 3 times higher than a small utility car.

In addition to the scope for improvement in reduction of scrap and wastage, recyclability of steel makes it as a key factor for sustainable usage. Once steel is manufactured, it can be reused numerous times. The life cycle of steel can be seen in Figure 3.12. With demand for vehicles on the rise, it is important to use steel efficiently. For instance, the Future Steel Vehicle (FSV) project has featured steel body structure designs with reduction in mass by more than 35% and reduction in total life-cycle GHG emissions by almost 70% (WSA, 2015).

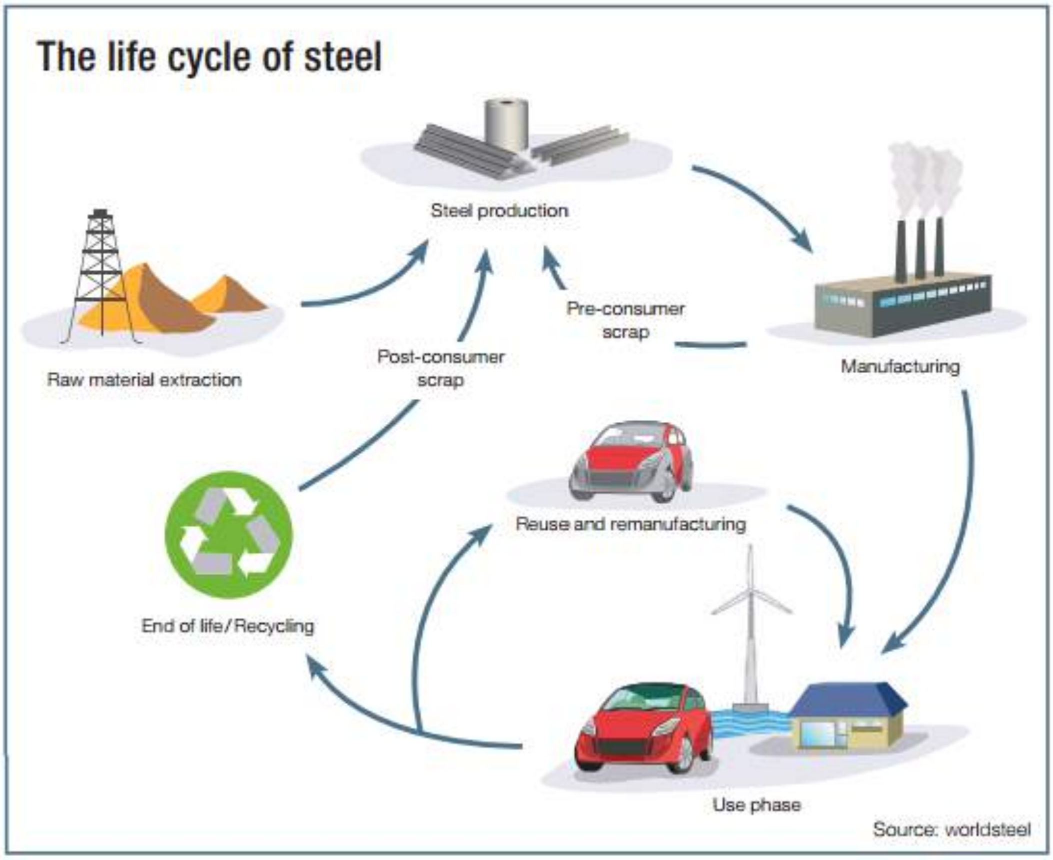


Figure 3.12: Life cycle of steel

(Source: WSA, 2013)

3.1.2.2 Aluminium

Uses of aluminium

Aluminium is one of the most important and widely used metals and finds usage across many sectors – transport, construction, electrical and packaging. Aluminium is lightweight, durable and silvery in appearance. It is a good conductor of heat and electricity and is easily shaped by moulding and extruding. Aluminium has two main advantages when compared with other metals. Firstly, it has a low density, about one third that of iron and copper. Secondly, although it reacts rapidly with the oxygen in air, it forms a thin, tough and impervious oxide layer which resists further oxidation. This removes the need for surface protection coatings such as those required with other metals, in particular with iron.

Aluminium as a material is almost always used in alloyed form. When adding other atomic elements into pure aluminium, such as magnesium, zinc, copper, manganese, silicon, tin, etc., the original softness, reactivity and formability of aluminium changes dramatically. Aluminium alloys can be made as strong as steel but with only half the weight of the same strength steel. Aluminium wire can be made as strong and ductile as copper wire but with only half the weight of copper wire of the same electrical conductivity.

Figure 3.13 presents the usage of aluminium by end use sector in India (in 2012); it can be seen that about 26% of aluminium[5] gets used up in the transportation sector, which includes the automotive, rail and aircraft industries, automotive accounting for the biggest fraction.

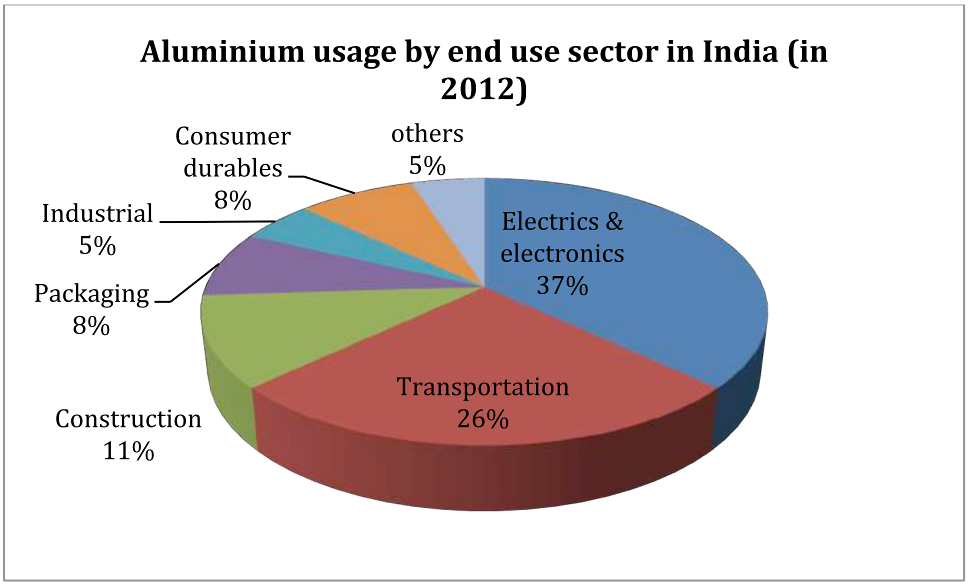


Figure 3.13: Sector wise aluminium usage in India (2012)

(Source: Gopalkrishnan, 2013)

Use of aluminium in the automotive sector

In recent years, there has been an increased use of aluminium, magnesium and carbon fibre composites in automobile manufacturing. Aluminium being much lighter than steel and having the same strength, is gradually replacing steel in the automobile industry, which has an overall impact on the cost of the vehicle[6]. Since the 1970s, the share of aluminium in the overall weight of an average car has been constantly on the rise: from 35 kg in the 1970s, to 152 kg in recent years. Experts project that by 2025, the average aluminium content in a car will reach 250 kg (Richman, 2013).

Traditionally, automakers in India have used aluminium for wheels, cylinder blocks, and other engine parts. However, this trend is changing in response to stringent fuel economy standards, and aluminium use has extended to other individual components such as interior decorations, bumper beams, brake components, etc. More recently, aluminium has also been adopted for use in chassis, suspension, and front-end systems. In fact, auto companies are now trying to make the entire car

[5] However, there is a lot of inconsistency in data; the Indian Minerals Yearbook (IBM, 2013a) states that 15% of aluminium gets consumed in the transportation sector.

[6] It has been estimated that for every 10% of weight eliminated from a vehicle's total weight, fuel economy improves by 7%; this also means that for every kg of weight reduced in a vehicle, there is about 20 kg of CO_2 emissions reduction (Ducker Worldwide, 2014; AAI, 2010).

body of aluminium, referred to as 'body-in-white'[7]. Every 10% reduction in weight is expected to improve fuel economy by 5–7% (Richman, 2013).

Aluminium has another very useful property, that of being almost twice as effective in absorbing shock compared to steel. For this reason, automakers have long been using aluminium in bumpers. Another reason why an aluminium body is superior to a steel body in terms of safety is because when aluminium parts get bent or deformed, the deformation remains localised to the areas of impact while the rest of the body retains the original shape, ensuring safety for the passenger compartment. Global forecasts suggest that by 2025, the average vehicle will get lighter by 180 kg, in part due to the enhanced application of aluminium on account of closures, body-in-white, bumper, and suspension components. Aluminium is expected to grow to 16% of kerb weight by 2025 (Richman, 2013). However, it is important to note that aluminium, unlike steel, is difficult to weld, limiting its use in other automobile parts.

Thus the automotive industry is a particularly compelling sector of growth for aluminium, on account of the fact that its usage could meet the mandates for increased fuel efficiency coupled with a need to continuously improve safety, function and comfort.

Ducker Worldwide (2009) has made systematic efforts and collected data on the growth and development of aluminium content in automotive light vehicle applications worldwide. Their estimate for 2009 was 112 kg per vehicle for the approximately 70 million light vehicles that were manufactured in North America, Europe, Asia and Australia. In 2009, North America had the highest aluminium penetration at 8.6% of kerb weight of vehicles and Africa/Middle East had the lowest aluminium penetration at 5.1% of kerb weight. The study forecast that worldwide light vehicle aluminium content would grow by around 1.8 – 2.2 kg per vehicle per year and approach 136 kg per vehicle worldwide by 2020. Growth of 1.8 – 2.2 kg per year might not appear significant; but when combined with the nearly 100 million light vehicles likely to be built in 2020, it would grow aluminium content from the current 7.7-8 billion kg per year to 12.7 – 13.6 billion kg of aluminium content per year by 2020, not including scrap and spare parts (Ducker Worldwide, 2009).

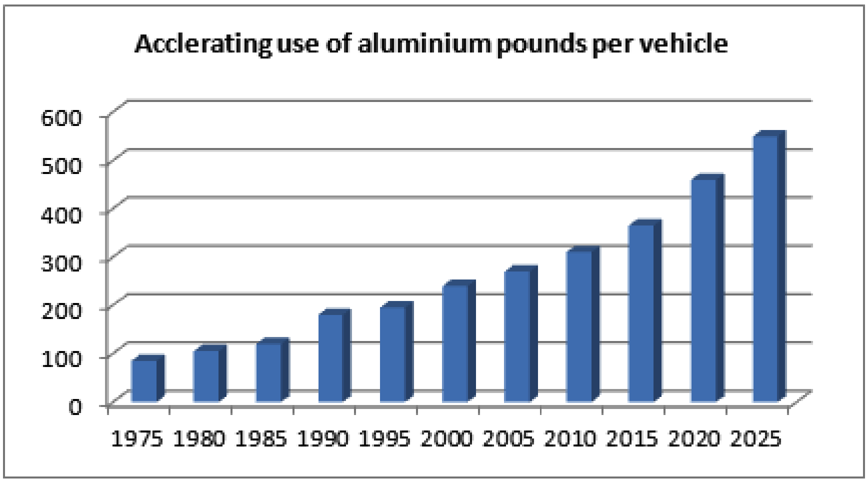


Figure 3.14: Accelerating aluminium use in vehicles

(Source: Richman, 2013)

[7] The year 2014 saw a milestone in the automotive industry, where an all-aluminium-body vehicle was released in the mass market segment: the latest iteration of the iconic Ford-150 truck, the USA's most popular pickup for the past 38 years. By switching to an all-aluminium design, the vehicle was made 315 kg lighter than the preceding model, allowing it to achieve much better fuel economy and significantly lower CO_2 emissions. The cargo carrying capacity also increased, and the model has better acceleration and braking characteristics (Miller & Ramsey, 2014).

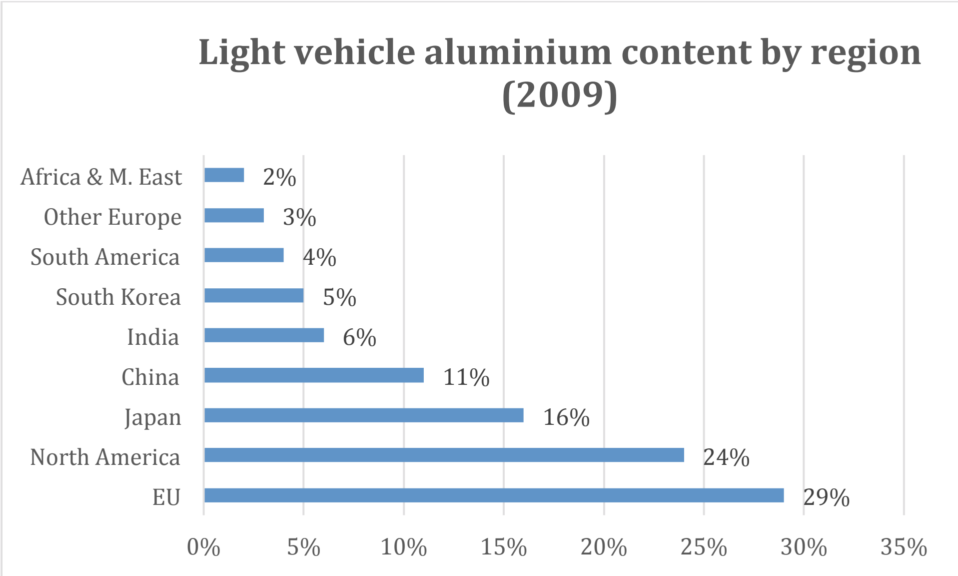


Figure 3.15: Aluminium content in light vehicles by region (2009)

(Source: Ducker Worldwide, 2009)

Availability and prices

Aluminium occurs naturally as the mineral bauxite, which generally contains 30-50% aluminium oxide. Aluminium is found in many rock minerals, usually combined with silicon and oxygen in compounds called alumina-silicates. The Indian production of aluminium at 1.72 million tonnes in 2012-13 registered an increase of 4% as compared to that in the previous year (Table 3.5).

Table 3.5: Production of aluminium in India

Year	Quantity (in tonnes)	Year	Quantity (in tonnes)
1995-96	517,806	2004-05	883,960
1996-97	520,688	2005-06	930,543
1997-98	553,255	2006-07	1,113,849
1998-99	543,451	2007-08	1,239,581
1999-00	612,968	2008-09	1,347,127
2000-01	624,206	2009-10	1,480,568
2001-02	635,573	2010-11	1,621,033
2002-03	688,912	2011-12	1,654,156
2003-04	810,282	2012-13 (provisional)	1,720,427

(Source: IBM, 2013a)

Exports of aluminium and alloys including scrap increased in 2012-13 to 567,000 tonnes from 506,000 tonnes in 2011-12. Imports of aluminium and alloys including scrap increased to 1.3 million tonnes in 2012-13 from 1.1 million tonnes in the previous year (Figures 3.16, 3.17).

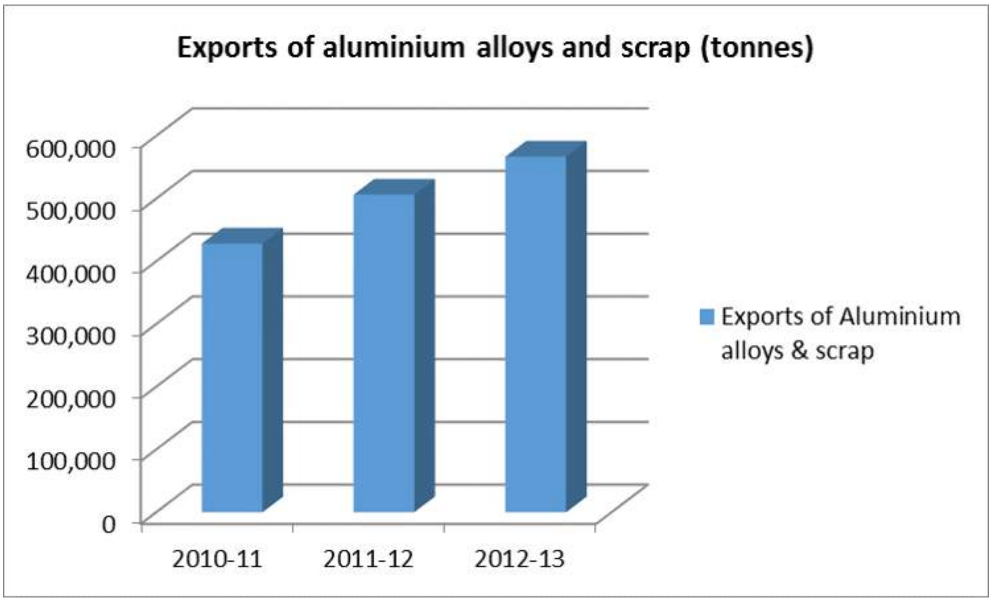


Figure 3.16: Exports of aluminium from India

(Source: MoCI Export Database)

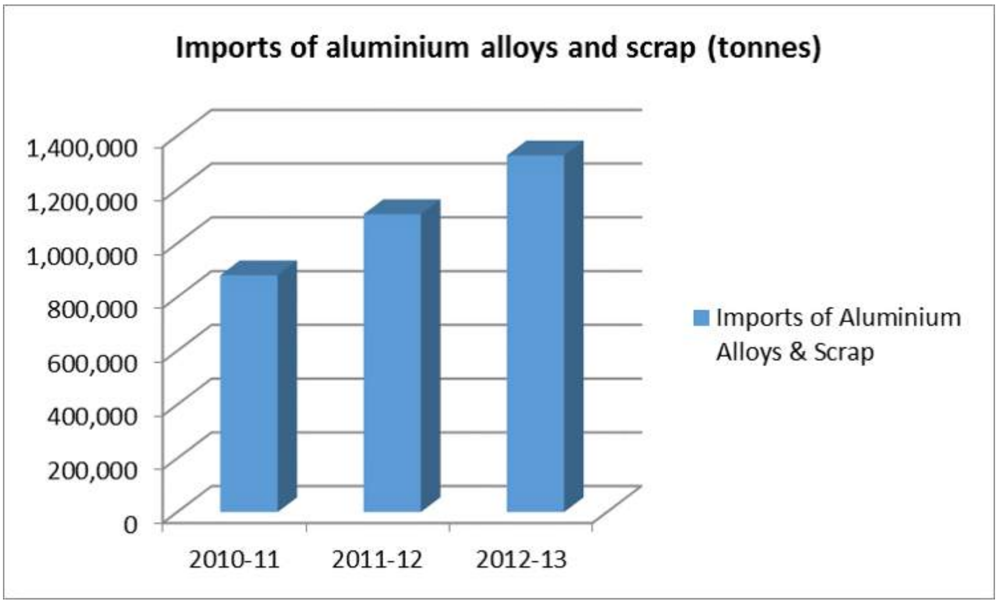


Figure 3.17: Imports of aluminium to India

(Source: MoCI Import Database)

The production of primary aluminium in India was 1.63 million tonnes in 2010-11 whereas the consumption during 2010 was 1.59 million tonnes, representing a per capita consumption of about 1.3 kg which was in the range of 0.5 kg about a decade back. However, this is much lower than the worldwide average of 7.4 kg (IBM, 2013a).

It is projected that aluminium production capacity in India at the end of the 12th Plan period (2017) would be about 4.7 million tonnes. This would require about 9.2 million tonnes of alumina. So, if all the announced alumina capacity additions fructify, India would be surplus in alumina and would be a significant player in alumina trade. To produce 13.3 million tonnes of alumina at the end of the 12th Plan period, the bauxite requirement would be about 40 million tonnes (IBM, 2013a).

Looking at the price data for aluminium (Figure 3.18), it is noted that though the prices have seen a rise, there have been fluctuations in these prices over the last 15 years.

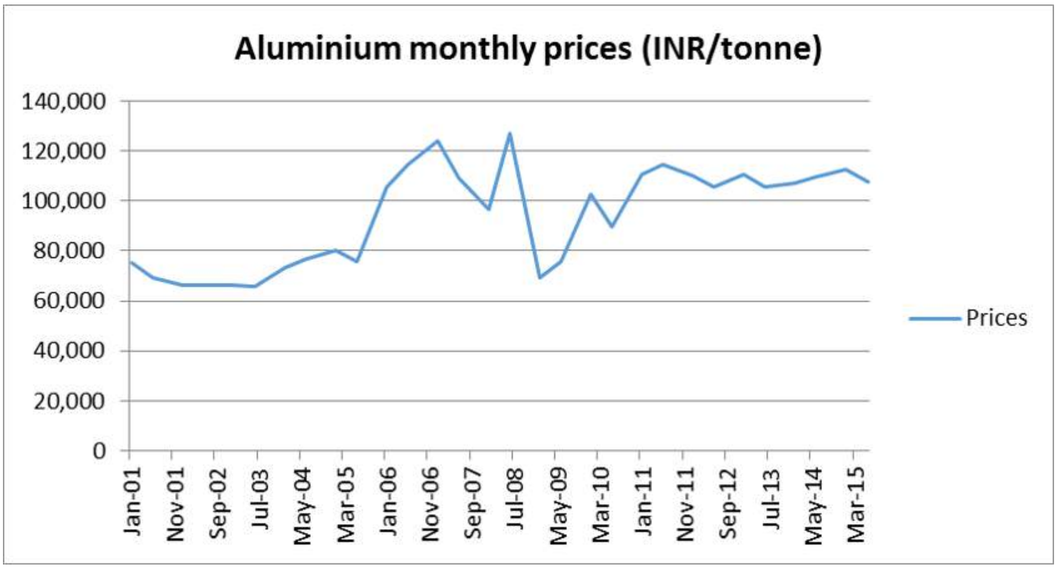


Figure 3.18: Aluminum monthly price, 2001-2015 (INR/metric tonne)

(Source: Indexmundi.com)

Environmental and social impacts of aluminium

Aluminium is extracted from raw bauxite through the process of open pit mining which is then smelted at very high temperature, and then through electrolysis the liquefied aluminium is extracted, cleaned and poured into solid ingots. Approximately 1 ton of aluminium is produced from every 4 tonnes of mined bauxite. This entire process of extraction of aluminium is extremely energy intensive which requires large amounts of electricity, water and other resources for its production. The USEPA has highlighted that perfluorocarbons released during aluminium smelting operations are 9,200 times more harmful than CO_2 emissions in terms of their impact on global warming. The extraction process of bauxite from the earth's surface (strip-mining process) removes the entire vegetation in the mining region leaving the land less productive and resulting in habitat loss for local wildlife as well as in soil erosion in the mining area and nearby (Leigh, 2010). Some other environmental issues associated with aluminium mining are changes in landscape, run off from the mine site, disturbance of hydrology, increase in waste generation, and noise pollution due to mining operations and transportation. Due to mining activity, deforestation and soil erosion occur which ultimately leads to natural disasters such as flooding and drought in some regions. Further, aluminium mining causes land degradation/land pollution as some of the by-products are not recycled and dumped at dump sites (Leigh, 2010).

The caustic red sludge and toxic mine tailings that are mostly left behind are deposited in the excavated mine pits through which they ultimately seep into aquifers, contaminating local water sources (groundwater and surface-water) in that region. During the process of smelting and processing, greenhouse gases such as carbon dioxide, perfluorocarbons, sodium fluoride, sulphur dioxide, polycyclic aromatic hydrocarbon, caustic aerosols, dust from bauxite, limestone, charred lime, alumina and sodium salt are released in the air. Some of these emissions deplete the ozone layer while others can cause various health problems like skin burns, skin cancer, respiratory illness as well as lung cancer (Leigh, 2010). Aluminium smelters generate large amounts of solid wastes arising from the relining of pots which takes place every 5-8 years. The carbon part of the spent potlining is the most hazardous waste as it contains fluoride, cyanide, PAH and reactive metal along with other material which adversely affects the heath of the mining workers and local residents (Leigh, 2010).

The International Council on Mining and Metals has developed common principles related to business ethics, social responsibility, environment, health and safety aimed at maximising benefits and minimising negative impacts of mining on society and the environment (Norsk Hydro, 2012). In most regions, aluminium mining activity is welcomed as it generates employment opportunities, income and tax generation, as well as indirectly leading to better civic amenities. However, some communities may be adversely affected by mining due to absence of proper rehabilitation and resettlement of affected people, loss of land for agriculture, and decline in traditional ways of living. Finally, the presence of the mine could enlarge the economic gap present between different groups of people and lead to social tensions in the long run.

According to the International Aluminium Institute, the application of aluminium in passenger vehicles and light trucks manufactured in 2006 would have led to a potential savings of approximately 140 million tonnes of GHG emissions and to energy savings equivalent to 55 billion litres of crude oil over the use phase of the lifecycle of these vehicles due to the reduced fuel consumption (TAA, 2011). However, the upstream emissions from aluminium are higher compared to steel due to larger energy demand for producing aluminium, which could partly/fully offset the reduced emissions from the use phase.

In a recent study, Murthy (2015) has estimated that 1 kg of aluminium replacing heavier materials in a car or light truck eliminates 20 kg of CO_2 over the vehicle's life. Thus, 15 million tonnes of aluminium used in transport applications – cars, buses, trucks, trains and ships can reduce CO_2 emissions up to 300 million tonnes on account of improved fuel efficiency. This reduction in CO_2 emissions is vital because the transport sector today generates about 19% of all manmade greenhouse gas emissions.

Recycling aluminium

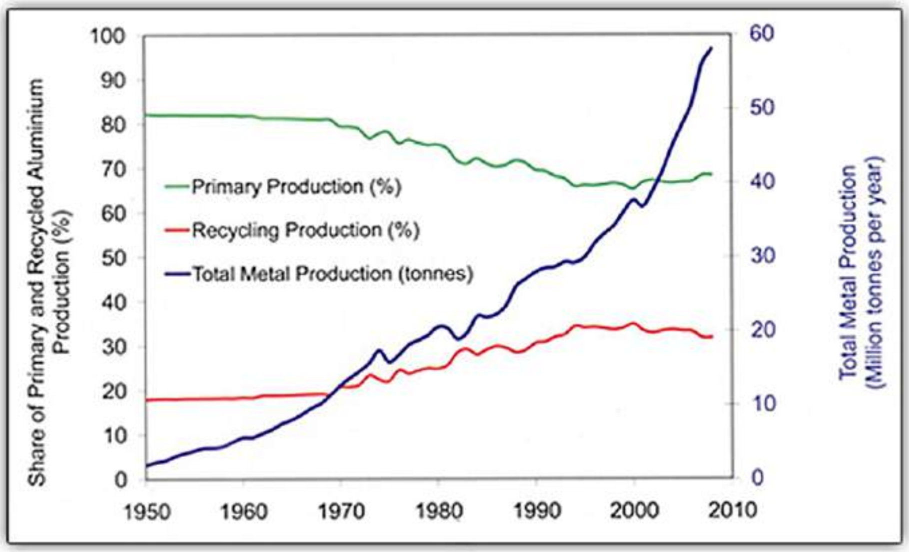


Figure 3.19: Global share of primary and recycled aluminium production

(Source: AAI, 2010)

Aluminium recycling saves huge economic and environmental costs compared with production from virgin ore. Each ton of aluminium recycled uses 95% less energy and saves one m^2 of land use, 24 barrels of crude oil equivalent of energy, more than 15 tonnes of water use, eliminates more than 9 tonnes of CO_2 equivalent of GHG, avoids 2.5 tonnes of solid waste and hundreds of kg of other air and water-borne emissions and effluents (TAA, 2011). Recycling of aluminium reduces the mining of bauxite ores as well as use of chemicals such as caustic soda, aluminium fluoride and lime. Aluminium is 100% recyclable and can be recycled numerous times without losing its quality.

In India, although the aluminium industry is over six decades old, the recycling sector with modern state-of-the-art technology is still in its nascent stage. Aluminium recycling has the potential to save 600,000 tonnes of bauxite resources every year in India (IBM, 2013a). As per an estimate from SIAM, with efficient recycling, India can hope to recover by the year 2020 over 1.5 million tonnes of steel scrap, 180,000 tonnes of aluminium scrap and 75,000 tonnes each of recoverable plastic and rubber from scrapped automobiles (Team-Bhp.com, 2011).

While today aluminium accounts for less than 10% of a car's total weight, it represents up to 50% of the total scrap value (TAA, 2011). Aluminium recycling is economical and yields consistent income for municipalities as well as employment and welfare of local communities. Therefore, it is in the interests of all stakeholders to promote aluminium recycling and expand the use of recycled content in automobile, trains and aircraft.

3.1.2.3 Copper

Uses of copper

Copper is a tough, malleable and highly conductive metal, making it one of the world's most important metals. Copper use in human history stretches back 7,000 years; today it is vital for many industrial sectors. Copper and copper alloys are used in building construction (roofing, wiring, and plumbing), power generation and transmission (cables, transformers), electronic appliance manufacturing (computers, cell phones, microwaves, etc.), the production of industrial machinery (gears, turbine blades, and heat exchange equipment) and transportation (vehicles, high speed trains). Use of copper in electric power and electronics are based on its excellent ability to conduct electricity. Copper is also used in other consumer products such as cookware, as well as in artistic applications such as musical instruments and sculptures. Brass is a very useful alloy of copper and zinc.

Mining for copper is costly and difficult, because copper ores typically contain a small percentage of the metal[8]. Pure copper metal is generally produced in a multistage process, beginning with the mining and concentrating of low-grade ores containing copper sulphide minerals, followed by smelting and electrolytic refining to produce a pure copper cathode. Mined copper ores generally contain between 0.5-3% copper and need to undergo a concentration process to increase the copper content to 25-35% before it can be smelted (BGS, 2007). The ore then undergoes metallurgical processes (extrusion, drawing, rolling, forging, melting, electrolysis, atomisation, fabrication) to produce high quality copper cathodes (99.99% Cu content), which are then casted by mills and foundries into copper rods (for wires), billets (tubes, rods, bar stocks), cakes (plate, sheets, foil), or ingots (alloying, casting).

Use of copper in the automotive sector

Copper is a multi-purpose material whose properties have assigned it a critical role in the transportation sector for functionality, efficiency, comfort and safety. Automobiles account for the largest share of copper usage in the transportation sector. Trains, ships, and aircraft, in that order, make up the balance. Copper is mostly used for electrical products, followed by heat transfer devices such as radiators and oil coolers, and bronze sleeve bearings. Traditionally, copper usage was distributed about equally among electrical systems (motors, generator/alternators, wiring harnesses), heat transfer systems (radiators, oil coolers, heater cores, and air-conditioning heat exchangers), and mechanical components such as bearings and shifter forks. Beginning in the late 1980s, electrical uses steadily increased, while heat transfer applications were gradually taken over by aluminium. However, despite downsizing and a general reduction in the weight of automotive components, the large increase in the number and complexity of electrical systems has actually led to an increase in copper usage per vehicle (KME, 2013).

The main uses of copper in automobiles can be classified as follows:

Automotive radiators and heaters: Copper's inherent superiority in thermal conductivity, corrosion resistance and strength has made it a preferred primary metal for radiators in cars and trucks. With new technologies, it can be used to make smaller, lighter and stronger copper radiators. However, there was a change in the trend that began in 1978, the year Volkswagen introduced a car equipped with an aluminium radiator. Today, the vast majority of automobile radiators for new cars are made from lighter-weight, lower-cost aluminium alloys, although truck, bus, heavy vehicle, and aftermarket radiators continue to be made from copper and brass. The copper industry remains active in improving copper and brass radiator design, manufacturability, and corrosion resistance.

Automotive wiring: Cars once typically had only three electric motors (for the starter, windshield wiper, and heater/ventilator blower), but modern vehicles contain up to 70 motors for various safety, comfort, and/or convenience features, many of which are now standard equipment. These motors, along with their wiring harnesses and connectors, add significantly to the modern vehicle's copper content.

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[8] Against the international average of metal content (in the ore) of 2.5%, Indian ore grade averages less than 1%.

New automotive applications: The trend toward so-called ‘smart’ vehicles has increased copper consumption by 40% for devices such as antilock-brake systems (ABS), burglar alarms, gyroscopes, collision-avoidance systems, and navigation computers.

Other automotive uses of copper and copper alloys include automotive hydraulic brake tubes, automotive radiators and heat exchangers, and automotive vehicle brake tubing. With technological advancements, the automotive industry has explored the importance of copper in producing more energy efficient, durable and higher quality parts in automobiles.

There are different estimates available for the use of copper in a vehicle. The weight of copper in a vehicle ranges from 15 kg for a small car to 28 kg for a luxury car (KME, 2013), which can correspond to about 1-2% of the total vehicle weight. “Hybrid” (ICE-electric) vehicles use almost double the amount of copper (approx. 45 kg) compared to that of traditional ICE vehicles (KME, 2013).

Looking at copper use in cars from a different perspective, it has been noted that in 1948, the average family car contained 55 copper wires with a total combined length that averaged 45 metres (150 feet). With improvements in electronics and consumer demand for power accessories in automobiles, today’s automobiles contain up to 1,500 copper wires that total about 1.6 km in length (KME, 2013).

Availability and prices

India is not self-sufficient in supply of copper ore. Thus, in addition to domestic production of ore and concentrates, India also imports copper concentrates for its smelters for metal production. The domestic demand for copper and its alloys is met through domestic production, recycling of scrap and by imports. The low grade quality of Indian copper ores and nature of ore bodies (narrow width) restrict large scale production from underground mines (IBM, 2012a).

The total resource of copper ore in India was estimated at 1.56 billion tonnes in 2010. Of this, only 394 million tonnes (25%) fall under reserve category (proven and probable), while the balance 1.16 billion tonnes (75%) are under remaining resources. The grade of copper ore reserves varies highly between 1% Cu and 1.85% Cu whereas identified resources contain less than 1% Cu grade. The largest resources are found in the state of Rajasthan (50%), followed by Madhya Pradesh (24%) and Jharkhand (18%), along with small occurrences in other states (IBM, 2012a).

The production of copper in India is shown in Table 3.6. It can be seen from this table that for copper ore, the production in 2010-11 was 3.62 million tonnes, which was an increase of 11% over the previous year, but production in 2011-12 declined by 3% to 3.48 million tonnes.

Table 3.6: Production of copper in India

Year	Copper ore (tonnes)	Copper concentrates (tonnes)	Copper metal (refined copper) (tonnes)			
			Copper blister	Copper cathodes	Copper electrolytic wire bars	Copper continuous cast wire rods
2009-10		124,577	17,864	532,865	-	312,447
2010-11	3,601,984	136,856	14,245	512,124	-	300,416
2011-12	3,479,189	130,456	19,473	504,677	-	287,550
2012-13	3,638,751	123,655	17,455	493,519	-	285,051

(Source: IBM, 2012a; 2013b)

Refined copper production in India is currently dominated by three major players: HCL, Hindalco and SIIL. While HCL produces copper metal from the ore produced at its captive mines, Hindalco and SIL have shore-based smelters and are dependent entirely on imported metal-in-concentrates (IBM, 2012a).

India is a net exporter of refined copper, though exports have reduced over the last few years, with the expansion of domestic demand and range-bound production. Refined copper exports account for 36% of domestic production. Nearly 50% of India's copper and alloy exports are to China, Saudi Arabia and the United Arab Emirates.

Refined copper imports, on the other hand accounted for less than 4% of the domestic demand for refined copper. Copper sales in India have increased at a CAGR of 8% during the last five years, whereas refined copper consumption has witnessed a growth of 10% CAGR (IBM, 2013b).

The per capita consumption of copper in India is around 0.5 kg as against 4.6 kg in China and 10 kg in developed nations. The estimated consumption of copper in India is given in Table 3.7. The consumption is expected to grow by 8-9% in the coming years driven by the government's increased expenditure in the power and transport sectors.

Table 3.7: Estimated total copper consumption[9] in India

Year	Quantity (tonnes)
1956	33,800
1970	55,000
1980-81	117,363
1990-91	207,170
2000-01	484,000
2008-09	650,000
2009-10	> 720,000

(Source: Sarkar, 2011)

Environmental and social impacts of copper

The process of mining copper starts with extraction of ore from the earth which is then smelted, processed and converted to copper plates. During this entire process, harmful substances such as sulphuric acid and sulphur dioxide are released in the air leading to air pollution. The traditional way of mining copper has resulted in production of many toxic waste products which negatively impacts the environment at the mining site. The negative environmental consequences of copper mining are substantial and have both acute and chronic impacts on the geography, water, air, vegetation, land and wildlife in and around the mines. Further, when the metal sulphides present in the underground ore are exposed to natural elements, the sulphides are oxidised to sulphuric acid and acid mine drainage (AMD) is caused which leaches toxic metals and contaminates the surrounding areas, thus making the affected area unable to sustain and support life for long time periods. Areas near mines typically have higher levels of copper and other heavy metals present in the ground water and surface water, thus affecting the health of mining workers and people nearby (Dudgeon, 2009).

The effects of copper mining on the health of the workers has been explored and studied extensively and two genetic disorders have been identified, namely Wilson's Disease and Menkes Disease. Both these diseases arise from mutations in enzymes that are involved in the transport of copper into body cells. Further, constant exposure to chronic high levels of copper is a major cause for lung cancer and coronary heart disease in mine workers. Various studies of copper workers pre and post mortem have showed the risk of chronic copper exposure on health by breaking down the risk according to various segments of the copper mining process (e.g. smelting, converting and plating) (Thomassen et al., 2004; Adam et al., 2001; Rencher et al., 1977).

Uncontrolled and unregulated copper smelting emits large quantities of particulate matter, trace elements and sulphur oxides which adversely affect human health. Sulphur dioxides (SO_2), sulphates

[9] Total consumption of copper includes Primary Refined Copper (Cathode + CCR + Wire Bars) + Imported Copper & Copper Alloy Semis + Secondary Copper (including scrap).

and sulphuric acid aerosols released during this process cause lung irritation and aggravate asthma. Further, sulphur dioxide emitted from the smelting process degrades workers' eyesight as well as increases acid deposition on land (Eldred et al., 1983; Trijonis, 1979; Yuhnke & Oppenheimer, 1984).

The mining of copper ore produces enormous amounts of liquid and solid wastes which often ends up affecting the health of the local community. Some hazardous wastes generated from the mining site include wastes such as ESP dust, spent catalyst, ETP cake, scrubber cake, nickel sludge, heavy metal sludge, oil sludge and used oil, which degrade land and soil as well as affects the health of mine workers (Office of Technology Assessment, 1988).

Sterlite Copper Limited (renamed as Vedanta Limited) is one of the leading copper producers in India and they have made efforts to convert environmental challenges to opportunities for innovative technology, minimising material usage, energy use and water use and encouraging waste recycling, driven by competitiveness benefits of these measures. Currently the company has invested around INR 1.78 billion (USD 28 million) in different areas such as waste disposal and management, emissions treatment and remediation, and environmental management to reduce negative externalities arising due to its operations. The company has further adopted an Energy and Carbon Policy supported by the ISO 50001 Energy Management System at its two stations (Thoothukudi and Silvassa) to improve energy conservation. Some other measures adopted to reduce the use of furnace oil consumption in the boiler super heater include measures such as elimination of super heater and replacing it by saturated steam turbine as well as installing additional DM water plant to conserve water and energy use. The company is also engaged in community development and through CSR activities has been able to enhance the livelihood of over 150,000 people living in 72 villages near their mining sites in terms of health, water, sanitation, education, sustainable farming, women empowerment, sports and culture development, infrastructure development, as well as investment in special projects of Government of India (e.g. Swachh Bharat Mission) (SIIL, 2013).

Hindustan Copper Limited (HCL) is one of the largest copper mining companies in India. It is fully committed to environmental conservation and promotes sustainability by encouraging eco-friendly operations and processes. The company mandates itself to strictly follow and adhere to the prescribed standards set by the Central Pollution Control Board. Regular monitoring of the ambient air quality is undertaken at all its mines, process plants and residential areas near its units; an environmental audit is also carried out annually through an expert agency and remedial measures are implemented to further improve the air quality in and around the sites. The company has adopted other measures such as effluent treatment, recycling of process-discharged water, and safe and scientific disposal of waste to protect the environment of the surrounding areas. To maintain ecological balance, the company regularly undertakes plantation of trees in and around its production units as well as adopts measures to protect the flora and fauna of the surrounding areas. The company also conducts environmental and social workshops and seminars to educate its staff about sustainable development and its benefits at regular intervals (HCL, undated).

Recycling copper

Copper is highly recyclable and nearly 90% of the available scrap is recycled in the world. Copper by-products from manufacturing and obsolete copper products are readily recycled and contribute significantly to copper supply. Copper, by itself and in any of its alloys such as brass and bronze, can be used indefinitely as it is completely recyclable. Copper recycling value is so great that premium-grade scrap generally has at least 95% of the value of the primary metal from newly mined ore (CDA, undated).

There are various economic and environmental benefits associated with recycling copper. Recycled copper uses much less energy, about 10 GJ/tonne, which is only 10% of the energy used for extracting or mining copper (CDA, undated). This energy conservation leads to saving valuable resources such as oil, gas or coal, as well as reduces GHG emissions. Economically, it is often cheaper to recycle the old copper rather than to mine and extract new or primary copper. Recycling copper helps to keep the prices of copper and copper products low.

In the USA, close to 10% of copper scrap is from radiators. Since roughly 12 million cars are scrapped each year, with an average radiator weight of 6 kg, about 70,000 tonnes of copper scrap are generated. Copper radiator scrap usually sells for around 50% of the price of virgin copper and zinc (CDA, undated). With advanced radiators, copper recyclability will be enhanced even further. Made without lead/tin solder, they will be significantly easier to reclaim, and the end product will be far cleaner than in the past. In fact, the recycled copper will be pure enough to fabricate directly into new radiator tube strip. In comparison, brazed aluminium radiators can only be recycled into less critical casting alloy because of their silicon content. In the USA, 43% of copper demand is satisfied by recycled scrap; the corresponding figures for Western Europe and Japan are 41% and 39% respectively (CDA, undated).

3.1.2.4 Zinc and Nickel

Uses of zinc and nickel

Zinc was discovered in metallic form centuries ago and its ores were used for making brass and zinc compounds as well as for some medicinal uses. Zinc is known for effectively protecting steel against corrosion, and its ability to die cast complicated components makes it indispensable in industry and household products. It is used to protect buildings, cars, nails, wire, pipes, etc. Zinc is further used in alloys, and zinc alloys are widely used in production of many components and die-casting fitting in automobile manufacturing and mechanical industries.

The amount of zinc present in these alloys varies from 10% to 40%. The most widely used alloy of zinc is brass, in which copper is alloyed with zinc along with smaller amounts of lead and tin. Other alloys of zinc are found in many commercial products such as batteries, paint, plastics, rubber products, pharmaceuticals, floor covering, inks, cosmetics, soap, and textiles. Zinc is also used to make batteries such as zinc-manganese batteries and zinc air batteries. 50% of zinc is used for galvanising, followed by other uses like zinc alloying (17%), brass and bronze (17%), chemicals (6%), and zinc semi-manufactures (6%) (ILZSG, undated).

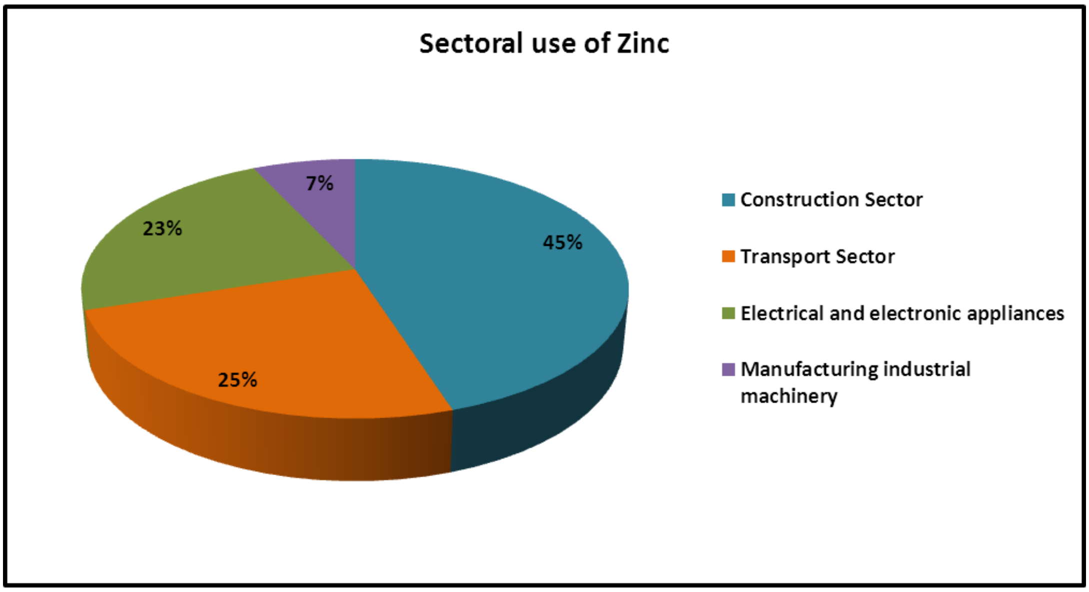


Figure 3.20: Major sectoral uses of zinc

(Source: IZA, undated)

Major share of zinc by sectoral use (Figure 3.20) is accounted for by the construction sector (45%), followed by the transport sector (25%), electrical and electronic appliances (23%), and manufacturing of industrial machinery (7%).

Nickel is a naturally occurring, lustrous, silvery-white metallic element and is present abundantly in the earth's crust in the form of ferro-nickel, nickel oxides and other chemicals as well as more or less as pure nickel metal. Some of the key characteristics of nickel metal include high melting point, resistance to corrosion and oxidation, ductile nature, and possession of catalytic properties and toughness.

Nickel is widely used in over 3,000 products for consumer, industrial, military, transport, aerospace, marine, and architecture applications. About 65% of the produced nickel is used to manufacture stainless steel, another 20% is used in other steel and non-ferrous alloys, about 9% is used in plating and 6% in other uses such as coins, electronics, and in batteries for portable equipment and hybrid cars. Nickel is widely used in alloying, particularly with chromium and other metals (frequently 8-12% nickel), to produce stainless and heat-resistant steel which can then be used for pots and pans, kitchen sinks, etc., as well as in buildings, food processing equipment, medical equipment and chemical plants. Further, iron and nickel alloys are used in electronics and specialised engineering, while copper and nickel alloys are used for coinage and marine engineering. Nickel forms an integral part of many rechargeable battery systems used in electronics, power tools, transport and emergency power supply; at present, the most important is nickel-metal hydride (NiMH). Further, nickel is an important ingredient in many catalysts used to make chemical reactions more efficient (Nickel Institute, undated).

Today nickel use is growing at about 4% each year while the use of nickel-containing stainless steel is growing at about 6%. The use of nickel has been expanding rapidly in Asia as nickel-containing materials are needed to modernise infrastructure, for industry and to satisfy the growing demand for consumer goods (Nickel Institute, undated).

Use of zinc and nickel in the automotive sector

Zinc and its alloys play a critical role in the automotive sector and with the development of zinc base alloys, the use of zinc in this sector has significantly increased. Various components of zinc such as rolled zinc, rolled zinc alloys, zinc wire, extruded zinc shapes and die-castings are used in the automotive sector. Zinc is an outstanding choice of alloy for constructing auto parts because it is unbending, hard, small, lightweight, non-sparking, non-corrosive, recyclable and non-toxic in nature (KDC, 2014). The zinc industry claims that zinc die casting is suitable for the manufacture of complex mechanical parts as they provide a near net shape out of the die, with smooth surfaces that need little in the way of finishing. The number of parts and components of the automobile which can be made of zinc are increasing annually.

Specific applications of zinc and zinc-nickel plating in the automotive sector include:

- Engine and other under-the-hood components
- Power steering systems
- Brake parts and systems
- Air-conditioning and components and systems
- Chassis hardware
- Climate control components
- Fuel systems

Particularly, galvanised steel with a very fine surface finish is used to produce vehicle bodies that are vulnerable to corrosion as zinc is corrosion resistant and makes the average automobile last longer. The use of galvanised advanced high strength steel helps in the reduction of vehicle body weight and emissions, and improves safety performance along with fuel efficiency. Estimates have suggested that 5-7 kg of zinc protect a vehicle from rust, 8 kg are used to make zinc die-cast parts like door handles and locks, and each tire contains about 0.2 kg of zinc, needed to cure rubber. In the past, 15-20 kg of zinc "Zamak" alloys were used in automotive die cast components. The recent decline in zinc alloys has been due to a combination of lightweighting and price factors (Anyadike, 2002; AGA, undated).

Nickel is widely used in the transport and automobile sectors with no single use dominating. It is estimated that the automotive sector accounts for 7-8% of new nickel use, i.e., approximately 90,000 tonnes of nickel each year (Nickel Institute, undated). Nickel-containing materials are used in automobiles, trucks and buses in the form of stainless steel, nickel alloys, nickel-plating and various nickel chemicals. Stainless steel is used in cast, wrought and powder metallurgy forms. Stainless steel applications include wipers, brackets, tubing, springs, clamps, fasteners, sensors, gaskets, air bag assemblies, flanges, wheels, fuel tanks, and bus structural/panels. Nickel containing alloys are sub-divided into various families based on other alloying substances. Nickel-chromium alloys and nickel-chromium-iron alloys are employed in heating elements and exhaust components such as exhaust valves and diesel glow-plugs. Nickel containing cast irons and cast nickel alloys are used in turbocharger housings and manifolds. Nickel containing alloy steels are used in gears, drive shafts, special vehicles for low temperature and/or high wear uses; a typical alloy of this kind contains about 17.5% of nickel. Copper-nickel alloy tubing is used in some brake fluid lines and nickel-aluminium alloys are used in pistons and cylinder inserts. Some nickel and nickel alloys are used in powder form in electronic shielding applications and batteries for hybrid electric vehicles. Further, austenitic stainless steels are used by the truck industry for tanks for food and dairy containment, cryogenic applications, chemicals and acids (Nickel Institute, undated).

The chemical composition of batteries is constantly evolving to enhance battery life and performance. In early hybrid cars, Nickel Metal Hydride (NiMH) was the standard battery, but in recent times some newer hybrids are using lithium ion batteries. These batteries use nickel as an important material in their formulation while some use cobalt. Further, fuel cell powered autos and buses are still in the early stages of commercialisation with a large number of demonstration vehicles. Many fuel cells also have nickel components (Nickel Institute, undated).

Availability and prices

Zinc

The Indian zinc industry has two major players – Hindustan Zinc and Binani Zinc. Hindustani zinc is a producer having its own mines and a market share of 60% while Binai zinc is a custom smelting producer of zinc. The main consumer of zinc at present in the domestic market is the steel industry – over 70% of zinc is used for galvanising, followed by other uses such as die-casting, guard rails for highways, and import-substituted zinc alloys (IZA, undated).

Due to high demand for infrastructure and industrial development including automobile and consumer durables, it has been estimated that the demand for zinc is expected to grow at about 12-15% annually (Indianmirror, undated) and India would require 1.4 million tonnes per annum of zinc by 2020 to be self-reliant. It is observed from Figure 3.21 that the production of zinc in India has been mostly increasing since 2002.

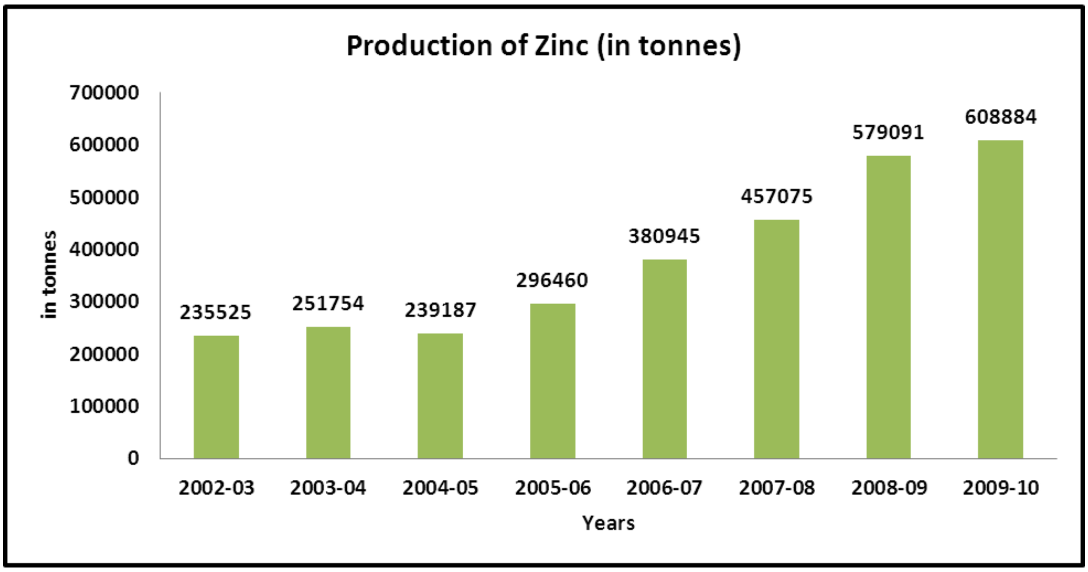


Figure 3.21: Production of zinc metal in India

(Source: IBM, 2011; 2012b; 2013c)

Currently, zinc supply in India comes from domestic production as well as imports since domestic production is not sufficient.

Table 3.8: Import of zinc ores and zinc metal and alloys

Year	Zinc ores and concentrates (in tonnes)	Zinc and alloys (in tonnes)	Zinc (scrap) (in tonnes)
2005-2006		168,155	97,288
2006-2007		130,564	48,470
2007-2008	49,493	73,642	32,572
2008-2009	78,201	80,129	14,565
2010-2011	88,171	82,411	29,817
2011-2012	63,194	82,852	48,580
2012-2013 (provisional)	111,912	102,672	61,252

(Source: FIMI, undated a; b; Government of India, undated)

Table 3.9: Export of zinc ores and zinc metal and alloys

Year	Zinc ores and concentrates (in tonnes)	Zinc and alloys (in tonnes)	Zinc (scrap) (in tonnes)
2005-2006		20,427	81
2006-2007		188,730	519
2007-2008	506,774	81,274	262
2008-2009	88,387	209,374	60
2010-2011	67,501	264,219	32
2011-2012	5,591	295,033	38
2012-2013 (provisional)	75,870	198,598	77

(Source: FIMI, undated c; d; Government of India, undated)

The trends in average monthly wholesale price index of zinc in India are given in Figure 3.22.

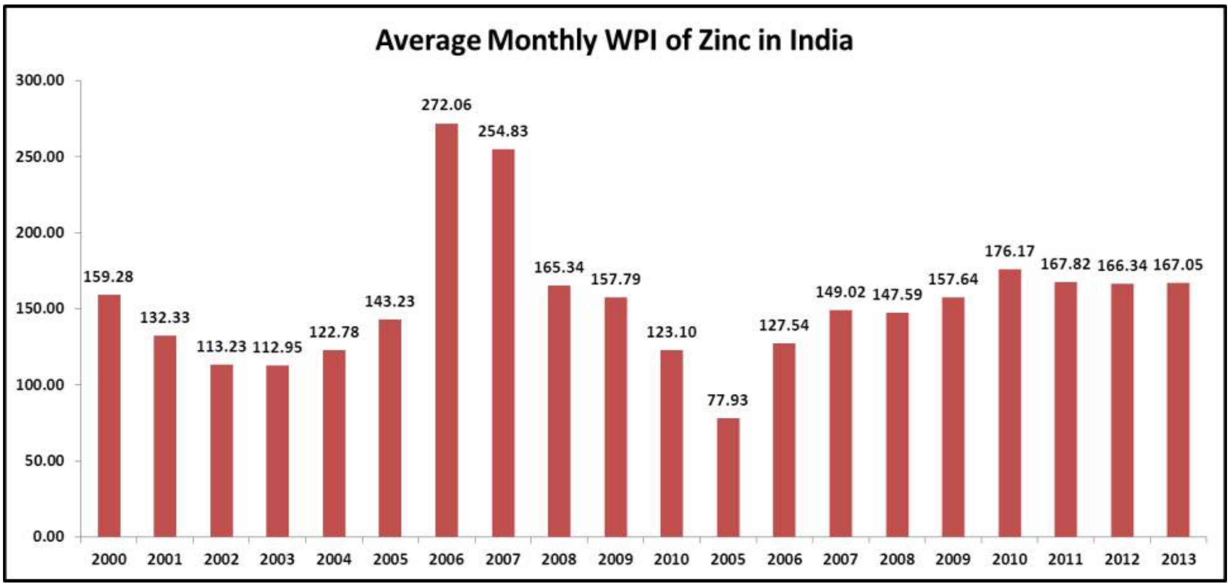


Figure 3.22: Average monthly wholesale price index (WPI) of zinc in India (2002-2013)

(Source: Indiastat.com)

Nickel

India currently does not produce nickel as there are no major identified nickel ore deposits in the country. A few potential sources for producing nickel in the country have been identified, but these sources are still being explored and no commercial production is currently taking place. One potential source of producing the metal is from lateritic oxides which is only available in Sukinda valley of Odisha state. Nickel also occurs in sulphide form along with copper mineralisation in East Singhbhum district, Jharkhand state. In addition, it is also found in Jaduguda and Jharkhand with uranium deposits and a process is being developed for its recovery. Other places where occurrences of nickel are found are in Karnataka, Kerala and Rajasthan. Polymetallic sea nodules are another potential source of nickel. As per UNFC, as of April 2010, the total resources of nickel ore have been estimated at 189 million tonnes (IBM, 2013d).

The Indian market is mostly dependent upon imports to meet its nickel demand. India imports around 30,000 tonnes of nickel each year. About 85% of Indian imports are in form of unwrought nickel. Russia is the main supplier of nickel to India and contributes nearly half of its imports, followed by Canada with 9% and Brazil with 7% (FIMI, undated a; b).

Table 3.10: Imports of nickel ores/minerals and alloys, 2010-11 and 2012-13

Ore /mineral	2010-2011	2011-2012	2012-2013 (provisional)
	Quantity (tonnes)	Quantity (tonnes)	Quantity (tonnes)
Nickel ores and concentrates	2,019	41,729	865
Ferro-nickel	6,862	6,864	31,801
Nickel and alloys	32,264	33,658	53,755
Nickel (scrap)	1,042	1,129	669

(Source: FIMI, undated a; b)

Table 3.11: Imports of nickel (item wise)

All Items	2010-2011	2011-2012	2012-2013
	Quantity (in tonnes)	Quantity (in tonnes)	Quantity (in tonnes)
All items	33,306	34,787	54,424
Nickel and alloys	32,264	33,658	53,755
Bars, rods, plates, sheets foil of nickel	663	505	1,017
Bars, rods, plates, sheets foil of nickel alloys	1,267	1,750	1,592
Nickel electroplated anode	19	12	-
Nickel and alloys: worked	613	747	4,156
Nickel and alloys: worked NES	2,387	453	350
Nickel and alloys: unwrought	2,839	2,957	950
Nickel: worked	8	2	6
Nickel except electroplated anode	24,461	27,225	45,679
Nickel mattes	6	-	1
Nickel oxide sinters and quarter intermediate	1	7	4
Nickel (scrap)	1,042	1,129	669

(Source: IBM, 2012b; 2013d)

The majority of India's consumption is of low nickel content stainless steel which uses 1-4% of the base metal. With increasing use and manufacturing of stainless steel, the demand for primary nickel is going to rapidly increase in the coming years. Nickel import in India is regulated by the Government of India with an import duty of 15% (ICEX, undated).

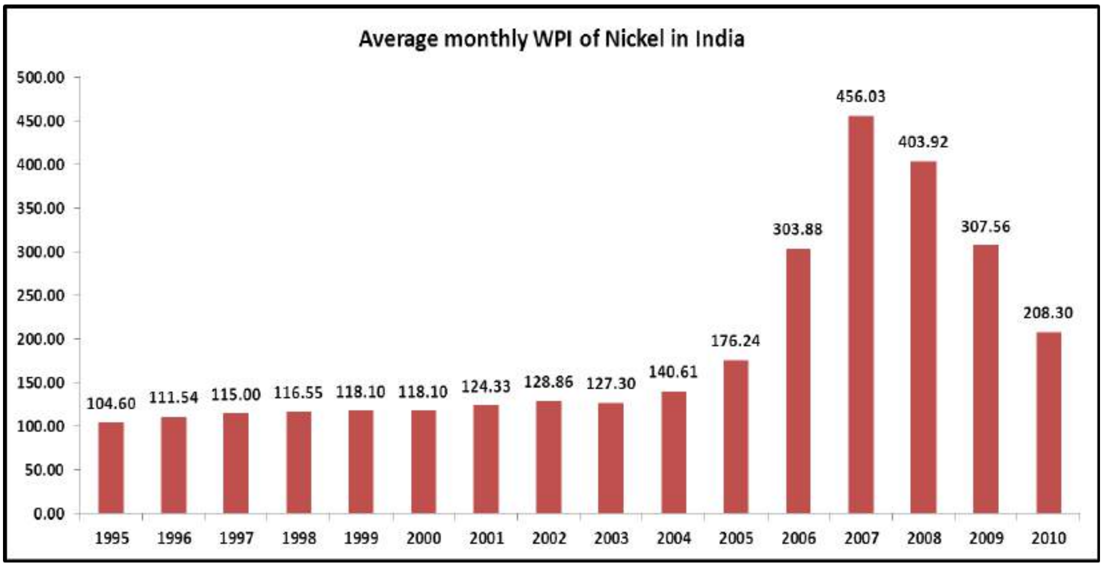


Figure 3.23: Average monthly wholesale price index (WPI) of nickel alloys in India (1995-2010)

(Source: Indiastat.com)

Environmental and social impacts of zinc and nickel

Zinc is a reactive metal and when it is combined with oxygen, other metals and with dilute acid, it releases hydrogen which can damage human health. Small amounts of zinc occurs naturally in air, water and soil, but at present zinc concentrations are increasing unnaturally due to industrial activities such as mining and combustion, which leads to contamination of the soil near mining and smelting areas. Zinc production involves processes such as crushing and grinding of the mined rocks which leaves behind large amounts of tailings which are also a major source of contamination. Winds blow away fine metal-bearing dust, spreading contamination to nearby non-mined areas (KGS, 2005). Zinc production leads to water pollution as large volumes of zinc are present in the wastewater flowing from the mining sites and processing plants. Due to mining of zinc, local water bodies as well as groundwater become contaminated with iron sulphide (from pyrite and marcasite) and other metallic sulphides which makes the water acidic. Acidic and zinc contaminated water negatively affects aquatic life and zinc also bio-magnifies up the food chain. Zinc contamination of soil and water decimates plant life in contaminated areas and reduces agricultural productivity (KGS, 2005).

While small amounts of zinc are beneficial for health, large amounts of zinc exposure can cause health hazards such as stomach cramps, skin irritation, vomiting, nausea and anaemia. Mine workers are exposed to extremely high levels of zinc concentrations which can cause damage to the pancreas, disturb protein metabolism, cause arteriosclerosis, respiratory illness, and even lung cancer. Zinc exposure is dangerous for unborn and new born children as it could negatively impact their physical and mental development (KGS, 2005).

Nickel is produced and released in the air by power plants and during mining and smelting processes which over time settles down on the ground through precipitation. As nickel enters the surface water it makes the water acidic and toxic in nature. High nickel concentrations in soils also damages plant life. Nickel in small quantities is essential for human and animals but when it exceeds tolerable levels it can cause various kinds of diseases including cancer. Nickel mining workers are exposed to nickel gas which can cause sickness and dizziness, asthma and chronic bronchitis, lung embolism, birth defects (physical and mental disorders in children), various allergies such as skin rashes and hair loss, as well as heart disorders. Exposure to nickel and its compounds can result in development of dermatitis known as “nickel itch” as well as pneumonitis in mine workers. Further, nickel tetracarbonyl, an intermediate in the Mond process for refining nickel, is extremely toxic in nature and can damage the lungs and heart over long periods of time (HE&W, undated). A US study has found that lung and nasal sinus cancer occur in workers who are exposed to more than 10 mg nickel, since nickel and its compounds are difficult to dissolve. Both the US Department of Health and Human Services and the USEPA have classified nickel as a human carcinogen, after studies on workers and laboratory animals (ATSDR, 2005).

Nickel mining leads to deforestation, land degradation and dumping of overburden rock mass in the form of large heaps. In many places, mining also causes displacement and loss of livelihood for local communities (Priyadarshi, 2012).

Nicomet Industries Limited is the only company in India which manufactures nickel. Nicomet uses hydrometallurgy solvent extraction technology for producing and manufacturing nickel to reduce its emission levels and improve plant operation. It maintains a zero water discharge policy and has a captive landfill site for disposing the solid waste in a systematic and scientific manner. The company strives to maintain high standards of safety, occupational health and environment by complying with various rules, regulations and standards (NCIL, 2008).

Recycling zinc and nickel

Zinc is recycled at all stages of production and different grades and varieties of zinc scrap are used to recover pure zinc. Zinc coated steel and zinc containing products are slow in entering the recycling cycle as they are quite durable. The general life of a zinc containing product ranges from 10-15 years for cars and household appliances to up to 100 years for zinc sheet used for roofing. Depending on the type of steel and the galvanising process, between 10% and 40% of the total consumed zinc ends up in residues. Zinc that is metallurgically combined with steel during the galvanising process cannot be easily separated from galvanised steel scrap. It is generally recovered from flue dust generated during the reprocessing of steel scrap (IZA, undated).

Globally, nickel is among the most recycled metals and about half of the nickel content of a stainless steel product comes from recycled sources. Nickel is rapidly recycled in many of its applications and large tonnages of secondary or ‘scrap’ nickel is used to supplement newly mined metals. The International Nickel Study group estimates that around 4.4-4.6 million tonnes of nickel bearing scrap are collected and recycled per year. This scrap is estimated to contain almost 350,000 tonnes of nickel (one quarter of the total demand) annually. Most of the collected scrap is stainless steel scrap from the demolition of obsolete factories, machinery and equipment, and consumer electronic goods (Nickel Institute, undated).

The nickel content in the auto shredder residue (ASR) sent to landfills is truly lost to all recycling loops. Stuecheli (2002) found that ASR is heterogeneous with nickel content ranging from 0.4-2.8 g/kg with a mean of 1.2 g/kg. The total nickel use in automotive applications has ranged from 128,600 tonnes in the past to 75,300 tonnes more recently; the nickel loss represents as little as 9% and as much as 16% of nickel used in automobiles. Therefore, it might be the case that nearly 20%

of the nickel in automobiles is lost to landfill. This leaves 40% of automobile nickel that is recycled into other metals which benefits the nickel containing alloys (Nickel Institute, undated).

In a nutshell, it can be said that approximately 40% of the nickel contained in automobiles and parts are re-used for its nickel content through part reuse and nickel containing stainless steel recycling. Another 40% is recycled into other metals and goes out of the nickel recycling loop. The remaining 20% is generally dispersed, including to landfill (Nickel Institute, undated).

3.1.2.5 Plastics and Composites

Plastics are lightweight, comparatively cheaper and durable materials used widely in manufacturing different types of products. They are derived mainly from by-products of fossil fuels. The two major processes used to produce plastics are called polymerisation and poly-condensation, and they both require specific catalysts. In a polymerisation reactor, monomers like ethylene and propylene are linked together to form long polymers chains, where each polymer has its own properties, structure and size depending on the various types of basic monomers used. Plastics are often manufactured as composites. This is achieved by adding reinforcements such as glass or carbon fibres to the plastics, increasing their strength and stability. Plastic foam is a different type of composite which combines plastic and gas. In the second half of the 20th century, plastics became one of the most universally-used and multipurpose materials in the global economy. Today, plastics are utilised in more and more applications/products and they have become essential to our modern economy.

Use of plastics in the automotive sector

Over the last 50 years, use of plastics components in manufacturing automobiles has increased significantly. Plastics are mostly used in manufacturing non-load bearing components and interiors of different categories of automobiles. Their increased application has made vehicles lighter and hence energy efficient, and has added durability due to their corrosion resistant properties. On average, it is estimated that a 10% reduction in vehicle weight will improve fuel efficiency in the range of 5-7%. Plastics also bring advantages of flexible design and reduced cost. Plastics have one of the largest applications in passenger cars, and are used for manufacturing exterior and interior components like bumpers, doors, headlights, certain safety components, windows, rear mirrors housing, trunk lids, hoods, wheel covers, battery frames, etc. Due to growing scarcity in metal resources, increased price competition and tightening fuel efficiency mandates, plastics will find larger applications in manufacturing of automobiles. Plastics and composites have second largest share by weight in automobiles after ferrous metals and alloys (like cast iron, steel, nickel). On an average, polymer composites and plastics accounts for 10-15% of the total weight of a vehicle (Szeteiová, 2012).

A typical automobile contains components made from 13 different high quality plastics although the number may vary slightly across different types of vehicles. However, out of the 13 different types of plastics, 3 types of plastics account for 66% of the applications. These include polypropylene (32%), polyurethane (17%) and polyvinyl chloride (16%) (Szeteiová, 2012). Table 3.12 outlines the 13 different category of plastics, their characteristics and key components manufactured from them.

Table 3.12: Major plastics used in manufacturing auto-components

Type of plastic	Property	Application
Polypropylene	Polypropylene is a thermoplastic polymer used in a wide variety of applications. A saturated addition polymer made from the monomer propylene, it is rugged and unusually resistant to many chemical solvents, bases and acids.	Bumper, bumper spoilers, wheel liners, body panels, dashboards, dash board carriers, consoles, chairs, door panels, and pockets
Polyurethane	Solid Polyurethane is an elastomeric material of exceptional physical properties including toughness, flexibility, and resistance to abrasion and temperature. Polyurethane has a broad hardness range, from eraser soft to bowling ball hard. Other polyurethane characteristics include extremely high flex-life, high load-bearing capacity and outstanding resistance to weather, ozone, radiation, oil, gasoline, and most solvents.	Flexible foam seating, foam insulation panels, elastomeric wheels and tires, automotive suspension bushings, cushions, electrical potting compounds, hard plastic parts
Poly-Vinyl-Chloride (PVC)	PVC has good flexibility, is flame retardant, and has good thermal stability, a high gloss, and low (to no) lead content. PVC moulding compounds can be extruded, injection moulded, compression moulded, calendered, and blow moulded to form a huge variety of products, either rigid or flexible depending on the amount and type of plasticisers used.	Automobile instrument panels, sheathing of electrical cables, pipes, doors
ABS (Acrylonitrile Butadiene Styrene)	ABS is a copolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The styrene gives the plastic a shiny, impervious surface. The butadiene, a rubbery substance, provides resilience even at low temperatures. A variety of modifications can be made to improve impact resistance, toughness, and heat resistance.	Automotive body parts, dashboards, wheel covers
Polyamide	Nylon 6/6 is a general-purpose nylon that can be both moulded and extruded. Nylon 6/6 has good mechanical properties and wear resistance. It is frequently used when a low cost, high mechanical strength, rigid and stable material is required. Nylon is highly water absorbent and will swell in watery environments.	Gears, bushes, cams, bearings, weather proof coatings
Polystyrene	Naturally clear, polystyrene exhibits excellent chemical and electrical resistance. Special high gloss and high impact grades are widely available. This easy to manufacture plastic has poor resistance to UV light.	Equipment housings, buttons, car fittings, display bases
Polyethylene	Polyethylene has high impact resistant, low density, and exhibits good toughness. It can be used in a wide variety of thermoplastic processing methods and is particularly useful where moisture resistance and low cost are required.	Car bodies (glass reinforced), electrical insulation

Polyoxymethylene (POM)	POM has excellent stiffness, rigidity, and yield strength. These properties are stable at low temperatures. POM also is highly chemical and fuel resistant.	Interior and exterior trims, fuel systems, small gears
Polycarbonate	Amorphous polycarbonate polymer offers a unique combination of stiffness, hardness and toughness. It exhibits excellent weathering, creep, impact, optical, electrical and thermal properties. Because of its extraordinary impact strength, it is the material for car bumpers, helmets of all kinds and bullet-proof glass substitutes.	Bumpers, headlamp lenses
Polymethyl methacrylate	A transparent thermoplastic, PMMA is often used as a lightweight or shatter-resistant alternative to glass. It is cheaper than polycarbonate but is also more prone to scratching and shattering.	Windows, displays, screens
Polybutylene terephthalate (PBT)	The thermoplastic PBT is used as an insulator in the electrical and electronics industries. It is highly chemical and heat resistant. Flame-retardant grades are available.	Door handles, bumpers, carburettor components
Polyethylene Teraphthalate (PET)	PET is commonly used to create synthetic fibers and plastic bottles, and is often referred to as "polyester."	Wiper arm and gear housings, headlamp retainer, engine cover, connector housings
ASA (Acrylonitrile Styrene Acrylate)	Similar to ABS, ASA has great toughness and rigidity, good chemical resistance and thermal stability, outstanding resistance to weather, aging and yellowing, and high gloss.	Housings, profiles, interior parts and outdoor applications.

(Source: Szeteiová, 2012)

As mentioned in the previous section, light weighting of automobiles is emerging as a key trend by the major OEMs for improving fuel efficiency, addressing affordable safety standards in low-cost cars, as well as for staying cost-competitive. In order to meet these targets, OEMs are replacing traditional steel in vehicles with high tensile steel, aluminium, (and light-weight alloys) as well as plastic. However, there is hardly any publicly available data on composition of plastics across different categories of vehicles manufactured in India, except for four wheelers and two wheelers. On an average, the plastics use in passenger cars is in the range of 8-10%. Since replacement opportunities for steel and other resources by light weighting materials are enormous, use of engineered plastics and composites are increasingly finding application in the production of non-critical car components like bumpers, fuel systems, lighting, upholstery, under bonnet components, electrical wiring, etc. However, this changing trend cannot be captured quantitatively due to limitations in data.

Figure 3.24 presents the distribution of plastics components in a typical passenger car weighing 1,200 kg (approximately)[10].

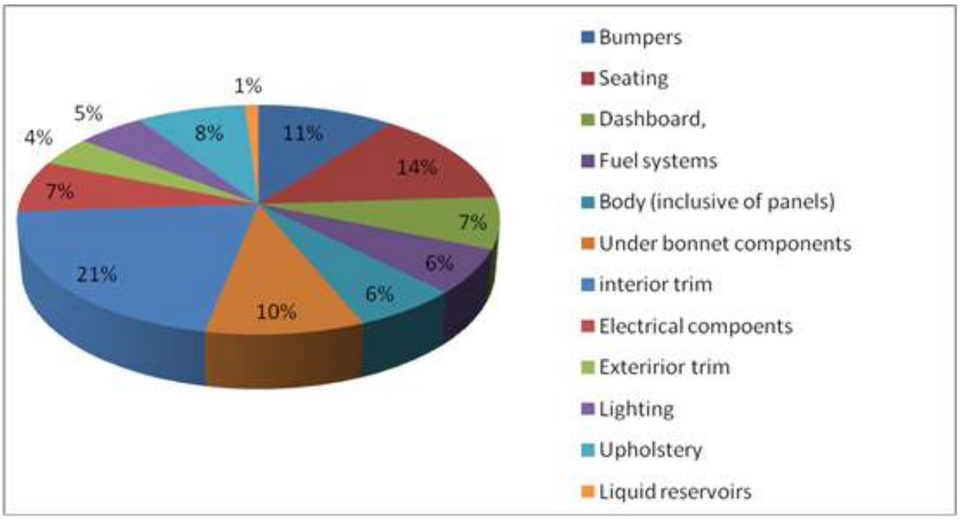


Figure 3.24: Percentage weights of different plastic components to total plastic use in a 1,200 kg car

(Source: Szeteiová, 2012)

Use of composites in the automotive sector

India is a leading consumer of composites, with an estimated consumption of more than 320,000 tonnes. Composites were first identified as suitable material for manufacturing components in railway coaches by the Indian Railways in the early 1980s, for e.g., in flooring, louvre and glass shutters, ceilings, trays for battery boxes, window sill and frame, etc. The replacement was a part of the Railways' initiative towards elimination of wood and wood products used in coaches. The present consumption of composite materials has been estimated at about 8,000 tonnes in the Indian Railways with an annual growth rate of 20% (Baksi & Biswas, 2009). The use of composites in the boat building industry has also been growing rapidly in recent decades due to advantages such as corrosion resistance, improved performance and lower cost.

The automobile industry is another sector that has seen significant growth in composite materials use in recent decades, especially for passenger cars and scooters. In 2008, the sector used 25,000 tonnes of composites, an increase of nearly 5,000 tonnes in only 2 years, with the most important applications being hoods, cabs, frames, cargo containers and passenger helmets (Baksi & Biswas, 2009).

Availability and prices

Over the years, the Indian plastics industry has emerged as a leading industry and also among the fastest growing. Commodity plastics, comprising of Polyethylene, Polypropylene, Polyvinyl Chloride (PVC), and Polystyrene, find the largest application, followed by engineering and specialty plastics. Between 2008 and 2013, the demand for plastics has grown at an average annual rate of 8%, rising from 5.8 million tonnes to 8.5 million tonnes (MoCF, 2014).

With a demand of more than 3.5 million tonnes, polyethylene is the most used plastic, followed by polypropylene at 2.1 million tonnes and PVC close to 2 million tonnes. Polystyrene demand in

[10] Global average

2013 has been estimated at 0.25 million tonnes while other polymers (like polycarbonate, ABS, etc.) demand stands at 0.1 million tonnes (MoCF, 2014). The change in demand for these plastics is presented in Figure 3.25.

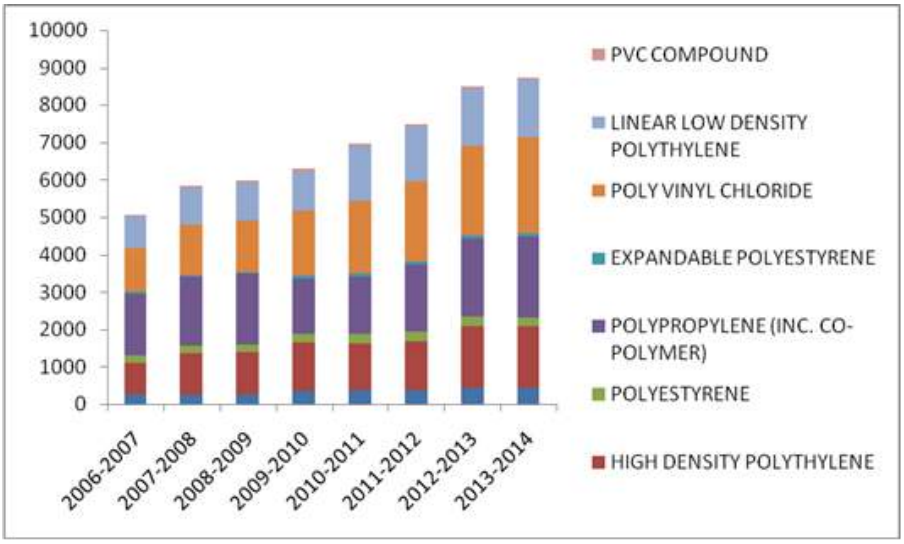


Figure 3.25: Indian consumption of different plastics from 2006 to 2013 (thousand tonnes)

(Source: MoCF, 2014)

A look at the production capacity of some of the major polymers in India reveals that their capacity has hardly increased in line with the increase in demand of polymers from 5.8 million tonnes to 8.5 million tonnes recorded between 2007 and 2013, except for linear low density polyethylene. Polyethylene is the most used plastic raw material in India (Figure 3.26).

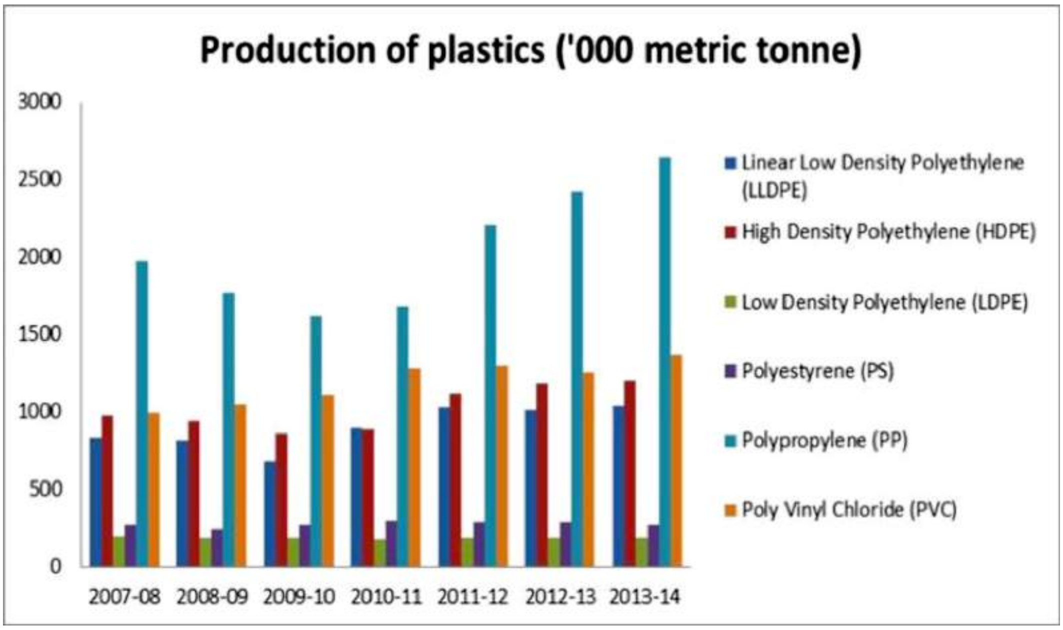


Figure 3.26: Indian production of key plastics (in thousand metric tonnes)

(Source: MoCF, 2014)

India's production capacity of polypropylene is 2.7 million tonnes while that of PVC is 1.3 million tonnes. These two polymers account for almost 50% of the total plastic use in the auto industry. India has the highest production capacity in polyethylene (at 2.9 million tonnes) out of which 1.6 million tonnes is high density PE, 1 million tonne is linear low-density PE and the remaining is low density PE. Further, production capacity of polystyrene and extended polystyrene are 0.4 and 0.1 million tonnes respectively. India is import dependent for polycarbonates and polyamides and other major engineering plastics (MoCF, 2014).

An overall assessment reveals that India is deficient with regard to plastics and quite a lot is imported to meet domestic demand. These are mostly imported from Saudi Arabia, Qatar, UAE, Korea, USA, Singapore, Thailand, Germany, Malaysia, etc. India recorded an increase in annual growth rate in import of plastics from 15% (2001-02 to 2005-06), to 36% (2006-07 to 2009-10). In 2013, India imported 1.2 million tonnes of PE, while the import of PP was 0.45 million tonnes. Further, 30% of India's demand for PVC (approximately 1 million tonne) is met through imports (MoCF, 2014). India's total polymer import over the last 8 years is presented in Figure 3.27.

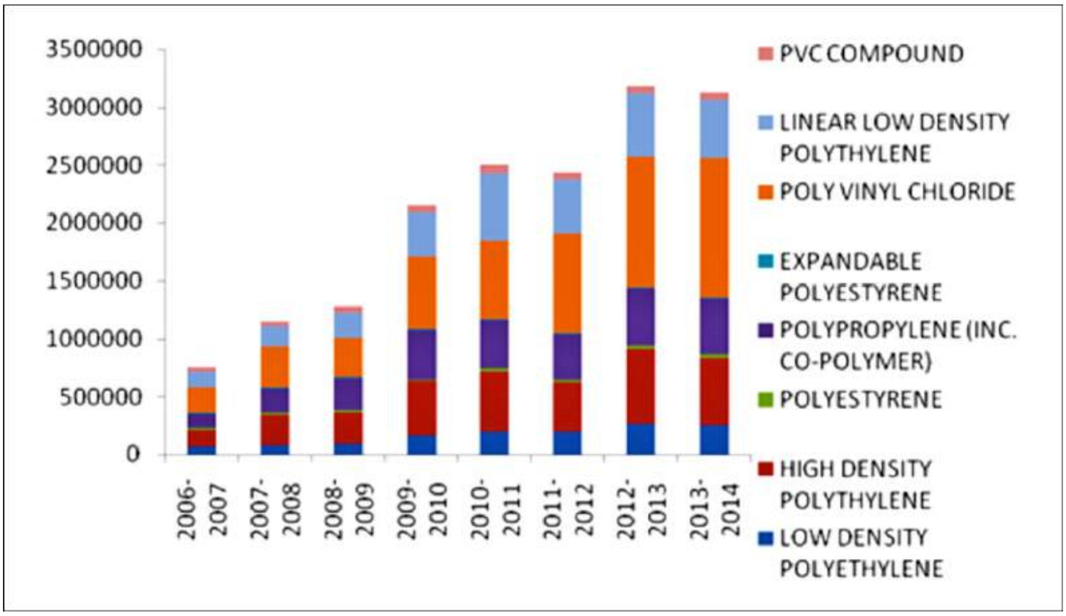


Figure 3.27: Gross import of polymers by India (in tonnes)

(Source: MoCF, 2014)

From Figure 3.27 it is evident that between 2006-07 and 2013-14, gross imports of polymers increased from 0.7 million tonnes to 3.1 million tonnes reflecting a more than 4 times increase, with a CAGR of 23%. At the same time, India became a net importer of polymers during the same period where net imports increased from -0.13 million tonnes to 1.93 million tonnes (MoCF, 2014).

Recycling plastics and composites

Given the growing demand and use of plastics, increased and improved recycling eventually must become a key step towards sustainability in this industry. Recycled plastics will eventually have lesser environmental impacts due to lower energy consumption, reduced GHG emissions, and water use. Unfortunately, formal recycling of plastics in India is low and there exists high potential, particularly when the sector is estimated to grow at 10% over the next 5-10 years. The current practices of disposal by industrial and retail consumers are poor that makes formal collection difficult.

There are also many difficulties associated with recycling plastics. Plastic cannot just be melted and formed into new components without quality loss. Also, plastic is of value for burning processes in incineration plants. Therefore, there is a potential competition between recycling plastics and simply burning them for energy recovery.

In order to improve recycling in India, there is need for segregation of waste at source, efficient collection and transportation. Further, there is a need to create waste management infrastructure and improved recycling centres. Better understanding of plastic recycling practices in developed and developing nations need to be learnt and adopted and a conducive policy environment created to attract investment. Finally there is a need for creation of public awareness and discipline for promoting recycling of plastic rejects.

3.1.2.6 Assessing Current and Future Demand of Materials

Current and future demand for resources have been estimated for the Indian automotive sector based on the average kerb weight of a representative vehicle under each category, namely trucks, buses, four wheelers, three wheelers and two wheelers. In estimating the net amount of the resource consumed by a vehicle, the kerb weight of a vehicle type is multiplied with the per cent (by weight) of the resource under consideration. However, this excludes the resource wasted or rejected during component manufacturing. Hence, to factor in this waste, an estimate of rejection and waste generation rate has been arrived, based on the review of literature and extensive discussion with stakeholders for each resource. Although an average has been used, it is important to note that there exists significant variations across auto component manufacturing industries depending on at what tier they are, their in-house capacities, etc. To get the industry estimates of gross resource consumption, the exercise is carried out for these five broad categories of vehicles, using current and future estimated production numbers. The results on estimated resource consumption by vehicle type are presented below.

Iron and steel

Steel is used to construct a car’s chassis and body including the roof, body and door panels, the beam between doors, mufflers and exhaust pipes. The aggregate steel demand (for the aforementioned five categories) is estimated to increase from 11.11 million tonnes (2015) to 80.66 million tonnes (2030). Buses will account for 50% of the iron and steel consumption within the sector, followed by four wheelers (33%) and 2-wheelers (10%) (Figure 3.28).

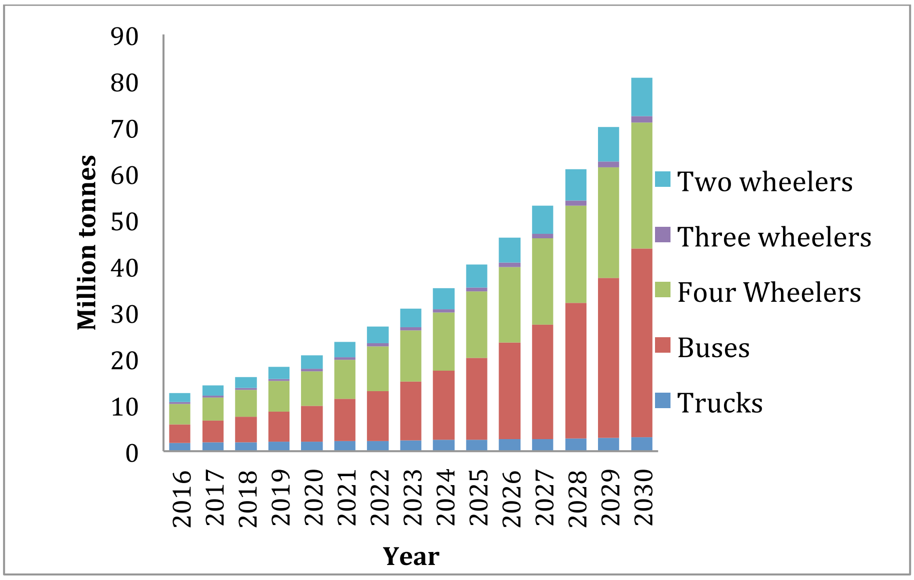


Figure 3.28: Expected increase in steel usage in Indian automotive sector (million tonnes)

(Source: Authors' analysis)

Aluminium

Developed countries have on an average 140 kg of aluminium per vehicle and in India, the estimates are only about 40 kg. It is assumed that the automotive sector will continue to experience current demand growth scenario for the next 15 years. Thus the estimated aluminium demand by the automotive industry would increase from its current level of 1.76 million tonnes to more than 10 million tonnes over the next 15 years. Buses will account for 46.7% of the future resource to be consumed in this sector followed by four wheelers (Figure 3.29).

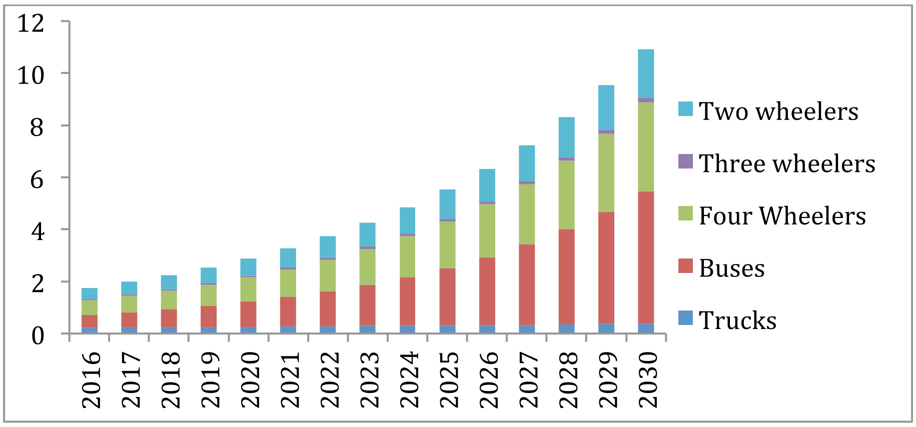


Figure 3.29: Expected increase in aluminium usage in Indian automotive sector (million tonnes)

(Source: Authors' analysis)

Copper

The Center for Transportation Analysis and Engineering Science and Technology Division, USA, published weight ranges of copper for different types of vehicles (Rauch, Eckelman & Gordon, 2007). As per their estimates, 20 kg Cu was used for a road tractor, 24 kg of Cu for a light truck and 21 kg Cu for a passenger vehicle. Using the figures for copper use based on the range of estimates available for length and weight of copper in a vehicle, particularly copper wiring, it has been assumed that the percentage share of copper is around 1.36% for all vehicles except two wheelers, where percentage is lower (around 0.5%). The estimated demand for copper by the auto industry in India will increase from its current estimated level of 0.21 million tonnes to about 1.6 million tonnes over the next 15 years. Buses and four wheelers will attribute 54% and 36% of the copper usage in the sector by 2030, respectively.

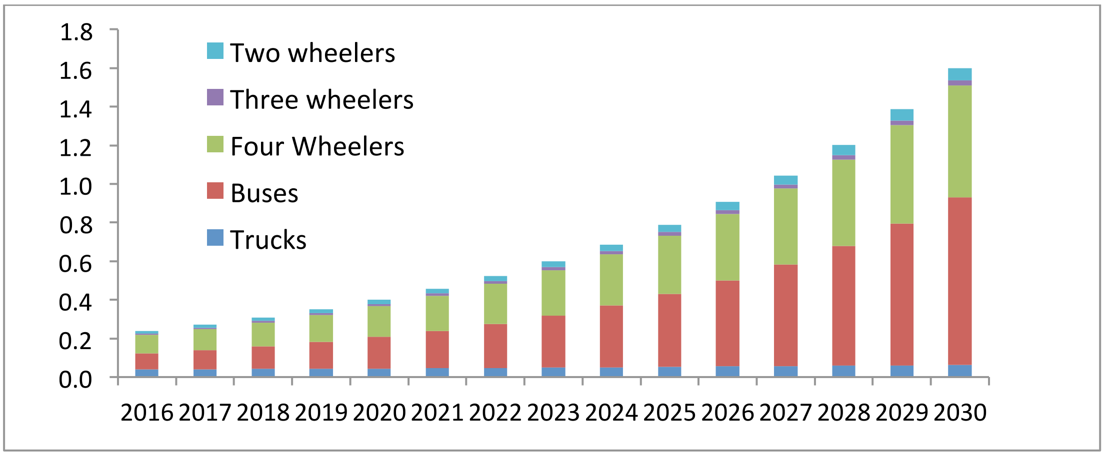


Figure 3.30: Expected increase in copper usage in Indian automotive sector (million tonnes)

(Source: Authors' analysis)

Zinc and Nickel

Literature review and stakeholder consultation have suggested that approximately 0.5% of zinc and nickel is used for all the five categories of vehicles – trucks, buses, four wheelers, three wheelers and two wheelers. This study estimated the demand for zinc and nickel across different types of vehicles. The expected gross consumption of zinc and nickel would be highest for buses (0.3 million tonnes), followed by four wheelers (0.19 million tonnes), and two wheelers (0.058 million tonnes).

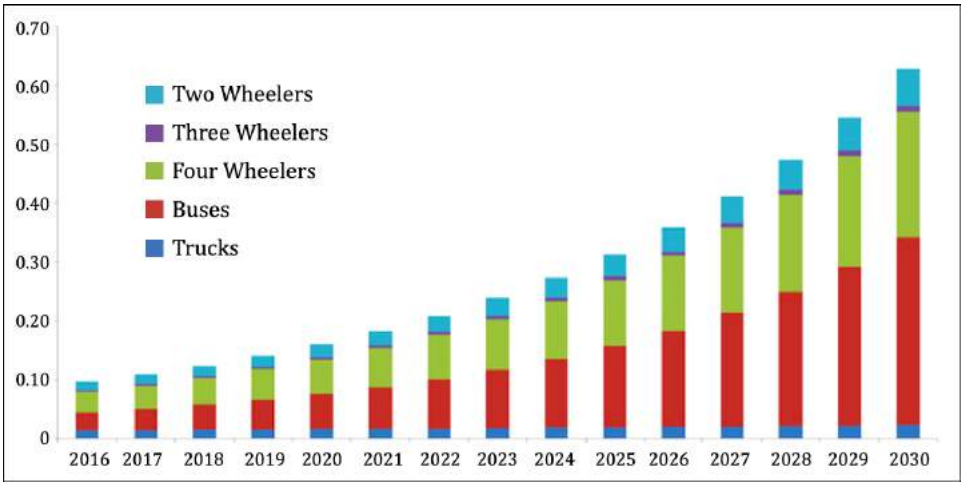


Figure 3.31: Expected increase in zinc and nickel usage in Indian automotive sector (million tonnes)

(Source: Authors' analysis)

Plastics and Composites

The estimated plastic demand by the auto industry will increase from its current estimated level of 1.13 million tonnes to more than 8 million tonnes over the next 15 years. Although 13 different high quality plastics are normally used in automobiles, application of 3 types of plastics – polypropylene, polyurethane and polyvinyl chloride – will find highest use in the sector. Between

2016 and 2030, total estimated use of composites in the automotive sector would increase from 44,000 tonnes to 131,000 tonnes.

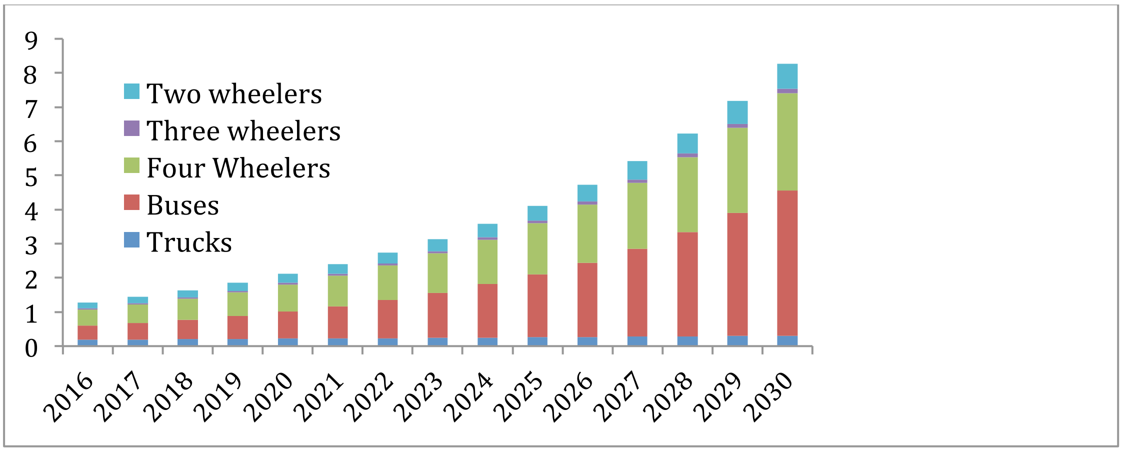


Figure 3.32: Expected increase in plastics usage in Indian automotive sector (million tonnes)

(Source: Authors' analysis)

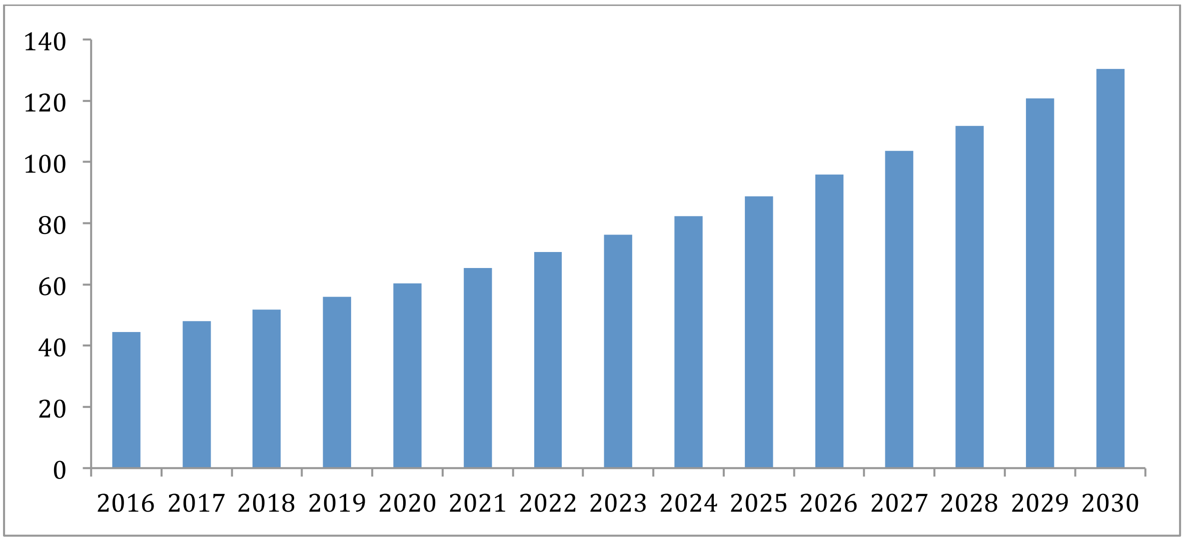


Figure 3.33: Expected increase in composites usage in Indian automotive sector (thousand tonnes)

(Source: Authors' analysis)

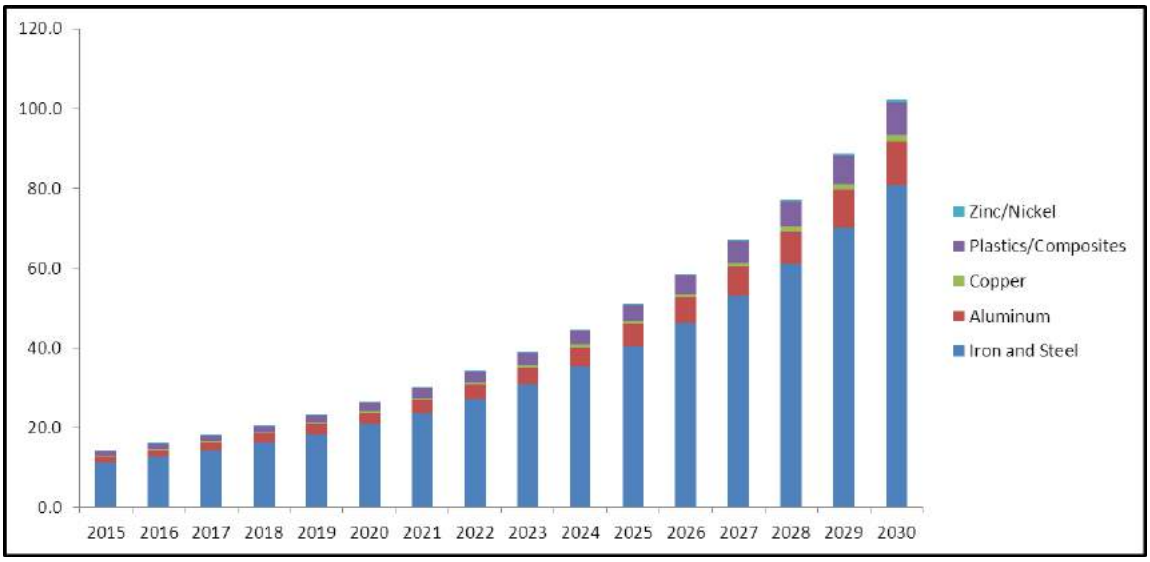


Figure 3.34: Expected increase in total material use in Indian automotive sector (million tonnes)

(Source: Authors' analysis)

For the 5 materials under consideration, the total material demand from 2015 to 2030 in the auto sector is expected to increase from 14.1 million tonnes to 102.1 million tonnes. The estimated total demand for iron and steel in 2030 is 80.7 million tonnes, followed by aluminium (10.9 million tonnes), plastics and composites (8.3 million tonnes), copper (1.6 million tonnes), and zinc and nickel (0.6 million tonnes) (Figure 3.34).

3.1.2.7 Estimating Material Rejects, Wastage and Recycling Potential

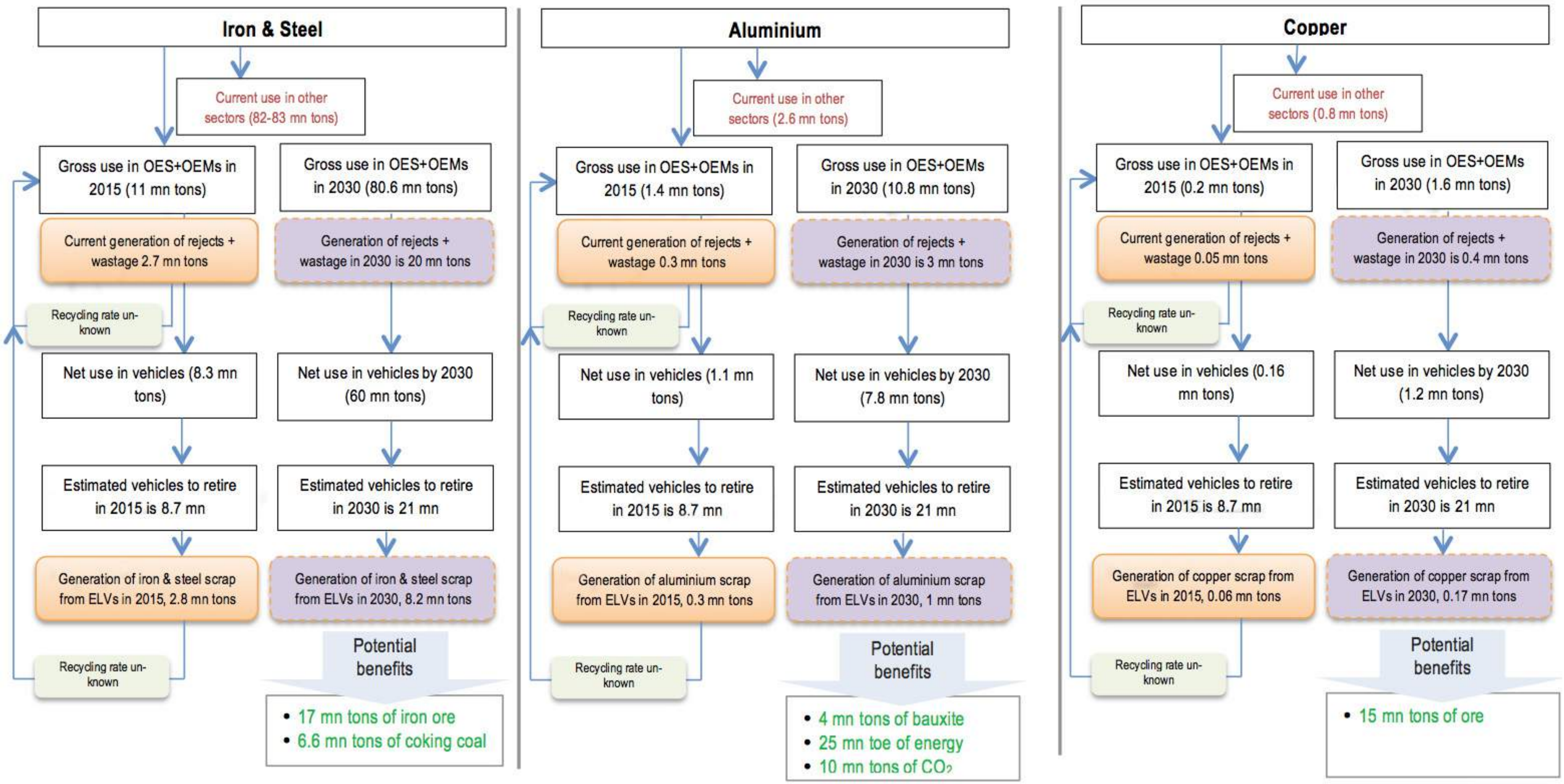
Figure 3.35 (on next page) presents the summary of material flows for the automotive sector once the resources, i.e., copper, iron and steel and aluminium, enter the auto components manufacturing chain in India. It presents the volume of generation of rejects and wastage during production as well as potential scrap generation from ELVs for the year 2015 and 2030 for these three resources.

Iron and steel

Out of the total crude steel production of almost 95 million tonnes in the country, 11 million tonnes is estimated to enter the automotive sector for component manufacturing. Using an estimate of 25% for wastage/rejects, based on the review of literature and extensive discussion with stakeholders (despite existence of significant variations across various industries depending on at what tier they are and their in-house capacities), the volume of reject generation and wastage is estimated at 2.7 million tonnes. No information is available regarding the extent of recyclability of these wastes and rejects. Hence, with an estimated production of more than 130 million vehicles by 2030, the volume of rejects and wastes will be as high as 20 million tonnes. India is further estimated to have 8 million ELVs in the next couple of years, while by 2030, the number can go up to 21 million. Hence the scrap generation from these ELVs will be 2.8 million tonnes and 8.2 million tonnes by 2015 and 2030 respectively. The implication of recycling 8.2 million tonnes of steel scrap by 2030 is significant as it will help in saving 17 million tonnes of iron ore and more than 6.5 million tonnes of coking coal.

Figure 3.35: Volume of generation of rejects and wastage during production as well as estimated scrap generation from ELVs for the years 2015 and 2030

(Source: Authors' analysis)



Aluminium

India produces about 4 million tonnes of aluminium, out of which the auto component manufacturing sector is estimated to consume 1.4 million tonnes with a waste/reject generation of 0.3 million tonnes (based on the rejection and waste generation rate of 25%). An estimated production of 130 million vehicles will result in generation of 3 million tonnes of rejects and wastes. Based on the ELV generation rates in 2015 and 2030 as given above, the estimated aluminium scrap generation will be 0.3 million tonnes and 1 million tonnes respectively. Recycling of 1 million tonnes of aluminium scrap from ELVs will help in a gross savings of 4 million tonnes of bauxite, 25 million TOE of energy as well as 10 million tonnes of CO_2.

Copper

India's auto sector has been estimated to consume 0.2 million tonnes of the total 0.8 million tonnes of copper produced annually. With an auto component industry average rejection and waste generation rate of 25%, the volume of current generation is estimated at 0.05 million tonnes while with a vehicle production of above 130 million, the expected generation will be 0.4 million tonnes by 2030. Based on the ELV generation rates in 2015 and 2030 as given above, the estimated copper scrap generation will be 0.06 million tonnes and 1 million tonnes respectively.

3.2 Construction Sector

3.2.1 Introduction

The construction sector in India is growing rapidly. The boom in the construction market is fueled by increasing urbanisation and rising per capita income of the people. The rise of the sector has significantly benefited the growth of the Indian economy. As per the Planning Commission, the contribution of the construction industry to India's GDP increased by INR 1 billion (USD 15 million) during 2006-2011. With a current contribution of 8% to India's GDP, the sector is the second largest in terms of employment generation after agriculture.

The Planning Commission forecasts for the market size of the construction industry for the Twelfth Plan period indicate that the aggregate output of the industry during the period 2012–13 to 2016–2017 is likely to be INR 5.2 trillion (USD 782 billion) (Planning Commission, 2013). The output of the industry is likely to be contributed almost equally by the buildings and infrastructure segments respectively. In view of this, India's Planning Commission has doubled the proposed spending on buildings and infrastructure in the Twelfth Five Year Plan (Figure 3.36).

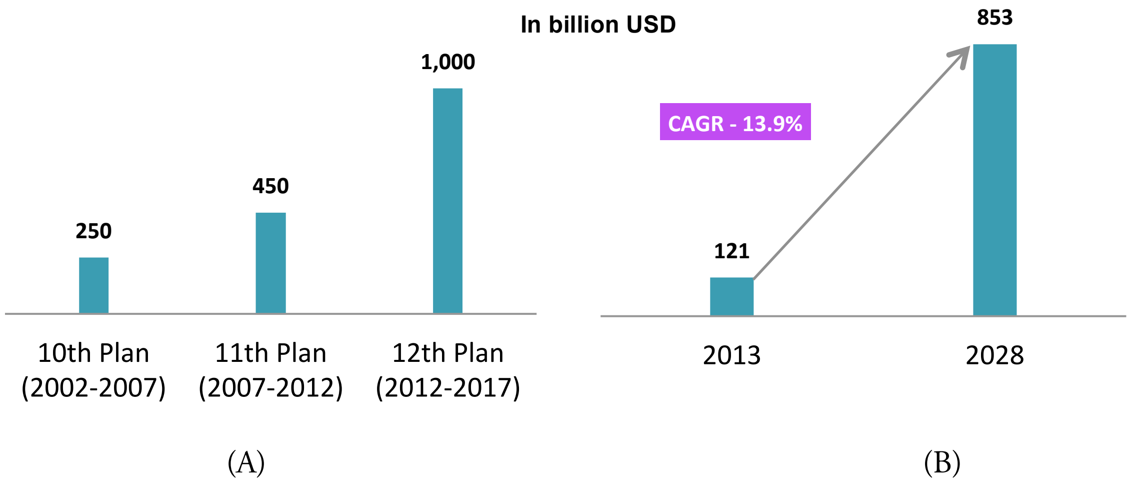


Figure 3.36: (A) India's spending on construction sector; (B) Value addition in real estate sector in India

(Source: KPMG, 2014)

Buildings, which include residential, commercial and office, hospitality and retail, have a share of 6.3% in GDP and this is expected to increase to 13% by 2028 (KPMG, 2014). The residential built-up area demand in 2030 is expected to increase by 5 times (ClimateWorks Foundation, 2010) compared to 2005 (Figure 3.37) owing to a shortage of 18.8 million houses which was estimated at the start of the Twelfth Five Year Plan. It is clear that residential buildings will dominate the demand in the future. On the infrastructural side, 1,000 km of expressways and 10,000 km of National Highways are planned to be built by the end of 2017. The rail network is also being expanded so that the north-eastern states are completely connected by the end of the year 2020 (Planning Commission, 2013).

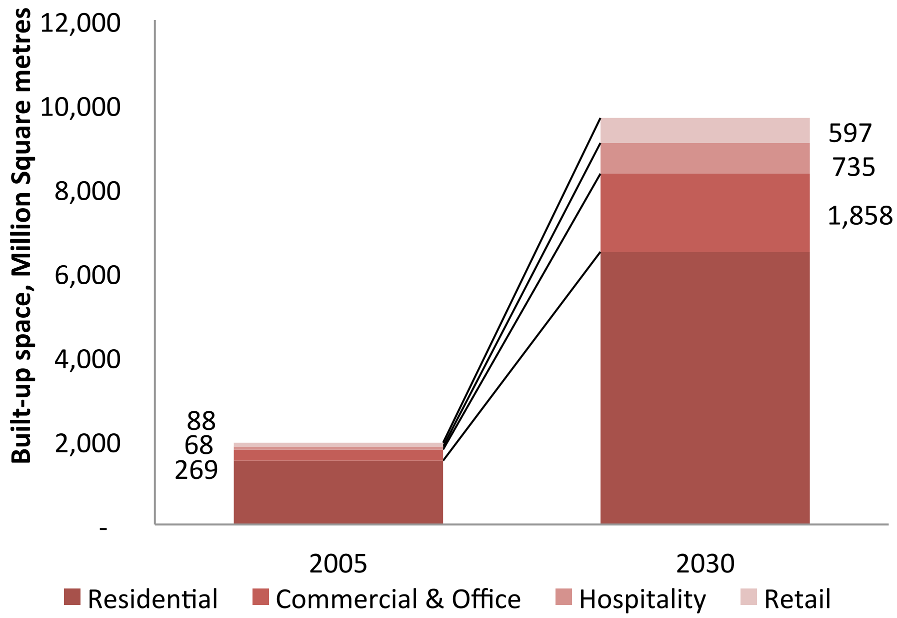


Figure 3.37: Increase in demand of residential built-up area in the year 2030

(Source: ClimateWorks Foundation, 2010)

In India, about 31.2% of the total population is currently living in urban areas (Census of India, 2011). The increase in urban population from 2001 to 2011 was more than double as compared to the increase in rural population in the same period. It is expected that the urban population will be equal to the rural population by the year 2039 (Figure 3.38). The per capita income in fast growing cities will increase 4 times by 2030 using 2008 as the base year (Mckinsey Global Institute, 2010). All these are clear indicators that the construction sector will see a steep rise in the future and play an important role in India's development.

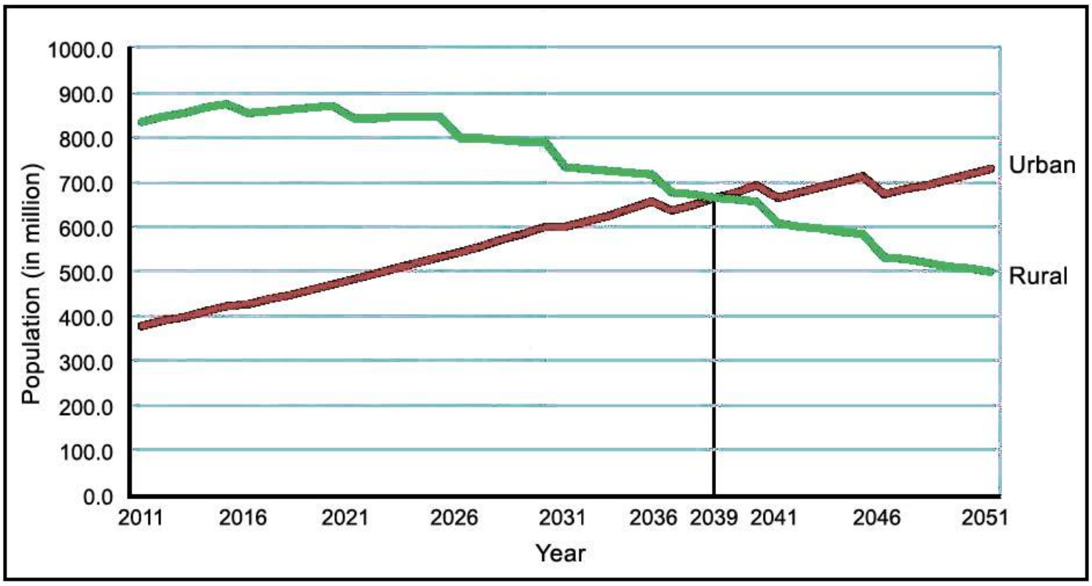


Figure 3.38: Projection of rural and urban population in India

(Source: Census of India, 2011)

To meet the expected growth of the construction sector, huge volumes of materials will be required. Sand (concrete and mortar), soil (bricks), stone (aggregates), limestone (cement) and iron and steel (bars and rods) are the most intensively used materials for building and construction purposes. Some of these materials are already facing scarcity issues. The extraction and use of these materials also has associated environmental and social impacts. Therefore, it is important to understand the flow of these materials in the market in order to identify competing users of these materials and points where interventions can be made. Material flow also gives an opportunity to assess the flow of waste that comes out during construction and at the end of life of buildings. Identified critical materials and their flows are discussed in detail in the following section.

3.2.2 Material Flow Analysis

The material flow follows an input and output approach where inputs are shown in terms of energy and material and outputs are shown in terms of end product and waste. Available statistical data is used to quantify resources along the flow. Wherever data is not available, proxies and assumptions are used to quantify the resources. Further, at the end of life of a building, possibilities for potential alternatives to close the loop are assessed. Resources are also analysed for their environmental and social impact and regional differences in prices and availability.

3.2.2.1 Sand

Sand is an essential resource for the construction industry as it is used for making concrete and brick, the key elements of a building. Sand is formed by weathering of rocks, a very slow and gradual geological process. However, the journey of sand from the riverbed to a landfill as part of building debris takes only about 50 to 100 years - the average life of a building.

Mining of sand in India is largely informal and unorganised. The process of sand mining is easy and does not require any sophisticated infrastructure, making it attractive to small players. This makes it difficult for the State to police the activities of the sand mining industry, which proliferates due to low investments and high returns. Additionally, the unscientific and unregulated extraction of sand from riverbeds has significant environmental impacts.

Due to the above reasons, there are no official national figures available on the amount of sand that is being extracted. While some states, for e.g., Andhra Pradesh and Telangana maintain information of leases granted for sand mining, this is likely to be a significant underestimate since illegal extraction is not fully accounted for.

Classification and uses of sand

In India, sand is classified and treated as a minor mineral if used for building and construction purposes and a major mineral if used for industrial applications such as for coal mines, manufacture of ceramic and sodium silicate, metallurgical purposes, etc. (Mines and Minerals (Regulation and Development) Act, 1957). However, the use of sand in industries is very limited and unaccounted in terms of inventory. This study focuses on the use of sand in building and construction, where it is primarily used for concrete and mortar mixing.

Technically, any sand that fulfills the criteria in Indian Standards 383 (1970), can be used for making concrete and mortar. Clay bricks and fly ash bricks also require sand in small quantities as a stabiliser.

The sources of sand extraction are clearly defined by MoEF&CC in its recent Sustainable Sand Mining Management Guideline (MoEF&CC, 2015). They are categorised as:

- Rivers (flood plain and river bed)
- Lakes and reservoirs
- Agricultural fields (Haryana)
- Coastal and marine sand
- Paleo channels (Rajasthan)

In terms of priority, river sand is the most preferred choice in the construction and brick sector due to the presence of silica, which is inert, hard and durable. This type of sand does not require much processing. Apart from chemical composition, the angular shape of river sand particles makes it suitable for concrete mixes and brick making. The next best choice for extraction of sand after rivers, are lakes and reservoirs. Coastal and marine sand is least preferred, as it is fine, rounded and contains salt, which affects the durability of reinforced concrete.

River sand is sourced from a vast network of rivers classified into two categories on the basis of their origin, Himalayan rivers and Peninsular rivers. The Himalayan river system covers most of the North and Eastern parts of India. Rivers are perennial under this system and carry a huge load of sand and silt. The sand is of good quality and therefore rivers in this system are exploited heavily for sand extraction. Peninsular river systems flow through the central, western and southern parts of the country. The rivers are seasonal in this system. Sand and silt content is less due to gentler slope and resulting lower erosion and the quality of sand is not as good as the Himalayan rivers (National Institute of Hydrology, 2013).

Sand extraction in Haryana is unique as it is obtained from agricultural fields that lie in the Yamuna flood plain (CSSRI, 2007). Haryana is devoid of river flows and hence is largely dependent on such alternatives. Rajasthan, a dry state, exploits paleo channels (remnants of an inactive river) for its sand requirement.

Concerns and conflicts

Though sand miners are required to obtain a permit from the state government and pay a royalty on the sand sold to the market, this procedure is seldom followed as mining is carried out in a decentralised and unorganised manner, frequently skirting the law. Illegal sand mining is a practice followed in almost every state. While the number of illegal mines is still unaccounted for, there are 12 illegal hotspots of sand mining that have been identified in the country (Figure 3.39). In the southern states where sand is scarce, there has been a greater challenge of illegal mining.

Some reports have indicated an amount of INR 10 billion (USD 150 million) being generated from illegal extraction of sand in India in 2011 (CSE, 2012), but comprehensive data on sand revenues is unavailable. The unregulated market and bans destabilise the rates at which sand is sold. Therefore, the lack of inventory of sand and wide variation in rates across the country becomes a barrier in examining the demand and supply gap. Available estimations suggest that about 1.4 billion tonnes of sand will be required by the year 2020 (Figure 3.40).

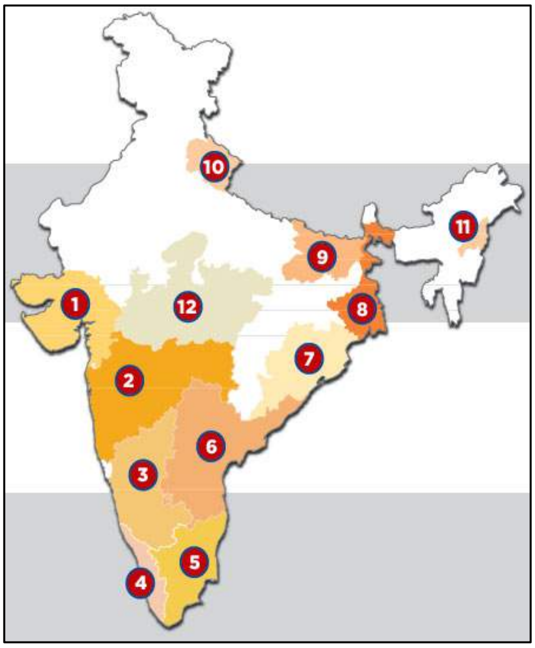


Figure 3.39: Illegal sand mining hotspots in India

(1: Gujarat; 2: Maharashtra; 3: Karnataka; 4: Kerala; 5: Tamil Nadu; 6: Andhra Pradesh; 7: Odisha; 8: West Bengal; 9: Bihar; 10: Uttarakhand; 11: Nagaland; 12: Madhya Pradesh)

(Source: Shrivastava et al., 2012)

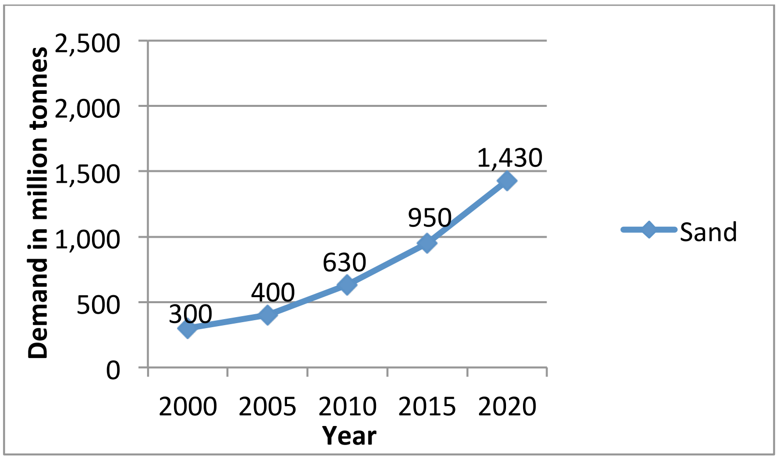


Figure 3.40: Projected sand demand in India

(Source: Aggregate Business International, 2013)

Thus, future projections clearly indicate that there is a need for alternatives of sand to satisfy its growing demand.

The second concern with sand mining is its environmental impacts. The Geological Survey of India (GSI) lists a series of ecological impacts related to riverbed sand mining, including alteration of in-stream floral and faunal habitat caused by increase in river gradient, suspended load, sediment deposition, increase in turbidity, change in temperature, etc. Sand mining's environmental impact on the river is long term; studies have suggested that rivers remain in their early stage of recovery even after 20 years of sand mining cessation (Bhushan & Banerjee, 2015). Table 3.13 categorises the impacts of sand mining on the environment.

Table 3.13: Environmental impacts of sand mining

S. No.	Impacts on	Description
1	Biodiversity	Impacts on related ecosystems (for example, fisheries)
2	Land losses	Both inland and coastal through erosion
3	Hydrological functions	Change in water flows, flood regulation and marine currents
4	Water supply	Through lowering of the water table and pollution
5	Infrastructure	Damage to bridges, river embankments and coastal infrastructures
6	Climate	Directly through transport emissions
7	Landscape	Coastal erosion, changes in deltaic structures, quarries, pollution of rivers
8	Extreme events	Decline of protection against extreme events (flood, drought, storm surge)

(Source: MoEF&CC, 2015)

Many instances of the detrimental impacts of sand mining have been recorded. A visible impact of sand mining was observed in the Yamuna River flowing through Gautam Budh Nagar, Uttar Pradesh. The river shifted by almost 500 metres towards manmade embankments made to protect surrounding areas from floods. The cause of the shift was illegal sand mining up to the depth of 15 to 20 feet (almost double the legal limit) within 30 metres of the embankment (Keelor, 2013). In another instance, the Neyyar River in Thiruvannathpuram district, Kerala, has changed its course due to continuous in-stream and flood plain sand mining. The riverbanks were widened by 69 metres in just 48 years causing a loss of almost 50 hectares of fertile land (Shaji & Anilkuar, 2014).

Any damage to the river has a direct impact on the surrounding communities. A change in the course of the river can damage the surrounding agricultural land and expose adjacent populations to floods. Further, loss of agricultural land has a direct impact on the socio-economic conditions of farmers. These conditions often compel farmers to search for other income opportunities; sometimes they are temporarily contracted in illegal sand mining. This opportunity lasts only till sand is available in the area after which they lose their livelihoods again.

Reports indicate that workers involved in sand mining face significant occupational hazards and health effects such as silicosis and cancer, in addition to low wages and poor working conditions. Some workers (known as divers), manually dredge creeks using only buckets and without any safety equipment. The use of child labour is also reportedly common (Sustainalytics, 2015).

Material flow

The demand and supply of sand is a matter of concern for almost all the states owing to the high risk caused by legal bans and price rises. The gap between demand and supply will increase in the future as the demand for infrastructure and housing continues to rise. To analyse the material flow for sand its major uses were assumed to be in concrete, mortar and fly ash bricks and back filling. Extraction of sand in India is done both mechanically and manually. As there are no official figures for sand demand in India, concrete can be used as proxy to calculate sand demand. There are no imports and exports associated with sand in India.

Sand demand for making concrete: It is estimated that per capita consumption of concrete in India is 1.5 tonnes/annum (CSE, 2011). Assuming an average of 28% sand in a concrete mix (considering coarse to fine mix) the sand consumption of concrete per annum is estimated to be 500 million tonnes[11]. Considering 2% losses[12] of sand in preparing concrete, gross demand of sand is estimated to be 510 million tonnes/annum.

Sand demand for making mortar: There is no reported data on amount of sand that goes into mortar. However it is estimated that the volume of mortar required for fixing a standard brick of size 230 mm X 110 mm X 70 mm[13] (BIS, 2007) considering 10 mm space from all four sides is 673,200 mm^3. Considering cement to sand ratio of 1:6 for mortar mix, amount of sand required per brick is 577,028 mm^3 or 0.00057 m^3. With a standard density of dry sand as 1,640 kg/m^3 and considering 260 billion brick production per annum in India (CPCB, 2015a), sand required for mortar can be roughly estimated to be about 243 million tonnes/annum. Assuming 2% losses of sand[12] in mortar preparation gross demand of sand is estimated to be 248 million tonnes/annum. (For detailed calculations, refer to Annex 2.)

[11] Population of India taken as 1.2 billion

[12] Based on expert consultation with Department of Civil Engineering, Indian Institute of Technology-Madras

[13] Length X Width X Height

Sand demand for making fly ash bricks: Total fly ash utilisation in fly ash bricks in 2014-2015 was estimated to be about 12 million tonnes (CEA, 2015). A standard fly ash brick of 2.7 kg utilises about 46% (1.2 kg) of sand. About 10 million fly ash bricks were produced in 2014-2015 (CEA, 2015). Therefore, sand required to produce all fly ash bricks in India annually can be roughly estimated to be about 0.01 million tonnes/annum[14].

Sand as waste from construction and demolition activities: Sand as waste comes out along with C&D activities. Total C&D waste generated in the country in 2015 is estimated to be 716 million tonnes[15]. Characterisation of C&D waste for various components was conducted by Technology Information Forecasting and Assessment Council (TIFAC) in the year 2001. Based on the percentages of various components, i.e. concrete, bricks, mortar, etc., estimated amount of sand that comes out along with C&D waste is about 153 million tonnes/annum. (For detailed calculations, refer to Annex 2.)

Current demand of sand from all the uses discussed above is estimated to be about 751 million tonnes/annum (ignoring data gaps). This means that demand of sand in the year 2020 will be about 2 times the current demand (refer to Figure 3.40).

A detailed material flow of sand in India is presented in Figure 3.41 on the following page.

Response of government and market

In response to the issues faced with regards to sand, the Ministry of Environment, Forest & Climate Change (MoEF&CC) has come up with the 'Draft Sustainable Sand Mining Management Guidelines' (MoEF&CC, 2015), which focus on policies and practices for sustainable extraction of the mineral in each state of India and propose alternatives to sand use in the construction sector. The guideline suggests ways to calculate sand potential of rivers and safe limits of sand that can be extracted from natural sources. This however requires detailed surveys of various sources of sand by state governments. Nevertheless, the guidelines bring a hope to curb illegal mining, maintain ecological balance of rivers and create national inventories to make informed decisions in sand management for each region in India.

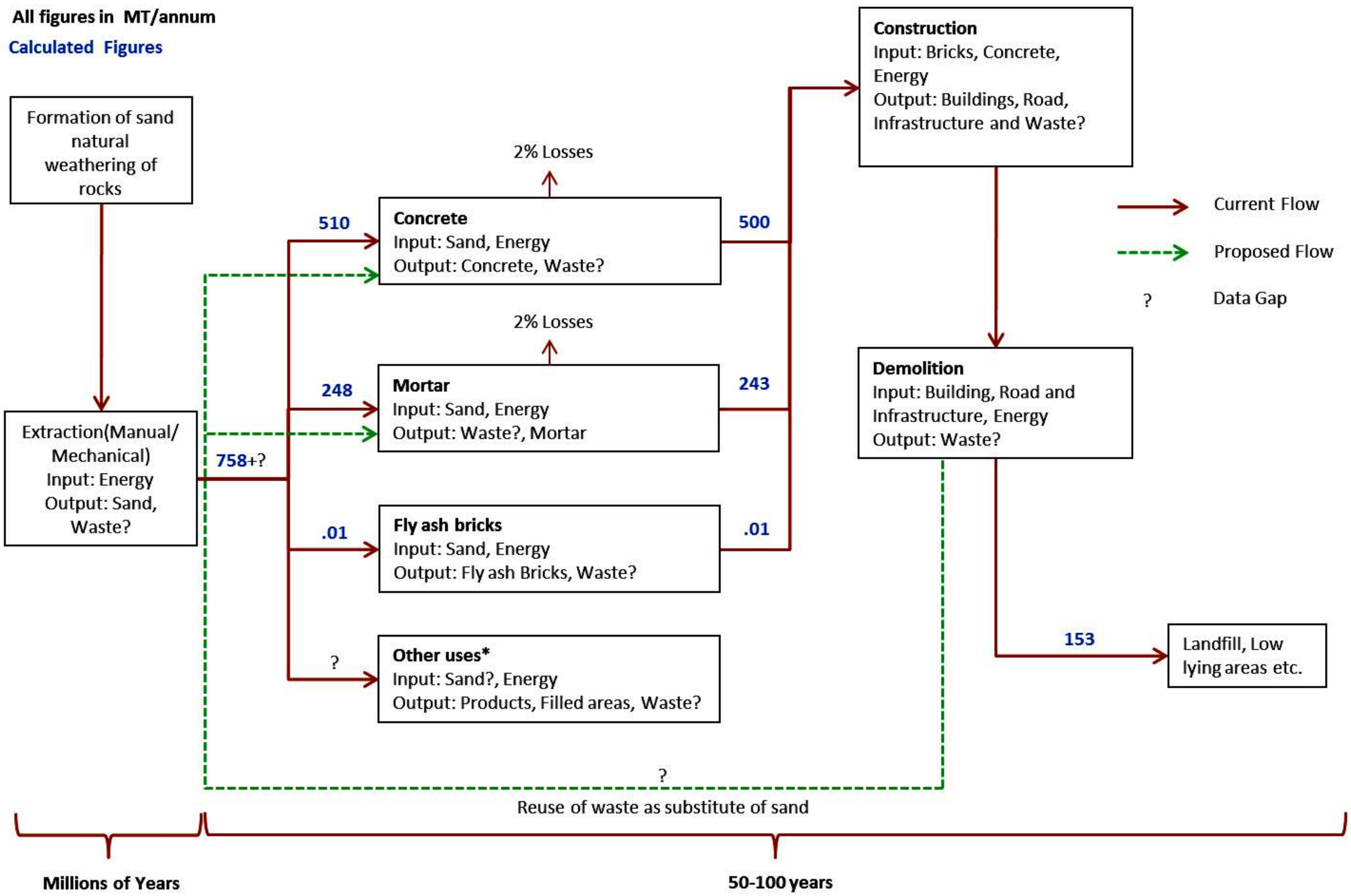
Each state also formulates its own guidelines for sand under the Minor Mineral Concession Rules. Given the trends of illegal and unscientific mining, several states have either imposed a ban on sand mining on certain rivers or imposed a blanket ban on sand mining within the state. Kerala recently imposed a ban on six rivers due to non-availability of minable sand (refer to Annex 1). Madhya Pradesh implements a ban on sand mining during monsoon season imposed by the National Green Tribunal (NGT). Rajasthan and Haryana have also been put under scrutiny and have been directed by the NGT to ban illegal sand mining. Sand mining, which causes obstruction in the flow of the Yamuna River, has also been banned by the NGT.

In contrast, states like Maharashtra, Andhra Pradesh, Telangana, and Rajasthan are moving towards legalising sand extraction, with provisions for online tendering and monitoring of sand mining operations within the states. The Revenue Department of Maharashtra, for instance, has implemented an online Sand Mining Approval and Tracking System. This system will enable contractors to order sand through their mobiles (Government of Maharashtra, 2015). The Maharashtra government also enacted the Maharashtra Minor Mineral Extraction (Development and Regulation) Rules in 2013 to ensure scientific mining of sand and other minor minerals in the

[14] Sand in fly ash (million tonnes) = ((10 million fly ash bricks X 1.2 kg)/1,000)/1,000,000)
[15] Authors' calculations based on survey of 10 cities across India (see GIZ, 2015b)

Figure 3.41: Material flow of sand in India

*Other Uses: Back filling of mines and pits, and Industrial purposes such as ceramic, metallurgical and optical products, etc.



states. Andhra Pradesh and Telangana maintain the data of sand availability and sale on a central portal. The sale of sand is now regularised and the amount of sand traded is readily available online (refer to Annex 1). The Department of Mines and Geology, Rajasthan has also proposed to amend the Rajasthan Minor Mineral Concession Rules, 1986, deciding to form clusters of small mines comprising areas with mining leases, quarry licenses or short-term permits, and develop Environmental Management Plans for them.

Governments have also imposed royalty on sand to regularise the sand market in India. Royalty rates of sand in selected states of India are mentioned below in Table 3.14.

Table 3.14: Royalty rates on sand in different Indian states

S. No.	State	Royalty Rate (INR)	Source
1	West Bengal	35 per mm^3 (USD 0.52)	West Bengal Minor Minerals Rules, 2002 (Amended 2011)
2	Karnataka	60 per metric tonne (USD 0.90)	Karnataka Minor Minerals Concession (Amendment) Rules, 2014
3	Madhya Pradesh	33 per mm^3 (USD 0.49)	Minerals and Resources Department, Government of Madhya Pradesh, 2015
4	Gujarat	30 per metric tonne (USD 0.45)	Gujarat Minor Minerals Rules, 1966 (Amended, 2010)

However, the market prices of sand can vary widely from region to region. A truck load of sand (600 ft^3 / $17m^3$) is available for INR 15,000 (USD 224.0) in Haryana, whereas it was available for INR 3,500 (USD 52.34) prior to it being banned in the state. In West Bengal, prices vary between INR 1,600-2,000 per truck (USD 24–30). But in some cities such as Bangalore, it may go up to INR 40,000 (USD 598) for a truckload of sand depending on the quality (Gupta, 2013). It is difficult to put one firm price on sand due to the existence of an underground market and price fluctuations caused by bans and restrictions. In the absence of any marketable alternative material, the price of sand is on an upward trajectory due to persistent and rising demand. Due to illegal extraction of sand, state governments lose out on substantial revenues that are generated from the sale of this material.

To shift the market focus to alternatives, the new draft guidelines released by MoEF&CC suggest promoting Manufactured Sand (m-sand) as an alternative to natural sand. M-Sand is produced by crushing hard granite stone to a suitable particle size. It also suggests using quarry dust, as well as accumulated sand and gravel at the bottom of dams as alternatives to sand. The guidelines also highlight the steps taken by the Government of India for use of alternatives. One that is specific for sand is permitting the use of slag - a waste from the steel industry, fly ash - a waste from coal-based thermal power plants, crushed over-burnt bricks and tiles - waste from clay brick and tile industry, in plain cement concrete as an alternative to sand/natural aggregate via concrete code IS 456. C&D waste can also be explored as possible alternative to be used as a source of m-sand.

With a plethora of issues plaguing it, the sand market has slowly started to respond to alternatives. Many southern states of India, where impacts of sand mining are most evident, have started shifting towards m-sand. The Department of Mines and Geology, Karnataka has identified 52 granite blocks where granite can be quarried and crushed to produce m-sand (Ashwini, 2015). There are around 100 m-sand manufacturing units existing in Karnataka (Govind, 2015). Tamil Nadu and Kerala also have manufacturing units of m-sand. Though the market and the government are slowly moving towards alternatives, the shift needs to be expedited. Rampant sand mining continues to destroy rivers and river systems while the construction industry still faces shortages of sand. Use of alternative materials to sand will not only protect the rivers but also relieve builders from relying solely on natural sand for construction purposes.

3.2.2.2 Soil

Fertile topsoil is one of the most exploited natural resources in India. Similar to sand, soil is also formed by constant weathering of rocks, a geological process that takes millions of years. About 56% of the total land area in India is classified as agricultural land which relies on soil fertility (Figure 3.42). Alluvial, red and black soils cover majority of land area in India and, in addition to agriculture, are used for road construction as base material, and for manufacture of clay bricks. Covering about 150 million hectares or about 45.6% of the total land area of the country, alluvial soils constitute the largest share among all soil types found in India (Negi, 2015) and are most popular for brick making. Red and black soils cover about 27% and 17% of the total land area respectively (Bhattacharyya, 2013).

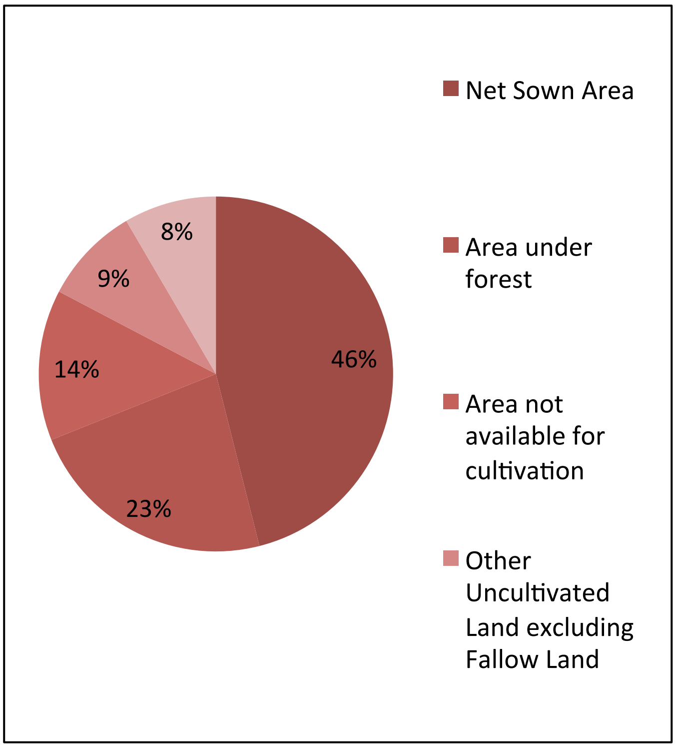


Figure 3.42: Land use of India

(Source: Ministry of Agriculture, 2015)

Increased urbanisation has led to excessive exploitation of topsoil for brick production. Soil extraction for brick production decreases agricultural productivity, which translates to increased food security concerns. Production of bricks also has serious environmental impacts such as air pollution, and social impacts such as labour exploitation.

Classification and uses of soil

Soil is classified as a minor mineral in India. Based on its end use, soil is further sub categorised as 'Brick Earth' and 'Ordinary Earth'. As the name suggests, brick earth is used for brick making while ordinary earth is used mainly in road construction. Soil is also used for back filling purposes but for the purpose of the study, soil use was assessed only for building and construction purposes.

The chemical composition of soil determines its suitability for either of the uses. Soils with clay content between 20% to 40%[16] are used for clay brick making, while soils with clay content between 9% to 18% are used for road making (according to BIS code IS 11650: 1991). Black soil and red

[16] Only for alluvial soils

soil can also be used as brick earth, but they need to be amended with certain stabilisers such as lime to make them suitable for brick making as they tend to break upon drying (KSCST, 2012).

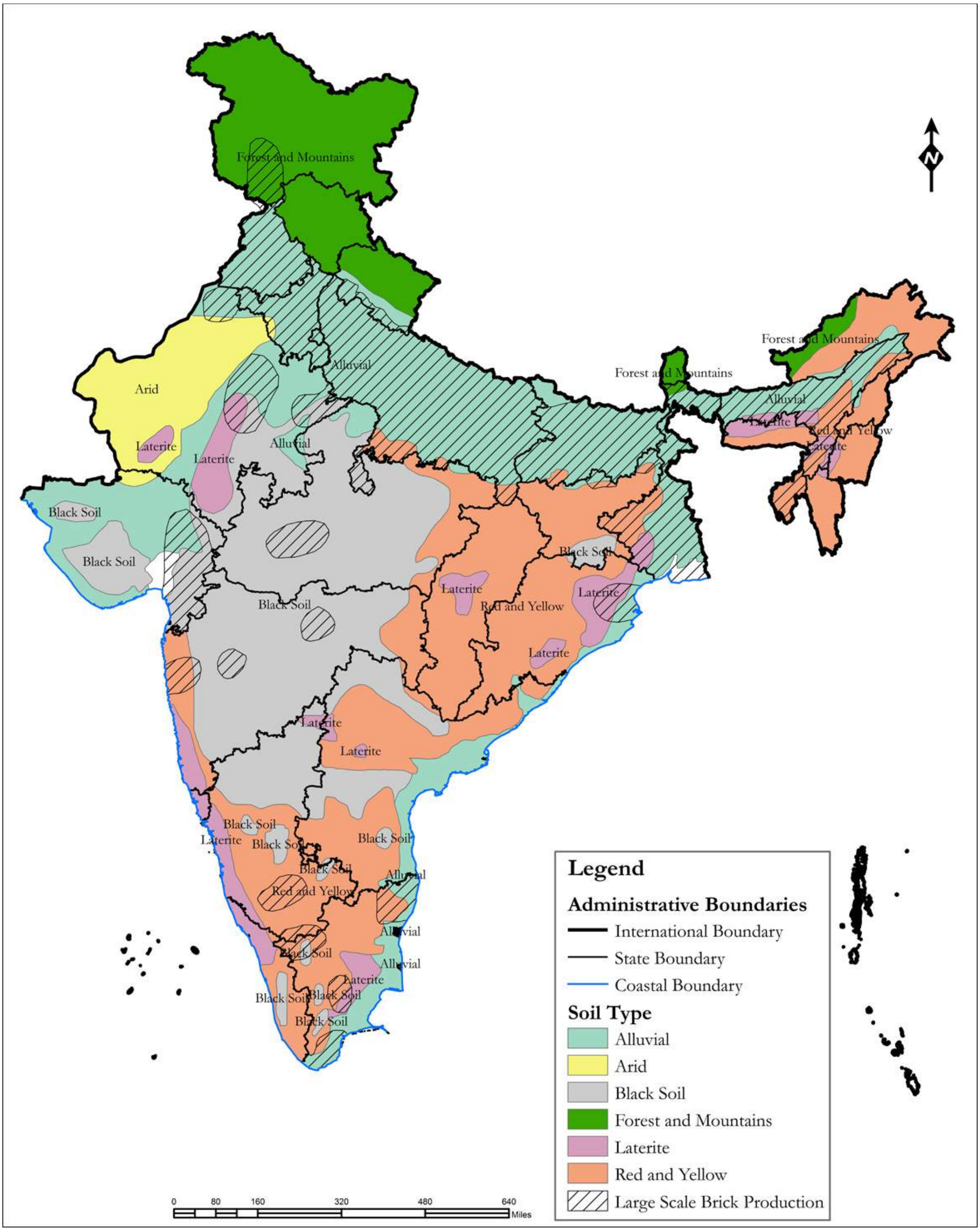


Figure 3.43: Overlap of major agricultural soil types with large-scale brick production in India

(Source: Adapted from Development Alternatives, 2012 and Maps of India, 2014)

According to MoEF&CC, the legal limit for soil mining in India is 2 metres below ground level (MoEF&CC, 2013). Together, alluvial, black and red soils cover almost 89% of the total land area of India, which equates to about 2.91 million km^2. Therefore, soil available for legal extraction for brick making per year is about 6 billion m^3. A large number of brick kilns are situated in the Indo-Gangetic plains of India which is rich in fertile alluvial soil (Figure 3.43). These soils also cover the arable land of India; thus there is a competing use of soil for agriculture and brick making. Though the top soil in Indo-Gangetic plains replenishes over time as the rivers are perennial, the rate of utilisation of soil for brick making is greater than its rate of replenishment; hence there is an overexploitation of soil in this region.

Concerns and conflicts

Brick kilns are typically found in concentrated clusters in India. Such concentration of kilns in an area puts immense pressure on land for soil resources. The norms that exist for soil extraction are seldom followed. In most cases, the depth of extraction exceeds 2 metres. As a result, the area suffers from land degradation. Since soil mining is an unorganised industry, mining above the legal limits is a common practice. In many cases, the mined pits are not back filled, creating a long-term impact on the land. In the rainy season, the pits are filled up with water and left stagnant, which gives rise to water borne diseases. In a study conducted in Thrivallur district of Tamil Nadu, it was found that in agricultural lands where soil mining was conducted, it took almost 3 years until it started to replenish to its natural state. Even then, the fertility and quality of the soil was not as good as its pre-mined state (Choube, 2015). It has been estimated that soil extraction for brick making is denuding 0.17 million km^2 of land every year (GIZ, 2015b). Brick kilns are also huge contributors of CO_2 emissions. CPCB estimates emissions from 140,000 kilns operating in the country to be about 66 million tonnes (CPCB, 2015a). Other harmful emissions from brick kilns include carbon monoxide, sulphur dioxide, nitrogen oxides (NO_x) and suspended particulate matter (SPM). Coal used for brick firing also leaves behind bottom ash as residue. The air pollution and bottom ash generated causes considerable health problems, especially related to respiratory health, while also causing damage to property and crops (CPCB, 2015a).

According to the Central Pollution Control Board (CPCB), brick kilns employ 9 million people across India. Use of bonded labour in brick kilns is illegal, yet a common practice followed across the industry. Labour is hired for 6 months with advance pay to produce as much as 15,000 bricks every day. They are made to work for as long as 16 hours a day on low wages (Wainwright, 2014). Workers involved in soil mining and brick manufacturing are provided with no health and safety measures. Such abuse of workers in the brick industry arises due to low cost of bricks and relatively high cost of production. Thus kiln owners exploit the labour force to keep up profits in the face of fierce competition. Such exploited workers include women and children in large numbers.

Material flow

As discussed earlier, soil as a resource finds its use in agriculture, brick manufacturing and road making. There are no exports and imports of soil in India.

Soil demand for brick making: Every year about 350 million m^3 of soil is required to produce bricks (GIZ, 2015b). Taking standard density of soil as 2.4 g/cc, the amount of soil required is about 840 million tonnes/annum. Considering 5% loss[17] of soil in brick making, gross demand of soil is estimated to be 884 million tonnes/annum.

Soil demand for road making: Soil required for road making cannot be accounted due to lack of data available on amount of land that is allotted for excavation of ordinary earth.

Soil demand for agriculture*:* As the soil is used in-situ by agriculture, there is no associated flow of soil; hence it is not accounted for in the material flow calculations.

Soil as waste from construction and demolition activities: The waste generated from construction and demolition has a soil component either as broken bricks, rubble mixed with soil, or as recovered bricks. Taking the C&D waste generation in the year 2015 to be 716 million tonnes[18] and taking TIFAC's characterisation of C&D waste, the total amount of soil waste generated from C&D waste is estimated to be 213 million tonnes/annum. (For detailed calculations refer to Annex 2.)

A detailed material flow is represented in Figure 3.44 (on the following page).

Response of government and market

Mining of soil for brick earth has become an environmental and social issue across the country. To streamline this unorganised sector, the Government of India (GoI) has put in place certain regulations. For instance, the MoEF&CC office memorandum which restricted mining of soil up to 2 metres below normal ground level also restricted any soil mining activities within 1 km from the boundary of national parks and wildlife sanctuaries. These restrictions have affected small scale brick manufacturers who are often poorly educated and not well informed but constitute the majority of brick making manufacturers. One solution to this problem is changing the input used for brick making; for example, by using waste material such as fly ash. To promote the use of fly ash, MoEF&CC issued a notification, S.O. 763 (E) in the year 1999, which mandated the use of fly ash in building materials for construction projects falling within a 100 km radius of coal or lignite based thermal power plants. The subsequent amendments to this notification directed builders to use at least 25% of fly ash in clay bricks and 50% of fly ash by weight in fly ash bricks, blocks, etc. The market responded positively to the sustained efforts of the government, and currently about 12% of total fly ash generated in India is used for the production of bricks and tiles (CEA, 2015). This needs to increase substantially if the pressure on soil resources is to be reduced.

However, soil is still a popular material for brick making in India and has a huge market. Prices of soil used for brick making are not compiled by the government, but a survey of contractors in the construction material supply industry suggests that brick kiln owners typically pay landowners between INR 1,500-2,000 (USD 22-30) for 8-10 metric tonnes of soil mined. Mining of brick earth or ordinary earth in India is done on the basis of a formal agreement between the kiln owner and the agricultural landowner. The area of land to be excavated is specified within the agreement. The kiln owner is required to acquire a permit from the State Environmental Impact Assessment Authority before excavating soil from agricultural land. Kilns are typically placed within 0.5 km to 5 km radius of the source of soil to reduce transportation costs.

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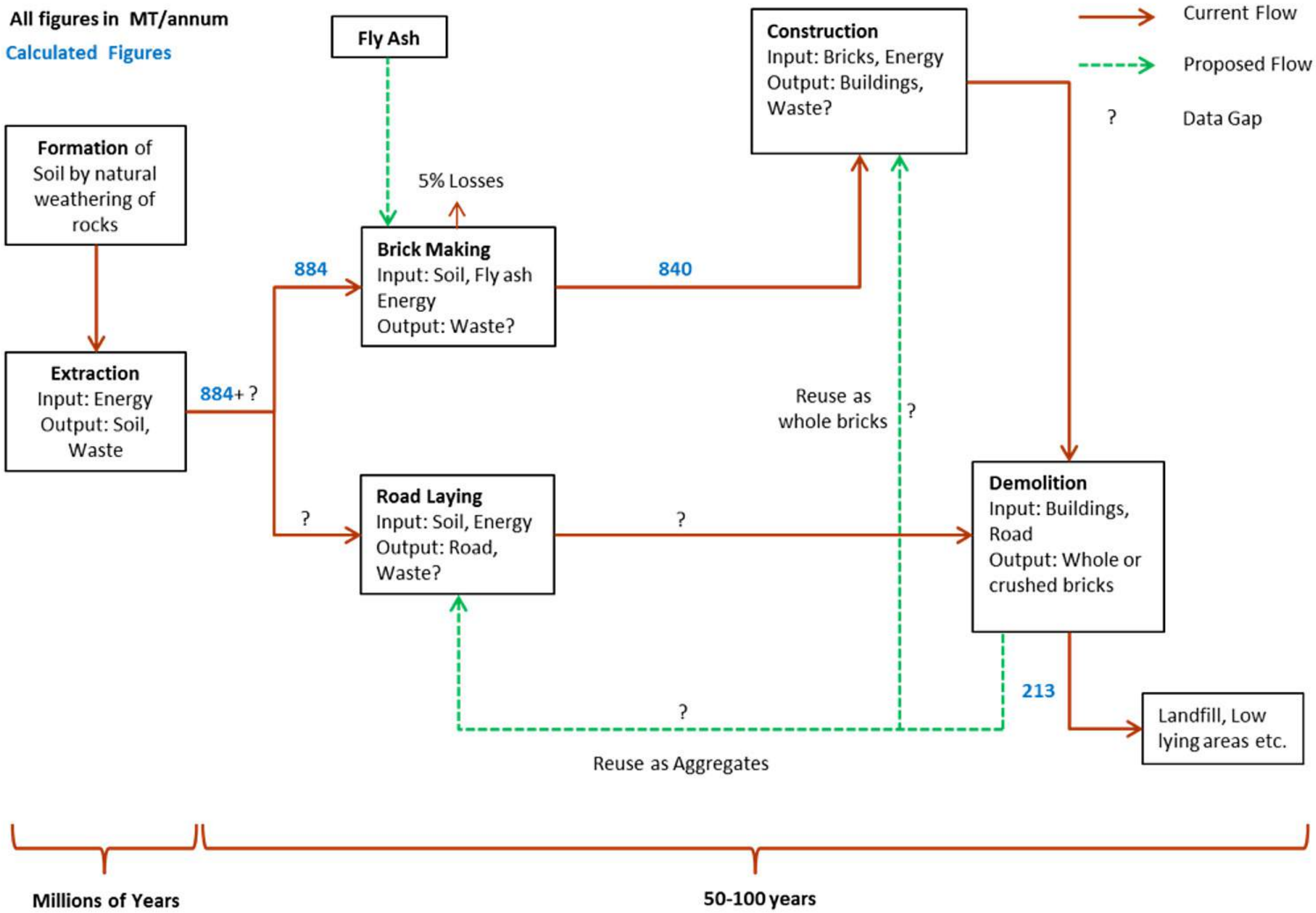
[17] Based on expert consultation with Dr. Sameer Maithel, Greentech Knowledge Solutions Pvt. Ltd.

[18] Authors' calculations based on survey of 10 cities (see GIZ, 2015b)

Figure 3.44: Material flow of soil in India



Soil once used for brick making can have indirect uses after the end of life of a building. Whole bricks in C&D waste are often reused as it is in non-load bearing structures, and the broken bricks have a huge potential to be used as aggregates in road laying. About 213 million tonnes of soil waste coming out from C&D activities (see Annex 2) can be reused every year if managed properly. Apart from reuse, there is a potential to reduce the use of soil in brick manufacturing by shifting to fly ash bricks. Though the market is gradually witnessing this shift, competing uses of fly ash in cement manufacturing has reduced its prevalence in brick making.

3.2.2.3 Stone (Aggregate)

India has rich deposits of stones suitable for construction activities. Historically, stone has been the mainstay of Indian architecture as a load bearing material. It has been used as dimensional stones[19] in famous monuments like the Taj Mahal, Qutub Minar, Red Fort, Sun Temple and many other ancient structures across India. Construction practices have changed in modern times and concrete took over dimensional stones as building material. Concrete utilises stones as coarse aggregates (crushed stone). Granite, basalt, limestone (other than cement grade), marble, quartzite and sandstone, all of which are used in the construction sector, either as crushed aggregates or dimensional stones, cumulatively contributed about INR 74 billion (USD 1.1 billion) to the production of minor minerals[20] in 2010-2011 (Ministry of Mines, 2013). This was the second largest group among minor minerals in the country.

Classification and uses of stone

Stones used for building purposes are categorised as minor minerals as per section 3(e) of the Mines and Minerals (Regulation and Development) Act, 1957. They are used in construction as aggregates for concrete mixing and as dimensional stones, i.e. as blocks or slabs of stone for roofing, flooring, tiles and decorative uses. India possesses a wide spectrum of stones that include granite, marble, sandstone, limestone, slate, laterite and basalt, spread across the country.

This study focuses on the use of stones as coarse aggregates. Stones as coarse aggregates are most widely utilised by the construction and infrastructure industry, including as base material for roads. In 2010, they represented two-fifths of all aggregate sales in the country (Aggregate Business International, 2013). India is currently witnessing a steep growth in the construction sector owing to rapid urbanisation and proposed public investments in infrastructure according to the 12th Five Year Plan. Therefore, stone will continue to be a prime requirement as coarse aggregate for concrete and roads. As per BIS code IS 383-1970 (Reaffirmed 2002), all types of rocks, i.e. igneous, sedimentary and metamorphic, can be used as concrete aggregates. Most durable of these rock types for use as aggregates are igneous rocks, due to their massive texture, low porosity and stable minerals. Basalt and granite are the most popular igneous rocks used as coarse aggregates. Basalt is popularly used as railway ballast[21] and as road-stone, while concrete mixing widely utilises granite as coarse aggregates. It is important to note that the Indian Bureau of Mines describes the use of granite only as a dimensional stone and no information is published on use of granite as coarse aggregates. A list of major stones in India and their uses is presented in Annex 3.

Granite deposits are spread out almost throughout the country except for some states in the northern, north-eastern and western parts of India. Basalt deposits are however limited to eastern

[19] Natural rock material quarried as blocks or slabs that meet specifications of width, length, thickness and shape
[20] Minor minerals are defined under the MMDR Act, 1957 and typically include all the minerals used in construction such as sand, stone, etc.
[21] Crushed stones laid on railway tracks

and central India (Figure 3.45). State geology departments or the Indian Bureau of Mines (IBM) do not report data on basalt availability. However, it is estimated that basalt deposits cover 0.6 million km^2 of area (Ministry of Mines, 2015).

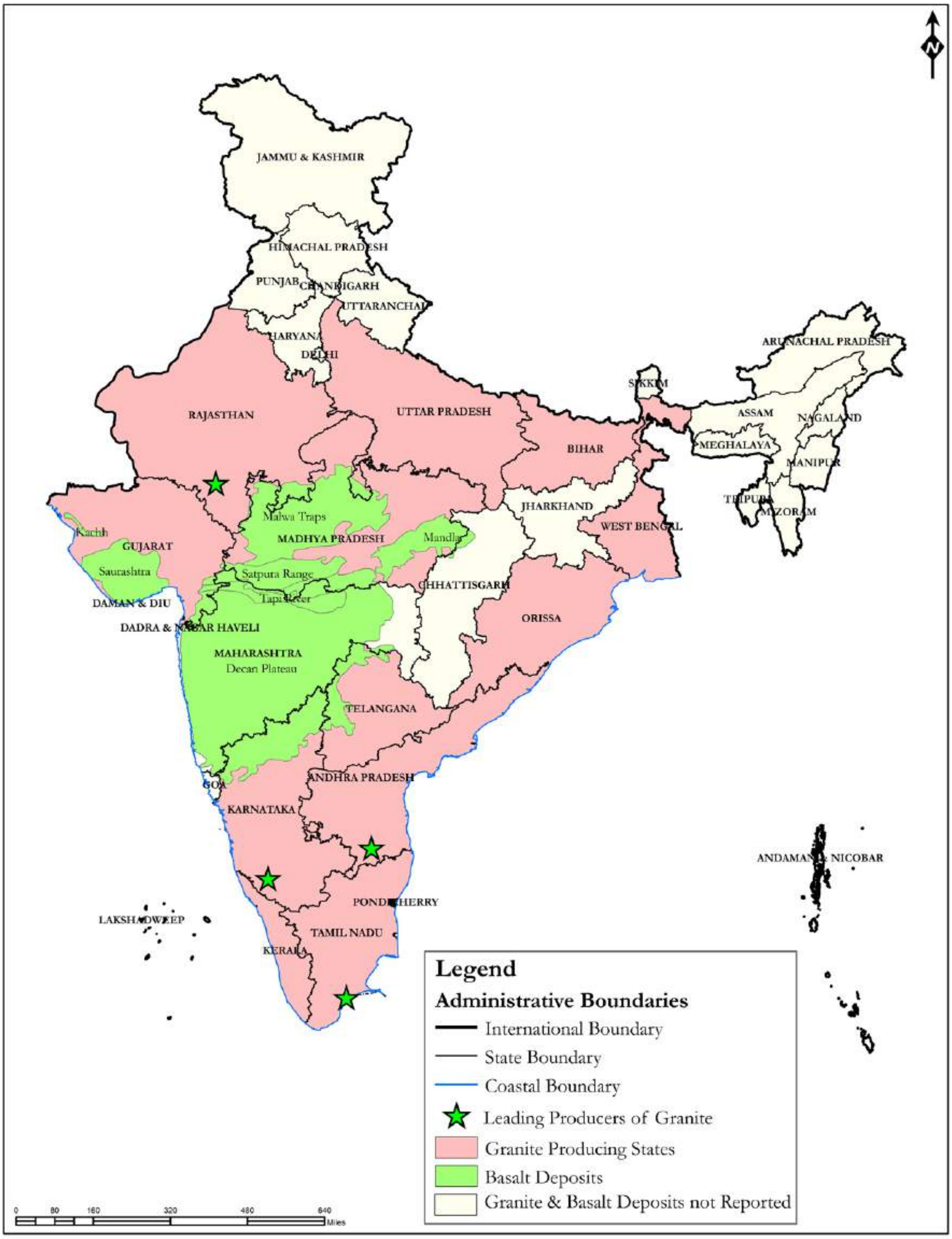


Figure 3.45: Granite producing states and basalt deposits in India

(Sources: Geological Survey of India, 2015; IBM, 2015a)

Almost 92% of the total granite production in India is contributed by southern states (IBM, 2015a). Andhra Pradesh and Karnataka are the leading granite producers in southern India while Rajasthan is the top contributor of granite production in northern India. Tamil Nadu, Kerala, Uttar Pradesh, Bihar, Telangana, Odisha and West Bengal also produce granite in small quantities.

Concerns and conflicts

Though granite and basalt deposits are fairly distributed across the country, hilly states where no granite or basalt resources are available are vulnerable to supply constraints due to distance from the granite resources and difficultly in transportation of processed granite. Additionally, there is a growing emphasis on use of granite as m-sand (refer section 3.2.2.1), which will further create pressure on granite supplies.

In the foreseeable future, the demand for coarse aggregates is expected to soar since concrete will remain the mainstay of construction. It is estimated that the construction industry will have a demand of more than 2 billion tonnes of coarse aggregates by 2020 (Figure 3.46). Further, the 12th Five Year Plan estimates an additional capacity of 1 billion tonnes of concrete to be created by 2027 to meet demands from road infrastructure and housing. Considering various mix ratios used for concrete, coarse aggregates range from a minimum of 2 to a maximum of 10 parts per unit of cement. Taking this into account, the coarse aggregate requirement in the year 2027 shall range between 2-10.3 billion tonnes. Apart from concrete, the demand for coarse aggregate required as road base material will also increase in view of the recent commitment of the Indian government to build 30 km of roads per day.

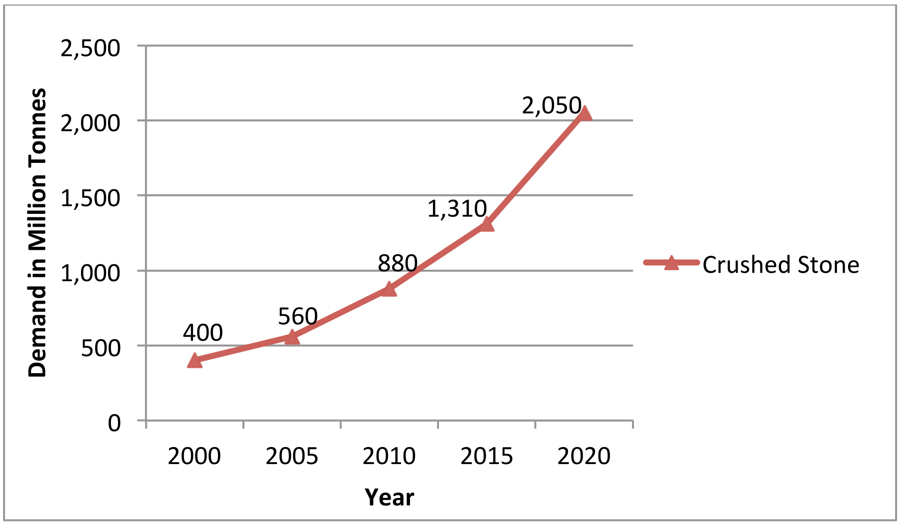


Figure 3.46: Demand of crushed stone by construction sector in India

(Source: Aggregate Business International, 2013)

The granite resource as on 2010 reported by IBM is about 126 billion tonnes[22]. But these are locked resources and exploration is needed to convert them to mineable reserves. This would require extensive mining and crushing operations to produce processed stones to be used as aggregates. Mining and crushing of stones have negative environmental implications, as modern techniques, which curb the pollution emitted from these operations, have largely not been adopted by the industry in India.

[22] Considering density of granite as 2.75 tonnes/m^3

Mining operations of basalt and granite involve drilling, blasting, cutting, manual hammering, and transport of rocks. The large chunks of stones are crushed in stone crushing plants, which are then transported to be used as coarse aggregates. The crushing units are generally located near the mine site. The basic procedure for mining and crushing of both the rocks is mostly similar.

Mining and crushing of stones have major impacts on air quality, soil, noise, and land. Stone crushing units not only emit particulate matter thereby causing air pollution, but the heavy equipment used in these units causes intense noise pollution. Quarrying operations also cause destruction of natural ecosystems and wildlife habitats, as well as disruption of hydrological resources. It is estimated that there are over 12,000 stone crushing units in India (CPCB, 2009). Though there is no official report on stone crushing units after 2009, the current number of stone crushing units must be significantly higher given that the demand of coarse aggregates has been rising steadily. Besides, stone crushing units are expected to expand in the future to meet the growing demand for aggregates in India.

Environmental impacts of stone mining are closely linked with social impacts around the mining and crushing areas. Stone quarrying has significant land use implications - quarrying of stone is often a source of conflict over traditional uses of land. The clearing of land to develop access roads and to open up mining sites reduces animal grazing areas and affects traditional livelihoods. Social challenges related to the increase in quarrying activities include: threats to health and safety from pollution as well as blasting, displacement of communities and damage to cultural sites. Unfortunately, the mining companies pick the biggest share of the benefits from quarrying, while local communities suffer from the negative impacts of these projects. This has led to persistent conflicts between the mine owners and local communities living near the quarry sites. Common conflicts revolve around resource control, land use, socio-cultural survival, pollution and land degradation (Samanth & Lad, 2014).

Over the years, not much has been done to change the social, economic and environmental dynamics of stone crushing units. These units still continue to employ informal labour and have adverse effects on the environment. Even if stones are to be replaced by waste material, crushing of the waste will be required to break it into suitable size aggregates to be used in concrete. Therefore, improving the processes of crushing units for better environmental performance should become the prime focus to reduce the pollution arising from their operations.

Table 3.15: Environmental impacts of stone mining and processing

Stone Type	Environmental Impacts	
	Mining	Processing
Granite and Basalt	Air and noise pollution due to blasting, drilling and movement of heavy vehicles. Degradation and removal of top soil (for unexposed rocks).	Sludge generated during cutting of granite, if disposed of in natural waterways, causes silting and pollution. Cutting of stones require coolants such as lime water and kerosene which may contaminate nearby waterways. Crushing, screening, and transfer points in the crushing unit cause air and noise pollution.

Using alternate materials for aggregates in place of natural stones is a way forward in reducing reliance on mining for this resource. The properties of recycled aggregates such as those derived from C&D waste have been established and demonstrated through several experimental and field projects successfully. It has been concluded that recycled aggregates can be readily used in construction of low rise buildings, concrete paving blocks and tiles, flooring, retaining walls, approach lanes, sewerage structures, sub base course of pavements, drainage layer in highways, and dry lean concrete, etc. (NBM&CW, 2011). India generates 716 million tonnes[23] of C&D waste per annum. Thus, there is a huge potential of C&D waste to be used as coarse aggregates.

Material flow

There are no national figures available on demand of stones as coarse aggregates. However concrete and road construction (in km) per year can be used as proxies to assess the material flow of stones as coarse aggregates. There are no imports and exports related to stone aggregates in India.

Demand of stone as coarse aggregates in concrete: It is estimated that per capita concrete demand in India is 1.5 tonnes per annum (refer section 3.2.2.1). Thus the total demand of concrete will be 1.8 billion tonnes/annum[24]. Crushed aggregate contribute about 60% of the concrete mix[25]. This implies that about 1.08 billion tonne per year of stone as crushed aggregate is required to meet the concrete demand. Considering 2% losses[26] of aggregates in concrete mixing, gross amount required as crushed aggregate is estimated to be 1.1 billion tonnes/annum (Figure 3.47).

Demand of stone as coarse aggregates in roads: Stones are used as coarse aggregates to make road base. During 2009-2014, average roads constructed per annum in India is estimated to be 4,860 km (Ministry of Road Transport and Highways, 2015). As per CRRI experts, about 1,000 tonnes of aggregate is required per km of road constructed[27]. Thus, net annual demand of coarse aggregates is estimated to be about 5 million tonnes/annum.

Stone as waste from construction and demolition activities: Stone comes out as waste from C&D of buildings in the form of concrete chunks as well as gravel. Considering C&D waste generation of 716 million tonnes/annum[28] in 2015 and TIFAC's characterisation of C&D waste, the amount of waste stone aggregate is estimated to be 254 million tonnes. (For detailed calculations, refer to Annex 2.)

Response of government and market

In 2012, the Union Ministry of Housing and Urban Poverty Alleviation alerted the Indian Parliament about the shortage of building materials, especially aggregates. Recycled aggregate is a viable solution to this problem. However, the recycled aggregate market in India is yet to take off in any meaningful way because the BIS Standards for concrete aggregates (IS: 323-1970), states that these should be 'naturally sourced' (Sustainability Outlook, 2015). While BIS is in the process of updating this standard, it will take time for the use of recycled aggregates to be widely accepted.

[23] Authors' calculations based on survey of 10 cities (see GIZ, 2015b)
[24] Considering population of India as 1.2 billion
[25] Average of coarse to fine mix of concrete
[26] Based on expert consultations with Department of Civil Engineering, Indian Institute of Technology-Madras
[27] Based on expert consultations with Central Road Research Institute
[28] Authors' calculations based on survey of 10 cities (see GIZ, 2015b)

To curb the pollution from stone crushing units, CPCB has developed norms, including emission caps on SPM (fugitive dust emissions). As per the norms, concentration of SPM at 10 to 50 metres from any processing equipment in a stone-crushing unit shall not exceed 600 micrograms/m^3 (CPCB, 2009). CPCB also suggested that crushing units adopt emission control options such as liquid injection during drilling, water wetting of stones during loading, using surface-active agents for roads, dust capture during crushing, screening and conveying, etc. As per CPCB, the captured dust can also be used for brick making. This can be an efficient option for dust utilisation from crushing units (refer to Annex 4).

Prices of stone aggregates depend on many factors including the distance of the quarry from the point of use, economic and aesthetic value of stone and availability. The price of stone aggregates in selected cities of India are provided in Table 3.16.

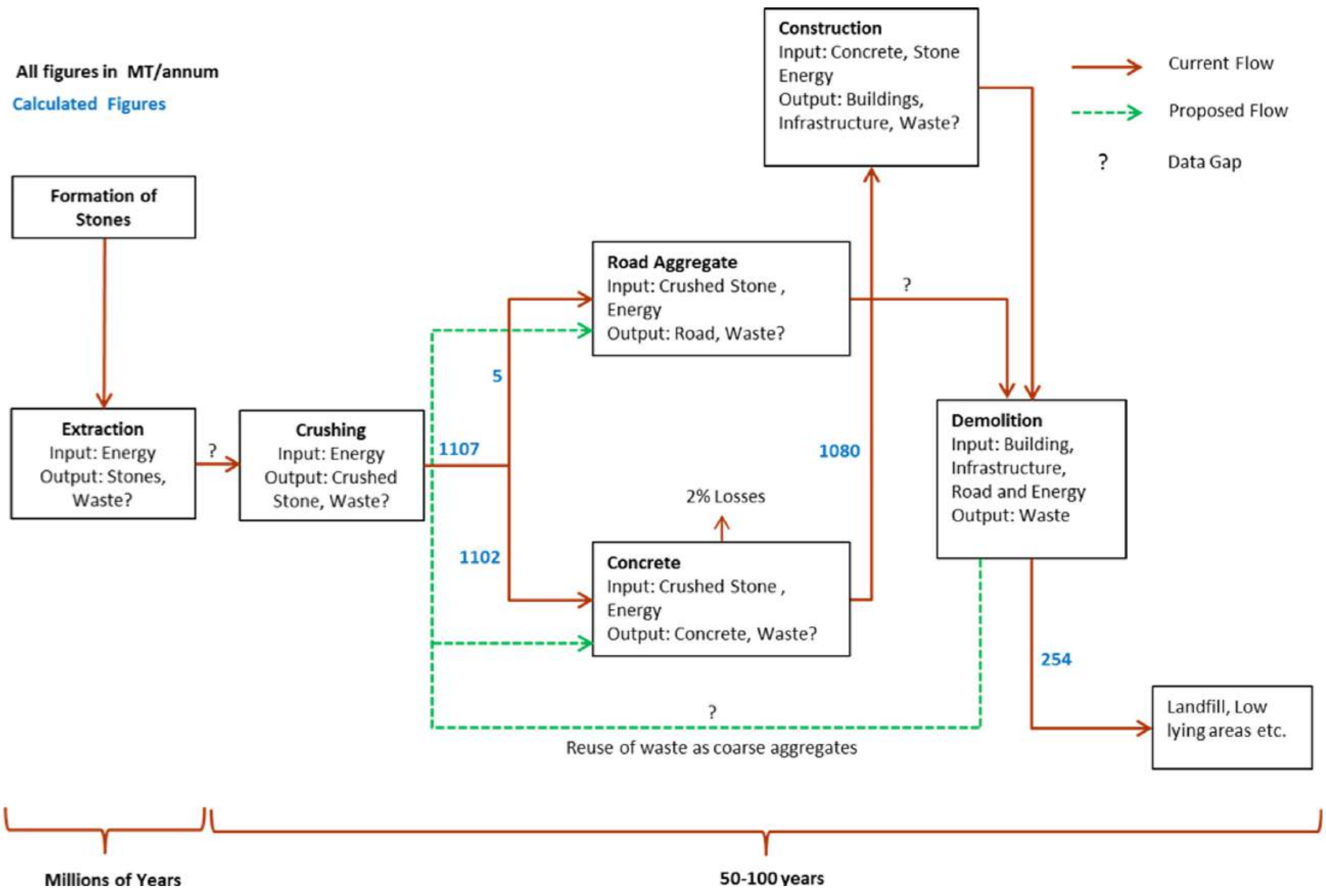
Table 3.16: Prices of stone aggregates in selected cities of India

S. No.	City	Stone Aggregate Price Range (INR/ft^3)
1	New Delhi	40-47 (USD 0.6 -0.7)
2	Gurgaon	35-40 (USD 0.5 -0.6)
3	Mumbai	30-35 (USD 0.4 -0.5)
4	Noida	38-44 (USD 0.5 -0.6)
5	Pune	15-22 (USD 0.2- 0.3)

(Source: Urbanhomez, 2015)

India generates about 716 million tonnes[28] of C&D waste per annum. There is a huge potential of this waste to be used as coarse aggregates in roads and concrete after proper processing and grading. Building materials such as paving blocks and curb stones have been successfully produced from C&D waste in India in pilot projects in Delhi and Ahmedabad. But due to low awareness about these products, they have struggled to find a market in the construction industry. Steps are being taken by the Bureau of Indian Standards (BIS) to formulate standards for using C&D waste as coarse aggregates in concrete.

Figure 3.47: Material flow of stone in India



3.2.2.4 Limestone

The term limestone is applied to any calcareous sedimentary rock consisting essentially of carbonates. It forms from the accumulation of shell, coral, algal and fecal debris or precipitation of calcium carbonate from lakes or ocean water. The process of limestone formation is slow and takes millions of years. Major constituents of limestone are calcium carbonate and magnesium carbonate. India has abundant resources of limestone distributed widely across the country. It is one of the most extracted minerals because of its varied uses in important industries like cement, iron and steel, chemical, etc. The cement industry is the principal consumer of limestone in India, followed by the iron and steel and chemical industries.

Classification and uses of limestone

Limestone is categorised as either a major or a minor mineral based on its end use as per the Mines and Minerals (Development and Regulation) Act, 1957. Limestone, if used for industrial purposes, is categorised as a major mineral and is regulated by the central government. When it is used for cement production, it is categorised as a minor mineral and is regulated by the respective state governments.

Total resources of limestone of all grades in India were estimated to be 185 billion tonnes in 2010. Out of the estimated resources, 15 billion tonnes were under mineable reserves[29] and 170 billion tonnes were under remaining resources[30] (IBM, 2015b).

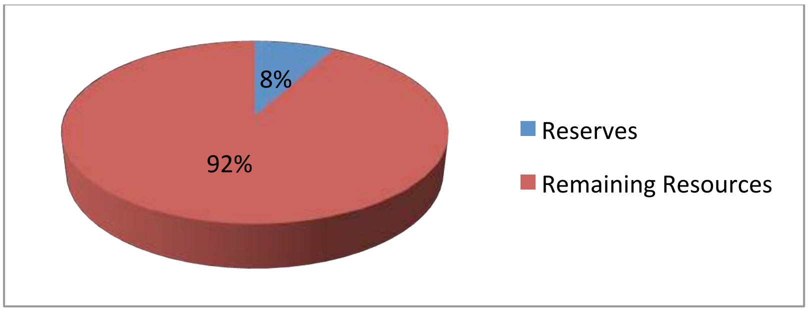


Figure 3.48: Reserves and remaining resources of limestone in India

(Source: IBM, 2015b)

Following are the uses of limestone in India:

- Cement industry uses limestone as a raw material for clinker.
- Iron and steel industry uses it as a slag former, i.e. to remove impurities from iron ore and to lower the temperature of melting.
- Chemical industries use limestone for manufacture of bleaching powder.
- Limestone also finds its use in industries such as fertiliser, sugar, aluminum, alloy steel, ferro-alloys, foundry, etc. The use of limestone by different industries depends mainly on its exact composition (CaO, MgO, $CaCO_3$, $MgCO_3$ content) (IBM, 2015b).

Grade wise classification of limestone reserves in India (Figure 3.49) shows that cement grade has majority share with about 69%, followed by iron and steel grades with about 12%, and chemical

[29] Limestone deposits that are accessible for mining.
[30] Limestone deposits remaining after subtracting reserves. These deposits are not accessible for mining.

grade with about 3%. The remaining 16% are others, not-known and unclassified grades (IBM, 2015b).

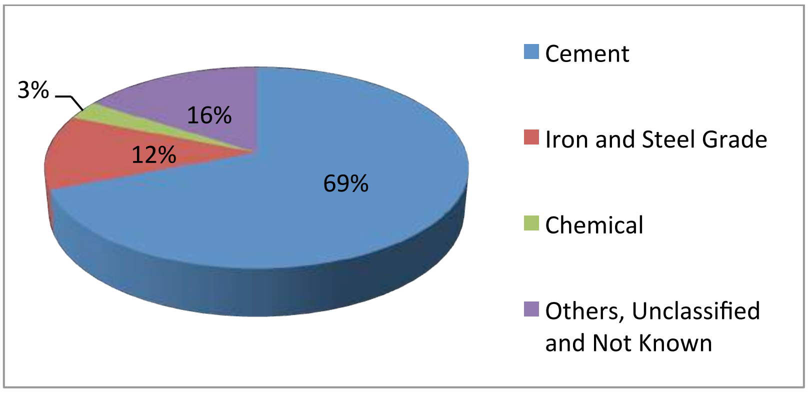


Figure 3.49: Grade-wise classification of limestone reserves in India

(Source: IBM, 2015b)

Figure 3.50 depicts limestone reserves and resources in India. The 13 states where limestone deposits are concentrated contributed about 99% of total production in 2012-2013. In the remaining states, either there is little or no production (less than 1 million tonnes/annum) or it is not reported. Karnataka is the leading producer of cement grade limestone in India. Gujarat leads in chemical grade limestone production. Iron and steel grade limestone is produced in small quantities in Andhra Pradesh, Karnataka, Tamil Nadu, Chhattisgarh, Madhya Pradesh, Rajasthan and Himachal Pradesh. State wise production of all grades of limestone in the year 2013-2013 is presented in Figure 3.51 (IBM, 2015b).

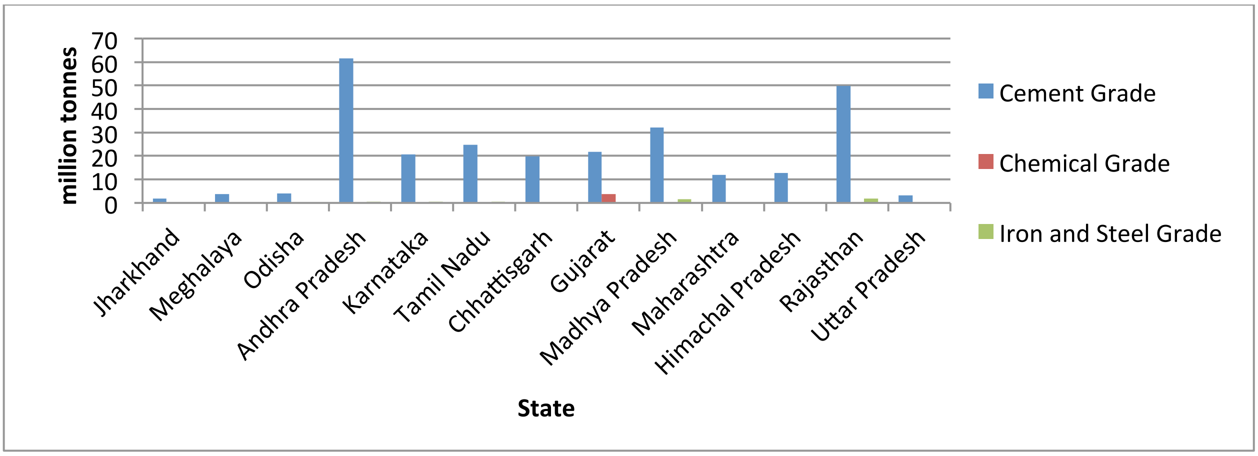


Figure 3.50: State-wise production of all grades of limestone in India

(Source: IBM, 2015b)

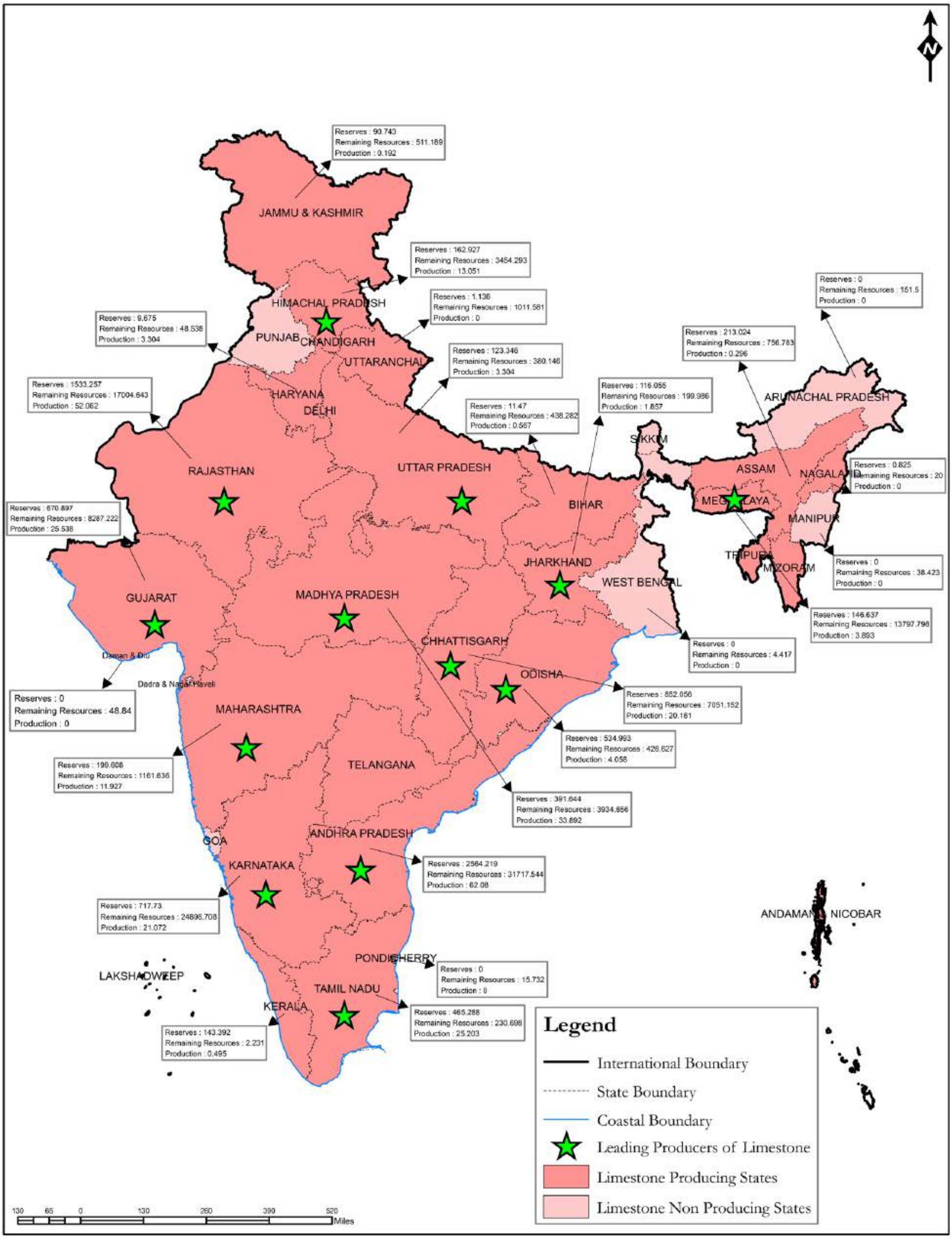


Figure 3.51: Limestone reserves, resources and production in India

(Source: IBM, 2015b)

Concerns and conflicts

Out of the present available resources of cement grade limestone, about 30% falls under forest, Coastal Regulation Zone (CRZ), and other regulated areas, which roughly translates to 34.7 billion tonnes (Ministry of Commerce and Industry, 2011). Taking this into account, the net available 'remaining resources' of cement grade limestone for future development is estimated to be about 89.3 billion tonnes. The huge investments planned by the Government of India in the infrastructure sector will require large quantities of cement grade limestone to meet the necessary cement demand. According to the Planning Commission, the maximum projected demand for cement grade limestone during the 12th Five Year Plan period (2012-2017) is estimated to be 3.4 billion tonnes, assuming GDP growth of 10% and cement manufacturing growth of 12% (IBM, 2015b). The Ministry of Commerce and Industry estimates that post 2017, the life of available cement grade limestone reserves is approximately 35-41 years (Ministry of Commerce and Industry, 2011). In this scenario, cement grade limestone may be completely exhausted by 2058 at the latest. It is clear that limestone resources will not be available forever. Therefore, there is a need to shift to alternative materials for cement production. Blended cement made of fly ash and other industrial and clay mining waste is a good option to reduce limestone consumption in cement manufacturing.

Social and environmental impacts of limestone mining are very similar to those of stone mining. Land degradation and water contamination are major concerns associated with limestone mines. According to a recent study in Meghalaya, surface water near a limestone quarry was found to have elevated levels of pH, EC, TDS, total hardness, alkalinity, calcium and sulphate concentrations, thus affecting local water supply (Lamare & Singh, 2014). With 30% of limestone reserves beneath regulated areas, the potential for loss of forest cover and land degradation is high. The limestone used as an input in manufacturing industries is required in small sizes; therefore blasting and crushing are the main activities in a limestone mine. Though blasting is a temporary operation, it creates fugitive dust emissions, noise and vibrations, which are major health, safety and environmental hazards to the surrounding areas. Mechanical processes used for crushing limestone to appropriate sizes for transportation are a continuous source of dust and noise. Additionally, limestone mining also contributes to CO_2 emissions. There are no national figures available on Global Warming Potential (GWP) of limestone mining in India. However, reported global average of limestone mining GWP is 0.0021 kg CO_2 per kg of limestone mined[31]. Therefore, it can be roughly estimated that CO_2 emissions from limestone mining in India was about 0.6 million tonnes[32] in the year 2012-2013.

Limestone mining also gives rise to land conflicts between local people and the mine owners. In the Khasi hills district of Meghalaya, the indigenous inhabitants of the region lost their local land rights to a limestone mine that was set up in the area. The mine operations also contaminated river water, which directly affected the livelihood of the people (Bhattacharjee, 2014).

Material flow

Out of the total production of limestone in 2011-2012, 93.8% was cement grade limestone, 4.5% was iron and steel grade and 1.5% was chemical grade (IBM, 2015b). Other grades of limestone were 0.2%. Production and consumption details of different grades of limestone in India in 2011-2012 are presented in Table 3.17.

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[31] Source from Ecoinvent Database of SIMAPRO software

[32] Production*GWP

Table 3.17: Production and consumption of different grades of limestone in India (million tonnes)

Grade	Production	Consumption
	2011-2012	2011-2012
Cement	246.09	211.08
Iron & Steel	11.7	9.33
Chemical	4.01	3
Other[33]	0.7	3.1
Total	262.5	226.51

(Source: IBM, 2015b)

Limestone is imported and exported by India. In 2011-2012, total imports of all grades of limestone were 8 million tonnes while total exports were 3 million tonnes (IBM, 2014).

Limestone as waste from construction and demolition activities: Limestone is an embedded material, which comes out as waste in the form of concrete and masonry. Considering 716 million tonnes[34] as annual C&D waste generation and using TIFAC's C&D waste characterisation for concrete and masonry, the amount of embedded limestone that comes out as waste is estimated to be 35 million tonnes/annum. (For detailed calculations, refer to Annex 2.)

The material flow of limestone is presented in Figure 3.52 (on the following page), considering production and consumption of all grades of limestone for the year 2011-2012.

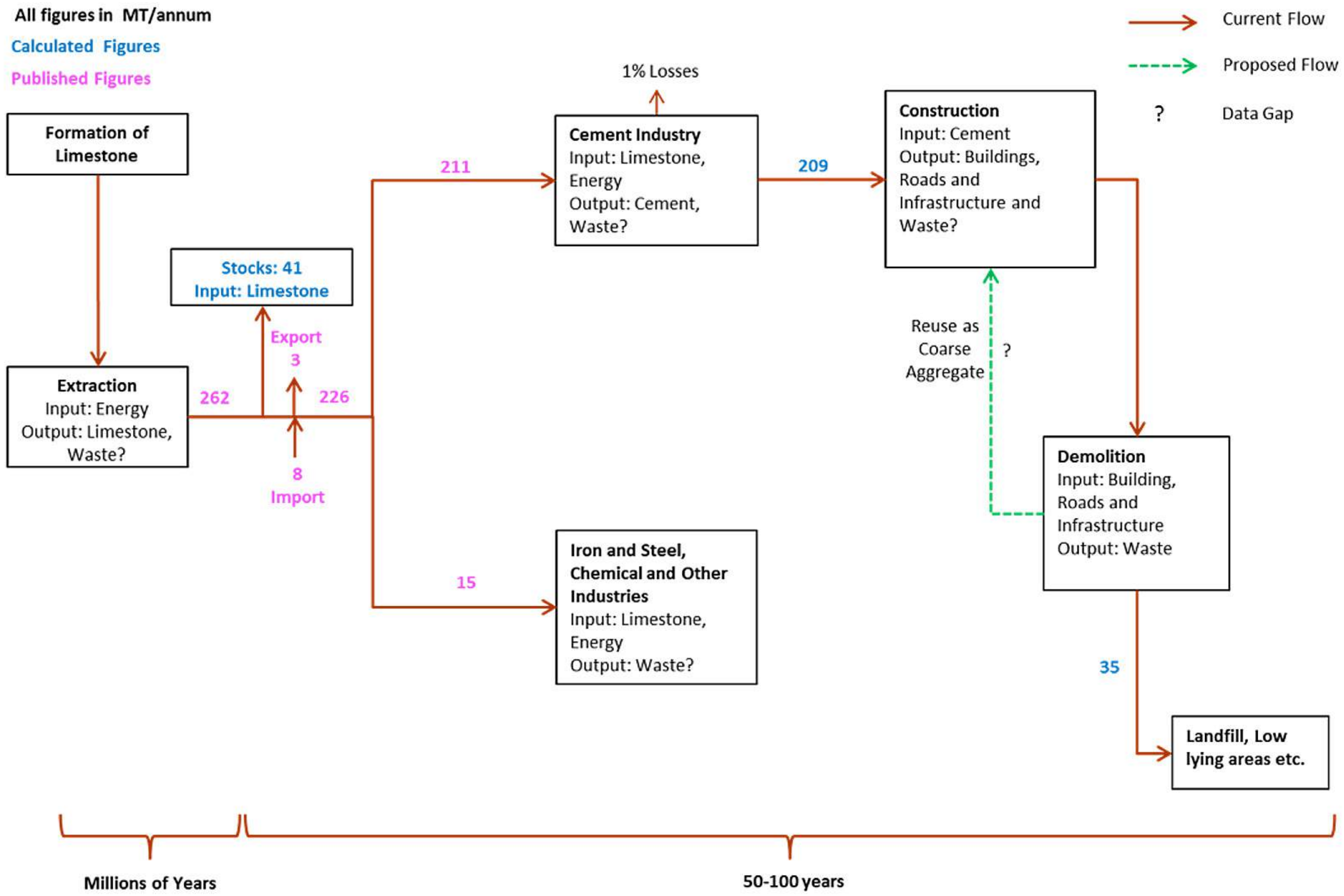
Response of government and market

Government led interventions have mandated the use of fly ash in cement production. A minimum of 15% fly ash by weight is to be used in cement as per the notification. In fact, almost 42% of total fly ash generated in India is used for the production of cement (CEA, 2015).

Royalty on limestone is decided by the central government; rates are fixed at INR 63/tonne (USD 0.94) (PIB, 2015). Market prices however vary significantly between states. In Kerala, 1 tonne of limestone costs INR 244/tonne (USD 3.6), while in Rajasthan it costs about INR 64/tonne[35](USD 0.94). This shows that prices of limestone are directly proportional to regional availability. Major cement plants in India are located near the limestone deposits to reduce transportation costs and promote ease of operations. Where limestone production is limited but the demand is high, market prices increases for cement manufacturers with no captive mines. To control prices and also to conserve cement grade limestone reserves, commercially viable alternatives to limestone need to be explored in cement production.

[33] Other includes industries such as asbestos products, ceramics, electrodes, explosives, lead & zinc, mining machinery, paints, pesticides, pharmaceutical, refractory, rubber, sponge iron, textiles, etc. Many of these industries require specific quality of limestone not available in India. Thus to fulfill requirement, they import limestone and hence the consumption is greater than production.
[34] Authors' calculations based on survey of 10 cities (see GIZ, 2015b)
[35] Calculated from revenue figures in respective State Mines and Geology Department websites

Figure 3.52: Material flow of limestone in India



3.2.2.5 Iron and Steel

The iron and steel industry is among the fastest growing industries in India. The leading demand drivers of iron and steel in India are the construction, infrastructure and automobile industries. Per capita consumption of steel in India is 59.2 kg per year which is low compared to the world average of 225 kg per year (IBM, 2015c); thus there is a huge potential for growth of steel production in the country. The demand is expected to increase in the future due to rise in infrastructure and housing as well as the thriving automobile sector. Backed by government's scale up plans for steel production, India is poised to become the world's 2nd largest producer of crude steel in the next 10 years (IBEF, 2015). Production of iron and steel requires iron ore as a raw material, which is found as deposits in sedimentary rocks. It is formed from chemical reactions that combine iron and oxygen in marine and fresh waters. The two important minerals in these deposits are Hematite and Magnetite which constitute total iron ore resources in India. Formation of iron ore is a slow and gradual process which takes millions of years. There are different varieties of iron and steel produced in India, from iron ore i.e. pig iron, to sponge iron to crude steel and finished steel. India is the largest producer of sponge iron in the world (IBM, 2015c). Pig iron, sponge iron and crude steel are converted to finished steel, which is then used by different industries.

Classification and uses of iron and steel

As already noted, the iron and steel industry in India comprises of pig iron, sponge iron, crude steel and finished steel. Pig iron is one of the basic raw materials required by the foundry and casting industry for manufacturing various types of castings (cast iron) for the engineering sector. It is also used for production of crude steel. Sponge iron is primarily used for production of steel. It is used as an alternative to 'steel melting scrap'[36] in crude steel production. The bulk of pig iron and sponge iron goes to the production of crude steel. Therefore most of the iron ore in India is ultimately utilised for production of crude steel. Crude steel is then utilised to manufacture a variety of finished products categorised as flat and long products, also known as finished steel (refer to Annex 5).

In the construction sector, finished steel is primarily used in bars and rods for Reinforced Concrete Cement (RCC). As per IBM (2015c), bars and rods consumed 35% of the total steel produced in 2014-2015 (April to December), which was higher in comparison to other products made of steel (refer to Annex 5). In the infrastructure sector, national highways, railways, power projects, power transmission lines and oil and gas sectors dominate the use of steel. The automobile sector is another heavy user of steel. The construction and infrastructure sectors are major consumers of steel, and their share is likely to rise owing to the big increase in investments planned for these sectors in the 12th Five Year Plan.

Iron ore, the basic raw material for production of iron and steel, is available in abundance in India. Collectively, 28.5 billion tonnes of iron ore resources are available in India of which 8.1 billion tonnes are under 'reserve' (accessible for mining) category and 20.4 billion tonnes are under 'remaining resources'. Odisha is the largest producer of iron ore in India followed by Chhattisgarh, Jharkhand, Karnataka and Goa (IBM, 2015d). These states together contribute about 97% to the total iron ore produced in India. Almost 99% of iron ore produced in India is consumed by the iron and steel industry and just 1% goes to the cement industry (Figure 3.53).

[36] Steel melting scrap is usually sourced from ship breaking yards and steel industries. It is scarce in the country and was frequently imported before the use of sponge iron (IBM, 2015c)

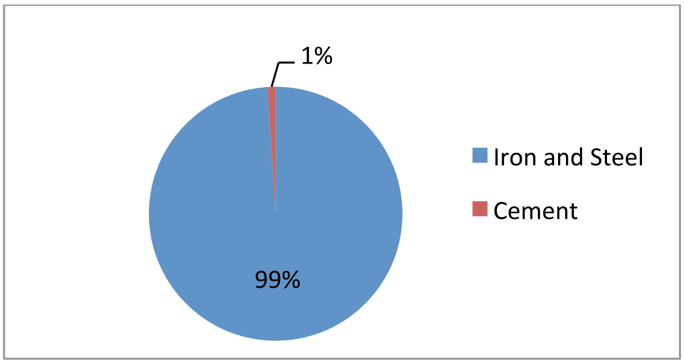


Figure 3.53: Consumption of iron ore in India (2012-13)

(Source: IBM, 2015d)

Integrated iron and steel plants reduce the iron ore to extract pure iron in molten form, also known as 'hot metal'. The hot metal is then solidified to make foundry grade and steel grade pig iron. Iron ore is also directly reduced to a solid state which is known as Direct Reduced Iron or Sponge Iron. Crude steel is made by removing impurities from hot metal, sponge iron and pig iron in Steel Making Shops. In the cement industry, iron ore is used to enhance process efficiency and impart colour to the mix. Other industries which use iron ore in their manufacturing processes are alloy steel, coal washeries (only magnetite), foundries, ferroalloys and glass. The consumption of iron ore by these industries is less than 0.1% of the total iron ore produced in the country (IBM, 2015d).

India is a net importer of iron ore. According to IBM, 3.06 million tonnes of iron ore was imported in 2012-2013. The imports increased to 15 million tonnes in 2014-15 and it is expected that in 2015-16 India will remain a net importer of iron ore (IBM, 2015d). Production of iron ore far exceeds consumption. But a dip in international prices of high grade iron ore and inconsistency in domestic supply is compelling big iron and steel manufacturers in India to rely on imports (Kulkarni, 2015). To reduce reliance on imports, auction of 20 major iron ore mines has been proposed in 2015 (Das, 2015).

India is self-sufficient in production of pig iron and sponge iron. Production of crude steel has also shown a sustained rise since 2009-10. The reason for this substantial growth in crude steel production is capacity expansion from 75 million tonnes in 2009-10 to 101 million tonnes in 2013-14, a growth of 9% (on a CAGR basis). Capacity and production of crude steel in India is presented in Figure 3.54.

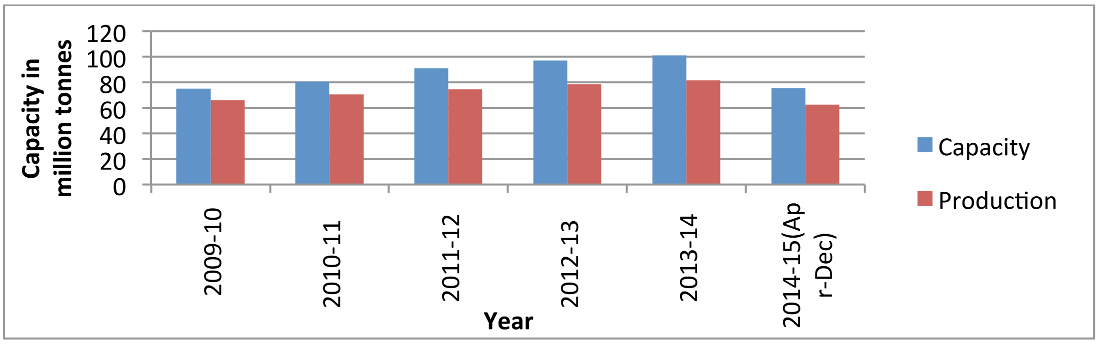
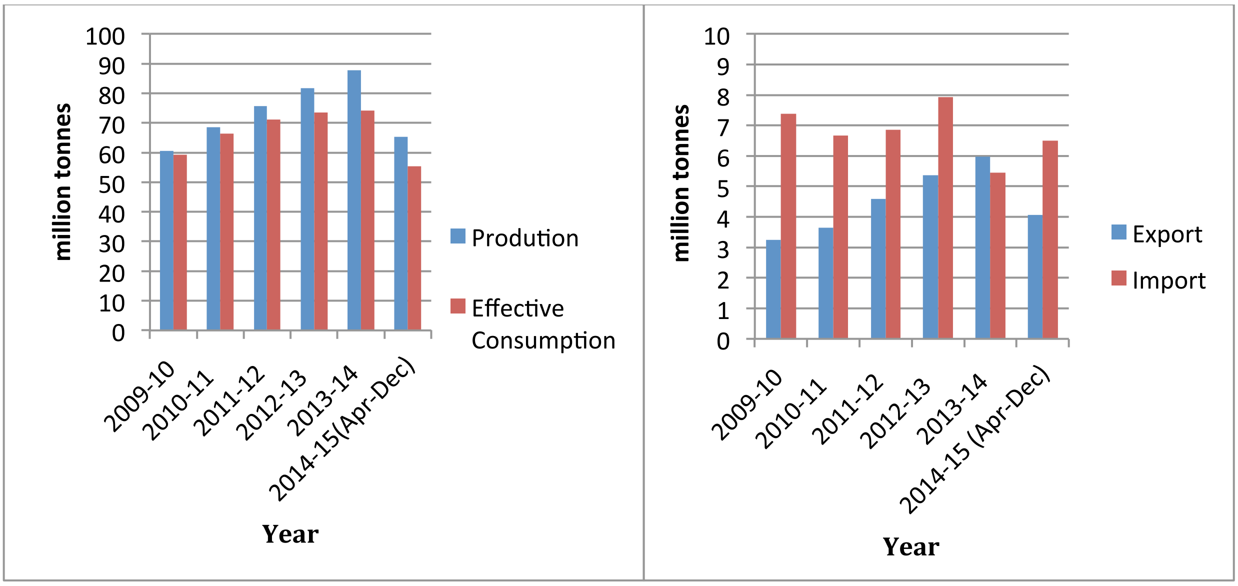


Figure 3.54: Capacity and production of crude steel in India

(Source: Ministry of Steel, 2015a)

Production of total finished steel also grew at a rate of 8.9% in CAGR terms during the five year period 2009-2014. In 2007-08, India was an importer of finished steel; however this changed in 2013-14, when it became an exporter. India's production reached 65.2 million tonnes in 2014-2015, but it went back to importing steel even though production levels remained higher than effective consumption[37]. The sudden surge of imports of finished steel in 2014-2015 is due to the cheap prices of steel imported from China and Korea (The Hindu, 2015). However, India only depends on imports of certain qualities of steel, especially those used in the automobile sector and production of engineering goods (PIB, 2015) (Figure 3.55).



(A) (B)

Figure 3.55: (A) Production, effective consumption (B) Export and import of finished steel in India

(Source: Ministry of Steel, 2015b)

The iron and steel industry is geographically spread out in India (Figure 3.56). There are 14 principal and 22 mini steel plants across India. Principal steel plants are the bulk producers and are concentrated near iron ore deposits. Mini steel plants are decentralised units with a capacity ranging from 10,000 to 500,000 tonnes. These units are located away from principal producers to meet local demand. Additionally, there are about 4,500 foundries which cast steel products for various industries (Ministry of Steel, 2015a).

Odisha, Karnataka, Andhra Pradesh, Tamil Nadu, Chhattisgarh, Jharkhand, West Bengal and Maharashtra are the major steel producing states of India. High altitude regions like Jammu & Kashmir, the northeastern states, Himachal Pradesh, and Uttarakhand have little or no contribution to India's steel production due to lack of iron ore reserves. Special emphasis is given on transport of steel to these states to fulfill local demand. In India, iron and steel is transported via roadways and railways. India has dedicated railway freight corridors for transportation of finished steel and iron ore. Road networks are also extensively used to transport finished steel. Decentralised mini steel plants also help in meeting demand for finished steel products in local markets and thus reduce transportation cost.

[37] Effective consumption is derived from exports, imports and adjustments in the stocks.

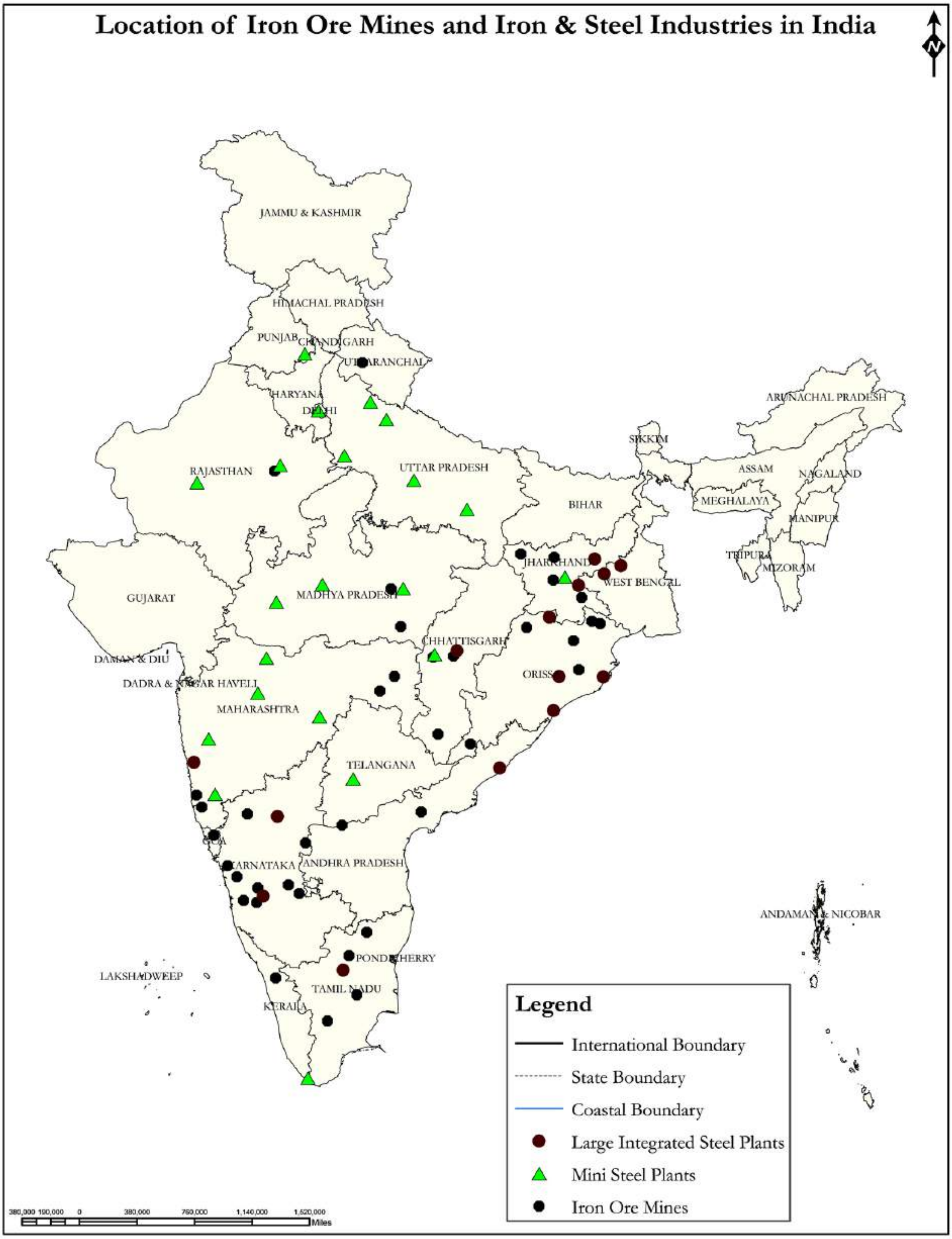


Figure 3.56: Location of iron ore mines and iron & steel industries in India

(Source: Ministry of Steel, 2015a)

Concerns and conflicts

Steel production involves melting of iron ore at high temperatures. The process is heavily reliant on coking coal as a fuel. Therefore, steel plants are highly energy intensive and leave huge CO_2 footprints. Starting from mining of ore to end use, steel has severe environmental impacts. Mining of iron ore has many impacts such as land disturbances, disturbances of natural watershed, air pollution, noise and vibrations due to blasting, etc. Environmental concerns have led to closing down of some mining operations in India. Kudremukh iron ore mine of KIOCL, which was located in a wildlife sanctuary, was closed in December 2005 (PIB, 2014).

Goa too is prone to siltation of agricultural fields, drainage ditches, riverbeds and creeks during the monsoon season when iron ore tailing dumps start to wash away into the land and water (IBM, 2015d). Disposal of tailings is a common problem associated with iron ore mines. To overcome these problems, check dams and water filter beds at higher contours have been constructed at many mine sites. Tailing ponds are also being maintained at some mines (IBM, 2015d).

Material flow

The construction industry is the biggest consumer of finished steel in India, accounting for 35% of total consumption in the financial year 2014-15; this is followed by infrastructure at 20% and automobiles at 12% (Figure 3.57).

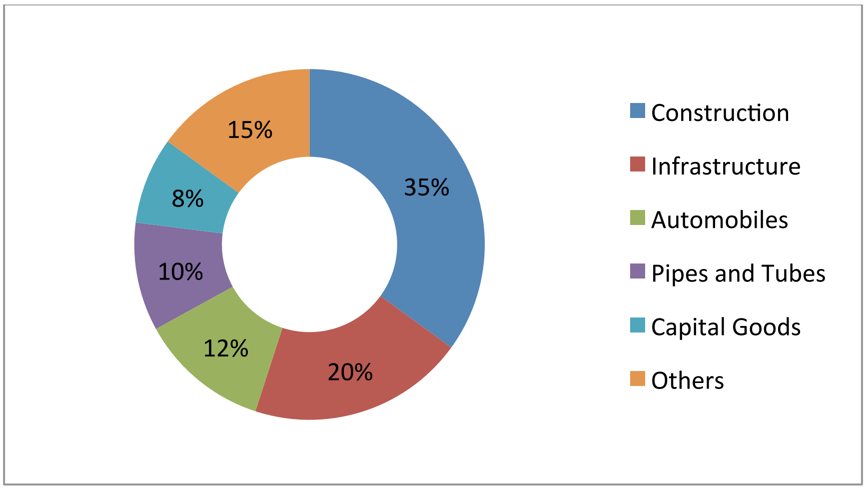


Figure 3.57: Sector-wise consumption of steel in India

(Source: IBEF, 2015)

Therefore, percent consumption by various sectors can be translated to amount of steel consumed using effective consumption of steel in 2014-2015. Sector wise consumption of steel in million tonnes is presented in Table 3.18.

Table 3.18: Steel consumption by various sectors in India (million tonnes)

Sector	Amount of steel consumed (2014-2015)
Construction and Infrastructure	30.4
Automobiles, Pipes and Tubes, Capital Goods, Others	24.8
Total	55.2

Steel as waste in construction and demolition activity: Ship breaking yards and construction and demolition waste are major sources of steel in India. Steel has a high recycling potential. Steel scrap from ship breaking yards is consumed by steel and foundry industries in India and contributes to about 1-2% of domestic steel consumption (IBM, 2015c)

Steel scrap generated from construction and demolition waste was estimated using TIFAC's estimation of metal content in C&D waste, which is about 5%. Considering 80% of metal to be iron and steel and 716 million tonnes[38] of C&D waste generated in India, the iron and steel scrap generated from C&D waste is estimated to be 29 million tonnes.

A material flow of steel is presented in Figure 3.58 (on the next page).

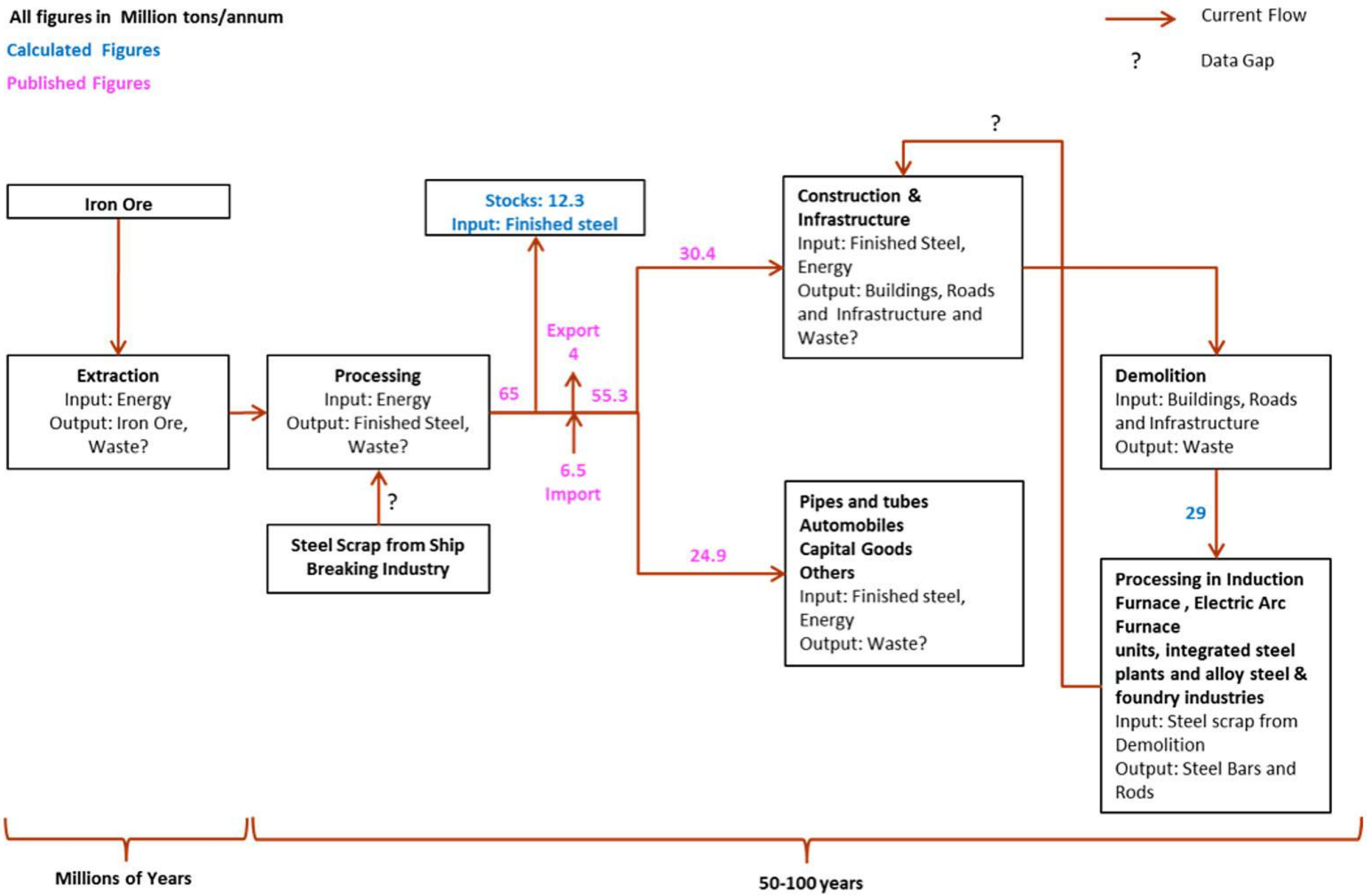
Response of government and market

Government interventions have led to a significant improvement in energy efficiency in the Indian steel sector over the past decade. In 2003-04, the Specific Energy Consumption (SEC) of major steel plants ranged from 8-10 Gcal/tcs (per tonne of crude steel), while in developed nations SEC ranged from 4-6 Gcal/tcs (Thakkar, 2008). The SEC of key Indian steel producers in 2014-2015 (April-Nov) has been reduced to 6–7 Gcal/tcs (Ministry of Steel, 2015b), although there is still scope for improvement. The average CO_2 emissions of Indian steel plants are 2.5 tonnes/tcs[39] which is higher than the world average of 1.8 tonnes/tcs (WSA, 2014b). However, there have been gradual reductions in CO_2 emissions from the Indian iron and steel industry in the past five years. To improve energy efficiency and reduce CO_2 emissions, the Indian steel industry has been adopting low carbon technologies. Steel Authority of India Limited (SAIL), one of the largest producers of steel in India, has started using natural gas along with coal for firing boilers. Rashtriya Ispat Nigam Ltd., another major producer of steel, has started generating electricity from waste heat. Steel plants are also investing in research and development to improve process efficiency and are introducing new processes that generate less waste. In India, all the key steel producers are ISO: 14001 (Environmental Management Systems) certified. The Ministry of Steel is also taking initiatives to reduce energy consumption and CO_2 footprint of the steel industry. Some of them are highlighted below (Ministry of Steel, 2015b).

- As a member of the National Action Plan on Climate Change, the Ministry of Steel coordinates the approval of the Clean Development Mechanism (CDM) projects in the iron and steel sector in the country.

[38] Authors' calculations from survey of 10 cities across India (see GIZ, 2015b)
[39] Derived from Annual Report (2014-2015) of Ministry of Steel, GoI (Ministry of Steel, 2015b)

Figure 3.58: Material flow of iron and steel in India



- The Ministry facilitated the adoption of low carbon technologies in 34 steel re-rolling mills (model units) to bring down energy consumption and reduce GHG emissions by 25-50%.
- The Ministry is coordinating with the Government of Japan for setting up of energy efficient, environment friendly projects in the steel sector.
- The Ministry launched the Perform Achieve & Trade (PAT) scheme under the National Mission for Enhanced Energy Efficiency in 2012. PAT is a market based mechanism through which energy savings can be achieved through various certifications and traded. It became effective in April 2012.

The steel sector, like all major industrial sectors, is also liable to undertake Corporate Social Responsibility (CSR) activities according to government mandate in India. Apart from directly employing about 600,000 people, provision of health care, education and vocational training to disadvantaged sections of society in local communities are common initiatives undertaken by steel companies (CCI, 2015).

In 1992, price regulations for iron and steel were abolished in India, and subsequently the interplay of market forces determines prices of steel. The main factors influencing domestic steel prices in India are price of raw materials, demand and supply conditions, and international price trends. The iron and steel industry is completely deregulated in India; the government acts only as a facilitator and monitors steel market conditions. A steel price monitoring committee has been constituted by the government with the aim to monitor price rationalisation, analyse price fluctuations and advise all concerned regarding any irrational price behavior of this important commodity (Ministry of Steel, 2015b). An overview of average prices of different grades of steel in selected cities of India is presented in Table 3.19.

Table 3.19: Prices of steel in selected cities of India

City	Rates in 2012-2013 (INR per tonne)
Delhi	34,930 (USD 522)
Mandi Gobindgarh (Punjab)	37,361 (USD 558)
Mumbai	34,466 (USD 515)
Kolkata	32,084 (USD 480)

(Source: IBM, 2015c)

The prices presented in Table 3.19 are average rates of various finished steel products that are sold in India. Recently, there have been no major fluctuations in steel prices in the domestic market. However, the prices of iron and steel are closely connected with coal and iron ore prices; thus any change in prices of these basic raw materials directly impact prices of finished steel.

India is self-sufficient in production of iron and steel. Iron ore availability is also sufficient to meet domestic demand. However, international price fluctuations and supply gaps due to legal issues with iron ore mines, as well as perceived quality concerns about domestic steel encourages steel manufactures to import finished steel. Iron and steel have high recyclability potential even after demolition of buildings and other infrastructure. Salvaged steel is seen as a valuable resource and fetches a high price in the secondary market. Local foundries reuse recovered iron and steel rods in finished steel production.

Chapter 4: Best Practices in Resource Efficiency in the Automotive and Construction Sectors

4.1 Automotive Sector

4.1.1 At National Level

Resource efficiency makes all the more sense in India as the government is currently championing programs like *"Make in India"* which will have huge implications on demands for resources, imports, and the environment in general. The automobile industry in India is gradually realising the importance of resource efficiency, typically being driven by material costs. Though not widespread, certain companies are developing or adopting methods to utilise material resources more efficiently and/or minimise wastages. Some recent trends that have gained publicity in India are mentioned in the following paragraphs.

Recovery from end-of-life vehicles (ELVs)
Vehicles that can no longer be used on roads are potential sources of secondary resources like steel, iron, aluminium, etc., as well as some very critical resources like copper, zinc, and platinum. Even though ELV handling in India is not properly regulated, the issue has been gaining in prominence. Currently, retired vehicles in India usually end up in the unorganised sector where after dismantling, the auto components are either refurbished or sent for recycling. Not surprisingly, the efficiency of material recovery is quite low, since the workers are not adequately trained and lack proper equipment to dismantle and recycle auto components.

The Ministry of Heavy Industry (MoHI) and the Society of Indian Automobile Manufacturers (SIAM) have made efforts to promote resource recovery from ELVs. An automobile dismantling center - Global Auto Research Centre (GARC), under the National Automotive Testing and R&D Infrastructure Project (NATRiP) at Oragadam, near Chennai[40], has been set up. GARC is labour intensive, unlike similar units in developed countries. The objective is to promote recycling activities with significant employment and also to manage the hazardous waste and encourage recovered material reuse by the auto industry. The centre, set up in collaboration with SIAM, is also expected to train and help upgrade current units in the unorganised sector (see NATRiP, 2015).

In Delhi, the Delhi Transport Department, along with the 3-wheeler manufacturers Bajaj and TVS, has set up the scrapping centers in the Mayapuri industrial area of Delhi. The Delhi Transport Department has implemented a policy to grant a new permit against the old permit only when there is a proof of physical scrapping of the old vehicle from the authorised centers.

Materials recovery from automobile industry waste
Paint sludge from automotive industries contains heavy metals. Safe disposal of this waste has always been a challenge for the industry. Besides, this waste contains a lot of resources which can be

[40] Chennai is one of the hubs of automobile manufacturing in India.

recovered and used to manufacture new products. The Ministry of Environment, Forest and Climate Change (MoEF&CC) awarded a project in 2008 on "Development and Demonstration of Environmentally Sound Technology for Regeneration/Recovery/Recycling of Paint Sludge" to the National Productivity Council, New Delhi and Maharani Paints Pvt. Ltd., Faridabad. A pilot recycling facility was setup for assessing technical and economic feasibility of converting paint sludge to recycled primer. Paint sludge samples were collected from different large-scale automobile units to undertake research and development work so as to meet quality criteria. The developed product was given to industries for undertaking quality tests on their own and the same was found to be in line with industry requirement. The results of the pilot study showed several benefits of the regeneration process including reduction in landfill waste, decline in energy consumption, avoided CO_2 emissions and waste load reduction. Apart from these environmental benefits, it was also found that the business model followed by recyclers for paint sludge regeneration was self-sustaining with a decent profit margin. The analysis of all the results clearly demonstrated that the project was technically feasible, environmentally sound and economically viable (MoEF&CC, 2009).

4.1.2 International Examples

Table 4.1 presents examples of resource efficient practices from the international context that clearly illustrate that resource efficiency can be achieved in more than one way.

Table 4.1: International examples of resource efficient practices in the automotive sector

Category	Specific Intervention
Design to dematerialise	The United States Environment Protection Agency (USEPA) and the automotive industry have jointly agreed on an initiative to cut down on the copper usage in brake pads to less than 5% by 2021 and less than 0.5% by 2025. The initiative also aims at reducing other metals like mercury, lead, cadmium, etc. from brake pads (USEPA, 2015). The i3 (in the i-series cars) by BMW runs on electric power alone, with a range of 130-160 km (81-99 miles) in everyday driving conditions when fully charged. i3's architecture is based on an aluminium module that encompasses the powertrain, battery and chassis with a passenger cell made of a carbon-fibre-reinforced plastic (CFRP). The main benefit of the CFRP is that it reduces the weight of the vehicle, and has been typically used on high-cost sports cars to provide additional speed. Around 25%, by weight, of the plastic used in the interior of the car has been replaced with recycled materials or renewable raw materials. This includes leather and wood that come from sustainable sources. In the course of the research process for the i3, BMW developed a world-first commercial-grade recycling concept for CFRP components, body components and segregated production waste. Using various methods, high grade materials from the production process, and even from damaged or end-of-life vehicles are reused, and are either placed back into the vehicle production process or for other uses in other industries. In the recycling process, a distinction is drawn between dry recycling of non-resin-impregnated carbon fibre and wet recycling of resin-impregnated components. Dry carbon offcuts from the production process can be reprocessed into high-grade non-woven fabrics and reused in the production manufacturing cycle. Indeed, this secondary material already accounts for around 10% of the carbon fibre used in the i3. For the recycling of resin-impregnated carbon-fibres, CFRP is first separated industrially from the other plastics and processed in a pyrolysis facility. The process heat from the breakdown of resins is used to separate the undamaged carbon fibres. These fibres can then be used to manufacture new components, thereby reducing the consumption of new fibre. For example, the rear seat pan is made from this recycled carbon fibre. The short or cut fibres can be used in the textiles or electronics industries (BMW Group, 2015).

Category	Specific Intervention
	Under an initiative of Volkswagen, sheets of steel are cut and heated to a temperature of above 900°C. The heated sheets are then placed in a forming liquid where towards the end of the process it changes into high strength steel at a temperature of about 180°C. The manufacturing process of steel is now shifted inside the gates of the company instead of the previous sheet manufacturer. Since the steel that is manufactured is light weight and has high strength, the overall weight of the vehicles and the material consumption is reduced. The vehicle used in this process is 100 kg lighter than the earlier model and a net 23 kg of resources are saved per vehicle. In addition to other models, this intervention was brought in the 'SEAT' model of passenger cars. In 2014, the production number for this model was 394,860. If 23 kg of steel was saved per vehicle in the production process on account of this intervention, then the estimated total savings of steel due to this intervention alone would be 9,081.78 tonnes for this model of passenger car in the year 2014 (Volkswagen, 2015a). Volkswagen has also started using a new process for gearbox manufacturing which saves a lot of resources, primarily steel. Daily, 30,000 gears are produced in the Kessel plant using this technology (Volkswagen, 2013). A type of generator that does not use any rare earth metals (neodymium and dysprosium) were incorporated by Honda in the motorcycles VFR800F and VFR800X launched in 2014 (Honda, 2015). At Hyundai, a significant weight reduction was achieved by using steel shafts that were made using hollow casting methods. Weight reductions between 10% and 30% using existing materials are expected from such new manufacturing technologies.
Recycling and re-use of waste	In 2015, approximately 200,000 end-of-life oil filters and approximately 180,000 end-of-life bumpers were collected and recycled by Honda. Honda Freed's splash guards and other components utilised the recycled bumpers (Honda, 2015). In order to improve aluminum yield by recycling and re-use of waste in the production process, Toyota undertook a two stage approach. In 2010, the first stage aimed to reduce the coolant contamination from 12% to less than 2%. For this, a centrifugal coolant recycling system to wash and then dry the contaminated swarf was implemented. This process was able to recover an additional 10% of coolant waste. In 2011, the 2nd stage was to re-melt the dry swarf safely in furnaces. For this, in order to achieve a dry swarf moisture content of less than 1%, Toyota used heat recovered from the furnace exhaust. The aluminium yield increased from 70% to 93%. In addition, aluminium deliveries were reduced by 10% and reprocessing costs dropped by 40% through resource efficiency improvements (TMC, 2012).
Design for re-valorisation	Volkswagen has dedicated special plants in Kessel, Germany and Dalian, China just to remanufacture engine and engine products so that they can be re-used/re-furbished into new components. Volkswagen also sells some of these components as spare parts. In this way, the whole process of components manufacturing – casting, foundry, machining, and so on – is bypassed and 2,000 tonnes of material savings are achieved. By the process of remanufacturing, the major savings are of steel, as most of the engine parts are made of steel. Around 70% of steel, which translates to 7,000 tonnes, is saved annually. Approximately 7.9 million engines, 2.9 million transmissions, and more than 78 million other vehicle components have been remanufactured and given a second lease of life in customer products (Volkswagen, 2013). With design focusing on dematerialising for the Honda Legend, aluminium was used for all the door skins through a technology that joins steel and aluminum ("3D Lock Seam"). With the implementation of this technology, a reduction in 11 kg was achieved in comparison to the conventional model (Honda, 2015). Toyota has initiated a program called 'battery to battery', wherein nickel from old Nickel-Hydrogen batteries used in hybrid vehicles is recovered and used in new batteries. Toyota

Category	Specific Intervention
	has established a unique system of battery collection through which it collects batteries from all over Japan. Extracting other rare earth metals from batteries has now been added to this program (TMC, 2012). To improve the recyclability of metals like steel, aluminium and copper, Toyota has made recyclability a focus in the designing phase of the vehicle itself. The vehicles are now designed in such a way that it is easy to dismantle and separate parts at the end of life. In financial year 2011, the following number of parts were remanufactured from used parts (TMC, 2012): Automatic transmission: 4,975 Power steering: 10,919 Torque converters: 4,429 At Volkswagen, the traditional polymer used in door trimmings and seat covers have been replaced by fibers of the curaua plant and plastic from PET bottles. A 30% reduction of non-renewable materials has been achieved (Volkswagen, 2013).
Training and Education Programme	The National Automotive Industry Training Board in Australia helped to integrate employees, employers, unions and educationists in a dynamic model to meet common goals such as resource efficiency in production and operations as well as meeting customer satisfaction goals. In the US state of Tennessee, Volkswagen worked with the Chattanooga State Community College to build a staff training center to train its staff on various aspects associated with the automotive sector. Similar training programmes have been seen at other auto manufacturing companies such as Mercedes with Alabama Industrial Development Training and Kia with Georgia Quick Start. The curriculum is completely focused on the automotive sector including topics such as efficient use of resources, new technological development, sustainable operations, maintaining environmentally-friendly working conditions, etc. (Jacinto, 2014). The BMW Group offers a wide range of training courses for its purchasers, employees, internal processing partners and suppliers to make them aware of the benefits of minimising wastage and adopting sustainable production processes and operations throughout the supply chain. Some of the methods adopted by the company to encourage sustainable production practices include interactive workshops, certification courses, round table and panel discussions (at the managerial level) and by encouraging research (Volkswagen, 2013). Audi launched the Vocational Training 2.0 program by using mobile applications for accessing informational materials on the automotive sector, sharing best practices and knowledge online to encourage eco-friendly production processes along with high levels of customer satisfaction (Volkswagen, 2015b).
ELV recycling (from deregistration to final disposal)	The United States recently introduced the American Mineral Security Act 2015 to identify critical minerals used in the economy to avoid supply shortages, price volatility and facilitate smooth performance of the economy (US Congress, 2015). In Taiwan, handing over the license plates to the concerned authorities meant deregistration of the vehicles. However, in order to promote recycling, the Waste Act was amended which requires the car owners to get a certificate from authorised recyclers before the vehicle can be deregistered. In Japan, vehicles are deregistered only when a notification ensuring successful dismantling of the vehicle is received from the recycling agencies.

4.2 Construction Sector

India is currently experiencing a boom in the construction sector which is fuelled by rapid urbanisation and population growth. India is poised to become the third largest construction market globally by 2018, with major construction in the residential and commercial sectors (Global Construction Perspectives and Oxford Economics, 2013). However, as established in chapter 3, this sector is highly resource and energy intensive. The material resources used for construction include sand, soil, stone and limestone. These critical resources are finite and take a long time to replenish. Since over 70% of the buildings estimated by 2030, are yet to be built (NRDC-ASCI, 2012), demand and pressure on limited stocks of these materials are expected to increase tremendously. On the other hand, it also provides tremendous opportunity to incorporate resource efficient measures in the sector and decouple resource use from economic growth.

Use of secondary raw materials is an interesting approach to achieving resource efficiency of critical building materials. Table 4.2 elaborates on the potential application of some secondary raw materials in the construction sector. Several drivers like favourable regulation, availability of appropriate technology, and suitable market mechanisms are essential to mainstream the use of these raw materials. Initiatives taken by India and other countries offer lessons for improving the resource efficiency in this sector by way of utilising secondary raw materials.

Table 4.2: Secondary raw materials and their potential uses in the construction sector

Primary Resource	Secondary Raw Material	Source	Application
Soil	Fly ash Industrial wastes like marble sludge	Thermal power plants Industries	Fly ash bricks Alternates / waste based bricks
Stone	Demolition waste	C&D waste	Recycled aggregate Replacement in asphalt mixtures, Portland cement concrete.
Sand	Demolition waste Natural stone	Construction Sites Quarry	M-sand
Limestone	Crushed limestone Calcined clay Fly ash Slag	Low quality limestone Overburden from clay mines Thermal power plants Sponge iron Industries	Blended cements

4.2.1 Regulation

The Government of India has been promoting the use of secondary raw materials in the construction sector by introducing policies and regulations. One of the most commendable policies is the **Fly Ash Notification (S.O. 763 (E))** issued by MoEF&CC in 1999. It was further amended in 2003, 2007 and 2009. It places restrictions on the excavation of top soil for manufacturing of bricks and promotes the utilisation of fly ash for the same. According to the regulation, all construction agencies within a radius of 100 km from a coal or lignite based thermal power plant shall use only fly ash based products for construction. These products will have a minimum of 50% of fly ash by weight. It also stipulates that thermal power plants should provide at least 20% of dry fly ash free of charge to units manufacturing fly ash or clay fly ash bricks, blocks and tiles on a priority basis over other users. Other Central and State Government agencies and State Electricity Boards should help manufacturers by making available land, electricity and water and provide access to the ash lifting area for setting up ash based units. The notification is again being amended to increase the radius to 500 km. If the manufacturing unit is within a radius of 100 km, the cost of transportation of fly ash to the manufacturing site should be borne by the power plant. Beyond that, the cost shall be borne equally by the manufacturers and the thermal power plants.

Fly Ash Brick Technology in India

Fly ash, a waste steam produced by coal based thermal power plants, can be used for the manufacture of building materials like bricks, blocks, tiles, etc. It has been successfully been mainstreamed into brick production in India, replacing soil as the raw material. 12.27% of the total fly ash produced in 2014-15 was used for fly ash brick production in India. The major fly ash brick producing areas are Maharashtra, Chhattisgarh, West Bengal, Andhra Pradesh, Tamil Nadu, Delhi, Odisha and Bihar (CEA, 2015).

Several efforts have been made by the Government, both at national and state levels, to formulate regulations and policies promoting use of fly ash in brick making. The notification issued by the MoEF&CC in 1999 (S.O. 763 (E)) and further amended in 2003, 2007, and 2009, placed restrictions on the excavation of top soil for manufacture of bricks and promotes utilisation of fly ash for the same. All construction agencies, within a radius of 100 km from a coal or lignite based thermal power plant shall only use fly ash based products (50% of fly ash by weight) for construction. The notification is again being amended to increase the radius to 500 km. In line with the central notification, several states like Odisha, Madhya Pradesh and Bihar have also issued notifications promoting use of fly ash bricks in public construction. Further, they have been included in the Schedule of Rates of State and Central Public Works Departments and their tenders. The Bureau of Indian Standards (BIS) has issued production and performance standards for fly ash bricks. A few states also provide incentives to fly ash entrepreneurs through their industrial policies. Other initiatives and policies are focused on promoting research and development and commercial application of this technology.

The use of these materials earns green building credits in the national green building certification programme – GRIHA, which is a voluntary program. Increased market demand of these bricks due to the boom in the construction sector is seen as an opportunity by the brick manufacturers to scale up the technology. Reduced profit margins of red bricks has also helped in the adoption of fly ash bricks by brick manufacturers and construction agencies. Workshops and awareness drives organised for users and entrepreneurs have also helped disseminate the benefits of the technology.

C&D waste is also a secondary raw material that can be used in the construction sector. Realising the potential of C&D waste in increasing resource efficiency in the construction sector, several countries have developed legislative frameworks and policies to fully utilise this resource.

The **Waste Framework Directive 2008/98/EC** of the European Union sets quantitative targets for reuse of C&D waste. It states "*by 2020, the preparing for reuse, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 percent by weight*" (European Commission (DG ENV), 2011).

Flanders, Belgium introduced the use of secondary raw materials in the Flemish legal framework from 1997 onwards. They also developed a plan for C&D waste in 1995. This plan for C&D waste introduced quantitative targets for the period 1995-2000. It aimed at recovering 75% of all C&D waste generated by 2000 and prevent its generation by 25% in the medium term. 85% of the waste had to be sorted into recyclable waste, recycling residue and hazardous waste by 2000. These wastes were also to be treated to allow recovery or recycling, thereby generating less recycling residue. Apart from these quantitative targets, it also aimed at generating market demand for products developed from recycled waste. The current target for recycling of C&D waste has increased to 90%. The Flemish Government is also planning to impose material use prescriptions by developing environmental profile of construction materials (European Commission (DG ENV), 2011).

Germany's Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal, 1994, sets principles for development of waste management in order to transition to a closed loop economy. It emphasises on the prevention of waste generation rather than recycling of waste. However, recycling is more preferable to the disposal of waste, and waste should only be disposed when recycling is not possible or is too expensive (European Commission (DG ENV), 2011). The Federal Cabinet of Germany adopted the German Resource Efficiency Programme (ProgRess) in 2012. ProgRess also promotes recycling of C&D waste (Federal Ministry for the Environment, 2012).

The **Second National Plan of C&D Waste 2008-2015 of Spain** sets out the objectives of prevention, re-use, recycling, other forms of recovery, and disposal, as well as outlines the means to achieve these objectives, including the financing system. Apart from setting quantitative targets for recycling of waste, it also sets qualitative targets. Among the qualitative targets are: the reduction of waste at the source, the correct management of all hazardous waste and the closure of landfills (European Commission (DG ENV), 2011).

Ireland's National Waste Policy aimed to achieve at least 85% recycling of C&D waste by 2013. They also published Best Practice Guidelines on the Preparation of Waste Management Plans for Construction and Demolition Waste Projects in 2006. Site Waste Management Plans in England, Wales, Scotland and Ireland ensure that building materials are managed efficiently and waste is disposed of legally, and material recycling, reuse and recovery is maximised (European Commission (DG ENV), 2011).

In 2000, **Japan** introduced the **Construction Waste Recycling Law**. It specifies the responsibility of contractors in sorting and recycling the demolition waste when the total floor area of the building demolished is greater than 80 m^2. Demolition contractors are required to separate and recycle specific construction wastes such as concrete, including precast plates, asphalt, and wood building materials (Ministry of the Environment, 2000).

Increasing landfill cost has emerged as a driver for increased recycling and processing of C&D waste. Many European countries as well as Australia and Hong Kong charge high fees for disposal of waste in landfills (Edge Environment Pvt. Ltd, 2011). In addition, Flanders (Belgium) and Netherlands have prohibited landfilling of C&D waste (European Commission (DG ENV), 2011).

Countries also give due importance to **estimation of C&D waste**. The holder of an urban planning licence in **Flanders** (Belgium) will have an architect or an expert appointed by the principal write up a waste material demolition inventory when demolishing or dismantling commercial or industrial buildings and a construction volume in excess of 1,000 m^3. **Spain, Hungary and Abu Dhabi** also emphasise on keeping records of C&D waste handled (Edge Environment Pvt. Ltd, 2011).

Codes and standards for use of recycled materials also play an important role in promoting the use of materials produced from C&D waste. South Korea has separate building codes for recycled asphalt concrete aggregates, recycled concrete aggregates, and road pavements (CSE, 2013). Germany and Spain have developed guidelines for use of recycled aggregates. As per the European Committee for Standardisation (CEN) Aggregate Quality Standards, Finland has set technical quality requirements for use of C&D waste minerals in the production of aggregates. In Flanders (Belgium), the implementation order of the waste framework policy assesses the conditions of use of secondary raw material in construction. These requirements are mandatory. Other voluntary standards on construction products, and particularly secondary raw materials, also encourage the use of secondary raw materials. In Finland, the Government Decree on the Recovery of Certain Wastes in Earth Construction (591/2006) promotes recycling of waste in some constructions activities such as public roads, parking areas, sports grounds, etc. (Edge Environment Pvt. Ltd, 2011).

4.2.2 Technology and Management

Deconstruction is popular in several countries like the USA, Germany, Spain, Flanders, Hungary, etc. Controlled deconstruction is one of the most commonly used waste management practices in Germany. Windows, doors, heating systems, etc. are taken out of the building and can sometimes be reused as such, thus reusing a high percentage of materials. After deconstruction, building materials are sorted by material (bricks, concrete, wood, etc.) on site. This practice has replaced the traditional wrecking ball in Germany, Austria, Switzerland and parts of Northern Italy. Before controlled demolition is carried out, a detailed planning, including a concept for controlled demolition and disposal or recovery has to be performed. Detailed planning for deconstruction has also been introduced in Spain (European Commission (DG ENV), 2011).

Initiatives are being taken by building administrators or Resident Welfare Associations (RWA) in townships in India to collect and dispose the C&D waste. RWAs in condominiums in Gurgaon, Haryana have issued notices to home owners not to mix the C&D waste with MSW. The waste is collected in separate bins and transported to designated dumpsites by contractors[41]. Such initiatives show the increasing levels of awareness on C&D waste in India.

[41] Based on authors' survey

The Indian cement industry is one of the most efficient in the world. It has made commendable efforts to reduce its energy and resource footprint by adopting best available technologies and environmental practices. The use of blended cements like Portland Pozzolana Cement and Portland Slag Cement has become popular in the country. By-products and waste from other industries and manufacturing processes have been used to substitute clinkers to reduce the use of carbon-based raw materials. Current practices routinely replace up to 30% or more of the Ordinary Portland Cement with blended materials, most commonly fly ash. The market share of blended cements increased to 67% of the total cement produced in 2010-11, from 37% in 2000-2001 (WBCSD & IEA, 2013).

C&D Waste Management in India

Processing of C&D waste has been initiated in Delhi, Ahmedabad and Bengaluru. Different products like paver blocks, aggregates for concrete, and m-sand are produced. These products are used in the construction of buildings and other infrastructure.

Delhi has been a pioneer in the processing and recycling of C&D waste. In collaboration with the Delhi Municipal Corporation, a pilot project was developed by IL&FS Environmental Infrastructure & Services Ltd. in 2010. In the processing facility, 2,000 tonnes per day of waste is collected from three designated zones of Delhi - Karolbagh, Sadar-Paharganj and City. The C&D waste is thereafter recycled into aggregates at the waste management facility, which is in turn converted to Ready Mix Concrete (RMC), pavement blocks, kerbstones and concrete bricks. Another processing facility with a capacity of 500 tonnes per day has been commissioned at Shastri Park, New Delhi. The Ahmedabad Municipal Corporation became the second ULB after Delhi to install and operate a C&D waste recycling unit with a processing capacity of 1,000 tonnes per day. This project is running on a PPP basis with Ahmedabad Enviro Projects Ltd. since June 2014, where C&D waste is processed and recycled into aggregates. These aggregates are used to prepare finished products including paver blocks, kerbstones, concrete tiles, prefabricated structures, etc.

Besides government led PPPs, the private sector has also taken an interest in the processing of C&D waste. Rock Crystals Pvt. Ltd., a stone crushing unit in Bengaluru, took the initiative to use demolition waste materials (mainly the cement concrete portion) as raw materials for construction material production on a small scale. The demolition waste from major construction and demolition projects are brought to the operator by the generator and the waste is being processed into aggregates of 6 mm, 12 mm, 20 mm, 40 mm, GSB, and m-sand. Looking at these models, more cities have expressed an interest in C&D waste management and processing. The Municipal Corporations of Mumbai, Bengaluru and Coimbatore are in the process of initiating C&D waste management systems.

4.2.3 Market Mechanisms

Green ratings for buildings and infrastructure and ecolabels are instrumental in popularising the use of secondary raw materials. Green ratings in **Australia, Germany and United Kingdom** promote the use of C&D waste in construction. The Green Building Council of Australia has developed Green Star tools for rating buildings on sustainability. C&D waste reduction is one of the criteria for rating. The green rating tool for infrastructure by the Australian Green Infrastructure Rating Council specifies the use of low embodied materials in construction (Edge Environment Pvt. Ltd, 2011). Leadership in Energy and Environmental Design (LEED) is the US based green rating system developed by the United States Green Building Council and is one of the most prominent rating systems for green buildings in the world. The German Sustainable Building Certificate, a voluntary scheme run by the German Sustainable Building Council sets the criteria to ensure the sustainability of buildings. These criteria also include C&D waste:

- Ease of dismantling and recycling
- Construction site/construction process, establishing that the waste produced on-site should be prevented or recycled, and, if not recyclable, disposed of in a way that prevents harm to the environment

The construction industry of Germany took the initiative to reduce the amount of landfilled C&D waste by 50%. It monitors its progress against voluntary commitments and issues bi-annual reports to the authorities, showing levels of accomplishment above targets (European Commission (DG ENV), 2011).

Green Rating for Integrated Habitat Assessment (GRIHA) is a national rating system for buildings in India jointly developed by The Energy and Resources Institute (TERI) and the Ministry of New and Renewable Energy (MNRE). GRIHA is a five star rating system to rate commercial, institutional as well as residential green buildings with a built-up area ranging from 2,500 m^2 to 150,000 m^2. A set of 34 criteria categorised under various sections has been developed under GRIHA. It also looks at the use of sustainable building materials in construction, in addition to operating energy efficiency and design and siting parameters. The criteria incorporating this are (GRIHA, 2015):

- Criterion number 19: Utilisation of BIS recommended waste materials (such as fly ash, blast furnace slag, etc.) in building structure
    - Minimum 15% replacement of Ordinary Portland Cement with fly ash by weight of cement used in structural concrete
    - Minimum 40% composition of building blocks/bricks by fly ash by volume, for 100% load bearing and non-load bearing walls
    - Minimum 15% replacement of Ordinary Portland Cement with fly ash in plaster/masonry mortar
- Criterion number 20: Reduction in embodied energy of building structure
    - Demonstrate reduction in combined embodied energy of load-bearing structure and masonry walls by 10-30% below the base case

The IGBC New Buildings Rating System also encourages the use of sustainable building materials. They promote the reuse of at least 50% (by area) of the structural and/or at least 25% (by area) of the non-structural (interior) elements of the existing building. Materials with recycled content in the building should be used such that the total recycled content constitutes at least 10% of the total cost of building materials. Points are also assigned for the use of locally available materials and wood based materials (IGBC, 2014). IGBC Green Homes Rating System also rates buildings on the following criteria:

- Reuse of salvageable materials
- Use of materials with recyclable content
- Use of local materials
- Use of rapidly renewable building materials and certified wood (IGBC, 2014).

4.2.4 Research and Development

Research on the use of industrial wastes as secondary raw materials has also been instrumental in developing and mainstreaming resource efficient products and production practices in India. Several academic and research institutes, industry and civil society organisations are engaged in research to utilise wastes like pond ash, foundry waste and marble sludge in brick making. These wastes substitute soil as the raw material in bricks. Research is also being conducted to develop different blended cements like Limestone Calcined Clay Cement (LC^3). LC^3 is a blend of limestone and calcined clay. It combines the use of abundantly available low-grade kaolinite clay and 15% of limestone, with no reduction in mechanical performance. It can be produced with existing equipment and reduces the clinker content in the cement (Bishnoi et al., 2014).

These good practices should be studied in greater detail to identify possible areas of intervention in India.

Chapter 5: Conclusions and Recommendations

5.1 Automotive Sector

5.1.1 Key Conclusions

Increased access and better forms of mobility are one of the key outcomes of growth and development of any economy. It can also be argued that increased mobility will further promote economic growth and development since it connects people to jobs, markets, and services, and gives people a chance to gain equity in the political, economic, and social spheres. India's automobile sector has emerged as a key sector for the economy having extensive forward and backward linkages with other sectors contributing towards economic growth. Over the last 15 years, the sector has experienced phenomenal growth and in the coming years factors like growing population, rising aspirations of the growing middle class, increased per-capita income, access to affordable finance, etc., will make the sector all the more relevant for the Indian economy.

India is the sixth largest producer of automobiles in terms of volume and value. The country has been experiencing one of the highest motorisation growth rates in the world over the last decade. Various materials such as conventional steel, stainless steel, iron, aluminium, rubber, copper, zinc, nickel, plastics/composites, brass, lubricants, etc., are used in automobile manufacturing and the sector is one of the most resource intensive industries of all major industrial sectors in the country. A common and growing trend in the material composition is the increasing use of lightweight materials, mainly plastics and aluminium. This study estimates that the total material demand in the auto sector is expected to increase from 14.1 million tonnes (2015) to 102.1 million tonnes (2030). The highest consumption demand is expected in iron and steel (80.7 million tonnes), followed by aluminium (10.9 million tonnes), plastics and composites (8.3 million tonnes), copper (1.6 million tonnes) and zinc and nickel (0.6 million tonnes).

As India is looking at very high potential growth of the automobile sector, fostering resource efficiency in the sector thus becomes extremely important and will help to limit the risks from resource constraints and reduce environmental impacts related to the sector. Resource efficiency is also a route to achieving economic, social and environmental policy goals **more easily, more securely, and at lower cost.**

Growing competition for certain resources will create scarcities and rising prices which will affect the Indian economy, and thus calls for efficient management of resources across sectors through the entire life cycle – from extraction, transport, transformation and consumption, to the disposal of waste. Thus, when considering environmental improvements and resource efficiency, the aim should be to optimise the ecological balance sheet of products not only at the production stage but also during the use phase and end-of-life phase. To give an example, aluminium is increasingly being used in place of steel as it reduces the weight of a car, which in turn cuts fuel consumption and therefore CO_2 emissions. But the production of aluminium generates far higher CO_2 emissions than the production of steel. So if we look at the entire life cycle, the lighter aluminium vehicle starts out with a much heavier legacy of CO_2 emissions than one made of steel. However, the aluminium car offsets this ecological burden during the use phase through its lower fuel consumption, and could emerge with a net lower ecological footprint if the weight advantage over steel is fully exploited.

In a scenario of increasing competition, resource efficiency thus emerges as the central lever for sustainable value creation in the auto industry. In the last few decades, efforts have been made to reduce the environmental impacts of the auto industry in India through process and technological innovations, technology transfers, and domestic as well as collaborative R&D activities, etc., which has opened avenues for material substitution, better resource-efficient vehicular design, adoption of cleaner fuels, etc. However, preliminary investigations during the study survey reveals enormous scope for achieving higher efficiency levels. While conventional wisdom is that market forces will drive resource efficiency in the auto-industry, yet it is extremely important that a conducive policy environment is developed through informed decision-making by policy makers.

5.1.2 Recommendations

Greater recovery of secondary materials from ELVs

Use of secondary raw materials by way of reuse and recycling is a viable option for enhancing resource efficiency. One tonne of primary steel produced in a Basic Oxygen Furnace (BOF) requires 1.6 tonnes of iron ore, 0.6 tonnes of coking coal and 0.21 tonnes of steel scrap. Extraction of iron from its ore is resource intensive and estimates suggested that production of 1 tonne of iron requires 1.4 tonnes of ore, 0.5-0.65 tonnes of coke, 0.25 tonnes of limestone or dolomite, and 1.8-2 tonnes of air (OECD, 2012; OECD & IEA, 2001). Currently, 64% of the raw material constituent in an average small car by weight is iron and steel, out of which 57% is steel and 7% is iron. Recycling one ton of steel conserves 1,134 kg of iron ore, 635 kg of coal and 54.4 kg of limestone (Sakai et al., 2013). As per known reuse statistics for India, up to 70% of a vehicle is dismantled and directly reused or sold to other manufacturers (Akolkar et al., 2015); however this is not done in an economically or environmentally optimal way. It is imperative to develop a comprehensive framework for "Environmentally Sound Management" of the End-of-Life Vehicles (ELV) sector to enhance resource recovery potential in the automotive sector. The GoI has taken an initiative in this direction by framing the draft guidelines for End-of-Life vehicle management (CPCB, 2015b).

The framework should promote socially inclusive and environmentally safe methods of recycling which also allows the companies for closed loop recycling and recovery. It is well documented that current recycling methods, particularly the handling of ELVs by informal dismantlers, leads to loss of resources and leakages of hazardous constituents like glass wool, waste oils, coolants, etc. Recycling also needs a well-organised collection system and energy-efficient recovery mechanisms to supply the market with competitively-priced, high-quality secondary materials.

Improved material flow management

Material flow management, which refers to the continuous and targeted optimisation of material and energy flows, is another option for enhancing resource efficiency (Volkswagen, 2013). It helps create transparency by identifying wastage of resources (scope of improvement) that can be captured, mapped and analysed before being allocated to the relevant process steps, which can enable and support comparison of various scenarios and technologies, thereby optimising the flow of individual materials. Some of the Indian component manufacturing units have adopted principles of lean manufacturing leading to an improvement in flow of material in the production lines thereby reducing reject rate.

Increased product life

It is also important to explore ways to increase the efficiency and life of the product. Iron and steel use has steadily decreased, while plastics and aluminium has steadily increased. The decline in steel used in automobiles is due to use of better and more compact steel components in recent years, particularly the use of the high strength steel plate (High-Tensile Steel). The use of this is rapidly increasing as the means of car body weight reduction, and in some types of automobiles, it is used in more than 50% of the car body. Aluminium and plastics are valuable car components not only for their lighter weight, but also because of their inherent corrosion resistance.

The example showcases that the strategy simultaneously supports three objectives: reduction in material and energy consumption as well as reduced environmental impact. The product and component manufacturers should focus on increasing the life of the product as well as its efficiency. The automobile industry can contribute to resource efficiency by prolonging the service life of the vehicles being produced. Manufacturers should support the longevity of vehicles and its components by ensuring that they can be serviced, repaired and maintained. The extension of the lifetime of a vehicle not only reduces costs for consumers, but also helps in conserving resources and energy.

Improved design to incorporate sustainable materials

Ways should be identified to increase the use of recycled materials and reduce the use of undesirable materials like hazardous metals in automobiles. Innovative usage for recycled materials in the non-metallic portions of the vehicle, which are typically composed of virgin materials, should be explored. For example, the Ford Motor Company had a Voluntary Recycled Content Usage Policy in North America for many years, which set goals for the use of non-metallic recycled content for each vehicle. These targets were increased year by year with each new model by Ford. Under this program, recycled materials are selected for all of Ford's vehicles, whenever technically and economically feasible.

Design for Recycling (DfR) focuses on promoting efficient recycling from the production stage itself that allows easy dismantling and removal of the hazardous constituents. At the design stage of the product, optimal use of a resource should be taken into consideration that can have dual benefits such as energy conservation as well as time saving and cost reduction. The companies can invest more in improving the quality of recycled material to substitute primary material and thus conserve energy and reduce emissions. Some of the by-products or waste products could be a valuable resource for some other processes; thus re-utilising and re-using these products should be encouraged instead of disposal.

Importance of training and capacity development

It is also important to train the personnel involved in the manufacturing process about the efficient use of resources and motivate/encourage them to adopt skills and knowledge in resource efficient techniques and processes. As resource productivity is a step-wise process, the enhanced capacities of the industry personnel leads to identification of the key challenges, identification of the measures and its implementation mechanism in a phased manner.

Reducing air pollution and GHG emissions

The transport sector in India is a leading emitter of greenhouse gases and increased transportation demand will further push up GHG emissions in future. Growing reliance on personalised modes of transport, particularly in urban areas, leads to negative impacts like road congestion, deterioration in ambient air quality and sound pollution. However, over the last two decades, environmental problems caused by the transport sector has caught the attention of policy makers. During this period, various steps adopted by the central and state governments have included elimination of lead in petrol, switching to natural gas particularly in public transport fleets, and adopting Euro emissions standards for new vehicles. India's Auto Fuel Policy of 2003 identified a roadmap for vehicular emissions and fuel quality standards. India's National Action Plan on Climate Change recognised that GHG emissions from the transport sector can be reduced further by adopting measures that include increased use of public transport, increased use of biofuels, as well as improving fuel efficiency of vehicles. Since there is likely to be a substantial increase in the share of diesel run vehicles in the short to medium term, it becomes very important to implement Bharat VI emission standards earlier than the proposed timeline (Sasi, 2016). This would help in taking advantage of the fuel savings from the use of latest diesel engine technology without worsening air pollution from diesel vehicles. At the same time, a comprehensive and stringent regulatory roadmap would help the oil and automotive sectors in India have better clarity and enable faster adoption of technology (Bansal & Bandivadekar, 2013).

Developing a broader perspective on mobility

If the automotive sector is considered in a broader context, a comparison should be made between different mobility options. The most environmentally-friendly and resource-efficient mobility options are walking and cycling, followed by mass public transportation. Therefore, urban infrastructure should be developed to support these forms of mobility rather than undermining them. Infrastructure for pedestrians and cyclists, as well as dedicated mass transit corridors, needs comprehensive planning. In India's fast growing megacities, these forms of transport are often threatened and marginalised by motor vehicles and their attendant infrastructure.

5.2 Construction Sector

5.2.1 Key Conclusions

To meet the current and projected demands of construction sector, the Indian economy will require materials in huge quantities. Sand (concrete and mortar), soil (bricks), stone (aggregates), limestone (cement) and iron and steel (bars and rods), are some of the most intensively used materials for building and construction purposes. With physical and economic scarcity as well as detrimental environmental and social impacts becoming more prominent, it is important to understand the resource flows and introduce interventions to reduce strains on the limited resource base sustaining the sector. Adoption of resource efficiency highlights the link between conserving resources and recycling raw materials to meet India's future demand of resources, while simultaneously reducing costs and thus strengthening the competitiveness of industries. As one of the largest consumer of resources in the country today, the construction sector needs to urgently emphasise issues of resource efficiency.

Fertile top soil is exploited by brick kilns to produce fired clay bricks, threatening food security of the nation (as a direct consequence of reduced fertility of the land). If an end-of-life building is demolished properly, most of the bricks can be recovered and reused. Bricks which are broken or are unusable could be utilised in road construction as base material. Another point of intervention in the flow is to enhance the use of industrial wastes such as fly ash in brick making, a process already under way but with potential for further expansion.

Rampant extraction of sand for use in concrete and mortar has led to the severe degradation of rivers and river systems in many parts of the country. Banned or restricted in many states, sand extraction, usually an informal activity, is increasingly moving into the illegal space. M-sand, manufactured from natural rock is emerging as a promising alternative. Similarly, the stone quarrying industry that supplies aggregates is poorly regulated and environmentally destructive. With the increasing popularity of m-sand, granite already has an emerging competing use.

Another potential material that can be used to manufacture sand is construction and demolition waste. From the study, India is estimated to generate 716 million tonnes of C&D waste per year. Most of this waste end up in landfills or is illegally dumped in river beds or road sides. To close the resource loop, the role of C&D wastes can be explored. The properties of recycled aggregates from C&D waste have been established and demonstrated successfully through several experimental and field projects. Due to a lack of standards and awareness, the popularity of recycled aggregates is not growing among builders and contractors. Steps are being taken by the Bureau of Indian Standards (BIS) to formulate standards for the use of C&D waste-based materials in construction.

Use of secondary raw materials like C&D waste presents a win-win approach for resource efficiency. Utilising a waste or by-product eliminates the problem of waste management, especially for bulky waste that needs a lot of valuable land for disposal. Simultaneously, by reducing pressure on virgin resources, it aids in reducing environmental degradation and pollution. The Draft Solid Waste Management Rules (2015) puts emphasis on the efficient management of C&D waste and specifies responsibilities of the major stakeholders. Use of the waste as a raw material for the construction sector will also help ULBs in complying with the new rules.

Pilot facilities in Delhi and Ahmedabad have led the way in proving feasibility of C&D waste reuse in India. Metals, wood and other materials like ceramics contribute to 10% of the total C&D waste generated in India. These materials already have a high recycling rate. They are segregated and sold in the secondary market by both the formal and informal sectors. The remaining waste consists of bulky materials. Of this, about 85% can be used effectively in the construction sector. The products produced by processing these wastes would be used in non-structural applications in the near future, and thus would not replace the demand for all kinds of building materials. However, they could alleviate the pressure on resources used in the production of ancillary products like paver blocks and kerb stones. In order to ensure their widespread use, it is essential to promote their use actively among public and private stakeholders. This is currently a major concern since low awareness of its potential is hampering wider adoption.

Construction and demolition waste has a very good potential for processing into aggregates and m-sand in India. Aggregates production from natural stones such as granite and basalt has significant environmental impact, not least in terms of CO_2 emissions. It is estimated that about 20 kg of CO_2 is emitted from processing 1,000 kg of natural aggregate. Processing includes quarrying, crushing and transport of aggregates. In contrast, processing 1,000 kg of recycled aggregate (C&D waste) emits about 12 kg of CO_2 (a 40% reduction)[42]. Thus, use of 1,000 kg of recycled aggregates

[42] Processing 1,000 kg of virgin aggregates requires about 235 MJ of energy while recycled aggregates require 129 MJ of energy (USEPA, 2003). The energy was converted to electricity (for processing) and fuel (for transportation). It was assumed that all the fuel required in transport and processing is

translates to CO_2 savings of about 8 kg. Aggregate demand in concrete and road laying in India is estimated to be about 1.1 billion tonnes per annum. If all of the aggregate is replaced by C&D waste there is a potential to save about 8 million tonnes of CO_2 per annum.

Natural sand can be replaced by m-sand. However, there is almost no processing required for natural sand and it is mostly locally sourced. Hence CO_2 emissions associated with natural sand is considered negligible. But sand mining has huge ecological impacts on rivers. Rampant mining has also led to its scarcity in many regions, which also has serious social and economic impacts in India. These impacts dwarf concerns about the CO_2 footprint from sand mining. M-sand is an alternative to natural sand, which is now being increasingly adopted in some states of India. It is made from natural stones such as granite. The CO_2 emissions associated with m-sand processing are believed to be more than that from production of aggregates from natural stones. This is because for production of m-sand, stones are crushed to finer particle sizes, which requires more fuel or electricity. If m-sand is produced using C&D waste, CO_2 savings of about 8 kg per 1,000 kg of C&D waste utilised can be achieved.

5.2.2 Recommendations

In order to promote resource efficiency in the construction sector through the use of secondary raw materials, policy and market decision makers should be informed about various available options and models of resource efficiency to create a complete ecosystem. The following measures need to be implemented to promote effective and widespread utilisation of C&D waste in the construction sector.

Accurate inventorisation of C&D waste

One of the first things that need to be addressed in terms of usage of secondary raw materials is to assess and estimate the quantum of waste generated. While the study conducted throws some light on the magnitude of the issues, a more detailed quantification and characterisation is required to better plan an effective waste management strategy. For effective inventorisation, the point of origin as categorised in the draft SWM Rules, 2015 should be considered as the starting point. Therefore, it is recommended that it should be mandatory for every demolition and renovation/retrofitting activity to take a permit from the respective urban local body (ULB). The permit shall necessarily include:

- Details of owner(s) of property
- Covered (built-up) area and site plan of the building being demolished/renovated/retrofitted
- Estimated quantum of C&D waste generated (at the time of issue of permit)
- C&D waste management plan
- Authorised demolition and transport contractor (authorisation given by ULB)
- Quantum of C&D waste picked up by authorised transport contractor (at the time of resubmission of permit to ULB)

The permit shall be resubmitted to the respective ULB after the building is demolished. The permit shall contain time clause for return of the permit. Suitable penalty clauses shall be included in case of non-compliance. The Draft Solid Waste Management Rules, 2015 provides a format for authorisation of a C&D waste processing facility, but there is no format of authorisation for generation of C&D waste. Such a permitting system will enable ULBs to create a comprehensive and

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diesel. CO_2 emission factor of electricity was taken as 0.8 tCO_2/MWh (CEA, 2014) and CO_2 emission factor for diesel was calculated as 3.16 tCO_2/Tonne of fuel (IPCC, 2006). Conversion factors used: 1 BTU = 0.001 MJ; 1 MJ = 0.27 kWh.

accurate inventory of C&D waste generation. Large infrastructure projects undertaken by public bodies such as PWD should also be covered under the system.

Building capacities of ULBs

The responsibility of managing waste including C&D waste is with the ULB. Thus it is important that ULB officials have the technical and managerial capacity to perform effective waste management. This is currently a gap due to the lack of easy access to tools, methodologies and technologies that can aid this process. It is recommended that every ULB should have a designated task force for C&D waste management. Ideally, such a task force should have representation from the ULB, expert institutions, local NGOs, as well as the SPCB. One aspect of future work can be the development of an easy-to-use guide for the taskforce to estimate and plan for the C&D waste generated. Good practice guidelines and manuals for the entire life cycle of waste management ranging from estimation, collection, segregation, processing and final disposal for C&D waste should be developed and shared with the ULBs.

Technical support to new entrepreneurs

Another hurdle faced in the effective use of secondary material streams like C&D waste is the availability and accessibility to appropriate technologies. There is often a knowledge gap about information on technology and service providers, business potential and challenges and success stories for setting up a facility. Furthermore, if such technologies are imported, as is often the case, there may not be adequate in-house capacity to operate, manage and troubleshooting. This lack of technical support often deters entrepreneurs from engaging in waste management ventures. Technical support to new entrepreneurs from the current processing units will encourage more entrepreneurs to engage in processing of C&D waste.

Building a business case for private entrepreneurs

Weak business models due to uncertainty in the supply of raw material and limited market penetration of the processed product are other barriers entrepreneurs face. Test results from this study (see GIZ, 2015b) show that paving blocks made with C&D waste from Ahmedabad and Bengaluru fulfil the properties of compressive strength (as per BIS 15658:2006) for non-traffic, light-traffic and even medium-traffic uses. In addition, they also offer cost reductions ranging from 19-33% depending on the availability of C&D waste. Thus, it can be an economically viable business for small entrepreneurs. However, potential entrepreneurs should be made aware of the technical and economic viability of the enterprises through IEC activities such as seminars, workshops, one-to-one interactions, advertisements and trade publications.

Large-scale awareness and sensitisation of users

Lack of familiarity with the products and hence inadequate confidence about their quality are obstacles for potential users. The general perception associating with a product made from waste is with regard to quality issues, especially when compared to those using virgin resources. This needs to be broken through large-scale awareness efforts as well as standardisation and certification. It is recommended that demonstration projects should be implemented and properly advertised to sensitise users about products made from secondary materials, especially architects, developers and contactors.

Developing favourable policies for products made from secondary materials

Codes and standards that ensure products meet quality standards will go a long way in building user confidence in the product. BIS codes should be supported by preferential procurement of products made from secondary materials. This can be done through amendments in tenders issued by public enterprises in the construction sector.

Furthermore, incentivising the market, as has been done for fly ash based bricks through preferential procurement policy, will help overcome initial market barriers. Even with current levels of C&D waste generation, there is scope for multiple reprocessing SMEs to come up in each city, ranging from 400 in Delhi to 10 in Coimbatore (for SME calculations, see GIZ, 2015b; p. 45).

However in order to safeguard the interests of these SMEs, it is essential to create a favourable policy environment wherein technology, economic and capacity concerns are dealt with. Advocating lessons from demonstrations and studies on the ground with decision makers in the public and private sectors will encourage them to explore, understand, assess and promote good practices that gradually become mainstream.

5.3 Future Outlook

The trends facing India, as outlined in Chapter 1, clearly demonstrate that India cannot afford to ignore the question of resource efficiency. On one hand, India is confronted with population growth, rapid urbanisation, and rising income leading to increasing demand from consumers and industry, while on the other, resource extraction, use and disposal is leading to land degradation, biodiversity loss, air and water pollution, as well as GHG emissions contributing to climate change. Further, provision of a stable resource supply to meet rapidly rising demand has been a challenge, giving rise to price shocks, shortages, black markets and illegal mining, and high import dependence, at least for some materials. All these trends are expected to worsen in future absent corrective action, and will severely hinder India's efforts to promote balanced and inclusive growth to improve living standards, improve infrastructure, and create macroeconomic stability.

Therefore, a farsighted and comprehensive resource policy is essential for India going forward in order to meet social, economic and environmental sustainability goals. The lessons coming out from the analysis of the two sectors in this report – automotive and construction – can be extended and applied to the wider economy as well. This is the broader goal of the Indian Resource Panel, set up under the project, as referred to in Chapter 1. A comprehensive resource policy would need to:

a) Involve a wide range of stakeholders, starting from coordination between different government ministries such as mining, transportation, heavy industry, etc., as well as between different levels of government including state and local, to research and standard setting organisations, to the private sector, and finally civil society.

b) Encompass the entire life cycle of resources – from extraction, to transportation, processing, manufacturing, use, disposal as well as recycling/reuse.

c) Emphasise education, awareness, outreach and capacity development at all levels – government, the private sector and civil society – with a special focus on green marketing.

Experience from other countries that have seriously embarked on promoting resource efficiency shows that such strategies, in addition to benefitting the environment, have tangible economic benefits in terms of competitiveness, protection from shocks and macroeconomic stability.

Moreover, a circular economy model is typically better in terms of employment generation, a prime concern for all governments. In India, like in many other developing countries, resource recycling in many sectors is often dominated by the informal sector that achieves surprising levels of efficiency and enormous livelihood generation potential. Working with the informal sector to address the many challenges it faces should be the underlying approach of any resource efficiency strategy in India.

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Annexures

Annex 1: Sand in States of India

S No	State/UT	Resource Information
1	Kerala	Minable sand available per year: 0.05 million tonnes (Government of Kerala, 2015) (sand above summer water level) Though the figure represent only 11 rivers. Out of these 11 rivers a total ban on of sand mining in 6 rivers has been imposed as the mineable sand above summer water level was found to be NIL. Demand: 0.06 million tonnes (Only for rail projects in Kerala in 3 years) (METSO, 2012)
2	Andhra Pradesh	Available Quantity in stock yards: 4.31 million tonnes ; Sand Sold: 2.02 million tonnes (Government of Andhra Pradesh, 2015)
3	Telangana	Available Quantity in stock yards: 0.02 million tonnes Sand Booked for purchase: 0.35 million tonnes (Government of Telangana, 2015)
4	Chattisgarh	Sand Available in legal leases: 2.06 million tonnes[43] Demand of sand: NA
5	Karnataka	Demand of sand in state : 28 million tonnes Supply: 7-8 million tonnes (Ashwini, 2015)
6	Goa	A total of 33 sand mining sites in the state have been identified. Studies are underway to put a cap on annual extraction of sand from these sites (Shaikh, 2015) Demand and supply data is not available for the state.
7	Maharashtra	Sand Mining approval and Tracking System (SMATS) Launched by Revenue Department to track and legalise sand mining in the state. Sand can be ordered by contractors using mobile via this system.
8	Odisha	Mahima Group is the biggest river sand supplier in Odisha. The maximum supply capacity claimed is 0.14 million tonnes per year (Mahima Group, 2015). Demand of sand is not available for the state.
9	Gujarat	769 sand mines given environmental clearance by SEIAA, Gujarat in 2015 (SEIAA, Gujarat, 2015). Demand and Supply information not available for state
10	Bihar	NA
11	Haryana	Total legal mining leases 31
12	Jammu and Kashmir	Total legal mining leases 650
13	Punjab	Total legal mining leases 155

[43] Collated from total Environmental Clearance Granted by SEIAA Chattisgarh in 2014-2015

S No	State/UT	Resource Information
14	Jharkhand	Total legal mining leases 397
15	Sikkim	Total legal mining leases 85
16	Tripura	Total legal mining leases 270
17	Chandigarh	NA
18	Himachal Pradesh	NA
19	Manipur	No legal mine leases
20	Meghalaya	No legal mine leases
21	Mizoram	NA
22	Nagaland	NA
23	Rajasthan	NA
24	Uttar Pradesh	NA
25	Lakshwadeep	Total legal sand mine leases 1,090
26	Madhya Pradesh	NA
27	Puducherry	NA
28	West Bengal	NA
29	NCT of Delhi	NA
30	Dadra Nagar Haveli	NA
31	Assam	NA
32	Andaman & Nicobar	No legal sand mining lease
33	Daman & Diu	NA
34	Tamil Nadu	NA
35	Uttarakhand	NA

Data on legal sand mining leases obtained from Sustainable Sand Mining Management Guideline (MoEF&CC, 2015)

NA=Not Available

Annex 2: Calculations

Sand in Mortar Calculations

S No	Particulars	Value	Unit
1	Size of 1 brick	230*110*76	mm^3
2	Space between two bricks	10	mm
3	Volume of 1 brick	1,922,800	mm^3
4	Volume of mortar for 1 brick((10*76*110)+(230*10*110))*2	673,200	mm^3
5	Cement to Sand ratio in Mortar	1 to 6	
6	Sand in Mortar for 1 brick (Vol of mortar for 1 brick/7)*6	577,028.57	mm^3
7	In cubic metres	0.00057	m^3
8	Density of Dry Sand	1,640	kg/m^3
9	Sand in Mortar for 1 brick (8*7)	0.9348	kg
10	Total Bricks produced 1 Annum in India	260	billion
	Total sand required for mortar (9*10)	243.048	billion kg
		0.243048	billion tonnes
		243.048	million tonnes

Materials in C&D Waste Calculations (all quantities in million tonnes)

Components of waste	C&D waste composition (TIFAC, 2001)	Total Annual C&D Waste generation (GIZ, 2015b)	Waste fraction /Annum	Soil	Sand	Stone	Lime stone	Steel Scrap
Soil, Sand & Gravel[1]	36%	716	256	26	77	154		
Bricks & Masonry[2]	31%	716	220	188	30		3	
Concrete	23%	716	167		47	100	32	
Metals	5%	716	36					29
Wood	2%	716	15					
Others	3%	716	22					
Total				213	153	254	35	29

Assumptions:

[1]Soil assumed as 10%, Sand assumed as 30% and Gravel Assumed as 60% in Mixture

[2] Bricks assumed to be 90% and Masonry assumed to be 10%

Bricks: Soil content in brick assumed to be 95% and sand content assumed to be 5%

Masonry: Sand content assumed to be 90% and Cement assumed to be 10%

Concrete: Sand Content assumed to be 28%, Stone assumed to be 60%, Cement assumed to be 12%

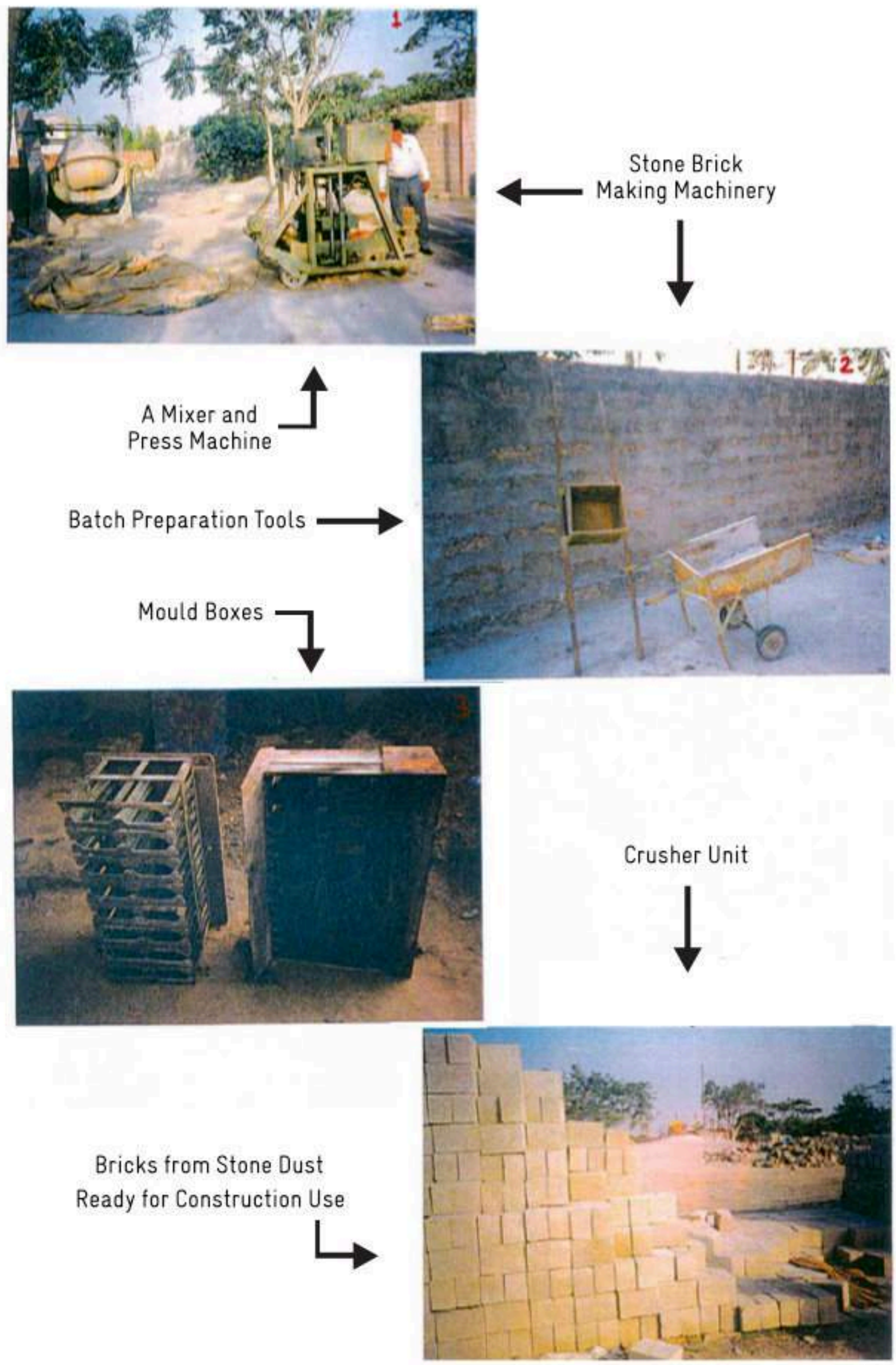
Metals: Assuming 80% of metal is Iron and Steel

Cement to Limestone ratio taken to be 1:1.6 i.e. for 1 tonne Cement, 1.6 tonnes of Limestone is required

Annex 3: Types of Stone and their Uses

S No	Stone Type	Type of rock	Uses
1	Marble	Metamorphic	Sculptures Landscaping Exterior and interior cladding Flooring in the forms of tiles Furniture in the forms of table tops, benches, etc. Temples and palaces As white pigment or filler in products such as toothpaste or paints
2	Granite	Igneous	Coarse aggregate for concrete mixing Exterior and interior cladding Flooring in the forms of tiles Sculptures Landscaping Furniture Monuments
3	Sandstone	Sedimentary	Sculptures Landscaping Flooring in the forms of tiles, cobbles, pebbles Exterior and interior cladding Furniture Extensively used as road metal
4	Dimensional Limestone	Sedimentary	Crushed for use as aggregate in the base for many roads as well as in asphalt concrete Flooring, wall cladding, pavings and facade Sculptures
5	Slate	Metamorphic	Exterior and interior flooring, stairs, walkways and wall cladding Used for laboratory bench tops and for billiard table tops Extensively used for blackboards and individual writing slates for which slate or chalk pencils were used
6	Basalt	Igneous	Railway ballast Coarse aggregate for concrete mixing
7	Laterite	Sedimentary	Dimensional stone As road metal As additive in cement industry

Annex 4: Stone Dust Brick Manufacturing



(Source: CPCB, 2009)

Annex 5: Category-wise Production of Finished Steel Products in India

In 2014-2015 (April-December)

S No	Category of Steel product	Production (million tonnes)
	Non-Alloy, Non-Flat Finished Steel	
1	Bars & Rods	22.899
2	Structurals	5.107
3	Railway Materials	0.627
4	Total Non - Flat (1 to 3)	28.633
	Non-Alloy Flat Finished Steel	
5	Plates	3.031
6	Hot Rolled Coils / Skelp	13.713
7	Hot Rolled Sheets	0.509
8	Cold Rolled Sheets / Coils	6.17
9	Galvanized Plain / Galvanized Corrugated Sheets	5.192
10	Electrical Sheets	0.114
11	Tinplate	0.211
12	Tin Mill Black Plate	0.004
13	Pipes (Large Diameter)	1.525
14	Tin free Steel	0.012
15	Total Flat (4 to 13)	30.481
16	Total Non - Alloy Finished Steel	59.114
17	Total Alloy Finished Steel	6.083
18	Total Finished Steel	65.197

(Source: Ministry of Steel, 2015b)

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