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Circulation Economics: Dynamic Material Flow Analysis Of Metal Trade In India

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ABSTRACT: *Natural resources play a vital part in a country's development process. Without the use of natural resources, industrialization is practically impossible in any country. The social and economic development of a nation depends on its capacity to utilize its natural resources, avoiding its wasteful use to the extent possible. With globalization increasing at an ever increasing rate, the extraction and production of natural resources do not necessarily mirror the resources' use within a particular country's national boundaries. Some countries have ample resources, which they extract and export; others rely heavily on imports of raw materials and products to satisfy consumer demand. Geographic heterogeneities and differences in the operational costs of extraction and processing of metal ores have led to large net trade imports and exports. This paper assesses the importance of dynamic material flow analysis in the metal trade sector in India. A material flow analysis of copper trade in the country for the financial year 2011-12 has also been carried out as a part of this project. Further, the various issues and challenges faced during the material flow analysis of the metal trade sector in India have also been discussed.*

I. INTRODUCTION

Natural resources play a vital part in a country's development process. Without the use of natural resources, industrialization is practically impossible in any country. The social and economic development of a nation depends on its capacity to utilize its natural resources, avoiding its wasteful use to the extent possible.India, a developing country, is sufficiently rich in natural resources which provide the country with a strong industrial base. The country is particularly rich in the metallic minerals of the ferrous group such as iron ores, manganese, chromites and titanium. It has the world's largest reserve in mica and bauxite. The reserves of petroleum and some non-ferrous metallic minerals especially copper, lead, zinc, tin, however, are inadequate. India fulfils internal demands for these minerals by importing them from other countries.Even though India continues to be largely self sufficient in minerals which constitute primary mineral raw material to industries like iron ore, ferro alloys, aluminium, cement, etc. and mineral fuels like coal (except low ash coking coal) etc., its value of imports still far exceeds its production. Exploitation of natural resources is a condition essential for humanity to exist. The exploitation of nature has been done mostly in a non-sustainable way, which is causing an increasing concern, as a non-sustainable exploitation of natural resource ultimately threatens the human existence. The continued growth of1 the human population has been argued to be the greatest threat to environment. The basis for this argument is that population affects many environmental issues such as the use of natural resources, the amount of waste pumped into the environment daily, the reduction of species habitat and the decimation of species through hunting and fishing among others.

The social, political, and economic importance of efficiently extracting and safely transporting natural resources cannot be underestimated. State, military, and geopolitical power, capital accumulation, social stability, industrial production, and the legitimacy of the state and economy all depend on large, increasing, and ever more concentrated withdrawals of natural resources from the earth (Bunker & Ciccantell, 2005; Gould, Pellow, & Schnaiberg, 2008; Klare, 2001, 2004; O'Connor, 1996 ;Schnaiberg & Gould, 2000). Moreover, because natural resources are the ultimate source of all the energy and goods we produce, consume, and throw away, natural resource extraction harms the environment not only at the "point of extraction" but globally as well. Computer production, for example, could not occur without the extraction of minerals, fossil fuels, and other natural resources from around the world. Computers also harm the environment during the production, assembly, consumer use, shipping, disposal, and recycling stages of their lives and thus affect the environment and human health around the world. Environmental impacts during these stages of a computer's life include abiotic depletion, global warming, the release of toxins into the environment, human exposure to highly toxic materials, acidification, ozone depletion, the formation of photoxidants, and water eutrophication (Choi, Shin, Lee, & Hur, 2006). Because computing power is so critical to globalization and economic growth, computer use also helps foster environmental problems associated with these phenomena. This is true, of course, of all the products we use and produce, including weapons systems, automobiles, solar panels, and cell phones. Thus, resource extraction is a pivotal link in the chain connecting human activity and social organization to environmental degradation.

Material Flow Analysis

"Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time." *-Brunner and Rechberger, 2004* With globalization increasing at an ever increasing rate, the extraction and production of natural resources do not necessarily mirror the resources' use within a particular country's national boundaries. Some countries have ample resources, which they extract and export; others rely heavily on imports of raw materials and products to satisfy consumer demand. Geographic heterogeneities and differences in the operational costs of extraction and processing of metal ores have led to large net trade imports and exports. These specializations have likely fueled greater efficiencies and lower prices due to economies of scale, whereas the trade imbalances have the consequence of outsourcing environmental harm, decreasing self-sufficiency, and localizing stock accumulation in the importing countries.

Resource Self-Sufficiency

With the current global economy largely being efficient and stable, international resource and manufacturing disparities in production are of little concern for issues relating to national security and may actually lead to lower cost of production. Times of war and intra-country strife can, however, upset this balance and lead to dramatic price spikes and temporary shortages. Anecdotal evidence points to a need for concern regarding heavy trade reliance for strategic materials. In 1978, for example, the Katangese rebellion in Zaire severely disrupted the availability of cobalt, a material important for its use in high-temperature applications, including aerospace and defense. Between 1977 and 1979, prices skyrocketed from $11 per kilogram to $51 per kilogram (Gabler 1994). Although demand also increased over this time period, most of this price increase is attributed to the effect of foreign instability. (*Jeremiah Johnson and T. E. Graedel)*

Motivation for MFA

- The demand for natural resources has been increasing steadily over the last decades, resulting from both the growing consumption in the established developed nations of the West and the economic growth of the developing nations
- Disposal of the materials employed increases to a scale where unwanted impacts on environment and society cannot be neglected anymore, neither locally nor globally.
- Material flows represent the core of local environmental problems such as leaching from landfills or oil spills.
- Rising concern about global climate change put a previously unimportant waste flow, carbon dioxide, on the top of the political and scientific agenda.
- The gradual shift from traditional to urban mining in developed countries requires a detailed assessment of in-use and obsolete stocks of materials within the human environment.
- Industries, government bodies, and other organisations therefore need a tool to complement economic accounting with systematic book-keeping of materials entering, staying, and leaving the anthroposphere.

Why is MFA needed?

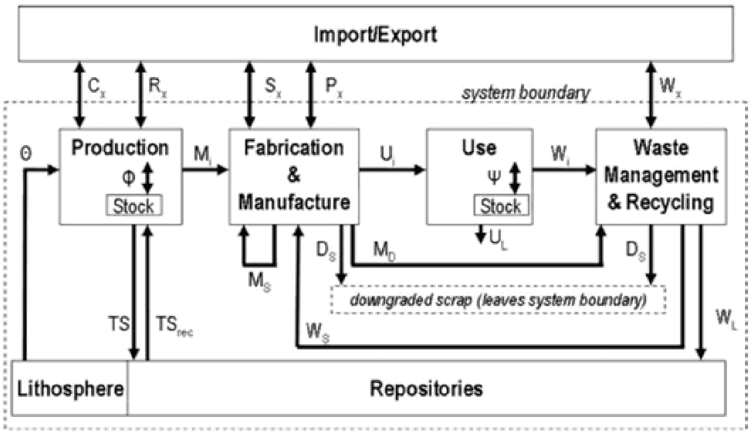
- Delineate system of material flows and stocks.
- Reduce system complexity while maintaining basis for decision-making.
- Assess relevant flows and stocks quantitatively, checking mass balance, sensitivities, and uncertainties
- Present system results in reproducible, understandable, transparent fashion.
- Use results as a basis for managing resources, the environment, and wastes

– Monitor accumulation or depletion of stocks, future environmental loadings.
– Design of environmentally-beneficial goods, processes and systems.

Objective of this paper is to assess the Indian trade of Copper (Cu) in all its forms, from ore through finished products and then as scrap for the year 2011-12 and review the aspect of material flow analysis in the Indian metal trade scenario.

II. METHODOLOGY

- Material flow analysis (MFA) tracks substances through their entire life cycles, in turn quantifying their stocks and flows.
- Biogeochemical cycles (e.g., the carbon cycle) are more widely known, but anthropogenic cycles are considered essential for the numerous elements that are mobilized in a greater amount by human activity.
- MFA studies are structured around a system boundary diagram, which determines which flows are included in the study and which are extraneous.



Θ	Ore mined	U_i	Flow into use
C_x	Ore and concentrate export	W_i	Flow into waste management and recycling
R_x	Refined metal export	M_s	New scrap
S_x	Semimanufactured goods export	M_D	Industrial discards
P_x	Finished products export	D_s	Downgraded scrap
W_x	Scrap export	Ψ	Flow into in-use stock
TS	Tailings and slag losses	W_s	Old scrap
TS_{rec}	Reclaimed tailings and slag	U_L	Dissipative losses during use
Φ	Flow into production and government stock	W_L	Flow into landfills or environment
M_i	Flow into fabrication and manufacture		

Figure 2.1: *A simplified diagram of a technological resource cycle, with successive life stages plotted from left to right. (Source: STAF, Yale University)*

The diagram shows the general system boundary diagram employed by The Stocks and Flows (STAF) project at Yale University, which is anchored by four life stages: production, fabrication and manufacture (F&M), use, and waste management and recycling.

- Production involves primary processing, including mining, milling, smelting, and refining.
- Fabrication & Manufacturing involves transforming the refined metal into semi-manufactured and finished products.
- The Use Life Cycle stage is where the product is employed, whether it is in the hands of a consumer or in an industrial application.
- Waste management and recycling are end-of-life processes.
- There are several opportunities for the material to return to earlier life stages through recycling and remanufacture.
- On all spatial scales except global-level cycles, import and export can occur

III. LITERATURE REVIEW

3.1 MFA & Economic Aspects

Jeremiah Johnson and Thomas Graedel, in their paper, *"The "Hidden" Trade of Metals in the United States"*, concluded that a comprehensive analysis for the United States for copper, lead, zinc, chromium, and silver, in which all trade flows are included, demonstrates that MTP flows can often be a large factor in determining a country's import/export dependence, accounting for between 13% (zinc) and 57% (silver) of traded metal in all forms.

In the paper, *"The Multilevel Cycle of Anthropogenic Zinc"*, Graedel et al. carried out a comprehensive annual cycle for stocks and flows of zinc, based on data from circa 1994 and incorporating information on extraction, processing, fabrication, use, discard, recycling, and land filling, at three discrete governmental unit levels—54 countries and 1 country group (which together comprise essentially all global anthropogenic zinc stocks and flows), nine world regions, and the planet as a whole. A "best estimate" global zinc cycle was constructed to resolve aggregation discrepancies. Among the most interesting results are the following:

(1) The accumulation ratio, that is, addition to in-use stock as a function of zinc entering use, is positive and large (2/3 of zinc entering use is added to stock) (country, regional, and global levels); (2) secondary input ratios (fractions of input to fabrication that are from recycled zinc) and domestic recycling percentages (fractions of discarded zinc that are recycled) differ among regions by as much as a factor of six (regional level); (3) worldwide, about 40% of the zinc that was discarded in various forms was recovered and reused or recycled (global level); (4) zinc cycles can usefully be characterized by a set of ratios, including, notably, the utilization efficiency (the ratio of manufacturing waste to manufacturing output: 0.090) and the prompt scrap ratio (new scrap as a fraction of manufacturing input: 0.070) (global level). Because capturable discards are a significant fraction of primary zinc inputs, if a larger proportion of discards were recaptured, extraction requirements would decrease significantly (global level). The results provide a framework for complementary studies in resource stocks, industrial resource utilization, energy consumption, waste management, industrial economics, and environmental impacts.

At the 31st International Conference of the System Dynamics Society held at Cambridge, Massachusetts, USA in July 2013, Simon Glöser, Marcel Soulier, Luis Tercero Espinoza and Martin Faulstich presented a paper on using Dynamic Stock & Flow Models for Global and Regional Material and Substance Flow Analysis in the Field of Industrial Ecology taking the example of a Global Copper Flow Model. Using the example of a global copper flow model, the authors present the potential outcomes of dynamic metal cycles including the results of a stochastic uncertainty analysis of the recycling efficiency of postconsumer copper scrap. In conclusion, they discuss the potential to enhance the material flow models and to link these cycles with further system dynamics models.

3.2 Material Flow Analysis of Copper Trade in India (2011-12)

3.2.1 Copper

Copper is a very important element and the oldest known commodity in the world that directly affects the world's economy. Copper is a malleable and ductile metallic element that is an excellent conductor of heat and electricity as well as being corrosion resistant and antimicrobial. It is found in sulfide deposits (as chalcopyrite, bornite, chalcocite, covellite), in carbonate deposits (as azurite and malachite), in silicate deposits (as chrysycolla and dioptase) and as pure "native" copper. Regardless of competition from substitutes like iron, aluminum, plastic & fibre, copper's chemical, physical and aesthetic properties make it a material of choice in a wide range of domestic, industrial and high technology applications. Copper is a critical metal being used in areas such as defence, space programme, railways, power cables, mint, electronics & communications, auto ancillaries etc.

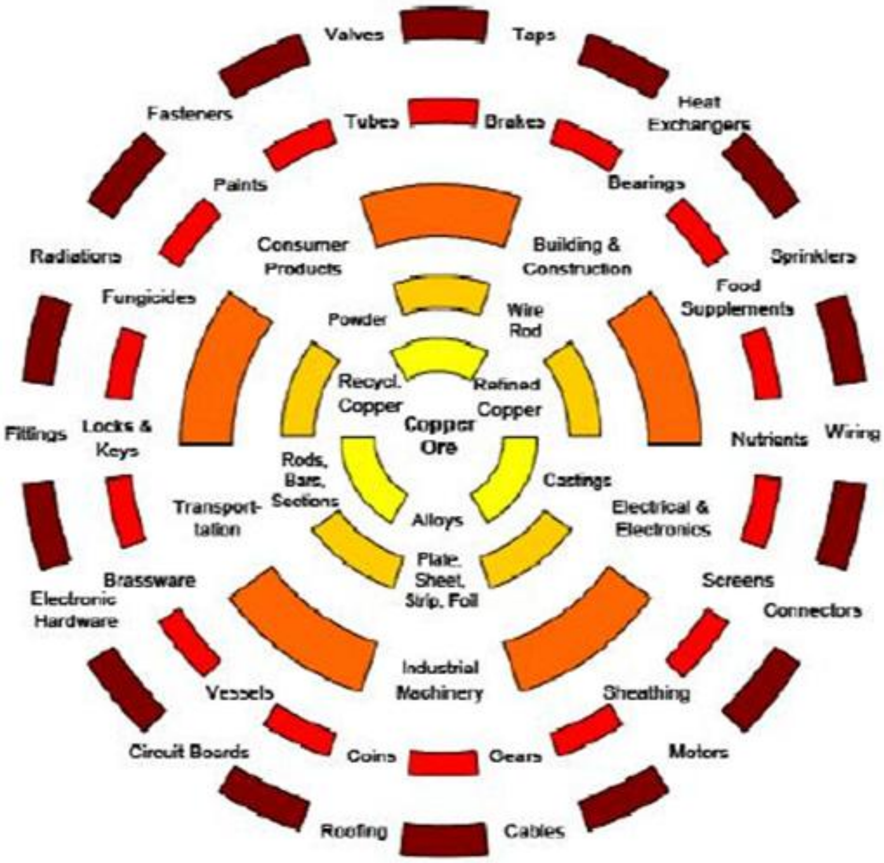
At present, the demand for copper minerals for primary copper production is met through two sources i.e. Copper ore mined from indigenous mines and imported concentrates. The indigenous mining activity among the primary copper producers is limited to only Hindustan Copper Limited (HCL). The other primary copper producers in the private sector import the required mineral in the form of concentrate.

Till 1997, the only producer of primary refined copper was Hindustan Copper Limited (HCL), a public sector enterprise under the Ministry of Mines. The installed capacity for refined copper production at its two integrated copper plants was around 47,500 tonne per year, which used to meet approximately 25-30% of India's requirement for refined copper. The balance demand was met through imports. However, the scenario has changed drastically after coming of the other two primary producers of Copper in private sector namely M/s Hindalco Ind. Ltd. (Unit: Birla Copper) and M/s. Sterlite Industries (I) Ltd. Their present annual capacities are 5,00,000 MT and 4,00,000 MT of refined copper respectively. The plants of M/s Hindalco Ind. Ltd. (Unit: Birla Copper) and M/s Sterlite Industries (I) Ltd. are based on imported copper concentrate.

3.2.1.1Uses of Copper

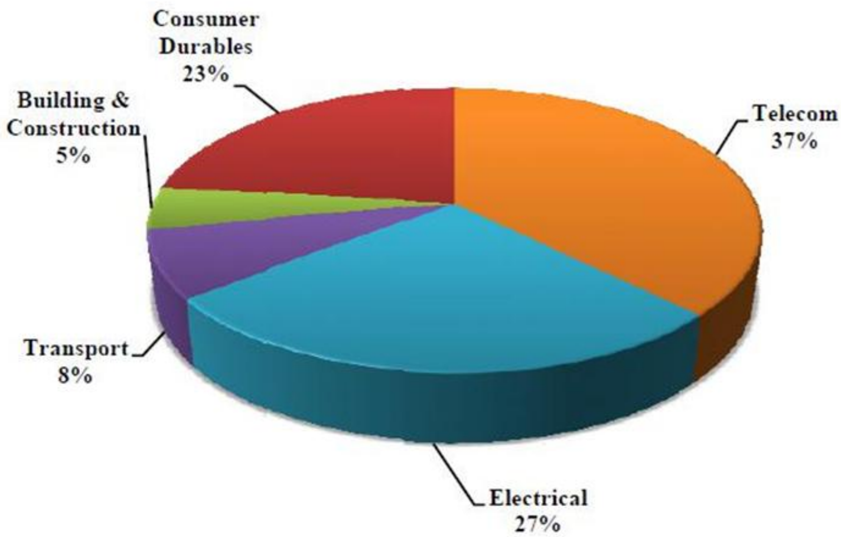
- Electrical, Electronics and Telecommunications sectors account for nearly 52% of copper usage in India.
- The demand again is primarily from the telecom, power and infrastructural sectors. There has been substantial reduction in demand of copper in telecom sector with increased application of fiber optic cables and fast penetration of wireless communication through cell phones, Wireless in Local Loop and Direct to Home (DTH) Telecasting.
- In the household wiring sector, despite many advantages of using copper conductors, aluminium conductors are widely used. The trend, however, has started reversing and increased usage of copper in this sector is perceptible.
- Usage of copper in building construction, as prevalent in Western World, is slowly making inroads into the country, mainly in metro cities and industrial projects.

Figure3.1: Varied Uses of Copper



Source: Market Survey On Copper, Indian Bureau of Mines, May

Figure 3.2: Copper Consumption by End Use



Source: Working Group on Exploration & Development for XIth Five Year Plan,

Planning Commission

The end-use of copper is determined by its chemical, physical, electrical, mechanical properties, etc. The major industries where copper is used are as follows:

1. Electrical industry as wires, cables etc.
2. Industrial and engineering applications
3. Building and construction

4. Transport
5. Coinage
6. Wrought copper & alloys
7. Copper compounds
8. Refrigeration & Air Conditioning

3.2.1.2 Material Flow Analysis for Copper (2011-12)

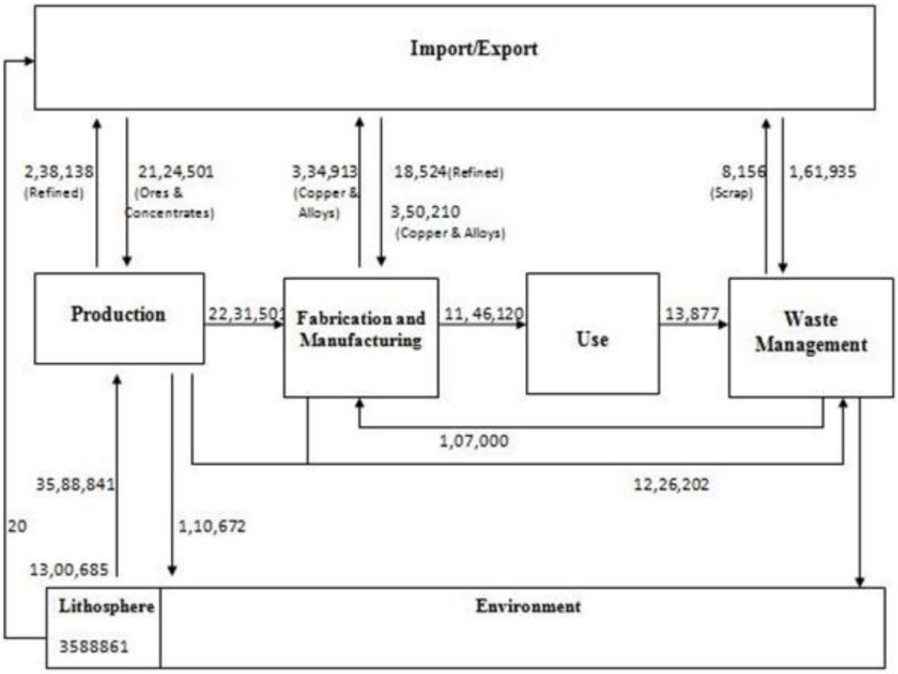


***Figure 3.3: A** simplified diagram depicting the flow of Copper in India (2011-12) with its successive life stages from left to right. (all values expressed in thousand tonnes)*

The above diagram depicts the material flow analysis done for copper in its various forms for the financial year 2011-12 in India.

- Starting from the time when copper ores are extracted, 3588861th. tonnes of copper was mined in the year 2011-12. 20 th. tonnes out of this was directly exported and 35,88,841 th. tonnes were sent for further production purposes.
- In the production sector, 2,38,138 th. tonnes of refined copper was exported and 21,24,504 th. tonnes of copper ore and concentrates were imported. From the production sector 22,31,501 th. tonnes of copper was further sent for fabrication and manufacturing purposes.
- The Fabrication and Manufacturing sector imported 18,524 th. tonnes of refined copper and 3,50,210 th. tonnes of copper and alloys. This sector exported 3,34,913 th. tonnes of copper and its alloys and received 1,07,000 th.tonnes of scrap copper for secondary copper production purposes.
- 11,46,120 th.tonnes of copper was then used in the end-use consumption sector.
- 13,877 th.tonnes of copper was discarded as waste from the end-use consumption sector. 8,156 th.tonnes of scrap copper was exported. India, being a major importer of scrap copper, imported 1,61,935 th.tonnes of scrap copper.
- The Waste Management sector also received 12,26,202 th. tonnes of copper from the Production and Fabrication & Manufacturing sectors.
- 1,10,672 th. tonnes from the production sector and 13,00,685 th. tonnes from the waste management sector was discarded back to the environment as it could no longer be use for further production purposes due to very low quality or toxicity which restricts it from further recycling.

3.2.2.3 Some Key Points

1. India became a net exporter from being a net importer of copper in the financial year 2011-12.
2. However, India remains heavily dependent on copper imports to meet its industrial needs as its own produced copper is not of high quality.
3. India is a major importer of copper scrap.
4. India exports copper ore and concentrates majorly to Liberia, the Netherlands and the UK while it imports the same majorly from Chile, Australia and Indonesia among others.

5. India exports refined copper and its alloys majorly to China, the UAE and Saudi Arabia among others while the same is imported majorly from Bhutan, Ukraine, Russia and China among others.
6. Copper scrap is mostly exported to China, Germany and South Korea and is imported mostly from the UAE, Germany and Saudi Arabia.

3.3 Material Flow Analysis of Metal Trade in the Indian Scenario

Any country whose development is also dependent on its industrial sector has a growing need to judiciously exploit its natural resources. The rising concern over global warming and climate change calls for even stricter norms on exploitation of natural resources globally. To address this, proper accounting of all natural resources is extremely important in order to achieve sustainability.This is where dynamic material flow analysis comes into picture. The technique of material flow analysis has not been incorporated in the green accounting mechanism of Indian natural resources. Studies of material flow of metal trade will benefit the Indian industry in a great way as metals form a significant part of the trade revenues as well as end-use consumption like electrical, automobile, telecommunications, etc.

3.3.1 Observations from MFA of Copper

By attempting to undertake the material flow analysis of copper trade in India for the year 2011-12, the following points were observed.

- Although India has large reserves in copper, it is still majorly dependent on copper imports as the copper extracted from Indian mines is of low quality.
- From being a net copper importer, India became a net copper exporter in 2011-12.
- India has a huge market for copper scrap and a significant amount of secondary copper is produced by recycling copper scrap.

3.4 Challenges in MFA in Indian Scenario

Some of the challenges in the material flow analysis in the Indian scenario are as follows:

- Data keeping in India is not up to the mark.
- India has a huge unorganized sector engaged in the production and fabrication of metals. Proper production and trade records are not maintained by this sector which causes underestimation of values of metal trade undertaken officially for the organized sector.
- Data for metal scrap (in this paper, copper scrap) is not readily available for even the organized sectors such as electrical, telecom, etc which demand the major chunk of copper produced for their further production and fabrication needs.

Although some of these issues need to be dealt with seriously, once resolved, the material flow analysis of metal trade in India will provide us with a better insight of the ongoing situation of the trade of different metals in the country. This will help with better policy making regarding metal trade and will lead a way towards sustainable exploitation of metallic ores and concentrates.

3.5 Key Findings by Other MFA Studies

Some key findings by material flow studies undertaken in other countries are:

- Industrial economies are becoming more efficient in their use of materials, but waste generation continues to increase.
- One half to three quarters of annual resource inputs to industrial economies are returned to the environment as wastes within a year.
- Outputs of some hazardous materials have been regulated and successfully reduced or stabilized but outputs of many potentially harmful materials continue to increase.
- The extraction and use of fossil energy resources dominate output flows in all industrial countries.

IV. CONCLUSION

The growing need for sustainable extraction of natural resources has given rise to the need for proper accounting of resource extraction and trade in an economy. In a country like India analysis and accounting for metal trade can prove to be beneficial both for the industry and the government for relevant policy making. Material flow analysis of metal trade in India is needed to be performed on a large scale basis covering all the metals relevant in the resource trade of the country. This will provide us with a broader insight into the extraction and trade of major metals required for industrial and consumption purposes in the country. The challenges of improper record-keeping, especially in the unorganized sector need to be addressed. With our surprisingly limited knowledge on resource use and waste outputs, there is an urgent need of physical accounts of natural resources. Further, material flow analysis will help in sustainable and efficient extraction of metals.

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