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MATERIAL FLOW ACCOUNTING OF ALUMINUM IN BANGLADESH WITH SPECIAL EMPHASIS ON CIVIL ENGINEERING SECTOR

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ABSTRACT

Aluminum (Al) is one of the most used materials in any economy. Accordingly, in the booming economy of Bangladesh, Al sector has become a flourishing industry fueled mainly by its heightened demand as a civil construction material and its uses in making electrical wires, kitchen utensils, and range of other household and industrial products by both public and private sectors. Rapid industrial and infrastructural development has elevated the consumption of all construction materials including Aluminum. On the other hand, as the world is thriving to attain sustainable development goals - the sustainability of material consumption has become a core concern due to the material criticality fueled by natural resources depletion owing to thier over-exploitation and the environmental burdens associated with the life cycles of materials uses. In reent time, to measure the sustainability of material, a number of tools and indicators has been developed including Material Flow Analysis (MFA) whcih can calculate resource consumption efficiency (RCE) and resource recycling efficiency (RRE) of an industrial entity, a region or a country beside helping to assess the environmental footprint and waste management situation associated with a specific material. Bangladesh needs to adopt MFA as a tool to design and monitor its sustainability in material use by conducting MFAs of major materials to make her development pursuits resource efficient. Accrdoingly, we have conducted an MFA of Al in the economy of Bangladesh. The temporal scope of the study was 2015 fiscal and the spatial boundary was the geographic boundary of Bangladesh. The aim was to quantify inflows, hidden flows, outflows, emissions, stocks related to Al besides calculating the input-output efficiency of Al based on publicly available data from Journal articles, UN's Commodity Trade Statistics database, World Bank databases, Bangladesh statistical bureau databases, different published reports and newspaper articles and expert opinions by using spreadsheet and STAN software. The study revealed that the country consumes 1.07 kg of Al per capita for the year 2015. Transport sector consumed the highest share of Al (30%) folllowed by packaging (29%). Building and construction sector is becoming a major consumer that accounted for 13% of the country's total requirements for Al in 2015. Bangladesh imported 109.16 thousand MT of Al in predominantly as unwrought Al (65%) and semi-products (25%) while the country exported 552.50 MT of Al in the form of different goods which indicates a sharp rise in on-the-use and scrap Al-stock in the country. Al was imported mainly from Singapore (36%), Malayasia (18%), India (15%), China (13%) and South Korea (8%) indicating need for diversification of Al sourcing to remain immune to geopolitical changes. Respective values of the Domestic Material Input (DMI), Domestic Processed output (DPO), Resource Consumption Efficiency (RCE) and Resource Recycling Efficiency (RRC) for Al in the economy of Bangladesh in 2015 were 136472 MT, 111679 MT, 1.526467 million USD/MT and 0.3177795 compared to 52490 thousand MT, 13451 thousand MT, 0.21079 million USD/MT and 0.13711 for China. The higher RCE and RRC of our economy compared to China was due to the use of processed Al and finished products which will change as we go for more Al casting industries. Hence, the policy makers should adopt measures to keep these indicators higher by devising appropriate policy measures to attain SDGs 9 and 12.

Keywords: *Aluminum, MFA, Material Flow Analysis, MFA indicators, Bangladesh.*

1. INTRODUCTION

Industrial ecology has emerged as a paradigm for environmentally sound development and is characterized by minimal physical exchanges with the environment, with internal material loops being driven by renewable energy flows (Bonnin et al. 2013; Maung et al. 2017; Buchner et al. 2015; Buchner et al. 2014). However, the industrial metabolism is over-loading the environment with waste and emissions in many respects (Rauch 2009; Bringezu and Moriguchi 2018; Sevigne-Itoiz et al. 2014). For that skyrocketed, sharpening and growing demand trends shifted from geological reserves to large in-use stocks of metals in society (Maung et al. 2017; Sujauddin et al. 2017; Hatayama et al. 2007).

Non-ferrous metals are acting as a vital functioning component of nature, humans and the modern society and always present all around us (Bertram et al. 2017; Chen, Shi, and Qian 2010). Aluminum(Al) is the most widely used nonferrous metals, and its applications in construction, transportation, electrical engineering and consumer goods like packaging have significantly flourished in the last decades (Liu and Müller 2012; Rauch 2009; Chen and Graedel 2012; Dahlström and Ekins 2007). Moreover, Al is stronger and tougher than plastic and lighter than steel that's why Apple uses predominantly Al parts replacing plastic and steel in its iPhones, iPADs and MacBooks. Experts predict that the average Al content in a car will increase by 60% by 2025 (Bonnin et al. 2013; Ciacci et al. 2013; Menzie et al. 2010). Al is also theoretically 100% recyclable with no loss of its natural properties (Bertram, Martchek, and Rombach 2009; Qiang et al. 2014). The largest portion of Al stock is in U.S. (28%), China (15%), Japan (7%), and Germany (6%) and so on. Major sectors which consume Al like building and construction (40%) and transportation (27%) globally (Liu and Muller 2013). According to (Cullen and Allwood 2013), demand for Al in final products has increased 30-fold since 1950 to 45 million tonnes per year, with forecasts predicting this exceptional growth to continue so that demand will reach 2−3 times today's levels by 2050 (Rauch 2009).

The depletion of nonrenewable resources and the availability of alternative raw materials are of great concern in the metallurgical industry, as in other base material industries (Koscielski, Rogowsky, & Laney-Cummings, 2010). Consequently, the use of Material Flow Analysis (MFA) gains increasing importance to companies operating in those regions where primary raw materials are limited/absent or dependent on expensive energy (Lovik, Modaresi, & Müller, 2014; Passarini, Ciacci, Nuss, & Manfredi, 2018). MFA has been defined as a systematic assessment of materials within a system defined in space and time (Brunner and Rechberger 2016; Hatayama et al. 2007). In a MFA study, a target material is characterized in terms of flows, processes and stocks of that material and overall environmental impact of that material within a predefined region and timeframe (Brunner and Rechberger 2016; Gloser et al. 2013). The purpose of MFA is to look for the potentials and measures of resource conservation and environment protection, and encouraging industrial system to meet the requirements of sustainable development (Muller et al. 2014; Spatari et al. 2002). Substance flow cycles can provide a picture of resource uses and losses through a geographic region, allowing us to evaluate regional resource management and estimate gross environmental impacts (Graedel et al. 2004; Guo and Song 2008; Spatari et al. 2002). This research performs a dynamic material stock and flow analysis of Al in Bangladesh (Daigo et al. 2009; Spatari et al. 2005). As the wrld is sought to achieve Sustainable Development Goals (SDGs), we need to enhance our material consumption efficiency which is more important for rapidly growing economies like Bangladesh. However, an MFA of Al has not yet been conducted in Bangladesh, primarily because of poorly kept and inaccessible statistics, both public and private. In this study, our aim is to conduct the first MFA of Al in Bangladesh to find the flow parameters and calcualte the efficiency indicators for making policy comments.

2. MATERIALS AND METHODS

2.1 Definition of System Boundary

In an MFA, a target material is characterized in terms of flows, processes and stocks of that material and overall environmental impacts of that material within a predefined region and timeframe (Brunner and Rechberger 2016; Ding, Yang, and Liu 2016; Moriguchi and Hashimoto 2016). In the current study the spatial system boundary was the geographical border of Bangladesh, while the temporal boundary was the year 2015. Because there is no operating Al-mine in Bangladesh, imports are the main inputs. Figure 1 shows every Al flow and stock that were determined, including imports and exports, losses into the environment as wastes and emissions etc.

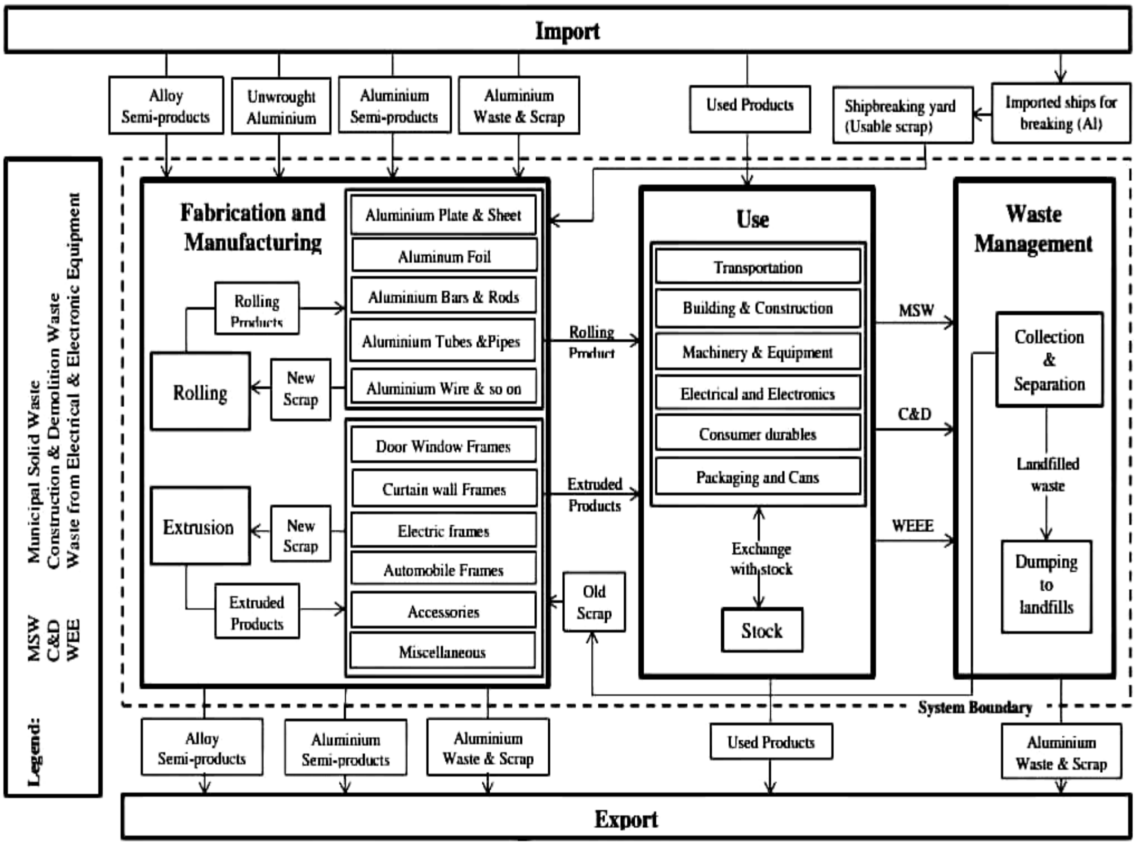

Figure 1: System boundary for MFA of Aluminum in Bangladesh for 2015

2.2 Flows and Stock Estimation

The system under study concerned only material flows. The calculation of both stocks and flows, which was then based only on the principle of mass conservation is performed by Eq. (1) (Bonnin et al. 2013).

$$I + P = C + \triangle S + E + \text{Loss through emission} \quad (1)$$

Here, I is imports, P is production, C is consumption, S is stock and E is export flows.

2.3 Data Collections

The actual data collection from each individual stage is preferred. However, it was not feasible due to the large scope of the present study. Data were collected various international databases as shown in Table 1, namely UN Comtrade (UN Comtrade 2018), the World Bank (World Bank 2017), World Integrated Trade Solution and some local database mainly Statistical yearbook by Bangladesh Bureau of Statistics (Statistical Yearbook 2017). As, local data were not available over a continuous time range, we prioritize international data sources for analysis. However, UNComtrade data were unavailable for import and export in 2014 for which we relied on the local databases for these instances (see Table 1 for details). Noteworthy to mention that data were obtained and analyzed utilizing both UN Comtrade and World Bank, at the initial phase of data collection, however because a similar trend in both datasets, we decided to continue with UN data for final calculation.

Table 1: Year wise data sources used for analysis

	2006-2013	**2014**	**2015**
Import	(UN Comtrade 2018)	(Statistical Yearbook 2017)	(UN Comtrade 2018)
Export	(UN Comtrade 2018)	(Statistical Yearbook 2017)	(UN Comtrade 2018)

2.4 Dealing with Data Uncertainties

Data uncertainties arise from various reasons as methods of data collection are different and statistical integrity of data collection is not the same in all cases. Another uncertainty arose from unclear definition of system boundary. To deal with the above-mentioned uncertainties in this study we tried to follow some consistent data sources and made some rules prior to selection of data.
In the case of UNComtrade, export and import data varied when Bangladesh was the reporter and other countries were partners and vice versa. To deal with this, the data of World Integrated Trade Solution Database was used for more accuracy. Again, in case of UNComtrade data was available for 2006 to 2013 and for 2015. But there is no data available for the year 2014. Hence, data was used from Statistical Year Book Bangladesh, 2017 to fill the gap for 2014.

2.5 Data Calculations

2.5.1 Fabrication and Manufacturing

Sources of import and export data are shown in Table 1. There was no data on the allocation of either Al-based products in different categories of finished products manufactured in Bangladesh. It was assumed as shown in Table 2 that the products are manufactured with the same ratios as they are imported.

Table 2: Ratio of different category of Al-based products

Aluminum	**Ratio**	**Reference**
Extruded products	0.5	Personal interview
Rolling products	0.2	Personal interview

2.5.2 Use

Aluminum industry is a flourishing sector in our growing economy fueled mainly by its heightened demand as a civil construction material and its use to make electrical wire, kitchen utensils, and other products by both public and private sectors (Erbel 2018; Nakajima et al. 2007). India's per capita Al-consumption was used under the consideration that GDP per capita Bangladesh is quite similar with GDP per capita in India and that both countries have similar kind of infrastructure and life standards.

2.5.3 Waste Management

From the use sector different types of waste flows entered into the waste management process stream. For calculating the waste flow, the following data given in Table 3 were used.

Table 3: Aluminum compositions in different types of wastes

Year	Waste types	Weight of waste (MT)	Al in waste (%)	Al (MT)	Reference
2015	MSW	2920000	0.434	12673	(Alamgir and Ahsan 2007)
2015	WEEE	1240000	7	86800	(Statista 2018)
2015	C & D	224000000	0.02	44800	Personal Interview

2.6 Tools and Software Used for Analysis

All the Calculations and graphs were prepared using Microsoft Excel 2010. Computation and steps are implemented by using the STAN (version 2.6.801) which is an opensource software widely used in MFA (Cencic and Rechberger 2008).

3. RESULTS AND DISCUSSION

3.1 Trend of Aluminium import and export in Bangladesh from 2006 to 2015

An aspect of MFA is to estimate the inflow of concerned material from outside the geographic boundary of a country in the form of import. Figure 2 shows year wise import of Al in Bangladesh for the year 2006 to 2015 which indicated that in 2014 the import volume was the highest 141.74 thousand metric tons. The trend shows increasing imports with GDP growth since 2010.

As UN Comtrade database was used for import data, it might be low or high from the actual data. However, the figure reflects that import has been increasing over time with increasing GDP in Bangladesh. This will continue with the increase due to increasing consumption of Al in different sectors in Bangladesh. In contrast, the export of Al from Bangladesh is still quite low but it is increasing over time. Export insignificantly increases after 2013 than the previous years and was the highest in 2015 (552.50 metric tons).

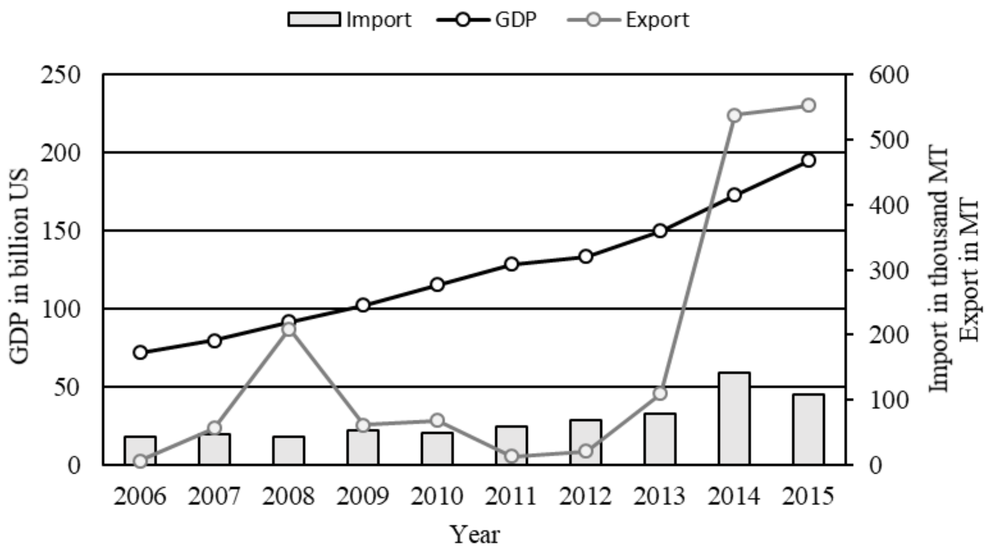

Figure 2: Year wise import and export of Aluminum in Bangladesh

3.2 Aluminum flows into fabrication and manufacturing process

Imported Al was the only inflow into Bangladesh unwrought Al, Al-semi-products, alloy semi-products, Al waste and scrap and others. Figure 3 shows an increasing trend for all types of imported aluminium in Bangladesh from 2011 to 2015. Of the total imported amount, about two-thirds of Al imported as unwrought Al and entered the inflow of fabrication and manufacturing process. Al flows into fabrication and manufacturing process increases over time and the highest value for unwrought Al, Al semi-products, alloy semi-products, Al waste and scrap were 72.70, 21.61, 7.04 and 5.23 thousand MT respectively.

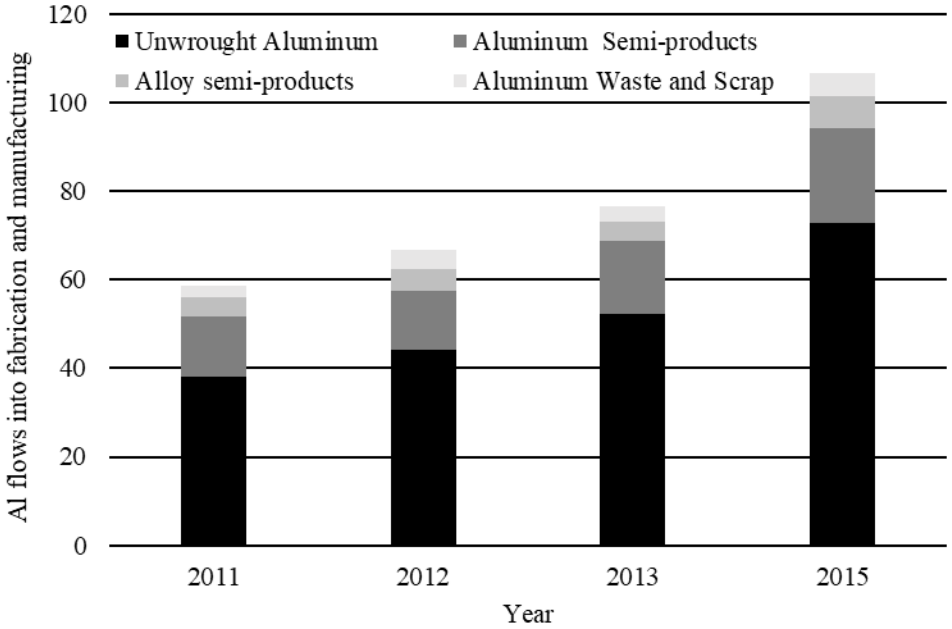

Figure 3: Category wise Aluminium flows into Fabrication and Manufacturing

3.3 Aluminum flows into different end-use sectors of society in Bangladesh

Figure 4 illustrates that the consumption pattern of Al in Bangladesh is different from the global consumption pattern. The demand for the Al industry has been predominantly from the transport sector accounting for 30 % of the total Al demand followed by packaging sector (29%)and building and construction sector (13%), electrical and engineering sector (8%) while 11% is consumed by consumer goods and others. Total domestic consumption was about 172 thousand metric tons in 2015.

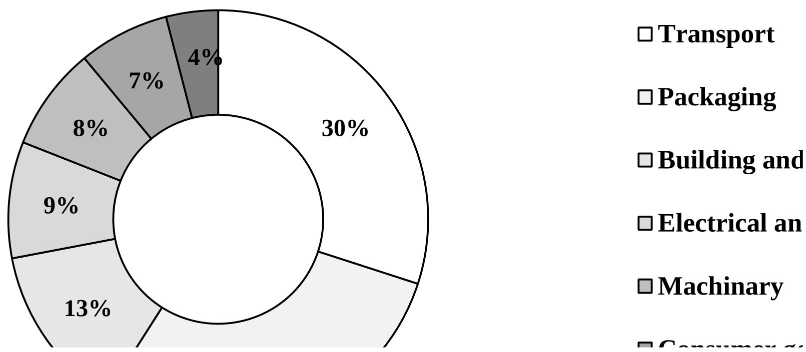

Figure 4: Aluminium usages by end-use sectors in Bangladesh

3.4 Top Aluminium sources for Bangladesh (2015)

Figure 5 represents that Bangladesh imported higher amount of Al form Singapore (36%) followed by Malaysia (18%), India (18%) and China (15%). Small amounts are imported from UAE and South Korea.

3.5 MFA of Aluminium in Bangladesh 2015

MFA of Al is shown in Figure 6. About 106622 metric tons of unwrought Al, Al semi- products, alloy semi-products and Al waste and scrap imported from different countries entered into the fabrication and manufacturing process. From ship breaking 29900 metric tons of Al scrap entered as inputs.

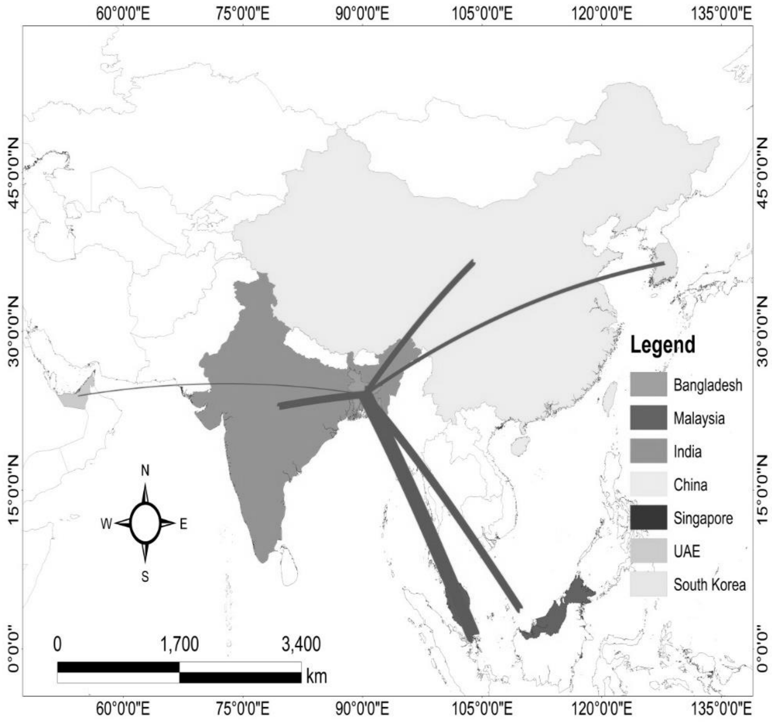

Figure 5: Aluminium supplier countries in Bangladesh for the year 2015

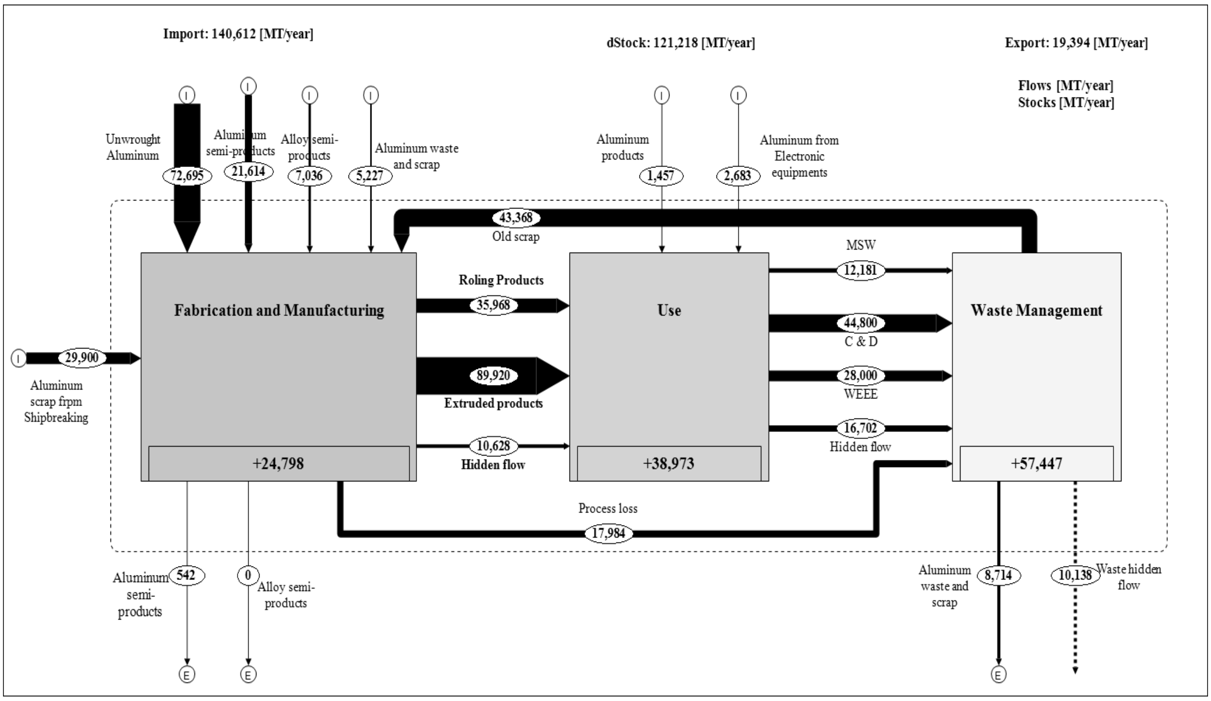

Figure 6: Material Flow Analysis of Aluminum in Bangladesh, 2015

Al and alloy products were outputs from fabrication and manufacturing. There is no data on their allocation; hence it was assumed that the products were manufactured at the same ratio as they were used. System loss of 10% from the fabrication process was added to the waste management process. About 125888 metric tons of rolling and extruded products entered use stage along with 2683 metric tons of electrical equipment. Substantial amount of MSW (12181 metric tons), Electrical waste (28000 metric ton) and construction waste (44800 metric ton) were generated of which 43368 metric tons were recycled into the system. Al waste and scrap were exported from waste management process. There was some hidden flow through different processes which were calculated. After all data input into three processes, the STAN software calculated the stock at every process.

Fabrication and manufacturing stock were 24789 metric tons which means after the production process some material remains in the system which can be further used as a raw material. In-use stocks were 38973 metric tons which means people don't bother about the huge generation of waste at every stage. Waste management stock 57447 metric tons means disposed in dumping station. Al waste and scrap were also exported from waste flow. Combining all the sub-processes, the total amount of imported Al was 140612 MT/year and the total exported amount was 19394 MT/year. The total calculated stock amount was 121218 MT/year.

3.6 MFA indicators for Aluminium in Bangladesh

Table 4 illustrates the MFA indicators for the MFA of Al in Bangladesh. Resource consumption efficiency indicates a significant amount of waste from the flow of material being unutilized that ultimately lowers the efficiency, but it is also related with the unavailability of data that how much waste had been recycled in 2015. Resource consumption efficiency in 2015 was 1.526467 million USD/MT and resource efficiency of material extraction was 0.274571. The total calculated stock amount was 121218 MT/year which can be used to reduce the pressure on ferrous metal.

Table 4: MFA indicators for Aluminium in Bangladesh

Type	Indicator	Definition	2015	Unit
Input	Direct Material Input (DMI)	Domestic raw material + Imports in MT	136472	MT
	Total Material Requirement (TMR)	DMI + HF* in MT	163802	MT
Output	Domestic Processed Output (DPO)	Emissions + waste in MT	111679	MT
	Total Domestic Output (TDO)	DPO + relevant HF in MT	121817	MT
Efficiency	Resource Consumption Efficiency (RCE)	GDP/DMI	1.526467	Million USD/MT
	Resource Recycle Efficiency (RRE)	Recycling waste/DMI	0.3177795	Ratio
	Resource Efficiency of material extraction	Unused/used= HF/DMI	0.2745471	Ratio

4. CONCLUSIONS

Rapid industrial and infrastructural development has raised the consumption of all construction materials including Al. On the other hand, the sustainability of material use has become a critical concern due to the material criticality fueled by natural resources depletion and the environmental burdens associated with the life cycle of material uses. The resulting MFA of Al in Bangladesh for 2015 showed the major flows related to Al by considering the geographic boundary of Bangladesh as the system boundary. As a developing country, the total consumption of Al in Bangladesh was low amounting to 172.48 thousand metric tons in 2015. Transport sector was the largest end user of Al accounting for 30% of the total Al demand. MFA indicators has been calculated for the year 2015 which showed a resource consumption efficiency of $1.526467*10^{-3}$ billion \$/MT and resource efficiency of material extraction is 0.2745471. The total calculated stock amount was 121218 MT/year. Flow of Al within the system boundary has also been produced for 2015 which can be used as a baseline in any future studies related to Al use in Bangladesh considering industrial ecology perspective for sustainable development of this industrial sector to attain sustainable development goals (SDGs) 9 and 12.

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