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On Techno-Economic Aspects of Wireline Telephone Recycling in India

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Abstract: *Sustainable Development Goals (SDG) Under United Nation Targets To Achieve Sustainable Human Society Which Includes Sustainable Industry. For Electronic AndElectrical (EE) Industry, That Means Creation Of Recyclable EE Products And Electronic Waste (E-Waste) Recycling Infrastructure That Work Well Under Market Economy Conditions. In This Paper, We Look Into How Wireline Telephone Set Recycling Can Be Made Economically Viable In India By Defining Profitable Recyclable Window (PRW) And Identifying The Most Influencing Factor In The Recycling Process That Affects The Profit Margin Of E-Waste Recycling. The Paper Also Provides Discussion On Technical Solutionsthat Could Improve E-Waste Recycling Profit Margin And Identifies Percentage Of Gold Composition In Virgin EE Products As The Key Factor Which Could Make Or Break Recycling Industry.*

Keywords – *E-Waste, PRW, SDG, Standards,Wireline Telephone*

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I. Introduction

The Sustainable Development Goals (SDG) Are A Set Of 17 "Global Goals" Under A United Nations Resolution Which Has Been Built On The Principles Of "The Future That We Want" [1,2]. It Is A Broader Intergovernmental Agreement Involving 193 Member Countries Of United Nations Which Cover A Broad Range Of Social And Economic Development Issues. The Issues Include Poverty, Hunger, Health, Education, Climate Change, Gender Equality, Water, Sanitation, Energy, Environment And Social Justice.The 17 Goals Have 169 Targets. SDG Goals 8, 9, 11, And 12 Have 9 Targets (Target 8.4, 9.2, 9.C, 11.3, 11.6, 12.4, 12.5, 12.6 And 12.8) Among Themselves Which Can Be Related To Electrical And Electronics (EE) Industry And Its Waste (Electronic Waste/ E-Waste). These Goals Call For Sustainable Economic Growth, Industrialization, Human Settlements, Consumption & Production Patterns, And Resource Utilization For Development. The Targets In These Goals Involve:

- Decoupling Of Economic Growth From Environmental Degradation Using Sustainable Consumption And Production,
- Promotion Of Inclusive And Sustainable Industrialization,
- Sustainable Increase Of Access To Information And Communication Technology For Promoting Relevant Information And Raising Of Awareness Related To Sustainable Development And Lifestyles That Are In Harmony With Nature,
- Enhancing Inclusive And Sustainable Urbanization By Reducing The Adverse Per Capita Environmental Impact Of Cities Including By Paying Special Attention To Waste Management,
- Achieving Environmentally Sound Management Of All Wastes Throughout Their Life Cycle And Significantly Reduce Their Release To Environment In Order To Minimize Their Adverse Impacts On Human Health And Environment,
- Substantial Reduction Of Waste Generation Through Prevention, Reduction, Recycling And Reuse; And Encouraging Companies, Especially Large And Transnational Companies To Adopt Sustainable Practices And To Integrate Sustainability Information Into Their Reporting Cycle

Use of EE products is slated to increase by many fold due to targets like increase of access to information and communication technology during implementation of SDGs. Among other reasons, this will also create more e-waste than current rate which will make it more difficult tomeet these SDG targets. Policy changes at appropriate level and changing & adopting standards, rules, laws and regulations as per requirements, which take into effect prevalent scenarios,would be vital in achieving these targets. A brief introduction is provided to e-waste recycling standardsin Table I while law, rules and regulations are described elsewhere [3,4].

Table I. Brief List of standards for e-waste recycling industry

Standards	Description/ Scope
R2:2013-Standards [5]	The Standard Is Applicable To Electronics Recycling & Refurbishing Industry And The Standard Ensures Quality, Transparency And Environmental & Social Responsibility Are Adhered By Recycling Facilities. The Standard Was Developed Through Multi-Stakeholder Process Which Is Consistent With ANSI Essential Requirements.
E-Stewards[6]	The Standard Is An Electronic Waste Recycling Standard Created The Basel Action Network And It Is Industry Specific Environmental Management System Standard For Responsible Recycling And Reuse Of Electronic Equipment. The Standard Ensures ISO 14001 Is In Place Along With Other Norms Such As No Use Of Prison Labour, No Dumping Of Toxic Materials In Municipal Landfills Etc.
Bureau OfIndian Standards (BIS) [7]/ International Electrotechnical Commission (IEC) Standards: TC111 – Environmental Standardization For Electrical And Electronic Products And Systems [8]	TC111 Technical Committee Prepares Necessary Guidelines, Basic And Horizontal Standards In The Environmental Area. These Standards Are In Addition To Environmental Aspects Of Product Standards. The Committee Has Created And Is Working On 24 Such Standards.
Electronic Product Environmental Assessment Tool (EPEAT) [9]	The Standard Provides Environmental Product Ratings To Electronics That Support Any Organization's It And Sustainability Goals. The Stake Holder Process Was Convened By Us Environmental Protection Agency. EPEAT Is Managed By The Green Electronics Council Which Currently Tracks More Than 4400 Products From More Than 60 Manufacturers Across 43 Countries. The Environmental Criteria Underlying The Standard Address Full Product Lifecycle From Design To Recycling. Products Such As Mobile Phones, Servers, Pcs, Displays, Imaging Equipment And So On Are Tracked By EPEAT.
Conflict-Free Smelter Program (CFSP) [10]	CFSP Is A Voluntary Initiative In Which An Independent Third Party Validates Smelter's Or Refiner's Management Processes By Auditing Their Procurement And Processing Activities To Verify That The Company Has Implemented Necessary Procedures Capable Of Producing Conflict-Free Products.
Recycling Industry Operating Standards (Rios) Certification [11]	Rios Is An Integrated Quality, Environmental, Health And Safety Management System Certification. By Integrating The Management System, Recyclers Are Able To More Efficiently Manage Their System, Which Results In Stronger Health And Safety Programs, Greater Environmental Responsibility And Better Operational Efficiency. The Standard Is Not Limited For Electronics Only.

According ToUN Data Published In 2017, The Global E-Waste Has Reached 447 Lakh Metric Tons (MT)And Is Slated To Reach 522 Lakh MT By 2021 [12]. In India, A Study Has Estimated E-Waste Tonnage InApril 2016 To Be 18.5 Lakh MT Which Could Increase At A Compound Annual Growth Rate Of 30% Till 2020 Thereby Increasing The Tonnage To 52 Lakh MT[13]. E-Waste Tonnage Data Gets Updated All The Time And Varies Among Agencies Due To Methodology Of Estimates Adopted For Study. The Tonnage Vales Help Provide Only An Estimate And Does Not Correspond To Exact Value Available For Collection By Recyclers. Although Various Steps Are Need To Be Taken At Various Levels Ofthe EE Product Life Cycle To Deal With Ever Increasing Tonnage And Increasing Rate Of Generation Of E-Waste, One Of The Key Step Will Be Creation Of Proper Recycling Structure With In India.

In This Paper, We Describe How Economics Is One Of The Key Challenges Of Indian E-Waste Recycling And How Cost Effective Technical Solutions Are Necessary To Solve It. Section II Describes The Economics Of E-Waste Recycling And Section III Presents A Case Study On Techno-Economics Of Wireline Telephones In India.The Study Describes Method Of Profit Margin Calculation For A Given Category Of E-Waste And Why Defining A Profitable Recyclable Window Is Necessary For This Purpose.ItEnds With Comment On How Economic Sustainability Of E-Waste Recycling Can Be Ensured Through EE Virgin Product Standards.

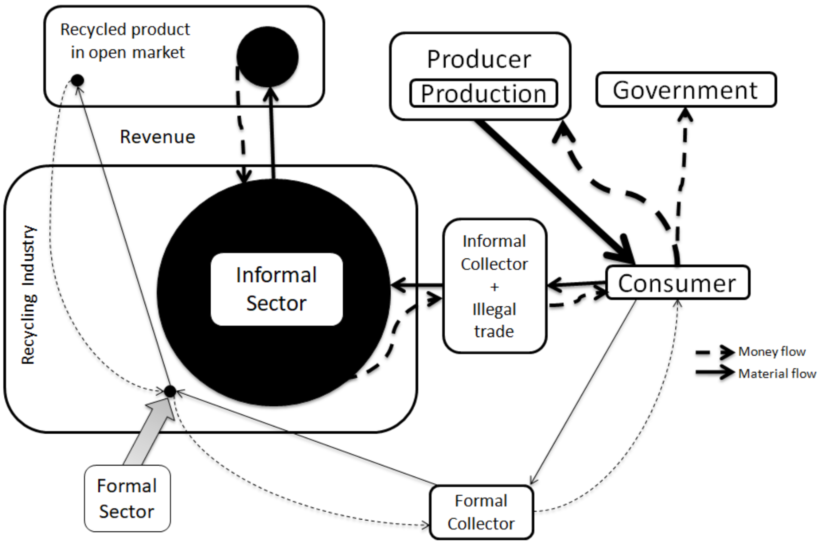


Fig. 1 Approximate Model Of Current E-Waste Recycling Economy In IndiaShowing Challenges Coming From Informal Sector For Achieving SDG Goals.

II. Economics OfE-Waste Recycling In India

Economics Of Recycling Is One Of The Major Challenges In Creation Of Recycling Structure With In India. Unless Economy Permits, Establishing Such Structure Will Not Be Sustainable In Long Run. Like Any Recycling Business, E-Waste Recycling Accounting Profitability Depends On Revenue Generation From Output Sell And Explicit Cost Incurred In Capital Investment And Running Of Operations (Manpower, Feedstock, Energy, Materials And Overheads). An Approximate Model Of Current E-Waste Recycling Economy In India Is Shown In Fig. 1 And Some Of The Key Challenges In Accounting Profitabilityof Formal Recyclers In India Include:

- High Infrastructure Investment Cost, Operation Cost, Capital Equipment Cost, Safety And Environmental Standards Costs.
- Steep Competition From Informal Sector. Collection Of Feedstock For Recycling Is Dominated By Informal Collection Supported By Illegal Trades. Informal Sector Is Able To Offer High Prices For Feedstock And Lower Prices For Recycled Products As Compared To Formal Sectors Due To Low Capital Investment And Operational Costs. Low Capital Investment Is Due To Low Cost Readily Available Technologies Which Are Inefficient And Are Not Environmental Friendly. Although The Technologies Are Inefficient, The Output (Volume And Quality) Is Good Enough To Provide Profit Margins That Are Able To Sustain The Informal Sector.

Fig. 2 Example of a typical wireline telephone set

- Fast Changing Electronics Technology Limits Total Tonnage And*Profitable Recycling Window* (PRW) Of Particular E-Waste Product. For Example, If Life Time Of A Product Is 5 Years And It Is Replaced By A New Technology Within 3 Years Of Its Launch, The PRW For That Product Will Be Only 3 Years After 5

Years From Launch. If Cost Effective Recycling Technology Is Not Present At The End Of 5 Years To Take Advantage During The 3 Years Of PRW Then Profitability Of The Recycling Of The Product Decreases And For Some Cases Such Products May Not Get Recycled At All. If Product Life Time Decreases To One Or Two Years Due To Increase In Rate Of Obsolescence Of Technology, A Likely Scenario In Advent And Adoption Of Artificial Intelligence (AI), Then Recycling Of The Product May Not At All Take Place Under Market Economy Conditions If New Technology Is Needed For Recycling.

- Volatility Of Market Price Of Virgin Products Makes It Difficult To Assess Profit Margin Before Recycling Is Carried Out. Assessing Profit Margin Is Necessary Before Recycling Because Business Could Run Into Losses If Total Profit In PRW Is Not Assessed Properly. For Example, Neodymium (Extensively Used In Magnets Utilized In Electronics Such As Hard Disks Etc.) Prices Jumped More Than 16 Times Between 2009 And 2011 But Then Fell 3.5 Times Till 2015 And Now The Price, Has Steadily Increased 2 Times The Value Of 2014 [14]. Recycled Neodymium Would Have Made Good Profit During The Upsurge Of Prices But Could Also Have Made Losses During Down Surge Depending On Recycling Cost Of Neodymium Over The Period Of 2009 To 2015.

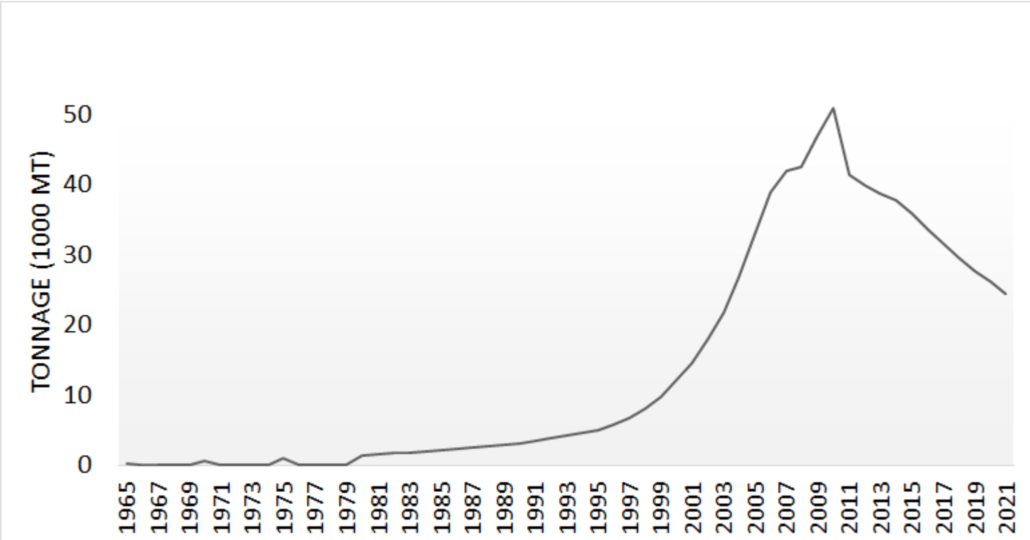


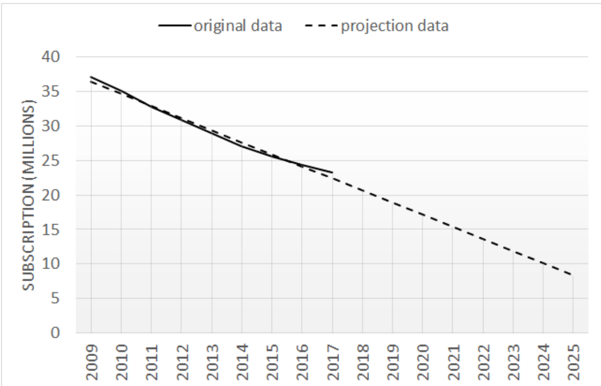
Fig. 3 Expected E-waste tonnage of wireline telephone set till 2021.

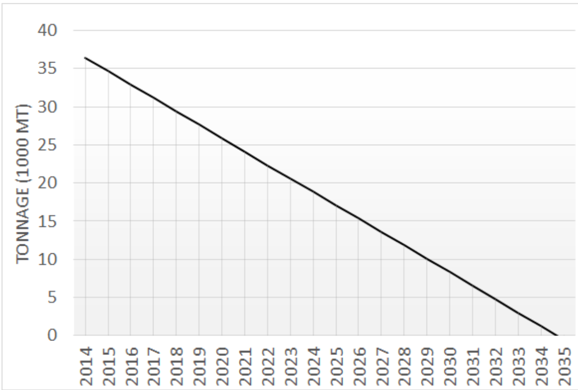
The Informal Sector Challenge Can Only Be Met With Enacting Adequate Rules And Regulations By Both Government Of India And State Governments With Compassionate Outlook Towards Informal Sector During Implementation. Choice Of Recycling Technology Plays An Important Role In Economics. Energy Intensive Recycling Technology Such As High Volume Pyrometallurgy Is A Solution That Has Been Adopted By Developed World As Their Feed Stock Collection Efficiency Is High. In India This Methodology Suffers From Two Major Disadvantages: A) Collection Efficiency Is Very Low And Is Estimated To Be Only 40% (Assuming Collection Efficiency Equals To E-Waste Tonnage Available For Recycling And E-Waste Storage Is Neglected)And Only 5% Of That Is Recycled By Formal Recyclers [15] And B) High Running Cost Due To Energy Intensive Recycling Process Makes It Difficult To Remain Profitable In PRW. Thus India Needs Technological Solutionsthat Can Provide High Energy Efficiency Recycling Process And Will Remain Profitable Even Under Low Volume Of Collection In PRW.In The Following Section We Provide A Case Study On Wireline Telephone E-Waste, Assessment Of Recycling Economics And Probable Technological Solutions To Remain Profitable In PRW.

III. Case Study On Wireline Telephone E-Waste

A Wireline Telephone Is A Phone That Uses Metal Wire As Transmission Medium For Communication. A Typical Example Of Such Phone Is Provided In Fig. 2. These Telephones Are Used By Retail Consumers (Households, PCO Operators, Shops, Coin Telephones Etc.) And By Bulk Consumers Such As In Offices. In India, E-Waste (Management) Rules 2016 Defines The Categories Of The Products That Are

Considered As E-Waste. Schedule I Of The Rules Describes These Product Categories. Wireline Telephones Come Under Three Product Categories, Namely ITEW12 (Telephones), ITEW13 (Pay Telephones), And ITEW14 (Cordless Telephones) [16]. Worldwide The Expected Accumulated Tonnage Of Fixed Line/ Wire Line Telephone Till 2016 Is 84087914755MT. The Tonnage Value Has Been Derived From Fixed Line Subscriber Data [17] Considering Average Weight Of 1 Kg Per Set. Assumptions For The Estimate Include No Recycling Carried Out From 1960 And One Set Per Subscriber. Similarly, Fig.3 Shows Wireline E-Waste Tonnage From 1965 To 2021 Considering Average Life Time Of 5 Years AndITEW13 (Pay Telephones), &ITEW14 (Cordless Telephones) Tonnage Have Assumed To Be Negligible As Compared To ITEW12 (Telephones). The Figure Shows That Since 2011, Tonnage Has A Decreasing Trend And Is Expected To Continue To Decrease As Wireline Subscriptions Are Steadily Decreasing. The Tonnage Is Expected To Decline To 8000 MT By 2030 And Nil By 2035 If The Current Trend Holds Good (Fig. 4(B)). The Projected Data InFig. 4(A) Is Based On Government Of India Wireline Subscription Data From 2009 To 2017 [18] And Linear Regression. However, Such Subscriptions Are Not Expected To Become Nil As Demands From Bulk Consumers Such As Offices And Clubbing Of Broadband Technologies With Wireline Services For Retail Consumers Are Expected To Continue. ThusOne Can Set PRW For Wireline Telephone Sets To Be From Present To 2030 (12 Years). Although Fig. 4(B) Is Good ForPRW Estimation, Profit Margin Requires Much Detailed Estimations And Is Described In Following Paragraph.





(a) (b)

Fig. 4 (a) Wireline Subscription Original Data And Projected Data For India And (B) Estimated Project Data For Wireline E-Waste Tonnage In India.

Depending Upon Current Indian Collection Efficiency Wireline Telephone E-Waste Tonnage Should Be ~ 580 Mt And ~160 Mt In 2018 And 2030, Respectively.Generally Any E-Waste Recycling Is Initiated With Dismantling And Sorting Stage. For The Wireline Telephone Set Shown In Fig.1, Output Of Such Activity Is Shown In Fig. 5. The Major Parts After Dismantling Of Wireline Telephone Are Plastic, Metal, Magnets And Printed Circuit Board (PCB). Glass And Batteries Can Also Be Found In Some Telephone Sets With LCD Displays With Back Lighting, However For The Telephone Set In Fig. 1, Glass And Battery Were Absent. Typical Composition By Weight Of Wireline Telephone Sets Is Provided In Table Ii (Obtained From Measurements From Fig.1 Telephone Model Set). Composition Depends On Product & Model Of A Feedstock Lot And Should Be Determined Every Time For Every New Lot During Profit Margin Estimation. Composition Tonnage Projection For 2018 And 2030 Is Also Provided In Table Ii. In This Paper We Focus On Recycling Of PCB& Metals Only As Valuable Metals Provide The Most Returns From E-Waste Recycling And Also As They Can Be Recycled Together. Table Ii Shows That PCB& Metal Availability Will Be Around ~127 Mt In 2018 And It Is Going To Decrease To ~35 Mt By 2030. Gold And Copper Top The List Of Return Due To Value And Volume Respectively. Other Metals Such As Iron, Aluminum, Tin Etc. Can Be Extracted Depending Upon Compositionin A Given Lot Of Feedstock. Approximate Composition OfGold & Copper By Weight In Depopulated PCB And Wires Are 0.025% And 50% Respectively; Which Are Capable Of Providing Returns More Than 99% Of Total Return From Metals.

Table II. Typical composition of wireline telephone sets

Material	Composition (%)	2018 (MT)	2030 (MT)
Plastic	73	424	117
PCB	13	75	21
Metal	9	52	14
Magnet	7	41	11

Fig. 5 Dismantled Wireline Telephone Parts Consisting Of Plastic Casing And Components, Wires, Magnet, Electrical Components (Switches, Capacitors, SMD Components), Metal Parts (Screws, Plates) And Printed Circuit Board.

The Most Economic Recovery Process Of Visible Gold From E-Waste Is Through Gold Stripping Solutions And Electroplating Them On Other Metals. This Method Provides Direct Sellable Products For The Market Such As Gold Plated Watches, Gold Plated Jewelry,Gold Plated Offerings For Temples Etc. And Requires Least Capital Cost. Hall Effect MeasurementsOn Such Products Revealedthatresistivity Of Such Electroplated Gold Is Approximately Three Orders Of Magnitude Higher Than Bulk Gold Resistivity. This Shows That Purity Of Gold Is Lower Than Electronic Purity And Generally Would Fetch Lower Than Market Price Of Gold. Alsothis Is Inefficient Method, As Gold And Other Valuable Metals Are Still Present In The Leftover PCB Boards. Pyrometallurgy Provides Extraction Of All Types Of Metals. Stripped Copper Wires And Depopulated PCB Boards Eliminate Possible Contamination Of Recycled Metals Which Can Fetch Better Prices In Market. Conventional Metal Extraction Process Is Depicted In Fig. 6 With Line Capacity Of 1000 Kg Of PCB.Generally, Output Of Such Process Provides Gold And Copper Outputs Every 2 Days While Others Such As Iron, Aluminum, Tin Every Month As Their Concentrations Are Generally Very Low In PCB Boards.

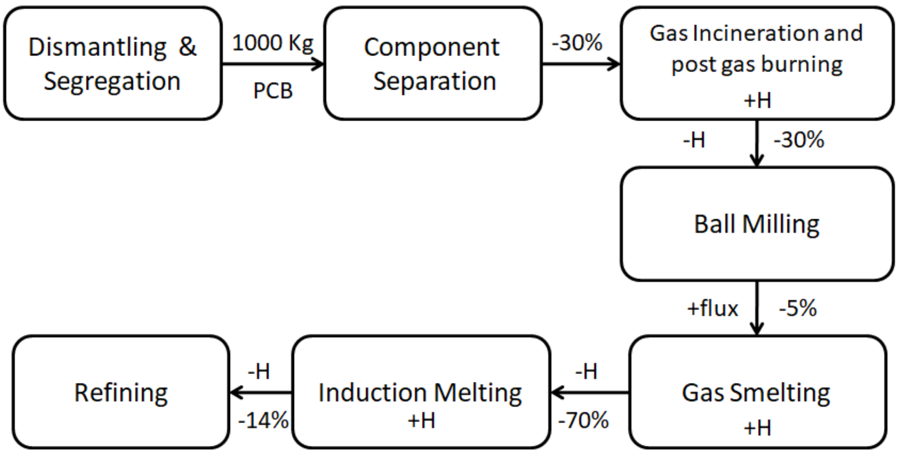
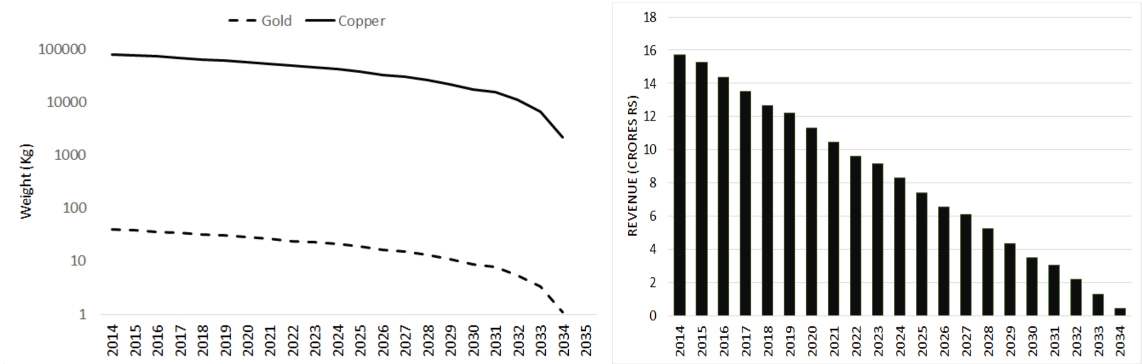


Fig. 6.PCB Recycling Process With Line Capacity Of 1000Kg. Tonnage Reduction Is Provided In % At Each Step. (+H – Heating, -H – Cooling)

Estimates Of Total Yearly Revenue From Recycled Gold And Copper For 5% Formal Collection Efficiency Is Shown In Fig.7. Thetotal Market Is Estimated To Be Of INR ~173 Crorestill 2030 And Average Return Per Day IsINR ~225000. With 100% Formal Collection, The Total Market Till 2030 Will Be INR 3450 Crores.At 1% Formal Collection Efficiency The Total Market Till 2030 Will Be INR ~35 Crores Only And Average Return Per Day Will Be INR ~ 4500. This Shows The Sensitivity Of Average Return Per Day On Formal Collection Efficiency. Revenue Per Day Is Dependent On Market Prices Of Metals And Formal Collection Efficiency; And Hence Should Be Calculated Before Every Recycle Run. Operational Cost Including Manpower Cost And Capital Cost Will Determine The Profit Margin For The Recycling Industry And If Such Recycling Is At All Possible Under Market Economy Conditions. In This Paper, Manpower Cost And Capital Cost Is Neglected And Profit Margin Is Based On Operational Cost (Without Manpower Cost) Only.The Justification Comes From The Fact That Manpower And Capital Costs Are Negotiable Entitieswhich Will Vary For Different Recycling Companies.For 10% Profit Margin, Average Operational Cost Per day should be less than INR ~2 lakh. Profit Margin Enhancement Is Possible,Under Low Formal Collection Efficiency,Using Following Steps:

- Lowering Line Capacity Can Bring In Informal Sector Into Formal Sector Domain, As Capital Cost, Manpower Cost, And Operational Cost Would Be Reduced. This Will Effectively Increase The Formal Collection Efficiency And Hence Profit Margin.
- Reducing Number Of Heating And Cooling Cycles In Recycling Process Will Make The Process More Energy Efficient Which Will Reduce Energy Cost And Profit Margin Is Expected To Go Up.
- The Energy Cost OfRecycling Process In Fig. 6 Is Approximately 23% (Gas Consumption Is Around 20% And While Electricity Consumption Is 3%). Gas Furnaces Are Not Very Energy Efficient And At Least Three Heating And Cooling Cycles In This Recycling Process (Fig. 6)Makes It More Inefficient And Costly. By Utilizing Energy Efficient Process Such As Microwave Heating-Based Pyrolysis, Which Is Expected To Have Lower Operational Cost (Expected Energy Cost Savings Is ~85% Based On Theoretical Energy For Melting Of Metals And INR 10/KWhr Rate) As Compared To Gas Based Furnace And Lower Processing Time (Up To 50%) As Compared To Conventional Ovens [19,20]. The Cost Is Expected To Increase Based On Furnace Capacity (Total Thermal Load) And Thermal Energy Transfer Efficiency From Susceptor To Thermal Load. Metal Extraction Is Easily Possible From The Output Of Microwave Pyrolysis And Only Requires Easy Step Of Mechanical Processing [21].
- Limiting Recycling Output To Pre-Refinery Stages Can Reduce The Cost Of Recycled Product Thereby Improving Profit Margin. Black Metal Technology Is One Such Product.

With Current Advancement In Technology The Gold Content In Electronics Is Reducing And Recycling Technologies Which Are Heavily Dependent On Principle Revenue From Gold Are Getting Obsolete And Profit Margins Are Reducing. Solutions For Such Circumstances Is Either To Make Recycling Cheaper By Methodologies As Described Earlier Or Changing The Recycled Product From Refined Valuable Metals Which Can Be Sold To Open Market To Intermediate Products Such As Black Metal Which Can Be Sold To Metal Refineries. Black Metal Valuation Can Be Done Based On Composition And Profit Margin Can Still Be Positive As Operating Cost Is Expected To Be Lower Than Technologies With Refining Stage. Although, Black Metal Profit Margin Is Dependent On Volume Rather Than Value Of The Product, Too Low Gold May Not Make The Black Metal Profitable. Under Such Circumstances Recycling Will Not Be Market Dependent And Has The Possibility Of Shutting Down. Although Reducing Gold Content Decreases Product Cost Of Virgin Products, Increase Profit Margin For Virgin Product Manufacturers And Creates Better Penetration Of Market Among Underdeveloped Market Economies Which Provides Better Inclusion As Per SDG Goals But Such Scenario Also Is Capable Of Closing Down Of E-Waste Market Economy Specifically Those Recycling Economies Where Recyclers Are Relying On Low Collection Efficiency. Hence, A Balance Needs To Be Created By Standardizing The Gold Content Of Electronics Product Which Will Provide Better Chance Of Achieving SDG Goals.



(a) (b)

Fig. 7 Expected Weight Of Valuable Metals (Gold And Copper) And Estimated Total Revenue From Them. Revenue Estimation Was Carried Out Using Market Price Of Gold And Copper On 7thMarch2018[22] .

IV. Conclusion

Successful Recycling Of E-Waste Is Essential For Achieving SDG Goals. Challenges In Establishing A Sustainable Recycling Infrastructure Has Been Described Which Shows Formal Collection Efficiency To Be The Most Important Factor In Establishing Economic Viability Of E-Waste Recycling In India. This Was Described Through A Techno-Economic Case Study For Wireline Telephone Set Which Estimated That 10% Profit Margin Could Be Booked If Operational Cost Is Lower Than INR ~2 Lakh Per Day. The *Profitable Recycling WindowF*or This Case Was Estimated To Be 12 Years From 2018.The Paper Also Shows How Profit Margins Can Be Improved By Adopting Lower Line Capacity, Reducing Number Of Heating And Cooling Cycles, Adopting Microwave-Based Pyrolysis And Making Products Such As Black Copper. It Has Been Identified That With The Advent Of The Advanced Technology, Gold Content In Electronic Products Are Slated To Decrease And Under Such Circumstances Recycling May Not Remain Viable Economically, Particularly For Those Cases Where Formal Collection Efficiency Is Low. Solution For Such Issue Lies In Standardizing The Gold Content In Electronics Product Such That Recycling Remains Profitable.

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