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Evaluation of Pcb Recycling Methods Based on Drivers Using Hybrid Mcdm Approach

KEYWORDS: PCB recycling, drivers, fuzzy-AHP

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ABSTRACT *In the contemporary business environment the life of the electronic parts is depressed with the raise of its application, which leads in E-waste or Electronic. Due to this high concern, many developing and developed nations shift their focus of this e-waste recycling management through many programs, legislative actions, etc. Especially in e-waste, PCB (Printed Circuit Board) plays a major role and due to its wide range of applications like televisions, mobile phones, computers etc. Even though the recycle of these printed circuit boards leads to recovery of precious metals, but inappropriate recycling methods lead to unnecessary wastage of cost, less material recovery and human illness due to the improper handling of hazardous metals during the recycling. Hence, in this paper we select the best sustainable PCB recycling method based on its drivers with the assistance of HMCDM (Hybrid Multi Criteria Decision Making) tool.*

Introduction:

The production of electrical and electronic equipment is one of the fastest growing sectors of the manufacturing industry in the world because of high applications in day to day life. The production of E-waste increases parallel to its waste because developing countries like India don't have the awareness or proper system for e-waste recycling. According to a survey in 2012 the outdated computers from government infrastructure, corporate houses, industries and household is of the order of 2 million nos., producers and assemblers in a single year are estimated to create around 1200 tons of electronic scrap (Saini et al., 2012) this is only for computers but E-waste includes a variety of products which need to address. If we consider in term of e-waste in every year world-wide about 20-50 million tons of wastes EOL (End of Life) electronic products are generated which causes serious health problems to human (Ortuno, 2006). Generally in e-waste, printed circuit boards and cathode ray tubes are difficult to recycle in which PCB has extended the application in the current developing scenario. On the concern of the WEEE Directive (European Commission 2003), the printed circuit boards (PCB) must be reprocessed and recycled in an environmentally sustainable manner (Hall et al., 2007). The recycling of printed circuit boards from obsolete electronic devices is, at present, a fairly new activity, although opportunities are available for expansion in this area. Many techniques have been used for the disposal of printed circuit boards such as land fill, incineration and low level reutilization or recycle (Theurer,2010). At present only land filling or solidification of printed circuit boards are practiced in large scale (Chien et al., 1999). The Printed Circuit Boards also known as Printed Wiring Boards are the platform in which micro-electronic components such as semi-conductors, chips and capacitors are mounted (Sohaili et al., 2012). The PCB's represent a significant part of electronic waste and hence recycling of PCB waste is important for the protection of the environment. In general the PCB waste contains approximately 30% metals and 70% non-metals (Li et al., 2011). The presence of these metals has encouraged recycling studies for an economic point of view. The recycling of PCB waste is also useful for recovery of valuable materials. The recycling of PCB's can be done by various methods such as a physical recycling method, chemical recycling method, thermal processing, non-thermal processing, liquefaction and hydrometallurgical process. But in recent years there has been increased recognition of mankind's impact on the environment and need to adopt a more sustainable to our consumption patterns (Goosey, 2004). In this high value this paper has an objective to select the best sustainable recycling method from alternatives based on the drivers with the assistance of Fuzzy AHP and AHP.

Literature review:

S.No	Author and Year	Research paper topic	Problem defined
1	Chehade et al (2012)	Recovery of gold, silver, palladium and copper from waste printed circuit boards	They designed a commercial process for the extraction of gold, silver, palladium and copper from waste printed circuit boards.
2	Gigliotti et al (2012)	Recycling of printed circuit boards	The paper had dealt with in the engineered material a new device which is capable of removing the material components from the printed circuit boards to prevent environmental pollution from non-recycled printed circuit boards.
3	Sohaili et al (2012)	A review on printed circuit board recycling technique	The paper explored the review on various technologies and potential reuses in the recycling process of printed circuit boards.
4.	Quan et al (2010)	Characterization of products recycling from PCB waste pyrolysis	This paper was studied on the recovering of valuable materials and energy from printed circuit boards.
5.	Wu et al (2010)	Recycling of waste printed circuit boards	They provided an update and latest results on recycling printed circuit boards which are more eco-friendly and efficient.
6.	Renteria et al (2009)	A systematic approach to define the reuse process of printed circuit board components	This paper presented an automated approach to support a decision on the best way for dismantling printed circuit boards in a non-destructive and selective mode.
7.	Marco et al (2008)	Pyrolysis of electrical and electronic wastes	The authors have made a study on pyrolysis for recovering the waste of electrical and electronic equipments (WEEE).

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8.	Xiang et al (2007)	Printed circuit board recycling process and its environment impact assessment	This research made a study in the recycling methods of printed circuit boards and its impact on the environment
9.	Yuan et al (2007)	Experimental studies on cryogenic recycling of printed circuit boards	The authors have presented results from a study of cryogenic decomposition as a potential alternative to method for recycling printed circuit boards.
10.	Zhou et al (2007)	Experimental study on metal recycling from waste PCB.	This paper explained about the method of Pyro metallurgy as a process of recycling printed circuit boards
11.	Goosey et al (2003)	Recycling technologies for the treatment of end of life printed circuit boards	This paper reports the results of a scoping study carried out to identify the technologies and processes that can be used to recycle materials from end of life PCBs.
12.	Legarth et al (1995)	Sustainable issues in printed circuit board recycling	This paper presented the resource, recovery and environmental issues on the recycling of printed circuit boards by secondary copper smelters.

Gap analysis:
From the literature review it is evident that there is no previous work which engages in the finding of best sustainable PCB recycling method. Even though some researchers explored the best method but they fail in sustainable context and it is a new approach of integrating MCDM tool with quantitative analysis in the investigation of sustainable PCB recycling methods.

Framework:

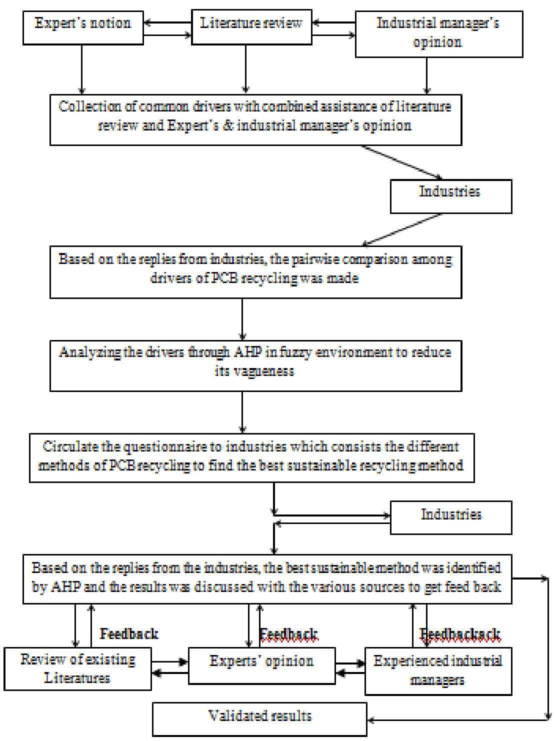

Fig 1 Proposed framework for identification of best sustainable PCB recycling method

Methodology:
In this study, the best sustainable PCB recycling method is identified based on the drivers of PCB recycling with the assistance of a hybrid MCDM tool. To achieve the goal of this study, the methodology consists of two phases which are mentioned below:

Phase I: Analyzing of drivers of PCB recycling:
This phase consists of consists of two steps to analyze the drivers of PCB recycling.

***Step 1:* Identification of PCB recycling drivers**
With the combined assistance of the literature survey, experts and industrial opinion, the drivers of PCB recycling were identified. It is done through direct meetings, e-mails and telephonic inquiries.

***Step 2:*Analyzing of drivers in fuzzy AHP**
From the replies of the industrial managers, the pairwise comparison among drivers was made on fuzzy environment based on Satty scale which is shown in table 2. These drivers are converted into crisp numbers from fuzzy numbers and the process is called as defuzzification which is shown in Table 3. Then the Defuzzified drivers were analyzed through the AHP based on the predefined steps proposed by salty, and the weightage of are shown in Table 4. There is a need to perform consistency checks to check whether the results are consistent which is mentioned below.

Sensitivity analysis:
There are many defuzzification methods but this paper considers only three methods of defuzzification namely Centroid method and Graded Mean Integration Representation (GMIR) method and Median method. The results obtained by these methods are shown in Fig 2 which shows the relationship and the deviation of the three methods from the linguistic method. From the sensitivity analysis, it is proved that the above results are trustworthy.

Phase II: Finding the best sustainable recycling method
This phase is the continuation of the previous phase, which defines the identification methodology of best sustainable PCB recycling method. The pairwise comparison of methods based on each driver is tabulated with the assistance of replies from the industrial managers. For an instance, the pairwise comparison and weightage of the method based on environmental conservation (D1) is shown in table 5, 5a and 5b. Similarly based on each and every driver, the weightage of recycling methods are calculated with the assistance of industrial manager's replies which is shown in table 6.

Table 2: Recycling methods and drivers of PCB recycling

S.No	PCB Recycling Methods	Drivers of PCB recycling
1.	Physical recycling method **(M1)**	Environmental conservation **(D1)**
2.	Chemical recycling method **(M2)**	Conservation of scarce resources **(D2)**
3.	Thermal processing **(M3)**	Reverse supply chain **(D3)**
4.	Nonthermal processing **(M4)**	Extended producer responsibility **(D4)**
5.	Liquefaction **(M5)**	Compliance with regulations **(D5)**
6.	Hydro metallurgical **(M6)**	Community groups **(D6)**
		Unemployment **(D7)**
		Pre-emption of future regulations **(D8)**
		Liability risk **(D9)**
		Sustainable support **(D10)**
		Financial support **(D11)**
		Societal pressure **(D12)**

Finally the weightage of recycling methods are calculated under the drivers which imply the sustainable integrations. The weightage of the recycling method was shown in table 6a.

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Results:

Table 2: Pairwise comparison among drivers in fuzzy environment

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
D1	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(3,4,5)	(4,5,6)	(2,3,4)	(2,3,4)	(1/3,1/2,1)	(4,5,6)	(4,5,6)	(1/3,1/2,1)	(1/3,1/2,1)
D2	(2,3,4)	(1,1,1)	(1,2,3)	(1/3,1/2,1)	(1/3,1/2,1)	(3,4,5)	(2,3,4)	(1/3,1/2,1)	(6,7,8)	(4,5,6)	(1/3,1/2,1)	(1/3,1/2,1)
D3	(1,2,3)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,2,3)	(1,2,3)	(1/4,1/3,1/2)	(3,4,5)	(2,3,4)	(1/3,1/2,1)	(1/3,1/2,1)
D4	(1/5,1/4,1/3)	(1,2,3)	(1,2,3)	(1,1,1)	(1,1,1)	(4,5,6)	(3,4,5)	(1,2,3)	(8,9,10)	(4,5,6)	(2,3,4)	(1,2,3)
D5	(1/6,1/5,1/4)	(1,2,3)	(1,2,3)	(1,,1,1)	(1,1,1)	(4,5,6)	(3,4,5)	(1,2,3)	(7,8,9)	(7,8,9)	(1,2,3)	(1,2,3)
D6	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1,2,3)	(1,2,3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)
D7	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,2,3)	(1,1,1)	(1/5,1/4,1/3)	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
D8	(1,2,3)	(1,2,3)	(2,3,4)	(1/3,1/2,1)	(1/3,1/2,1)	(4,5,6)	(3,4,5)	(1,1,1)	(8,9,10)	(7,8,9)	(1,2,3)	(1,2,3)
D9	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1/5,1/4,1/3)	(1/10,1/9,1/8)	(1/9,1/8,1/7)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/10,1/9,1/8)	(1,1,1)	(1/3,1/2,1)	(1/9,1/8,1/7)	(1/9,1/8,1/7)
D10	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/9,1/8,1/7)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/9,1/8,1/7)	(1,2,3)	(1,,1,1)	(1/7,1/6,1/5)	(1/7,1/6,1/5)
D11	(1,2,3)	(1,2,3)	(1,2,3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(3,4,5)	(2,3,4)	(1/3,1/2,1)	(7,8,9)	(5,6,7)	(1,1,1)	(1,1,1)
D12	(1,2,3)	(1,2,3)	(1,2,3)	(1/3,1/2,1)	(1/3,1/2,1)	(3,4,5)	(2,3,4)	(1/3,1/2,1)	(7,8,9)	(5,6,7)	(1,1,1)	(1,1,1)

Table 3: Defuzzifed matrix in linguistic method

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
M1	1	0.333333	0.5	4	5	3	3	0.5	5	5	0.5	0.5
M2	3	1	2	0.5	0.5	4	3	0.5	7	5	0.5	0.5
M3	2	0.5	1	0.5	0.5	2	2	0.333333	4	3	0.5	0.5
M4	0.25	2	2	1	1	5	4	2	9	5	3	2
M5	0.2	2	2	1	1	5	4	2	8	8	2	2
M6	0.333333	0.25	0.5	0.2	0.2	1	0.5	0.2	2	2	0.25	0.25
M7	0.333333	0.333333	0.5	0.25	0.25	2	1	0.25	3	3	0.333333	0.333333
M8	2	2	3	0.5	0.5	5	4	1	9	8	2	2
M9	0.2	0.142857	0.25	0.111111	0.125	0.5	0.333333	0.111111	1	0.5	0.125	0.125
M10	0.2	0.2	0.333333	0.2	0.125	0.5	0.333333	0.125	2	1	0.166667	0.166667
M11	2	2	2	0.333333	0.5	4	3	0.5	8	6	1	1
M12	2	2	2	0.5	0.5	4	3	0.5	8	6	1	1

Table 4: Standardized matrix - linguistic method

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	Weightage
M1	0.073983	0.026124	0.031088	0.439829	0.490196	0.083333	0.106509	0.062348	0.075758	0.095238	0.043956	0.048193	0.13137960
M2	0.221948	0.078373	0.124352	0.054979	0.04902	0.111111	0.106509	0.062348	0.106061	0.095238	0.043956	0.048193	0.09184063
M3	0.147965	0.039186	0.062176	0.054979	0.04902	0.055556	0.071006	0.041566	0.060606	0.057143	0.043956	0.048193	0.06094592
M4	0.018496	0.156746	0.124352	0.109957	0.098039	0.138889	0.142012	0.249394	0.136364	0.095238	0.263736	0.192771	0.14383281
M5	0.014797	0.156746	0.124352	0.109957	0.098039	0.138889	0.142012	0.249394	0.121212	0.152381	0.175824	0.192771	0.13969782
M6	0.024661	0.019593	0.031088	0.021991	0.019608	0.027778	0.017751	0.024939	0.030303	0.038095	0.021978	0.024096	0.02515690
M7	0.024661	0.026124	0.031088	0.027489	0.02451	0.055556	0.035503	0.031174	0.045455	0.057143	0.029304	0.032129	0.03501125
M8	0.147965	0.156746	0.186528	0.054979	0.04902	0.138889	0.142012	0.124697	0.136364	0.152381	0.175824	0.192771	0.13818127
M9	0.014797	0.011196	0.015544	0.012217	0.012255	0.013889	0.011834	0.013855	0.015152	0.009524	0.010989	0.012048	0.01277500
M10	0.014797	0.015675	0.020725	0.021991	0.012255	0.013889	0.011834	0.015587	0.030303	0.019048	0.014652	0.016064	0.01723500
M11	0.147965	0.156746	0.124352	0.036652	0.04902	0.111111	0.106509	0.062348	0.121212	0.114286	0.087912	0.096386	0.10120828
M12	0.147965	0.156746	0.124352	0.054979	0.04902	0.111111	0.106509	0.062348	0.121212	0.114286	0.087912	0.096386	0.102735467

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Procedures for consistency Check:

AX= λAvg X

□	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
M1	1	0.33	0.5	4	5	3	3	0.5	5	5	0.5	0.5
M2	3	1	2	0.5	0.5	4	3	0.5	7	5	0.5	0.5
M3	2	0.5	1	0.5	0.5	2	2	0.33	4	3	0.5	0.5
M4	0.25	2	2	1	1	5	4	2	9	5	3	2
M5	0.2	2	2	1	1	5	4	2	8	8	2	2
M6	0.33	0.25	0.5	0.2	0.2	1	0.5	0.2	2	2	0.25	0.25
M7	0.33	0.33	0.5	0.25	0.25	2	1	0.25	3	3	0.33	0.33
M8	2	2	3	0.5	0.5	5	4	1	9	8	2	2
M9	0.2	0.143	0.25	0.111	0.125	0.5	0.33	0.11	1	0.5	0.125	0.125
M10	0.2	0.2	0.33	0.2	0.125	0.5	0.33	0.125	2	1	0.167	0.167
M11	2	2	2	0.33	0.5	4	3	0.5	8	6	1	1
M12	2	2	2	0.5	0.5	4	3	0.5	8	6	1	1

$$\text{x} \begin{bmatrix} X \\ 0.131 \\ 0.092 \\ 0.061 \\ 0.144 \\ 0.140 \\ 0.025 \\ 0.035 \\ 0.138 \\ 0.012 \\ 0.017 \\ 0.101 \\ 0.102 \end{bmatrix} = \lambda_{Avg}\text{x} \begin{bmatrix} X \\ 0.131 \\ 0.092 \\ 0.061 \\ 0.144 \\ 0.140 \\ 0.025 \\ 0.035 \\ 0.138 \\ 0.012 \\ 0.017 \\ 0.101 \\ 0.102 \end{bmatrix}$$

$$\begin{bmatrix} AX \\ 1.968 \\ 1.302 \\ 0.882 \\ 1.874 \\ 1.805 \\ 0.335 \\ 0.453 \\ 1.836 \\ 0.175 \\ 0.229 \\ 1.370 \\ 1.394 \end{bmatrix} = \lambda_{Avg}\text{x} \begin{bmatrix} X \\ 0.131 \\ 0.092 \\ 0.061 \\ 0.144 \\ 0.140 \\ 0.025 \\ 0.035 \\ 0.138 \\ 0.012 \\ 0.017 \\ 0.101 \\ 0.102 \end{bmatrix}$$

$$\begin{bmatrix} AX \\ 1.968 \\ 1.302 \\ 0.882 \\ 1.874 \\ 1.805 \\ 0.335 \\ 0.453 \\ 1.836 \\ 0.175 \\ 0.229 \\ 1.370 \\ 1.394 \end{bmatrix} \div \begin{bmatrix} X \\ 0.131 \\ 0.092 \\ 0.061 \\ 0.144 \\ 0.140 \\ 0.025 \\ 0.035 \\ 0.138 \\ 0.012 \\ 0.017 \\ 0.101 \\ 0.102 \end{bmatrix} = \lambda_{Avg}\lambda_{Avg} = \begin{bmatrix} 14.979 \\ 14.176 \\ 14.481 \\ 13.302 \\ 12.925 \\ 13.326 \\ 12.957 \\ 13.285 \\ 13.664 \\ 13.315 \\ 13.541 \\ 13.573 \end{bmatrix} \qquad \lambda_{Avg} = 13.6$$

C.I = $(\lambda_{Avg-n}) \div (n-1)$
= (13.6 - 12) ÷ (12-1)
C. I= 0.146

Random index for n matrix

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

R.I = 1.48
C.R =0.099 < 0.1
The C.R is less than 0.1, so the evaluation is consistent and correct

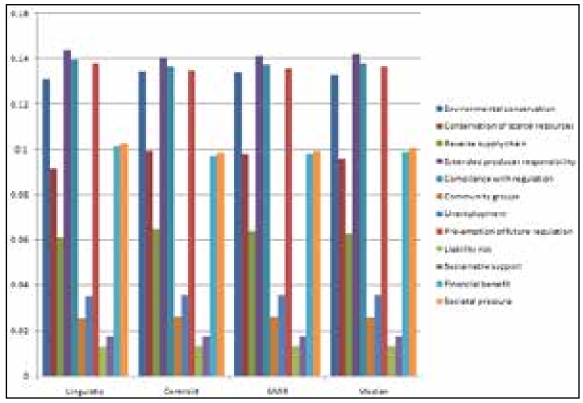

Fig 2: Sensitivity analysis between different defuzzification methods

Table 5: Environmental conservation

	Physical recycling method **(M1)**	Chemical recycling method **(M2)**	Thermal processing **(M3)**	Non-thermal processing **(M4)**	Liquefaction **(M5)**	Hydrometallurgical **(M6)**
Physical recycling method **(M1)**	1.00	0.17	0.25	0.50	0.33	0.33
Chemical recycling method **(M2)**	6.00	1.00	2.00	4.00	2.00	1.33
Thermal processing **(M3)**	4.00	0.50	1.00	2.00	4.00	2.00
Non-thermal processing **(M4)**	2.00	0.25	0.50	1.00	1.33	2.00
Liquefaction **(M5)**	3.00	0.50	0.25	0.75	1.00	0.50
Hydrometallurgical **(M6)**	3.00	0.75	0.50	0.50	2.00	1.00
	19.00	3.17	4.50	8.75	10.67	7.17

Table 5a: standardized matrix

	M1	**M2**	**M3**	**M4**	**M5**	**M6**
M1	0.05	0.05	0.06	0.06	0.03	0.05
M2	0.32	0.32	0.44	0.46	0.19	0.19
M3	0.21	0.16	0.22	0.23	0.38	0.28
M4	0.11	0.08	0.11	0.11	0.13	0.28
M5	0.16	0.16	0.06	0.09	0.09	0.07
M6	0.16	0.24	0.11	0.06	0.19	0.14

Table 5b: Weightage of Methods corresponding to driver

Sum of rows	Eigen values
0.30	0.05
1.91	0.32
1.47	0.25
0.81	0.14
0.62	0.10
0.89	0.15
6.00	

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Table 6: Overall weightage of methods based on drivers

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Physical recycling method (M1)	0.00719	0.00698	0.009667	0.007878	0.006162	0.00506	0.00459	0.003045	0.0014	0.001255	0.000862	0.000639
Chemical recycling method (M2)	0.046016	0.040484	0.045573	0.044642	0.034918	0.03036	0.028458	0.018879	0.01155	0.007781	0.006203	0.004853
Thermal processing (M3)	0.03595	0.0349	0.017953	0.027573	0.021567	0.021252	0.020196	0.013398	0.0091	0.005773	0.002757	0.002682
Non-thermal processing (M4)	0.020132	0.022336	0.026239	0.022321	0.017459	0.014168	0.015606	0.008526	0.00455	0.003263	0.003446	0.002171
Liquefaction (M5)	0.01438	0.018148	0.02762	0.017069	0.013351	0.013156	0.01377	0.007917	0.00595	0.004016	0.00224	0.001405
Hydrometallurgical (M6)	0.02157	0.016752	0.009667	0.01313	0.01027	0.017204	0.00918	0.009135	0.00245	0.003263	0.001895	0.001022

Table 6a: PCB recycling methods rankings

PCB Recycling Methods	Sum of rows	Weightage	Rank
Physical recycling method	0.054727	0.054600311	VI
Chemical recycling method	0.3197164	0.318976279	I
Thermal processing	0.2131005	0.212607188	II
Non-thermal processing	0.1602169	0.159846009	III
Liquefaction	0.1390216	0.138699775	IV
Hydrometallurgical	0.1155379	0.115270438	V
	1.0023203		

The above tabulated results were sent to the industries from where the drivers were collected for discussion. They replied us through email stating that the results derived by us from the replies to the questionnaire was apt to their results to and they also added that the experimental results in their industries were also coinciding with our theoretical results.

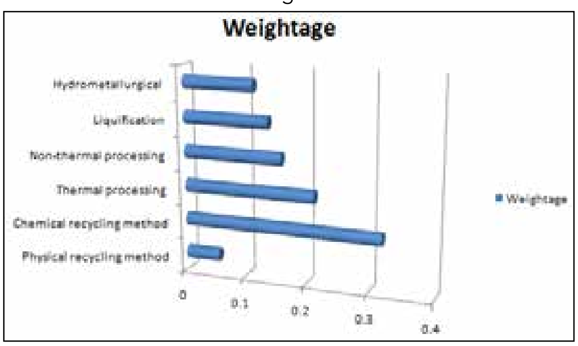

Fig 3 Pictorial representation of best sustainable recycling methods among other PCB recycling methods

Conclusion:

PCB recycling is currently focused on much concern because of the growing waste volumes which contains hazardous materials and valuable source of recyclable and reusable materials.Due to the huge waste, they were disposed by the process of land fillings, but by land filling many precious metals present in those PCBs were lost, so there is high need to recycle for its value recovery. In this concern, this work has been defined the best methodology for a selective a best sustainable PCB recycling method from collected all possible methods based on its drivers. In this study it is found that the extended producer responsibility (D4) is the high impact driver which yields more weightage among other drivers of PCB recycling, based on this the research revealed that the chemical recycling method (M2) is the best sustainable method among other PCB recycling methods which has lot of economic, environment and Societal implications. SThis study is also providing some future scope by diversifying the drivers and MCDM tools.

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