IMAGE: A MAP OF THE STARS OF THE ORION CONSTELLATION

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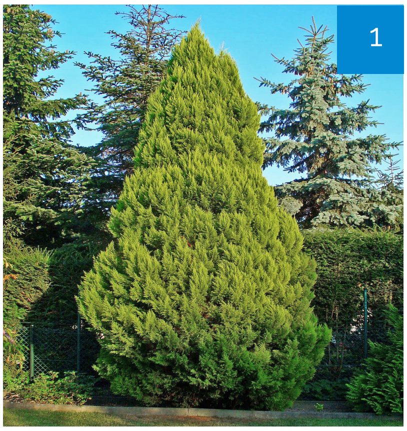

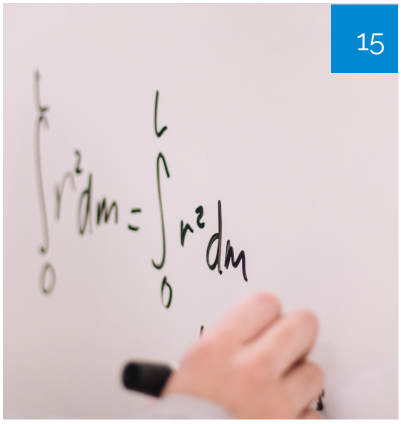

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Yuri Kang & Woonjung Kim

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ABSTRACT

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Keywords: chamaecyparis obtusa leaf, senile body odor, antioxidant capacity, antimicrobial, 2-nonenal removal.

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ABSTRACT

In this research, extracts were extracted at an ethanol ratio to find out the active ingredients with the effect of removing 2-nonenal($C_9H_{16}O$), which is the cause of senile body odor, of the hot water extract of Chamaecyparis obtusa leaf. Also, the component analysis, antioxidant capacity, polyphenol, and flavonoid quantitative analysis, antimicrobial activity, and 2-nonenal removal efficiency were investigated. In the measurement of chromaticity, the higher the ethanol ratio in the Chamaecyparis obtusa leaf extract, the more the yellowness decreased, and the redness increased. GC-MS component analysis showed the active ingredient of the sesquiterpene group. LC-MS quantitative analysis showed a high polyphenol content in 40% ethanol extract. In the antioxidant experiment of Chamaecyparis obtusa leaf extract, more than 50 % of the ethanol extract showed higher antioxidant activity than the ascorbic acid control. It showed more than 80 % antimicrobial activity against Staphylococcus aureus strain, a food poisoning-causing bacterium, under all extraction conditions. Among them, 100 % ethanol extract showed high antimicrobial activity of 99.9 %. In addition, the highest 2-nonenal removal efficacy was investigated in the ethanol 40 % extraction.

Keywords: *chamaecyparis obtusa leaf, senile body odor, antioxidant capacity, antimicrobial, 2-nonenal removal.*

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I. INTRODUCTION

In the era of the aging population rapidly increased, as interest in health increases, researches on functional bioactive materials for suppressing aging and maintaining health is being extensively studied in each field [1]. The most notable cause of aging in the body is free radicals, which damage skin cells and tissues and break down the antioxidant defense system so that it causes disease and accelerates aging [2]. Therefore, as it is recently recognized that the cause of adult disease and aging is due to free radicals, researches on antioxidants known as substances that can control or remove the free radicals have been reported [3]. In addition, the changes in the monounsaturated fatty acid composition of the skin surface that appear as aging progress cause an increase in lipid peroxides related to aging and then produce 2-nonenal [4]. It is reported that 2-nonenal, which has been pointed out as the main cause of senile body odor, has a correlation with the increase in age. Still, the sensitivity of smell decreases in the older adults, and more than three-quarters of the 80's elderly cannot smell at all, regardless of living conditions or cultural levels [5]. For this reason, the elderly may not be aware of it, but it may affect those around them and cause conflicts. According to recent research trends related to natural substances, it is reported that ingredients with excellent physiological activity among extracts such as wood and leaves of trees can be used as functional materials [6].

Chamaecyparis obtusa is an evergreen coniferous tree of the *Cupressaceae* family in the Chamaecyparis genus, which is native to Japan, and it is mainly grown in Jeju Island and southern regions of Korea. The main component of phytoncide, which is reported to be contained in a large amount in Chamaecyparis obtusa leaves, is a terpene, which gives a forest bathing effect with a characteristic scent from the stern and has various functional effects such as antimicrobial, insect repellent, and deodorizing properties [7-8]. Essential oil of Chamaecyparis obtusa consists of about

66% monoterpenes and 25% sesquiterpenes, and the main components are sabinene, limonene, bornyl acetate, borneol+α-terpineol, and elemol ($C_{15}H_{26}O$) [9].

According to the previous researches on Chamaecyparis obtusa, there are studies on the component analysis and immune efficacy of Chamaecyparis obtusa leaf extract [10], studies on antioxidant and whitening effects [11], studies suggesting the possibilities of using it as a natural preservative [12], studies suggesting the practical potential as a skin improvement agent for atopic infants [13], and studies suggesting that terpinen-4-ol($C_{10}H_{18}O$), a monoterpene type of Chamaecyparis essential oil, is an effective antifungal agent and has an insect repellent function [14].

A general method for extracting such a natural product includes a steam distillation method using a solvent, a methanol extraction method, an ethanol extraction method, an ether extraction method, a propylene glycol extraction method, a supercritical fluid extraction method using carbon dioxide, and the like. The filtration methods for separating natural products include the vacuum-filtration (VF) method and micro-filtration (MF) method [15].

Among them, most studies related to Chamaecyparis obtusa extract have been conducted by extracting Chamaecyparis essential oil. These are mainly reported as studies related to component analysis, activity studies, and antimicrobial action of the essential oils [11]. Accordingly, in this research, the hot water extraction method was used to confirm the differences in the components appearing according to the extraction method. The composition of the extraction components was compared according to the ratio of the extraction solvent. In addition, by applying the Chamaecyparis obtusa leaf extract, the removal efficacy of 2-nonenal was investigated along with component analysis, antioxidant action, and antimicrobial action.

II. EXPERIMENT

2.1 Sample

The Chamaecyparis obtusa leaf used in the experiment was domesticated (collected from the Chamaecyparis obtusa forest in Jangseong-gun, Jeollanam-do) and was purchased in February 2021. Samples were prepared by taking only the leaves after washing and removing stems and refrigerated until use for the experiment.

2.2 Chamaecyparis obtusa leaf extract

For extraction of Chamaecyparis Obtusa leaves, 0 ~ 100 % ethanol was used as the solvent. The solvent was set to 300 ㎖, and the sample was set to 30 g. Using a high-pressure hot water extractor (KSP-240L, KYUNGSEO E&P, Incheon, South Korea), the extraction process was performed for the sample at a temperature of 80 ℃, a pressure of 0.06 MPa, and an extraction time of 3 hours. The extracted solution was filtered under reduced pressure using a 5~8 ㎛ filter. The filtrate was concentrated with a vacuum concentrator and refrigerated at four ℃ for storing.

2.3 Colorimetric Analysis for Chamaecyparis Obtusa Leaf Extract

The Chamaecyparis obtusa leaf extracts according to the ethanol concentration was measured using a colorimeter (CR-400, Konica Minolta, Tokyo, Japan), and the average value was calculated by measuring three times in the same manner. The measured values were expressed as the values of L*(brightness), a*(redness), b*(yellowness)

2.4 Component analysis for Chamaecyparis obtusa leaf extract

A GC-MS analysis method was used to analyze the composition of the Chamaecyparis obtusa leaf extract. For GC (Agilent 19091S-433) analysis, HP-5ms (30 m x 250 μm x 0.25 μm) was used as the column. Helium (He) was used for the carrier gas. After maintaining the initial temperature at 60 °C for 2 minutes, the oven temperature was increased by ten °C/min to the final temperature of 270 °C. Then the analysis was carried out while maintaining the temperature for 10 minutes.

2.5 Content analysis for polyphenol and flavonoid in Chamaecyparis obtusa leaf extract

Polyphenol content analysis was confirmed using the LC-MS analysis method. Pretreatment was conducted by diluting the polyphenol standard sample (Gallic acid, Daejung Chemicals & Metals Co. Ltd, Siheung, Korea) and the sample preparation. The ULTIMATE3000 RSLC was used for LC equipment, and The Q-EXACTIVE ORBITRAP PLUS MS was used for MS equipment. The injection volume was set to 5 ㎕, and MS condition was performed in negative mode. The quantitative analysis set the auxiliary gas flow rate to 13, the capillary temperature to 263 °C, and the auxiliary gas heater temperature to 25 °C.

The analysis method for the standard sample (Quercetin, SIGMA, Missouri, USA) used for flavonoid content analysis was set with the same equipment and experimental conditions as the polyphenol content analysis equipment. The quantitative analysis was performed by setting the auxiliary heater temperature to 425 °C.

2.6 Antioxidant efficacy analysis for Chamaecy paris obtusa leaf extract

The DPPH method is a representative experimental method to confirm the scavenging ability for free radicals. The DPPH standard sample used in this experiment was 2,2-Diphenyl -1- picrylhydrazyl(free radical), 95 % Powder from Alfa Aesar. As for the experimental method, adding each of 1 ㎖ of extracts of various concen- trations to a 1.5 mM DPPH solution dissolved in methanol, mixing them, and then leaving the mixture at room temperature for 10 minutes, the absorbance was measured at 517 ㎚ using UV/Vis spectrophotometer(KLAB, Deajeon, Korea). The DPPH scavenging activity inhibition rate (IR) was calculated using the following equation with the absorbance values of the control group to which the sample was not added and the experimental group to which the sample was added [16].

$$IR(\%) = \frac{Abs_{(control)} - Abs_{(sample)}}{Abs_{(control)}} \text{ x } 100$$

$$(Abs_{sample} = Abs_{test} - Abs_{color})$$

2.7 Antimicrobial activity analysis for Chamaecyparis obtusa leaf extract

The strain used for the measurement of antimicrobial activity was test-sterilized *Staphylococcus aureus* (ATCC 6538) (from the Korea National Institutes of Health) in an Autoclave (121 ± 2℃) for 15 minutes. Phosphate buffer (pH 7.2, SIGMA, Taufkirchen, Germany) was set to 50 ㎖, and the weight of the sample was set to 1.0 ㎖ for analysis.

2.8 2-Nonenal removal efficacy analysis for Chamaecyparis obtusa leaf extract

The trans-2-Nonenal used for the analysis of 2-nonenal removal efficacy was purchased from TOKYO CHEMICAL INDUSTRY. 50 ㎕ of Chamaecyparis obtusa leaf extract was injected into 1 ㎖ trans-2-Nonenal reference material diluted to 0.0075 % and dispersed at 500 RPM for 30 minutes. Solutions A and B were each injected in 150 ㎕ and left in an oven at 60 ℃ for 15 minutes. After that, only the supernatant was taken, and the absorbance was measured at 300 ㎚.

III. RESULTS AND DISCUSSION

3.1 Chamaecyparis obtusa leaf extract

The yield of the Chamaecyparis obtusa leaf extract, according to the extraction conditions, showed a tendency to decrease as the ethanol content increased. It was estimated that this was due to the effect of evaporation in the extraction process (80 ℃) since the boiling point of ethanol is 78 ℃. As a result, it was confirmed that a very low yield of 1.7 % was obtained in 100% ethanol. The result is shown in Table Ⅰ.

Table I : The yield for Chamaecyparis obtusa leaf

No	Water : Ethanol	After decompression(g)	After concentration(g)	Yield(%)
A	100 : 0	354.0	339.0	95.7
B	80 : 20	279.0	173.0	62.0
C	60 : 40	230.0	154.0	66.9
D	50 : 50	245.0	177.0	72.2
E	40 : 60	326.0	137.0	42.0
F	20 : 80	285.0	82.0	28.7
G	0 : 100	289.0	5.0	1.7

3.2 Colorimetric for Chamaecyparis obtusa leaf extract

From the colorimetric measurement results for Chamaecyparis obtusa leaf extract as shown in Table Ⅱ and Figure 1. the L value and the yellowness b* show a tendency to sharply decrease as the ethanol content increases. Still, the redness a* shows a tendency to gradually increase.

Table II: Colorimetric results of Chamaecyparis obtusa leaf

	A	B	C	D	E	F	G
L*	39.57	39.40	38.80	31.60	28.62	21.13	8.41
a*	0.87	1.22	1.24	1.28	1.31	1.36	2.90
b*	17.62	16.27	10.94	10.39	7.27	3.24	1.77

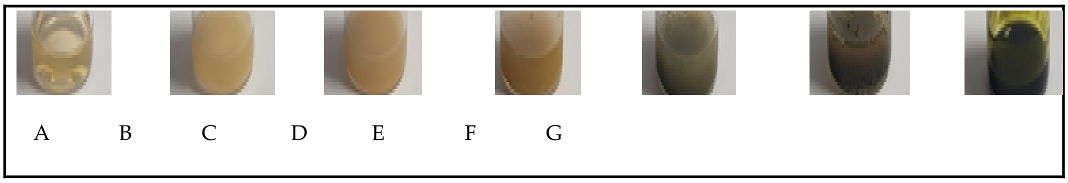

Figure 1: Chamaecyparis obtusa leaf extract

3.3 GC-MS analysis for active ingredients of Chamaecyparis obtusa leaf extract

As the result of GC-MS analysis, various aromatic components were identified in the Chamaecyparis obtusa leaf extract. When compared by the concentration of the extract, the most active ingredient was detected at 100 % ethanol. The results are shown in Figure 2. to Figure 8.

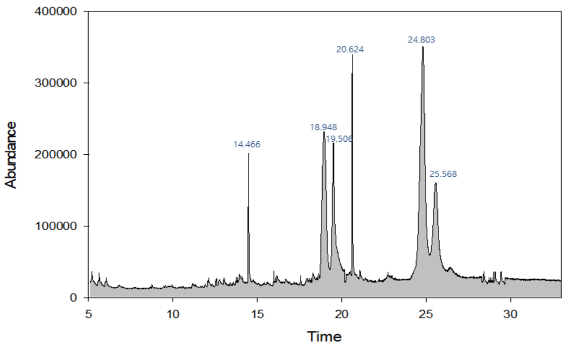

Figure 2: GC-MS chromatogram of 0 % ethanol extracts A of Chamaecyparis obtusa leaf

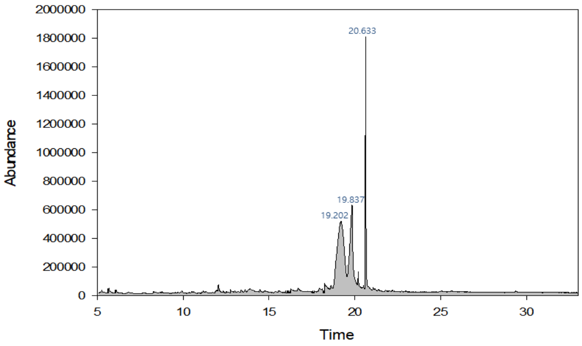

Figure 3: GC-MS chromatogram of 20 % ethanol extracts B of Chamaecyparis obtusa leaf

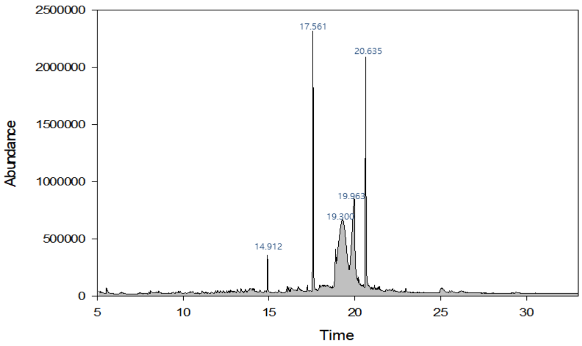

Figure 4: GC-MS chromatogram of 40 % ethanol extracts C of Chamaecyparis obtusa leaf

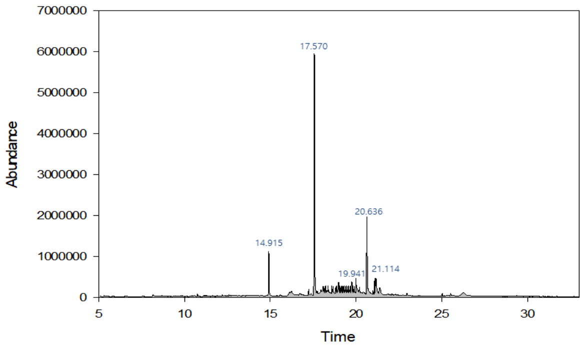

Figure 5: GC-MS chromatogram of 50 % ethanol extracts D of Chamaecyparis obtusa leaf

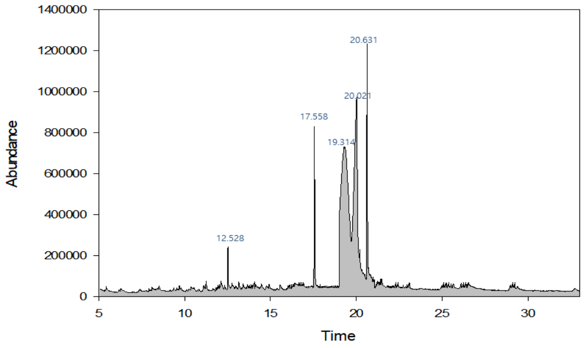

Figure 6: GC-MS chromatogram of 60 % ethanol extracts E of Chamaecyparis obtusa leaf

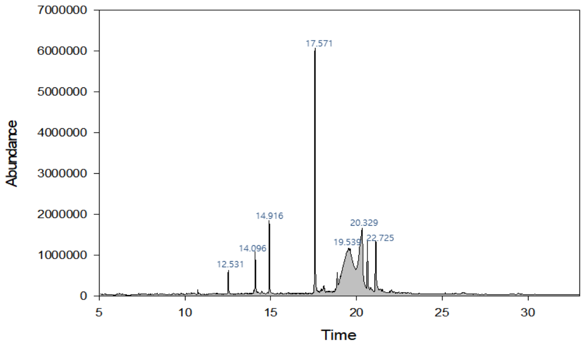

Figure 7: GC-MS chromatogram of 80% ethanol extracts F of Chamaecyparis obtusa leaf

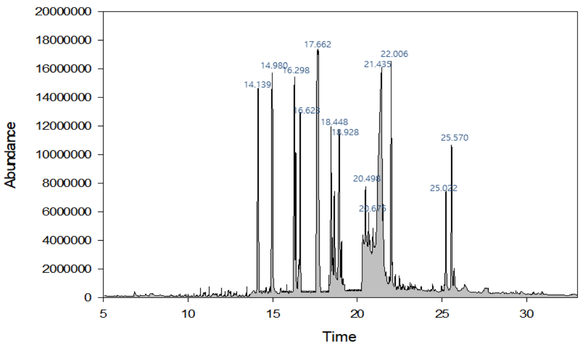

Figure 8: GC-MS chromatogram of 100% ethanol extracts G of Chamaecyparis obtusa leaf

When compared by extract concentration, the higher the ethanol content, the higher the active ingredient was detected. As shown in Figure 8. The most active ingredients and concentrations were confirmed at ethanol 100 %. The extract components analyzed by GC-MS are shown in Table Ⅲ to Table Ⅸ.

Table III: GC-MS chromatogram profile of 0 % ethanol extracts A of Chamaecyparis obtusa leaf

Retention time (RT)	Name of the compound	Quality	Area peak (%)
14.466	vinylphenol	96	2.69
18.948 19.506	MOME INOSITOL	58 43	18.54 12.69
20.624	Eudesmol	87	4.05
24.803 25.568	Heptamethoxyflavone	50 91	35.23 14.64

Table IV: GC-MS chromatogram profile of 20 % ethanol extracts B of Chamaecyparis obtusa leaf

Retention time (RT)	Name of the compound	Quality	Area peak (%)
19.202	MOME INOSITOL	62	41.45
19.837	Terpinen-4-ol	53	24.04
20.633	Eudesmol	91	13.88

Table V: GC-MS chromatogram profile of 40 % ethanol extracts C of Chamaecyparis obtusa leaf

Retention time (RT)	Name of the compound	Quality	Area peak (%)
14.912	CARENE	94	1.33
17.561	Elemol	91	9.06
19.300	MOME INOSITOL	93	33.63
19.963	Terpinen-4-ol	58	19.04
20.635	Eudesmol	83	10.67

Table VI: GC-MS chromatogram profile of 50 % ethanol extracts D of Chamaecyparis obtusa leaf

Retention time (RT)	Name of the compound	Quality	Area peak (%)
14.915	CARENE	94	2.91

17.570	Elemol	91	16.14
19.941	MOME INOSITOL	55	12.24
20.636	Eudesmol	87	7.44

Table VII: GC-MS chromatogram profile of 60 % ethanol extracts E of Chamaecyparis obtusa leaf

Retention time (RT)	Name of the compound	Quality	Area peak (%)
12.528	Terpinen-4-ol	98	0.92
17.558	Elemol	89	2.95
19.314	MOME INOSITOL	96	35.73
20.021	cyclopentane	64	20.26
20.631	Eudesmol	91	6.01

Table VIII: GC-MS chromatogram profile of 80 % ethanol extracts F of Chamaecyparis obtusa leaf

Retention time (RT)	Name of the compound	Quality	Area peak (%)
12.531	Terpinen-4-ol	97	1.09
14.096	Bornyl acetate	99	1.87
14.916	CARENE	93	2.95
17.571	Elemol	91	10.53
19.539	MOME INOSITOL	96	18.69
20.329		43	18.75
22.725	Furanone	58	0.07

Table IX: GC-MS chromatogram profile of 100 % ethanol extracts G of Chamaecyparis obtusa leaf

Retention time (RT)	Name of the compound	Quality	Area peak (%)
14.139	Acetic acid	98	3.72
14.980	CARENE	93	4.62
16.286	Thujopsene	99	3.34
16.623	Bicyclosesquiphellandrene	95	2.65
17.662	Elemol	91	9.41
18.448	Cedrol	96	2.03
18.928	Eudesmol	98	3.29
20.486	MOME INOSITOL	25	2.98
20.675	Thiophene	38	2.83
21.435	Phenol	18	15.60
22.006	Beyerene	99	3.38
25.236	Phenanthrenol	95	1.47
25.570		99	2.14

3.4 Antioxidant effect analysis for active ingredients of Chamaecyparis obtusa leaf extract

As a result of measuring the DPPH radical scavenging ability of the Chamaecyparis obtusa leaf extract, the IC_{50} value of ascorbic acid used as a control group was 1.70; A was 3.04, B was 2.44, D was 1.70, E was 1.66, F was 1.58 and G was 1.63, so it was found that the extracts E ~ G with more than 50 % of ethanol showed higher antioxidant effect than ascorbic acid.

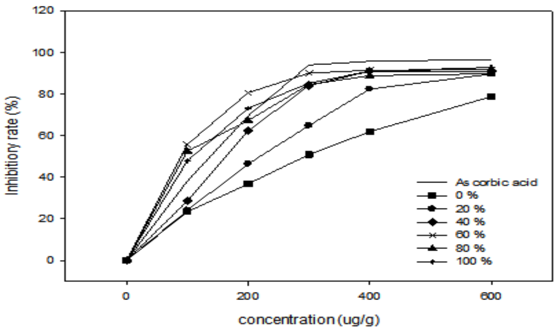

Figure 9: Comparison of the inhibitory rate of the extract by ethanol ratio.

3.5 Analysis of polyphenol and flavonoid contents

The total polyphenol content of the Chamaecyparis obtusa leaf extract was measured using gallic acid as reference material. The total polyphenol content of Chamaecyparis obtusa leaf extract converted to gallic acid is shown in Table Ⅹ, and the graph comparing the polyphenol content of each extract is shown in Figure 10. As a result of the experiment, the highest polyphenol content was confirmed at the ethanol 40 % extract C.

The total flavonoid content of the Chamaecyparis obtusa leaf extract was measured using Quercetin as reference material. The total flavonoid content of Chamaecyparis obtusa leaf extract converted to Quercetin is shown in Table ⅩⅠ, and the graph comparing the flavonoid content of each extract is shown in Figure 11. As a result of the experiment, the highest flavonoid content was confirmed at the ethanol 100 % extract G.

Table X: Polyphenol content level

	Final conc. (ug/ml)	Area peak
A	1.760	6,293,210
B	0.890	2,982,439
C	6.359	23,794,093
D	1.372	4,819,903
E	1.136	3,919,670
F	1.512	5,349,640
G	1.732	6,188,643

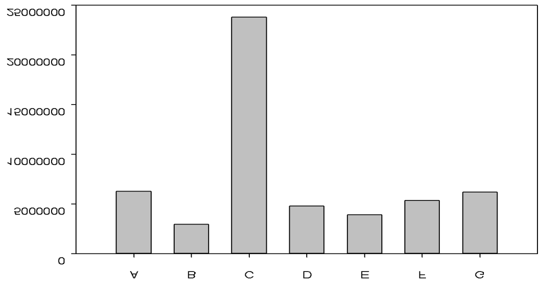

Figure 10: Polyphenol levels comparison

Table XI: Flavonoid content level

	Final conc. (ug/ml)	Area peak
A	104.767	36,208,117
B	131.684	55,389,930
C	103.646	35,409,359
D	106.466	37,418,502
E	106.274	37,282,180
F	95.901	29,889,743
G	200.985	104,775,356

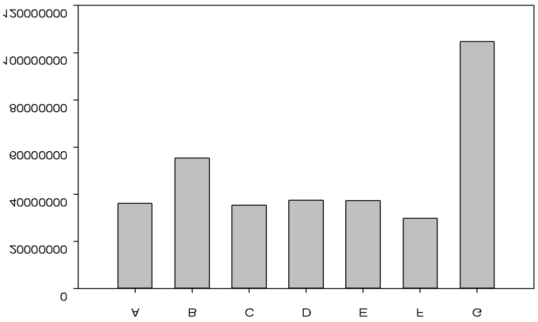

Figure 11: Flavonoid levels comparison

3.6 Antimicrobial analysis for active ingredient of Chamaecyparis obtusa leaf extract

The results of the antimicrobial analysis of Chamaecyparis obtusa leaf extract are shown in Table ⅩⅡ, and the comparative graph of the bacterial reduction rate of each extract is shown in Figure 12. As a result of the experiment, it was found that the antimicrobial activity increased as the ethanol content increased. In particular, the 100 % ethanol extract G showed a high bacterial reduction rate of 99.9 % after 24 hours. Therefore, as a result of the antimicrobial analysis, it was confirmed that the hot water extract component of the Chamaecyparis obtusa leaf had a high antimicrobial effect on *Staphylococcus aureus* bacteria.

Table XII: Results of an antimicrobial analysis of Chamaecyparis obtusa leaf for *Staphylococcus aureus*

	Blank	A	B	C
Initial number of bacteria	2.1×10^5	2.1×10^5	2.1×10^5	2.1×10^5
after 24 hours	1.5×10^5	2.0×10^4	1.9×10^4	8.2×10^3
Bacterial reduction rate	-	86.7	87.3	94.5
	D	E	H	G
Initial number of bacteria	2.1×10^5	2.1×10^5	2.1×10^5	2.1×10^5
after 24 hours	4.6×10^3	5.0×10^3	2.5×10^3	< 30
Bacterial reduction rate	96.9	96.7	98.3	99.9

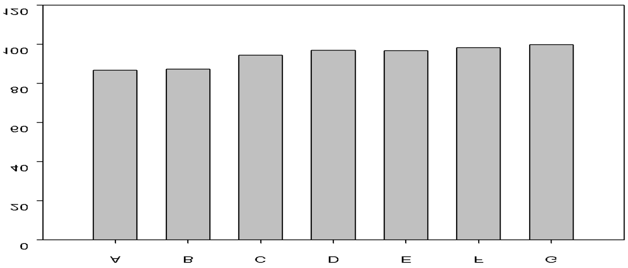

Figure 12: Comparison of antibacterial activity against *Staphylococcus aureus* of Chamaecyparis obtusa leaf extract

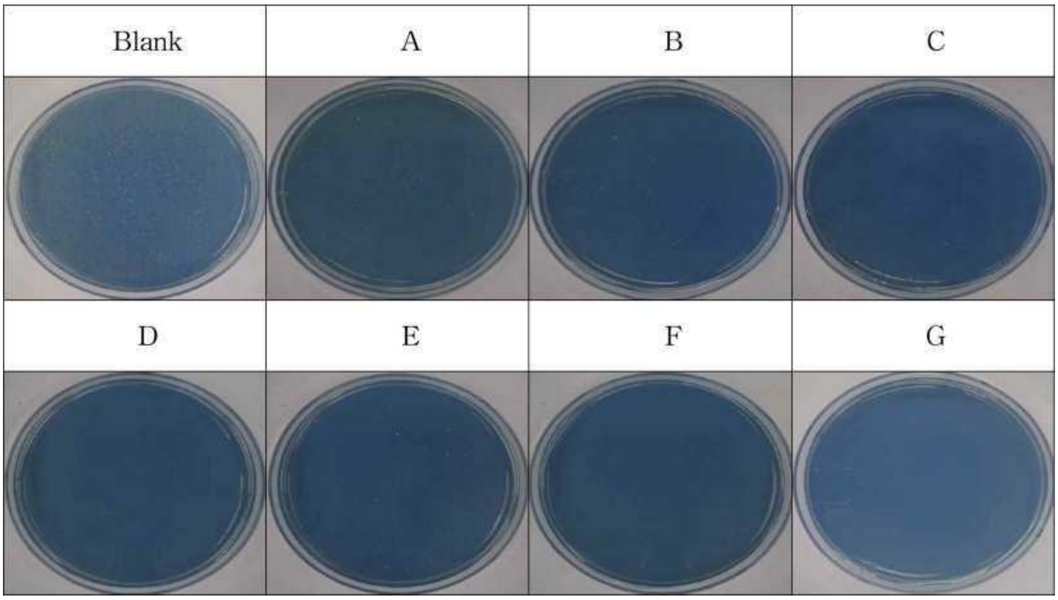

Figure 13: Analysis of the antibacterial properties of Chamaecyparis obtusa leaf for Staphylococcus aureus

Analysis for 2-nonenal removal effect for active ingredient of Chamaecyparis obtusa leaf extract. The result of the 2-nonenal removal effect is shown in Table XⅢ. A high removal rate of 97.09 % was confirmed at the ethanol 40 % extract C.

Table XIII: Absorbance measurement results to determine 2-nonenal removal effect

	Absorbance (300 ㎚)	Removal rate (%)
Control	1.304	
A	0.85	34.82
B	0.367	71.86
C	0.038	97.09
D	0.834	36.04
E	0.963	26.15
F	0.858	34.20
G	1.351	-

IV. CONCLUSIONS

As a result of the efficacy analysis of the hot water extract of Chamaecyparis obtusa leaf, the following conclusions were confirmed.

1. As a result of colorimetric analysis, the L value and the yellowness b* show a tendency to sharply decrease as the ethanol content increases. Still, the redness a* shows a tendency to gradually increase.
2. As a result of GC-MS analysis for Chamaecyparis obtusa leaf extract, a large amount of sesquiterpene was found in hot water extracts, unlike most monoterpene were detected in essential oil extracts of Chamaecyparis obtusa leaf.
3. As a result of LC-MS quantitative analysis for polyphenol and flavonoid of Chamaecyparis obtusa leaf, the highest polyphenol component was found at ethanol 40 % extract.
4. As a result of the DPPH radical scavenging ability of the Chamaecyparis obtusa leaf, more than 50% of ethanol extract showed a higher antioxidant effect than ascorbic acid, of which reason it was estimated that the connects of Elemo, MOME INOSITOL components were extracted high.
5. As a result of antimicrobial analysis of Chamaecyparis obtusa leaf extract, the antibacterial activity against the *Staphylo- coccus aureus* strain causing food poisoning was high, of which the reason was estimated to be due to the extractable active ingredients of Eudesmol, Terpinen-4-ol in Chamaecyparis obtusa leaf extract.
6. As a result of the 2-nonenal removal effect, the highest nonenal removal effect was confirmed at 40 % ethanol extract, of which reason was estimated to be due to the extractable active ingredient of polyphenol and Terpinen-4-ol that was detected at the highest level at 40 % ethanol extract.

Accordingly, the results of this research are expected that the high-pressure hot water extract of Chamaecyparis obtusa leaves not only removes free radicals, which are the causative agents of aging and disease caused by active radicals but also has useful value as a functional natural materials in various bio-industry fields such as antimicrobial and senile body odor removal.

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Several Rules of Prime Distribution

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ABSTRACT

In this paper probability and statistics were applied to study the distribution of prime numbers. The result not only confirmed some previously advanced conjectures, but also drew new conclusions on prime distribution.

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In this paper probability and statistics were applied to study the distribution of prime numbers. The result not only confirmed some previously advanced conjectures, but also drew new conclusions on prime distribution.

Keywords: prime number, distribution, rules.

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Definition: According to the increasing order, the ith prime number is denoted as a_i; all natural numbers smaller than a_{i+1}^2 constitute the ith session, denoted as s_i; all ranges $(a_i \times j, \ a_i \times (j+1)]$ $(j \geq 0)$ on s_i is a_i long and denoted as r_j.

Theorem 1 Every composite on s_i has at least one prime factor smaller than or equal to a_i.

Proof:

Assumption there is a composite $m = b \times c$ (b, c are primes, $b > a_i$, $c > a_i$; m is on s_i).
Since $b > a_i$ and $c > a_i$,
then $b \geq a_{i+1}$, $c \geq a_{i+1}$
$b \times c \geq a_{i+1}^2$
Namely, $m \geq a_{i+1}^2$

This contradicts the definition of s_i (all numbers on s_i are smaller than a_{i+1}^2).

Therefore the above assumption does not hold. Namely, all composites on s_i have at least one prime factor smaller than or equal to a_i.

This completes the proof.

Theorem 2 If all primes on s_i cannot divide exactly a natural number m, m is either a prime or a composite greater than a_{i+1}^2.

Proof:

Assumption A natural number m on s_i) is a composite.

According to **Theorem 1**, m must have a prime factor $f \leq a_i$.

This contradicts the condition given in the theorem (all primes on s_i cannot divide exactly a natural number m). Therefore the above assumption does not hold, namely, m is either not a composite or a composite not on s_i (greater than a_{i+1}^2).

This completes the proof.

Theorem 3 Among any p consecutive natural numbers, there is one and only one number that can be divided exactly by p.

Proof:

1) *Assume* there is no number in p consecutive natural numbers that can be divided exactly by p.

Suppose the p consecutive natural numbers are c_1, c_2, c_3 ...... c_p, and s is a natural number.

If $s = c_1 \bmod p$, then $p > s > 0$, $p - s > 0$, it implies that c_1 is $p - s$ less than the next multiple of p. Apparently, $p > p - s$, namely, the $(p - s)^{th}$ number after c_1 (within the scope of p consecutive natural numbers starting with c_1) there must be a multiple of p. Put in another way, there is a number in p consecutive natural numbers that can be divided exactly by p, contradicting the above assumption.

2) *Assume* there are two numbers, m and n, in p consecutive natural numbers, and m and n both can be divided exactly by p.

Suppose there are two different natural numbers x and y, $m = p \times x$, and $n = p \times y$.

$$\begin{aligned} m - n &= (p \times x) - (p \times y) \\ &= p \times (x - y) \\ &\geq p \end{aligned}$$

$m - n \geq p$ is impossible since the difference among p consecutive natural number must be smaller than p. Therefore the above assumption does not hold, namely, there are no two numbers among p consecutive natural numbers that can be divided exactly by p.

It is easy to prove, in a similar way, that there no more than two numbers among p consecutive natural numbers that can be divided exactly by p.

Therefore there is no more than one number among p consecutive natural numbers that can be divided exactly by p.

In summary, since there is at least one multiple of p among p consecutive natural numbers and the number of such multiples cannot be greater than 1, there must be one and only one number in p consecutive natural numbers that can be divided exactly by p.

This completes the proof.

Theorem 4 There are 1 to i primes on each range r_j on s_i.

Proof:

Whether $a \nmid m$ and whether $b \nmid m$ are two independent events. Probability for both $a \nmid m$ and $b \nmid m$ is the product of probability of $a \nmid m$ and probability of $b \nmid m$. Therefore the probability of m on s_i being a prime, P_m, is the product of probabilities of all primes smaller or equal to a_i cannot divide m exactly.

Since probability of $a_i \nmid m = \frac{a_i - 1}{a_i}$

$$\begin{aligned} P_m &= \frac{1}{2} \times \frac{2}{3} \times \frac{4}{5} \times \frac{6}{7} \times \frac{10}{11} \times \frac{12}{13} \times \frac{16}{17} \times \cdots\cdots \times \frac{a_i - 1}{a_i} \\ &> \frac{1}{2} \times \frac{2}{3} \times \mathbf{\frac{3}{4}} \times \frac{4}{5} \times \mathbf{\frac{5}{6}} \times \frac{6}{7} \times \mathbf{\frac{7}{8}} \times \mathbf{\frac{8}{9}} \times \mathbf{\frac{9}{10}} \times \frac{10}{11} \times \mathbf{\frac{11}{12}} \times \frac{12}{13} \times \mathbf{\frac{13}{14}} \times \mathbf{\frac{14}{15}} \times \mathbf{\frac{15}{16}} \times \frac{16}{17} \times \cdots\cdots \times \frac{a_i - 2}{a_i - 1} \times \frac{a_i - 1}{a_i} \\ &= \frac{1}{a_i} \end{aligned} \quad (1)$$

Namely, $P_{\mathrm{m}} > \frac{1}{a_i}$

The prediction of the formula (1) has been confirmed by the distribution of primes (Figure 1, Table 1, 2).

Since there are a_i natural numbers on each range r_j in s_i,

Number of primes on each $r_j = P_{\mathrm{m}} \times a_i > \frac{1}{a_i} \times a_i = 1$

Namely, there is at least one prime on each range r_j in s_i.

When $j = 0$, $r_j = (0, a_i]$, obviously there are i primes on r_j in s_i.

This completes the proof of **Theorem 4**.

When $j = 1$， $r_j = (a_i, 2a_i]$, **Theorem 4** introduces **Corollary 1**.

Corollary 1 There must be a prime between a and $2a$, where a is a prime.

When $j = a_i$-1， $r_j = (a_i^2 - a_i, a_i^2] \in \mathrm{s_i}$. **Theorem 4** introduces **Corollary 2**.

Corollary 2 There must be at least one prime between $a^2 - a$ and a^2, where a is a prime.

When $j = a_i$, $r_j = (a_i^2, a_i^2 + a_i] \in \mathrm{s_i}$. **Theorem 4** introduces **Corollary 3**.

Corollary 3 There must be at least one prime between a^2 and a^2+a, where a is a prime.

Since $(a_i^2, a_i^2 + a_i] \in (a_i^2, a_i^2 + 2a_i + 1] = (a_i^2, (a_i+1)^2] \in \mathrm{s_i}$, **Corollary 3** implies that "There must be at least one prime between n^2 and $(n+1)^2$", when n is a prime. This was listed as a hard problem by Hua [1] on page 90, and now is proven. Therefore there is **Corollary 4**.

Corollary 4 There must be at least one prime between a^2 and $(a+1)^2$, where a is a prime.

Since $a_{i+1}^2 - a_i^2 = (a_{i+1} - a_i)(a_{i+1} + a_i) > 2{*}2a_i$ (except $a_i = 2$), the number of primes in (a_i^2, a_{i+1}^2) is $2 * 2a_i * \frac{1}{a_i} > 4$. Therefore **Theorem 4** introduces **Corollary 5**.

Corollary 5 There must be at least four primes between a_{i+1}^2 and a_i^2, where a_{i+1} and a_i are primes, $a_i \neq 2$.

According to **Theorem 4**, There are at least 1 prime on each range r_j on s_i. The differences between numbers in two adjacent ranges, r_j and r_{j+1}, are smaller than $2a_i$. Therefore **Corollary 6** is introduced.

Corollary 6 The difference between two primes on adjacent ranges in s_i is smaller than $2a_i$.

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Tabel 1: Statistics of primes on s_i and comparison with theoretical calculation. For example, in the second column, s_i ranges from 1 to 25, in which there are 8 ranges of length 3, and the upper limit is 24. According to **Formula (1)**, probability of numbers on s_i being primes is 0.333, number of primes should be 24×0.333 = 8 while the actual number is 9, and accuracy is 0.889. As s_i increases, the accuracy approaches completely accurate (1.0) (Figure 1).

,

s_i upper limit	9	25	49	121	169	289	361	529	841	961	1369	1681	1849	2209	2809	3481	3721	4489	5041	5329	6241	6889	7921	9409	10201
Range length a_i	2	3	5	7	11	13	17	19	23	29	31	37	41	43	47	53	59	61	67	71	73	79	83	89	97
Number of ranges	8	24	45	119	165	286	357	513	828	957	1364	1665	1845	2193	2773	3445	3717	4453	5025	5325	6205	6873	7885	9345	10185
Probablity	0.5	0.333	0.267	0.229	0.208	0.192	0.181	0.171	0.164	0.158	0.153	0.149	0.145	0.142	0.139	0.136	0.134	0.132	0.13	0.128	0.126	0.124	0.123	0.122	0.12
Calculated number of primes on s_i	4	8	12.01	27.25	34.32	54.91	64.61	87.72	135.8	151.2	208.7	248.1	267.5	311.4	385.4	468.5	498.1	587.8	653.3	681.6	781.8	852.3	969.9	1140	1222.2
Actual number of primes on s_i	4	9	14	30	38	61	71	97	144	162	218	261	282	327	403	481	518	605	674	705	807	885	997	1157	1251
Calculating accuracy	1	0.889	0.858	0.908	0.903	0.900	0.910	0.904	0.943	0.933	0.957	0.951	0.949	0.952	0.956	0.974	0.962	0.972	0.969	0.967	0.969	0.963	0.973	0.985	0.977

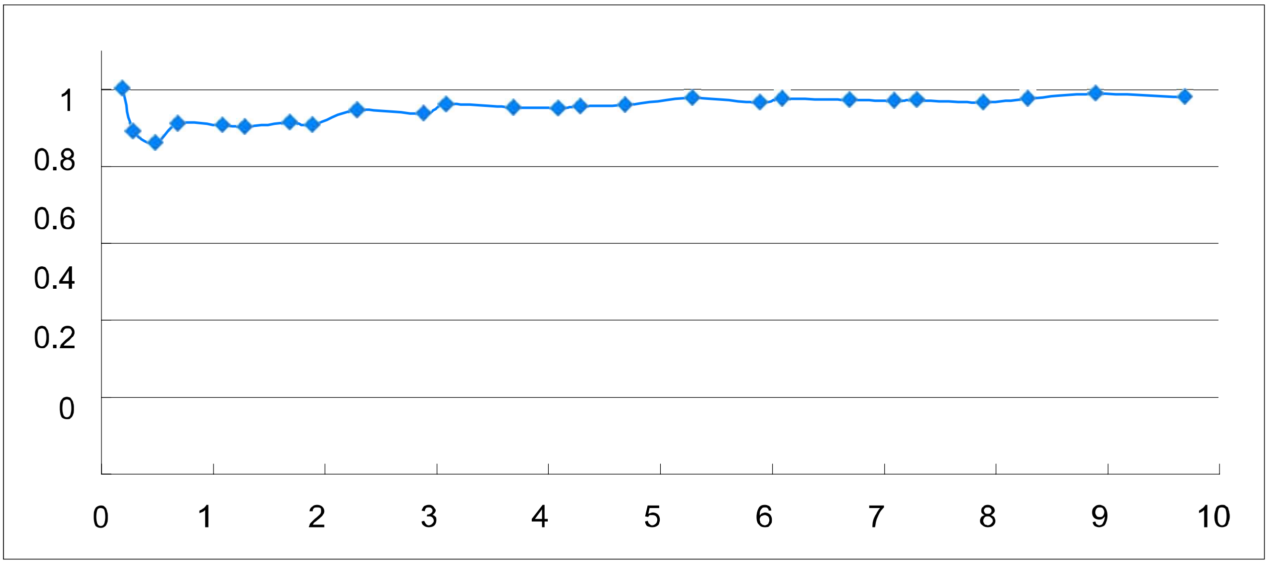

Figure 1: The accuracy of theoretical prediction approaches 1.0, as primes grow greater.

Tabel 2: Statistics of primes on different ranges on s_i. For example, in the second line, s_i ranges from 1 to 25, in which there are 8 ranges of length 3, there are 2, 1, 1, 1, 1, 1, 1, 1 primes in each range, respectively, the maximum is 2, and minimum is 1. As the session and range lengths increase, the maximum and minimum generally increase.

Upper limit of s_i	Number of ranges in s_i	Range length, a_i	Numbers of primes on each range	Max	min
9	4	2	1, 1, 1, 1,	1	1
25	8	3	2, 1, 1, 1, 1, 1, 1, 1,	2	1
49	9	5	3, 1, 2, 2, 1, 1, 1, 1, 2,	3	1
121	17	7	4, 2, 2, 1, 2, 2, 2, 1, 2, 1, 2, 2, 1, 1, 2, 2, 1,	4	1
169	15	11	5, 3, 3, 3, 2, 2, 3, 2, 2, 4, 1, 2, 2, 2, 2,	5	1
289	22	13	6, 3, 3, 3, 3, 3, 3, 3, 3, 1, 3, 2, 3, 3, 2, 2, 1, 4, 2, 2, 3, 3,	6	1
361	21	17	7, 4, 4, 4, 4, 3, 4, 2, 4, 3, 3, 4, 1, 4, 3, 4, 3, 1, 4, 2, 3,	7	1
529	27	19	8, 4, 4, 5, 3, 6, 2, 4, 3, 3, 4, 3, 4, 3, 5, 1, 4, 2, 4, 3, 3, 2, 4, 3, 4, 3, 3,	8	1
841	36	23	9, 5, 5, 5, 6, 3, 4, 5, 4, 4, 4, 4, 4, 4, 2, 5, 4, 3, 4, 4, 4, 4, 3, 2, 4, 3, 6, 3, 4, 3, 3, 3, 4, 3, 2, 5,	9	2
961	33	29	10, 6, 7, 7, 4, 6, 6, 4, 5, 6, 5, 3, 5, 5, 5, 6, 4, 4, 3, 5, 5, 4, 6, 4, 3, 5, 4, 4, 5, 4, 4, 3, 5,	10	3
1369	44	31	11, 7, 6, 6, 6, 6, 5, 6, 6, 4, 5, 5, 6, 5, 6, 4, 5, 3, 5, 7, 4, 5, 4, 5, 5, 2, 6, 5, 4, 4, 4, 5, 5, 5, 3, 6, 3, 4, 4, 6, 2, 7, 5, 1,	11	1

1681	45	37	12, 9, 8, 5, 8, 5, 8, 7, 5, 6, 6, 7, 6, 5, 4, 6, 7, 7, 5, 5, 6, 4, 5, 8, 3, 5, 6, 6, 6, 6, 3, 5, 5, 5, 6, 7, 2, 3, 6, 5, 7, 5, 5, 8, 3,	12	2
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2809	59	47	15, 9, 10, 8, 9, 9, 6, 8, 8, 9, 6, 6, 8, 8, 7, 7, 6, 7, 8, 5, 7, 8, 6, 8, 5, 6, 6, 9, 4, 5, 8, 8, 5, 7, 8, 4, 7, 6, 6, 7, 4, 5, 8, 5, 8, 7, 3, 6, 7, 6, 8, 6, 5, 3, 6, 5, 7, 9, 6,	15	3
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Circular Supply Chain – A Systematic Review of Assessment of Environmental, Economic, and Social Impacts of Electric Vehicles (EV) Batteries Over Their Entire Life Cycle

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ABSTRACT

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Circular Supply Chain – A Systematic Review of Assessment of Environmental, Economic, and Social Impacts of Electric Vehicles (EV) Batteries Over Their Entire Life Cycle

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Highlights

- Linear supply chains need to transform to circular supply chain - scarce resources.
- Circular economy principles help innovative businesses transform trash into cash.
- Nations unprepared in handling battery waste -High growth in Electric Vehicles.
- Recycling and battery capacity improvements-drive the sustainability of lithium-ion cells.

ABSTRACT

The conventional linear supply chain is fast giving way to circular supply chain as nations and businesses begin to recognize the need for recycling scarce resources while demand keeps multiplying. Besides regulatory obligations for the innocuous disposal and reuse of discarded manufactured goods, there's an unmistakable hint that customers prefer businesses that recycle materials, and several leading businesses are finding added value through circular supply chains.

Purpose: The purpose of this paper is to apply circular supply chain model for the assessment of environmental, economic, or social impacts of electric vehicles (EV) batteries over their entire life cycle.

Methodology: The study uses systematic literature review. We identify 101 papers and filtered them using the key words to arrive at the requisite number of articles necessary to draw the conclusion.

Findings: EVs are vital to attaining global targets of carbon emissions reduction. However, it is evident from new research that the world is unprepared to handle the Lithium-Ion Battery (LIB) waste generated once EVs complete their useful life span. Recycling and battery capacity improvements could be the best solution.

Conclusion: EV sector presents the possibility of recycling and drawing benefits from a circular economy. LIB waste recycling will help cut down toxic waste generation besides abating social menaces of child labor. The best benefit of EVs is the demonstration of how recycling can be used by an industry to grow and meet growing demand. This is the key to directing nations to adopt policies supporting application of CE approach to production.

Keywords: circular economy, circular supply chain, recycle, refurbish, social, environmental impact, electric vehicle, batteries, lithium, lthiuimion battery, battery waste, EV batteries.

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List of Abbreviations

CSCM	Circular Supply Chain Management
CE	Circular Economy
CNETE	National Center in Environmental Technology and Electrochemistry
CSR	Corporate Social Responsibility
DRC	Democratic Republic of Congo
EOL	End of Life
EV	Electric Vehicle
GHG	Green House Gas
HEVs	Hybrid Electric Vehicles
ICE	Internal Combustion Engine
ICEVs	Internal Combustion Engine Vehicles
LIB	Lithium-Ion Battery

LCO	Lithium cobalt oxide
NRC	National Research Council of Canada
NiMH	Nickel Metal Hydride
ReLieVe	Recycling Li-ion batteries for electric Vehicle

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I. INTRODUCTION

There is no denying the fact that resources, required to meet the uncountable and ever increasing needs of human beings, are scarce and have several alternative uses (Robbins, 2007). That is the whole essence of Economics and the crux of Lionel Robbin's definition of economics. It is also the key to understanding the need for recycling products to reduce wastefulness and ensure the optimum utilization of resources to meet human needs. Consumptions, across the world, are growing at an alarming rate. The global final consumption expenditure (at constant 2010 USD) has expanded by about 300% in the last 5 decades (World Bank, 2019). Consequently, several natural resources will be seriously depleted in the near future creating a huge shortfall unless there occurs a significant change in the manner in which we acquire, manufacture, deliver, consume, reclaim and regenerate products (Hazen et al., 2017).

The research focuses on explaining the 'circular economy' (CE) methodology that will help to sustain such high levels of consumption and the necessary production. This methodology is expected to transmute or alter the purpose that these resources serve in the economy. Waste from industrial units would turn into a valuable input for process and the products could be overhauled, refurbished, reused or improved instead of being disposed off (Preston, 2012). One of the key industries that can utilize this technology is the automotive industry especially the massively expanding EV segment where the vehicle batteries need to be replaced every 8 to 10 years (Union of Concerned Scientists, 2018) creating pile of toxic wastes with adverse environmental implications (Harper et al., 2019a; Stojanović et al., 2018). There are other issues – economic and social, associated with the manufacturing of EV batteries. The article discusses the concepts of circular economy and circular supply chain from various perspectives with special emphasis on EV battery recycling and its socio-economic and environmental impacts.

Circular supply chain in EV batteries being still a nascent concept, there is a dearth of research in this segment. The research pertaining to the application of circular economy in manufacturing falls short of its widespread practical applications (Adams, Osmani, Thorpe, & Thornback, 2017). In the field of research most articles on the electric vehicle batteries focus on the technical aspects of improving efficiencies, optimizing re-use or improvement in the performance metrics (Chen et al., 2020; Gucciardi et al., 2021; Kamath et al., 2020; Patten et al., 2011). Several articles discuss the secondary use of batteries or the effect of the re-cycling on the government subsidy policy to electric vehicle manufacturers (Gu et al., 2018, 2021; Mirzaei Omrani & Jannesari, 2019). A study by Ahuja also highlights in its finding the need for regulatory intervention if the recycling or the circular economy in EVs is to be profitable and in his study Ajay highlights the importance of Battery swapping as well as the challenge of adoption of EVs in India (Ahuja et al., 2020; Serohi, 2021). There are some studies that aim at creating models to forecast the number of critical materials that can be recovered from Lithium Batteries through recycling end of life EV and analyzing the potential of a closed-loop supply or the challenges in the process (Ellingsen et al., 2014; Olivetti et al., 2017; Olsson et al., 2018; Pagliaro & Meneguzzo, 2019; Sato & Nakata, 2019). In some studies measures to decrease environmental impacts related to resource usage and strengthen the availability of raw materials to become more competitive in the global economy, is discussed as a key strategy (Díaz-Ramírez et al., 2020; Glöser-Chahoud & Schultmann, 2019; Omahne et al., 2021). Moreover, several studies have looked at issues related to battery recycling for electric vehicles (Beaudet et al., 2020; Harper et al., 2019b). One study analyzes all life cycle phases of an electric vehicle battery from the material extraction, processing, manufacturing, and operation phases to the end-of-life phases of vehicles and batteries, with the result highlighting that the manufacturing phase is the most influential phase in terms of socio-economic impacts compared to other life cycle phases, whereas operation phase is the most dominant phase in the terms of environmental impacts (Onat et al., 2014).

Circular EV battery supply chains are still a nascent concept and the coverage of CEs in this domain is fragmented. The Figure 1 shows the number of references in peer-reviewed literature mentioning circular economy from 1999 through 2019. The figure indicates an increase in this category of publication in peer-reviewed literature since 2015(Bjørnbet et al., 2021). The objective of this review is to examine the impact of the implementation of the CE principles in manufacturing companies with particular focus on the recycling of electric vehicle batteries over their lifetime. A search of relevant databases reveals that few studies discuss the application of circular economy in manufacturing and fall short of discussing the widespread practical applications in the Environmental, Economic, and Social sectors (Adams, Osmani, Thorpe, & Thornback, 2017). This paper besides trying to partially fulfil this gap also brings to light an important emerging aspect of the circular economy - a retaliation from traditional fuel economy. While vehicle manufacturers can shift from ICE models to BEV models, it is difficult for suppliers of traditional fuel to change over to an alternative. They will suffer a massive drop in revenue putting their existence at stake. This article introduces the topic and therefore, lays the foundation for future research.

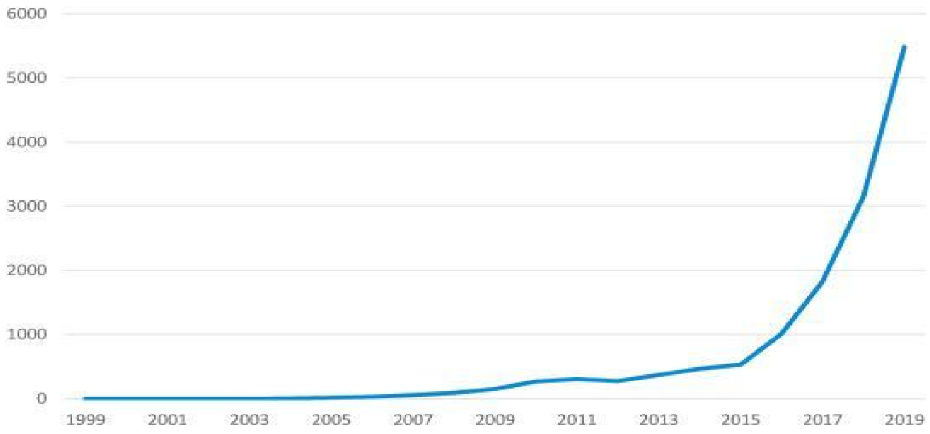

Figure 1: Number of hits in Scopus on the search string ‘circular economy’, 1999–2019

The article is divided into 6 sections with several subsections. *Section 1* of the thesis introduces the topic, provides background, research rationale and the aims and objectives of the study. *Section 2* presents the literature review that explains the topic, talks about the emergence of the concept, its progression and evolution. *Section 3* explains the research methodology. Section 4 analyzes the data gathered from various sources while *Section 5* presents a discussion collating the previous 2 sections. *Section 6*, the conclusion, is the presentation of the researcher’s opinion on the basis of the foregoing research.

II. LITERATURE REVIEW

2.1 Understanding a circular economy and its benefits

Circular Economy (CE) (figure 2) is a concept that has attracted many scholars and hence research studies. Such an economy is believed to turn commodities, that are at or near the end of their useful life, into resources for other products, and in the process completes loops in industrial ecosystems, reduces wastage to the minimum and adheres to sustainable methods (Geisendorf & Pietrulla,2018; Khan & Haleem, 2020; Nascimento et al., 2019; Ünal et al., 2019). According to the definition provided by the Ellen MacArthur Foundation (2015, p. 2) a CE refers to an economy that is "restorative or regenerative by intention and design" and the objective of such an economy is "to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles"(The Ellen MacArthur Foundation, 2015).

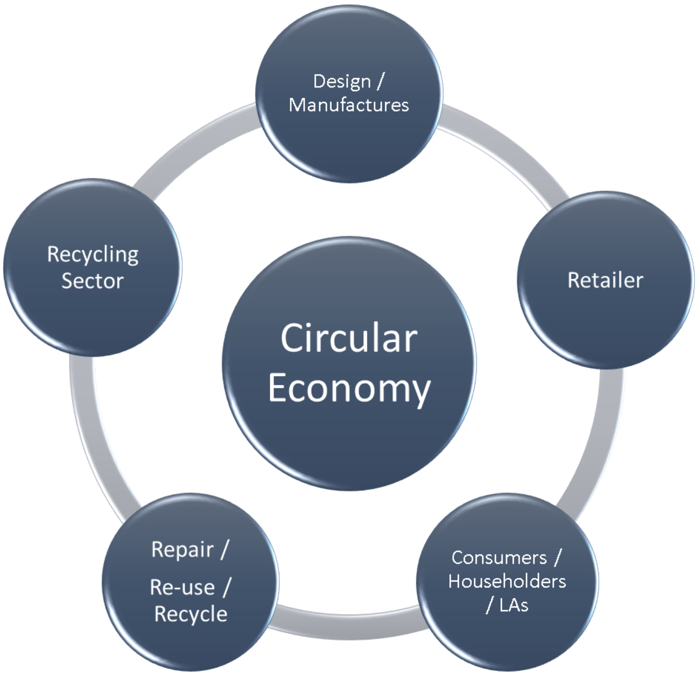

Figure 2: Circular economy

A CE strives to reconstitute capital, which could be either human or natural or manufactured, or social or financial. The rebuilding makes sure that movements of goods and services improve and increase over time. A circular economy, therefore, is associated with green development or sustainable development (Nascimento et al., 2019; Sanguino et al., 2020; Schroeder et al., 2019). It refers to that procedure of resources utilization which encompasses 3 Rs – "reduction, reuse and recycling" of resources (Geng et al., 2019; González- Sánchez et al., 2020). Minimization of material waste along with the application of biodegradable products help to recycle the discarded products back to the environment (Valavanidis, 2018). The topic is fast gaining popularity amongst practitioners and scholars (Kirchherr et al.,2017). The ultimate focus of this new economic model is on dissociating global economic development from consumption of limited resources. Depending upon the dissemination of approaches concerning green management, manufacturers have paid a lot of attention to the impact, on environment, of production procedures in addition to avoidance of waste, "recycling, reuse and reduction" to the minimum of final discarding of end-of-life products (Isernia et al., 2019).

Migration to a more circular economy is believed to make such benefits available as releasing a significant part of the stress on the environment, ensuring that the raw materials supply is more stable and secure, developing and maintaining the competitive edge, encouraging innovation, providing a thrust to the general economic growth, generating employment (580,000 jobs creation in the European Union alone) (European Parliament, 2015). Further, a switch to a CE improves the synergy between the community and the industry because the participants as well as the stakeholders in a closed looped supply chain extend collaboration to make it a success. strengthens the connection between the society and industry (Kumar et al., 2019).

2.2 Need for Circular Supply Chain Management

The circular economy delineates a domain in which reuse by way of reparation, reconditioning and overhaul is the established social and economic model (Charter, 2018). Therefore, the aim of a circular economy is to extort maximum benefit from the materials, energy and wastes pertaining to an industry. For enhancing the efficiency of resources, a circular economy links the supply and demand of supply chain Industries (Manavalan & Jayakrishna, 2019). The need to safeguard and provide support to an incessantly expanding global demand, in a sustainable manner, calls for an efficient and sufficient management of operations pertaining to the supply chain (Theophilus et al., 2019). Here, the concept of circular supply chain assumes importance. A circular supply chain is different from the traditional supply chain which is characterized by a desegregated course that consists of procurement of raw materials and components, fabrication and assembly of products, along with delivery of the final products to consumers by means of distribution or retail or both (Manavalan & Jayakrishna, 2019). The circular supply chain provides a model capable of encouraging the producers and Product sellers to procure cast-off materials and turn them into a product for resale (De Angelis et al., 2018; Jain et al., 2018; Kuebix, 2019; Nandi et al., 2020; Yang et al., 2018) thereby reducing pollution on the one hand and enhancing profitability on the other. For instance, there has been an explosion in the demand for electricity-driven cars which run on batteries that have a short lifespan. Therefore, there would be millions of waste batteries with negative abandonment values. Therefore, recycling these batteries (employing emerging technologies) would make the supply chains more sustainable and reduce the cost of the cars in the longer run.

Over the years, the United Nations (UN) in consort with more than a few of the biggest production economies in the world have put into operation certain policy directives concerning sustainability of resource, reduction of emission, and effective management of waste material (Koh et al., 2017). The conventional linear economy is made up of uncomplicated linear value chain which moves along the following simple path (Hannon et al., 2016). Encouraging and impelling the shift from the present linear "extraction - use - disposal" method of resource utilization, to a more circular methodology having alternative conduits for by products, emissions, as also waste products were the objectives driving the development of these policies (Huysman et al., 2015). Therefore, for several producers and supply chain participants, the persuasion for moving towards a circular supply chain was the product of federal government efforts and policies (Robinson, 2020). The government imposes certain restrictions regarding the type of products that can be discarded as waste, and the products that should be reclaimed, the quantum of raw materials that can be consumed by certain entity, and also define the procedures that must be followed by the supply chain entities who have renounced the conventional methodology of production and sale. Nevertheless, consumers appear to be the obvious and the most important impetus behind the circular supply chain(Robinson, 2020).

Circular supply chain refers to an integrated supply chain model that encompasses forward as well as reverse aspects of the supply chain (Baporikar, 2020). It involves the complete process of reverse logistics, that helps to continue a growth trajectory in order to become sustainable in the near future when there will be no unlimited supply of resources (Robinson, 2020). Management of supply chain in the circular economy concentrates on elimination of waste for the improvement of operational efficiency and reduction of expenditures. Therefore, it becomes necessary for the businesses to examine and evaluate their processes, labor pools, and the supporting apparatuses in order to discover opportunities for the formation and reinforcement of a circular supply chain (Jain et al., 2018).

Management of supply chain for a circular economy is chiefly concerned with reduction of waste through reuse or recycling every conceivable material, spanning across packaging of product and shipping policies. Shipping materials that are reusable will be capable of putting off waste through the closure of loops and ostracizing waste materials from dumping grounds (Accorsi et al., 2019). There are a couple of views that have been taken into consideration for the purpose of delineating a circular supply chain. From the point of view of materials, the circular supply chain delineates a supply chain that uses, recycles and reuses materials repeatedly at the end of their practical life thereby ensuring generation of minimum material wastes all through the supply chain. Recycling refers to those materials that have been reclaimed for being utilized in diverse range of products and includes those materials that are recovered and converted into new batteries(Jungst, 2001). Several studies have demonstrated that the processes of optimized waste management may perhaps represent a germane approach towards attainment of socio-economic and environmental paybacks expected from the embracing the CE approaches (Isernia et al., 2019). Integrating circular economy into supply chain management may make several advantages available from the perspective of sustainability (Farooque et al., 2019).

Several research papers corroborate the significance of good supply chain management for several economies across the world. Better results can be ensured through the development of policies and procedures that can achieve a more effective and maintainable supply chain. This can be achieved by way of fabricating cost-efficient programs, simplifying and expediting the flow, maintaining "just-in-time" deliveries inside the supply chains, implementing the 3Rs – reduce, reuse and recycle, and developing or enhancing the sustainability of the procedures (González-Sánchez et al., 2020). Through the integration of the theory of circular economy into supply chain management, Circular Supply Chain Management (CSCM) offers a new and convincing picture of the supply chain sustainability domain (Farooque et al., 2019). As a consequence, there is increasing research interest in the subject matter. Administration of total cost within the supply chain must take into account various aspects including cost of transportation, penalizations for deferrals and stoppages of regular operations, emission related expenditures, etc. Several of these costs will have an impact not only on the profit and loss account, but also on the feasibility and continuity of the supply process (Guo et al., 2017; Zhu et al., 2017).

2.3 Sectors that can benefit from CSCM

In the last few years, research undertaken by McKinsey has indicated that the circular economy, that involves using and reprocessing natural capital as usefully as possible and discovering value throughout the life cycles of finished products, has the potential to be, a significant part, if not the whole of the solution towards industries obtaining a reliable method to enhance their profitability and at the same time reduce their reliance on natural resources ("Mapping the Benefits of a Circular Economy," 2017). Every sphere of consumption is seeing continuous expansion and automobile sector is just one of them. Other sectors that might benefit from the circular economy philosophy. IT and telecommunication, automotive, packaging, furniture, apparel, are only a few names of industries that can profit from circular economy and circular supply chain management.

Supply chain is a key management consideration for every construction project and is a major progression that affects a circular economy. It is essential to break down costs and trace them back to actions, people, wherewithal, data, logistics, organization and most definitely to products and services that utilize raw materials to turn out finished products that satisfy customer needs, in order to get a grip on supply chain management (Tatlici & Sertyesilisik, 2019, p. 261). SCM is not restricted to simple cost reduction. It is a lot beyond that. It emphasizes on economic value added. The stress in on improving the final product or service in terms of quality, technology, delivery, and after sales service by managing the total content and the total process, the ultimate goal being meeting the consumers' requirements (Mulla Aneesa.I, Gupta, & Desai, 2015, p. 36). A cohesive administration and supervision of material and resources throughout the entire supply chain will translate into benefits in terms of expansion of the value-added by members of the supply chain, waste removal, cost cutting, and enhancement of customer satisfaction (Handfield & Nichols, 2002). Focusing on reusable materials allows firms extract the greatest advantage out of the procured resources or inputs (Blood-Rojas, 2017).

Studies reveal that investment in a circular supply chain have the possibility to bring in a superior return on investment (ROI) for the investing firm (Aalpega, 2021). A contemporary report on organic waste residue in Amsterdam, the Netherlands, discovered that exploiting bio-refineries, it was possible for waste separation and return logistics to generate €150 million in value addition, besides generating 900,000 tons of savings in materials and an annual CO_2 emission reduction amounting to 600,000 tons (Ellen MacArthur Foundation, 2017).

IKEA revealed its strategy, in 2018, to turn into a circular business by 2030, through the elimination of waste alongside a promise to employ only those materials that are renewable or salvageable, across the complete range of its products. Annually Coca-Cola produces 3 million tons of plastic packaging. It has confirmed Sweden to be the first market where it will produce all its bottles from totally recyclable materials ("Better Bottling Thanks to Cognex Vision," 2007). The construction industry and a myriad of other everyday names including the industrial zone of Vallejo, located in Mexico, are planning moving to a circular economy by altering their production approaches and procedures in an attempt to transit towards an economy that has lower dependence on natural resources (Ghisetti & Montresor, 2020; Sfakianaki, 2015). Rapid urbanization and industrialization have led to massive expansion of demand for both passenger and commercial vehicles. The obvious fallout was the steady rise in pollution that has now attracted environmental activists, scientist, leaders and the general public. Data pertaining to emissions indicate that transport has emerged as the key element behind global-warming and pollution (Milman, 2018). The thrust on reducing environmental pollutants has led to the vehicle manufacturers seeking an alternate power source for their vehicles leading to the advent of hybrid and electric vehicles.

2.4 Emergence and progression of the EV sector in recent times

There has been a lot of apprehensions among auto-manufacturers across the world regarding the kind of reaction that EVs would receive from consumers. However, EVs are not new. They were plying the streets of USA since the late 1800s but by 1935, electric car lost popularity due to the increasing demand of internal-combustion engine (Thompson, 2017) and gradually came to be replaced by vehicles that run on fossil fuel. With the rapid growth in car demand fuel supplies started depleting at an alarming rate while pollution kept growing giving rise to serious environmental issues and attracting displeasure from environmental activists and scientists.

1970 saw the establishment of the Clean Air Act, that made it necessary for the states to take the responsibility of controlling their air quality along with meeting several standards by specified deadlines (Thompson, 2017). The Act exemplified a vital move in the responsibility of the federal government towards controlling the exposure of the citizens of United States to air pollution through the authorization of regulatory norms that would limit the emission of harmful gases and particles from stationary as also transportable sources (Ross et al., 2012). This was followed by the 1973 OPEC oil embargo that led to gasoline prices increasing sharply, and in turn triggered interest in vehicles that use alternatives fuels (Thompson, 2017). The drive to use the new breed of vehicles running on electricity instead of polluting cars that use petrol and diesel regained momentum in 2017 and the aggregated number of electric cars in the US is forecast to exceed 4.8 m in 2020, while in 2030 it is anticipated to be over 20.8 m. In the European Union the values are, respectively, app. 2 m in 2020 and 9 m in 2030. In the EU, countries with the biggest aggregated number of electric cars are Germany with 348 thousand in 2020 and 1.9 m in Great Britain with 342 thousand in 2020 and 1.6 m in 2030. Japan is characterized with the lowest expected values of app. 1.3 m in 2020 and 5.3 m in 2030. It ought to be stressed that even though the aggregated number of electric cars anticipated for the coming years is the lowest in Japan, the country clearly outpaces the European Union if the value is recalculated into the number of residents. Depending on the year, the value in Japan is, on average, three times higher than in the EU (Statharas et al., 2019; Tucki et al., 2020).

Despite a few launches the interest in EVs faded in US by 1979 due to certain drawbacks, only to reappear in early 1990s on the back of new federal and state regulations and in 1996 General Motors launched EV1, the EV that was designed and developed from the elementary principles. First mass production of hybrid vehicles was done by Toyota in 1997 and from there today EVs and hybrid vehicles have come to play an important role in the US automotive and transport sectors (Klass, 2019). Overcrowding and worsening of air quality present serious challenges to several cities in South East Asia which have induced governments to bend towards EV adoption (Agaton et al., 2020).

UK and France were the pioneers in supporting largescale EV development in Europe. Modern day EVs were launched in Europe over a decade ago and had received good response and acceptance from the consumers in the region. Compliance with more stringent emission norms require the European vehicle producers to turn to the production of plug-in hybrid electric vehicle (Ortar & Ryghaug, 2019). There is a clear rise in the demand for vehicles running on electricity not only in developed but also developing countries, despite the lack in development of infrastructure to run them in terms of availability of public charging points ("European Automobile Manufacturers' Association: Auto Makers and Electricity Sector Call for Rapid Action on Charging Points under EU Recovery Plan," 2020). There in a strong need to develop and deploy not only cost-effective but also energy-efficient resolutions for reutilizing end-of-life EV batteries and the need is becoming all the more urgent (Beaudet et al., 2020) due to the rise in the demand for EVs and the consequent spurt in demand for EV batteries leading to a stock.

Several technologies have emerged, as a result of research and development initiatives undertaken at both government and corporate levels in various countries, that promise to effectively recycle EV batteries. There are several instances of R&D initiatives that hold a lot of potential. These include the "Recycling Li-ion batteries for electric Vehicle" (ReLieVe) project be of special interest to Eramet, Suez, BASF, Chimie ParisTech and the Norwegian University of Science and Technology (Beaudet et al., 2020); the ReCell Center at Argonne National Laboratory and its proposals to develop a new straightforward recycling process (*Energy Department Announces Opening of Battery Recycling Center at Argonne National Lab*, 2019) and a number of projects undertaken in Canada that involve the Hydro-Quebec Center of Excellence in Transportation Electrification and Energy Storage, the University of Montreal, the National Research Council of Canada (NRC) and the National Center in Environmental Technology and Electrochemistry (CNETE) (Beaudet et al., 2020).

2.5 Environmental, Economic, and Social Impacts of Electric Vehicles

Societal benefits for EVs include national security benefits from reduced dependence on imports of fossil fuel, (Malmgren, 2016), domestic economic development will open up due to the possibility of using alternative energy routes to acquire mobility and the possibility of reducing the dependence of road transport on crude oil (Perujo, Thiel, & Nemry, 2011). Environmental benefits will be in the form of better air quality and health due to reduction in emission of CO2 and other pollutants (Malmgren, 2016). However, there is likely to be a general rise in Sulphur Dioxide (SO_2) caused by the emanation of pollutants from the generation of necessary electricity (Saylav).

The global sales of EV is forecasted to reach 11m by 2025 (Simlett & Mortier, 2019). While replacement of ICE vehicles by EVs is inevitable, such change and spurt in demand is expected to leave 11 million tons of spent lithium-ion batteries (LIBs) that need to be recycled between now and 2030 (Gardiner, 2017; Kavanagh et al., 2018). The demise of EV batteries has intensified with several of them reaching their end-of-life, posed significant challenges in terms of ecological safekeeping and sustainable progress (Tang, Zhang, Li, & Li, 2019). From the point of view of both commerce and environment, the issue regarding the way an increasing stockpile of EV batteries is to be dealt with, is set to become a very crucial one (Simlett & Mortier, 2019). At the global level stockpile of these batteries is estimated to be in excess of 3.4 million by 2025, as against almost 55,000 in 2018 reflecting nearly 62-fold rise in just 7 years (IER, 2019). Efficient management of the battery life cycle is expected to be the prime factor driving the growth and development of EVs in the future (Simlett & Mortier, 2019). The manufacturers of EVs are now facing the challenge of bridging the gap between supply of and demand for EV components, for instance batteries, battery management systems, and powertrains, and so on ("Asia-Pacific EV Powertrain Market to 2027 - Regional Analysis and Forecasts by Product Type; Application," 2020).

LIB technology is the most prevalent in today's EV sphere (Sigurðsson, 2010). Majority of batteries used in electric vehicle have lithium as their key component and depend on a mix of cobalt, manganese, nickel, and graphite and some additional primary components (Union of Concerned Scientists, 2018). In case of EVs, battery comprises lion's share of the cost and hence its disposal is twice as much costly, particularly if the waste is full of expensive materials (Jungst, 2001; Sigurðsson, 2010).

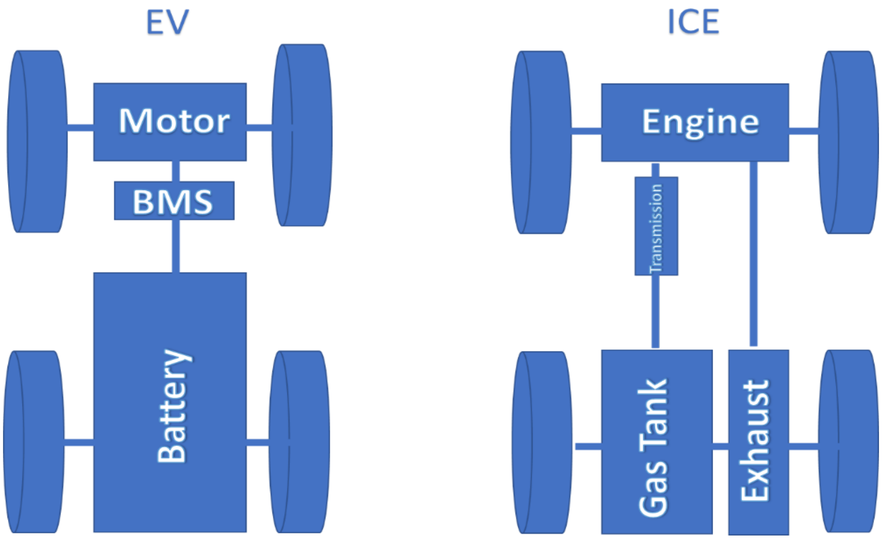

Figure 3: Basic building blocks of ICE based cars and EVs

Batteries of EVs normally need to be replaced after a span of 7 to 10 years for smaller-sized vehicles and 3 to 4 years for such bigger vehicles as buses and vans (IER, 2019). Majority of these EV batteries have an 8-year warranty or a drive limit of 160,000km (100,000 mile) (University, 2017). The performance of a typical EV lithium-ion battery pack, post a few thousand charging cycles, starts to deteriorate rapidly. The battery is no longer capable of adequately and properly running the vehicle and needs to be replaced by a new one. However, this does not signify that the battery has reached its end. With appropriate systems and the right kinds of markets in position, these seemingly used and exhausted batteries have the potential to continue their journey and enjoy additional, two to three lives in uses that are less rigorous. Even in the present day, businesses, for instance utility companies and operators of telecom towers, are cashing in on recycled batteries to improve on their operational cost front (Simlett & Mortier, 2019).

2.6 Life cycle of EV batteries and its socio-economic and environmental impacts

Spent batteries can provide an opportunity to effectively cope with the serious challenges emerging for battery producers with respect to end-of-life waste-management. Producers need to gain access to strategic elements that are crucial for manufacturing EVs. Recycled lithium-ion batteries from EVs are believed to be able to provide a valuable secondary source for these indispensable materials (Harper et al., 2019a). The supply chain of EVs with the recycle of the batteries at EOL is shown in figure 4 below.

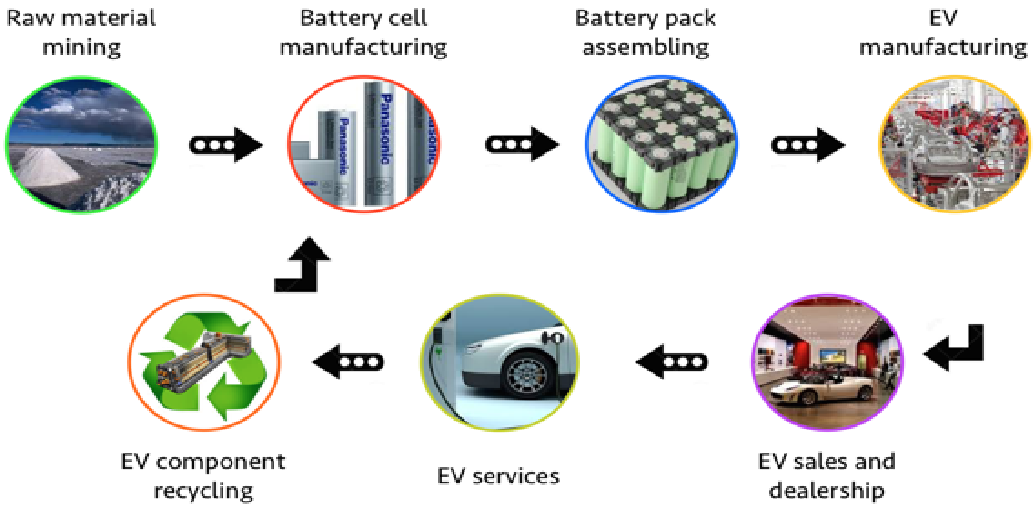

Figure 4: EV supply chain

Less arduous, secondary usages for these batteries are likely to prolong their terms of operation, or in certain instances refurbishment might also be contemplated. At the end of the day, however, the battery needs to be processed in a manner that permits recycling all the valuable and/or hazardous components and materials (Jungst, 2001). Recycling presents the scope for reducing the life cycle costs by way of reclamation of expensive materials which in turn helps to forestall the expenses associated with disposal of hazardous waste materials. This is the key reason for the developers of power sources for EVs having recycling of maximum possible material at the end of their useful lives as one of their objectives (Jungst, 2001).

It goes without saying that exponential rise of EVs is the key factor responsible for the substantive and comparable development of the market for rechargeable batteries. However, the Special issue on strategic battery raw materials, a report released by the United Nations Conference on Trade and Development has underlined several environmental and socio-economic effects of mining the raw materials required for battery manufacturing (UNCTAD, 2020; Zhou et al., 2016). If not dealt with in a timely manner, these concerns are likely to diminish the importance that EVs receive as a form of transportation that has better conscientious (Gandhi, 2020).

Cobalt is an essential ingredient for manufacturing rechargeable batteries that are used to fuel smart phones and EVs (Clowes, 2019). Cobalt is necessary to keep the EV batteries from getting overheated and facilitates capacity maintenance throughout charging and recharging cycles (Lightfoot, 2019). However, lithium-ion batteries, that are expected to power approximately 30 million EVs globally by 2025, have not received the consideration that they deserve. Also, there are quite a few challenges that must be encountered when using cobalt in lithium-ion batteries, making it more difficult for electric vehicle manufactures to pull down EV costs (Lightfoot, 2019).

The metal itself is very rare. The Democratic Republic of Congo (DRC) contributes to almost 72% of global cobalt production (Clowes, 2019) out of which 20% Cobalt comes not from mines run by strongly regulated international mining firms but from small artisanal mines that are believed to have been associated with child labor and human rights exploitations by Amnesty International, among others (Campbell, 2020; Laudati & Mertens, 2019; Sanderson, 2019;

UNCTAD, 2020). In June 2019, the DRC witnessed the death of 43 artisan miners due to landslide at a large copper and cobalt pit in one of the industrial mines that was being operated by Anglo-Swiss mining giant Glencore (Bordoni, 2019; Lightfoot, 2019). The supply chain of raw materials used in the EV battery production is shown in figure.

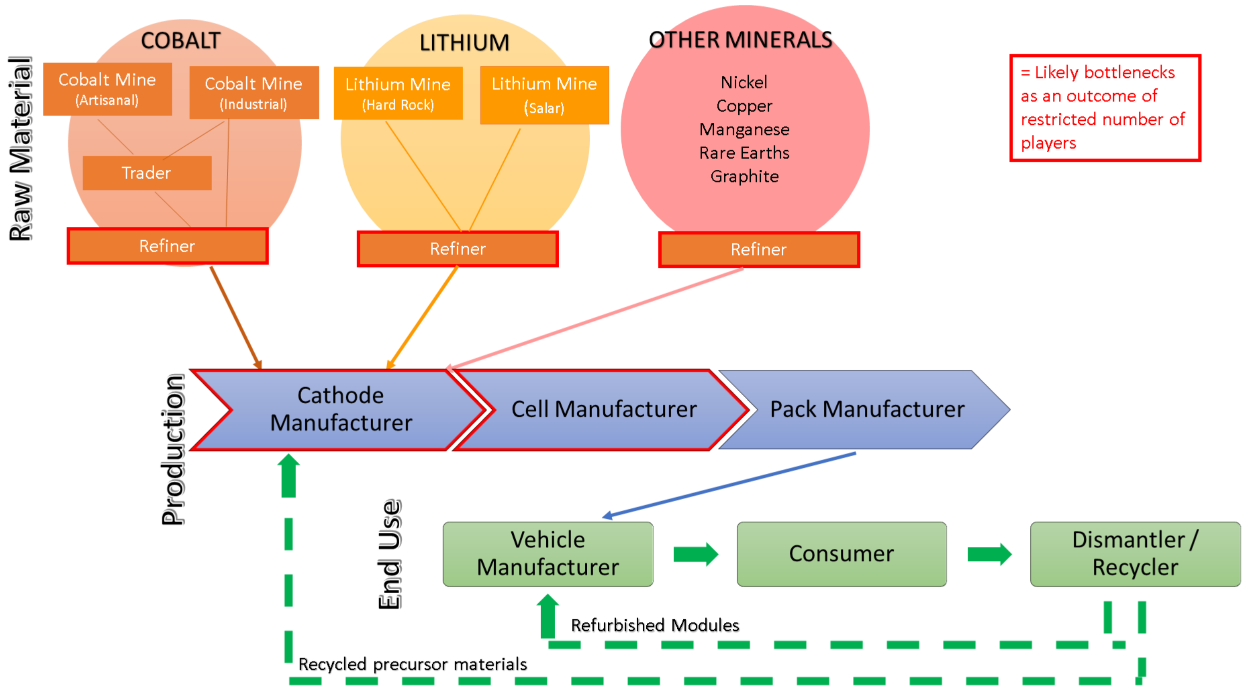

Figure 5: EV Battery production - Supply Chain

A historic lawsuit has been filed against some of the world's largest tech companies including Dell, Apple, Google, and Microsoft, by families of child laborer in Congo who became fatal casualties or were physically disabled while working in the mines that produce cobalt needed by the battery manufacturers as a raw material for the batteries that are used in smartphones, laptops and electric cars (Kelly, 2019). With the decline in the usage of fossil fuels providing traction for electric vehicles, the International Energy Agency has updated its 10-year forecast for the e-mobility segment, which notifies that economic and global political concerns will triumph over the environmental courtesies in terms of recycling industrial wastes (Hall, 2020; IEA, 2020).

2.7 *Emerging Technologies*

Society has come of age and environmental awareness amongst the masses has also resulted in the increased demand for EVs. This is also related to the age, education level, income of the individual, awareness amongst individuals about the implications of leading a green lifestyle (the envisages significant lifestyle changes and changes in shopping habits over the previous 5 years) and playing their part by changing consumption patterns. Research reveals that all these factors bear a positive correlation with the intent of purchasing an EV (Hanke et al., 2014).

Batteries being the most expensive component of EVs contributing to almost 30% of an average mid-size vehicle (Anonymous, 2020). Besides increasing the risk of exhausting power, leaving the driver stranded, a weakening battery fast damages a vehicle's second-hand value. Tesla, the Californian EV maker, has a million-mile (1.6m km) batteries project going on (Anonymous, 2020). Tesla plans to launch an original low-cost, long-life battery in its Model 3 sedan in China, late 2020 or early 2021, that is expected to make the cost of EVs comparable to ICE models, besides allowing these batteries to have 2-3 lives in the electric power grid (Shirouzu & Lienert, 2020).

Vehicles using LIBs (also used in cellphones) are likely to get replaced over the next few years by cars and trucks manufactured using lithium-iron phosphate and other chemistries. Besides reducing costs, it is expected to prolong vehicle ranges to at least 400 miles between charges and allow batteries to last for 1 million miles (Mullaney, 2020).

III. RESEARCH METHODOLOGY

3.1 Systemic Review

As the research methodology I have adopted a systematic literature review. Systematic review refers to the examination of a distinctly formulated question which puts to use systematic and unambiguous methods for the purpose of identifying, selecting, and critically appraising pertinent research, and for collecting and analyzing data from various studies that are included in the review (Baumeister & Leary, 1997). Literature identifies, critically appraises and assimilates the findings of various high-quality individual studies that are of relevance to the subject of research and in so doing it addresses the research questions identified (Baumeister & Leary, 1997). This research has undertaken a thorough literature review of the field of study in order to examine both earlier and contemporary work of connoisseurs in the fields of circular economy and electric vehicles (Johnston, 2014).

3.2 Results

From January 2000 to March 2021, we found 782 articles with the search term circular economy in general and recycling and supply chain in particular were selected initially for evaluation using most popular search engines for scholarly works, for instance, Google, Scholar, Springer., MDPI., Emerald., Sage., Science Direct., and Wiley. Online Libraries. After removing the duplicates, the articles remaining for analysis was 675. Out of these articles 135 articles were removed due to poor language context or being non English papers or book reviews. Finally, 540 randomly chosen articles were analyzed and of these 204 systematic reviews and/or meta-analysis met our inclusion criteria. Among these 84 articles were removed because these papers focussed more on the technical attributes of battery metrics rather than the management perspective (see Figure 6).

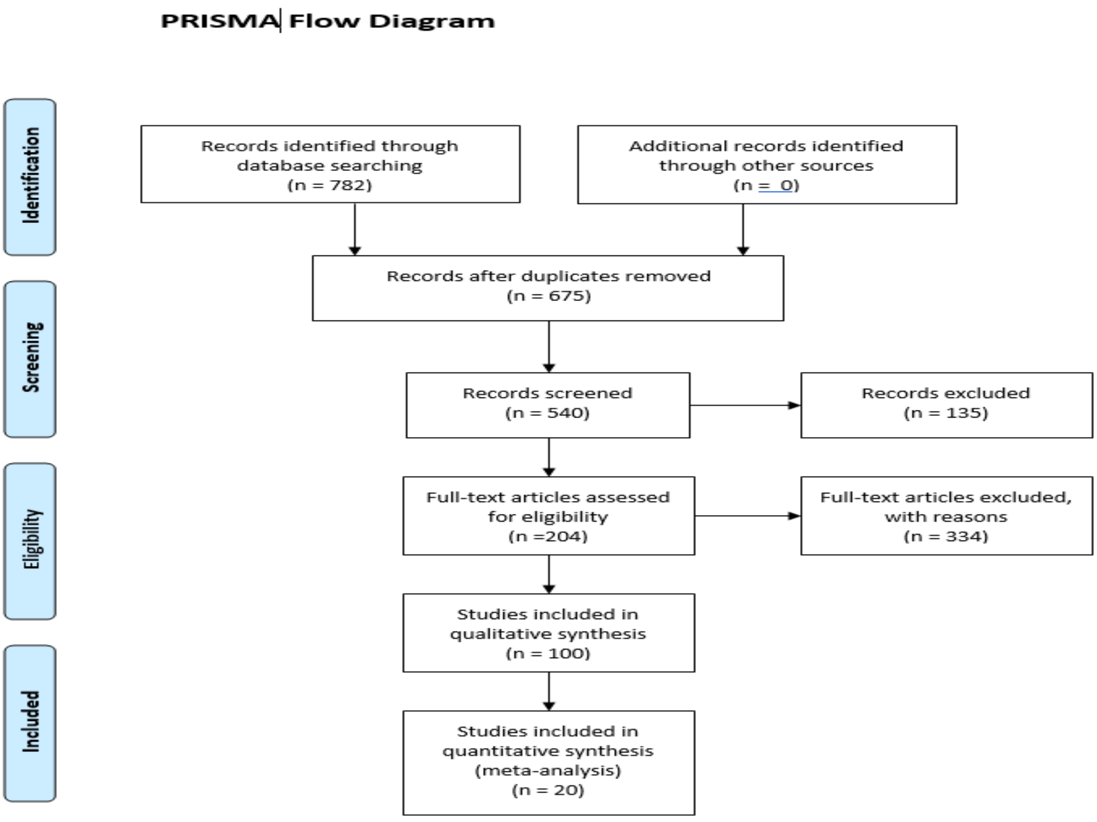

Figure 6: PRISMA Flow Diagram for the Meta-Analysis (Vu-Ngoc et al., 2018)

A comprehensive search of the literature was undertaken, followed by conjoining descriptions and tabular methods for the synthesis of literature (Bjørnbet, Skaar, Fet, & Schulte, 2021). Following this a filtering process was used to reduce the number of papers using a selection of keywords that specifically cover both the circular economy in general and recycling and supply chain in particular (Beaudet et al., 2020; Mo & Jeon, 2018; Nascimento et al., 2019). For the purpose of conducting this review dependably across conventional Supply Chain Management, sustainable Supply Chain Management and Circular Economy, phrases such as 'circular supply chains', 'circular economy', 'sustainable supply chains', recycling, waste management, 'reverse logistics,' 'closed loop' and several other combinations covering similar terminology, as our principal search terms were used.

3.3 Secondary Analysis

Secondary data presents excellent resources for research. Since the data has already been collected, cleansed, organized in a useful manner and published, it reduces the difficulties faced while handling primary and raw data. Time and resource constraints justify the use of secondary data. Secondary analysis involves empirical exercise applying the same fundamental research philosophies as research that utilize primary data (Johnston, 2014).

The research is based on secondary data that has been collected from various publications issued by various reliable agencies across the world. Charts and graphs offer an extremely efficient way to decode any patterns or trends present in the numerical data, on any variable, discernible though the quantitative data analysis. Appropriate visual representations help to present a clear unambiguous picture of any trend underlying the data. We have gathered data from authentic national and international sources (World Bank, UNCTAD, International Energy Agency and Statista) including government data bases across the world and globally renowned research houses (e.g. McKinsey, J.P. Morgan and Bloomberg). Several charts such including simple bar charts, clustered bar charts, composite bar diagrams, pie chart and line diagrams have been used to draw out useful information. The data has been analyzed using charts and diagrams in order to bring out important trends and components.

IV. RESULTS

Countries across the world are fast implementing clean air policy and switching over to EVs is an important part of it. As of now, transport policies that target no-emission vehicles or phasing out of internal combustion engine (ICE) vehicles through 2050 have been publicized by 17 nations (IEA, 2020). This entails steady rise in EV sales and gradual but significant decline in conventional internal combustion engine (ICE) vehicles.

2019 saw global sales of electric cars crossing 2.1 million, exceeding levels reached 2018 (considered a record year) boosting the stock of electric cars to 7.2 million (IEA, 2020) of which battery fueled electric cars are estimated at around 1.7 million approximately in 2019 (Statista, 2020). The International Energy Agency estimates there will be 140m electric cars globally by 2030 depending on whether nations meet targets set in the Paris climate agreement (Gardiner, 2017).

In 2019 electric cars represented 2.6% of worldwide car sales and approximately 1% of global car stock, recording a 40% growth, year-on-year (IEA, 2020). In 2018 EV sales jumped 65% above 2017 figures. However, in 2019, there was only 9% year-on-year increase in the number of units sold to 2.3 million. The evolution of the EV stock and the growth of BEVs in comparison to EVs is shown in figure 7. Even the first quarter of 2020 saw sales decline by 25%. This indicates an easing of the rapid expansion. Overall, Europe witnessed the strongest growth in EVs (Gersdorf et al., 2020). Europe, however, went against the trend to record a 44% growth with its market share expanding to 26% (Gersdorf et al., 2020). HEV sales peaked in 2003 then gradually declined only to spike again in 2019.

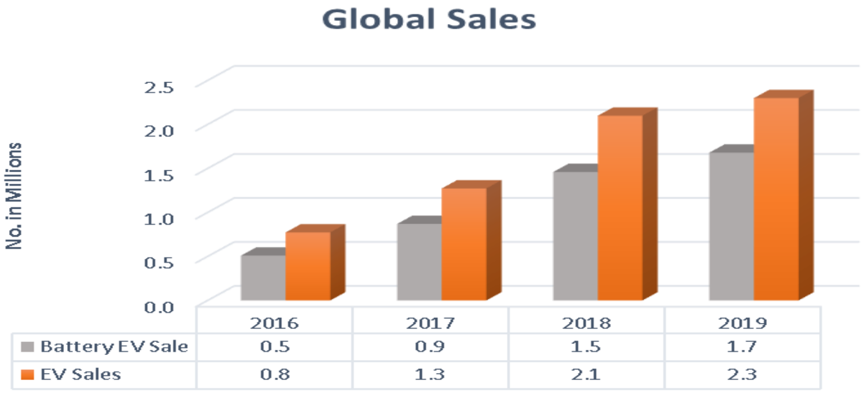

Figure 7: Global sales of electric vehicles vs battery-electric vehicle (Statista, 2020)

Notwithstanding the general contraction in sales, EV market penetration at the global level expanded by 30 basis points in 2019 to 2.8% from 2.5% in 2018, due to the additional growth witnessed in the first quarter of 2020 (Gersdorf et al., 2020).

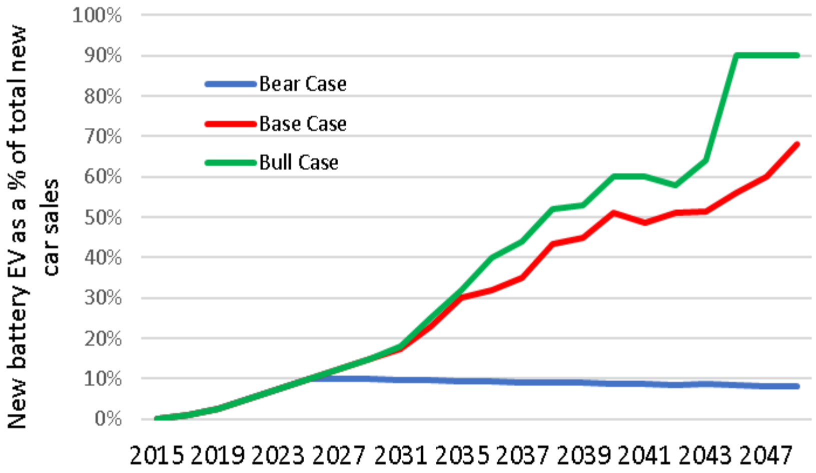

Figure 8: Projected growth in BEV

In the figure 8, the projection assumes the base case scenario to be cumulative of a billion all-electric vehicles on the roads globally by 2050 (Lambert, 2017) and projects the demand for EVs under 3 scenarios – base case, bull case and bear case. Research indicate that electric car sales are expected to take off beyond 2022. Bloomberg forecasts for annual EV sales is 10m by 2025, 28m by 2030, and 56m by 2040. According to Bloomberg NEF's "Electric Vehicle Outlook 2020" report, Passenger EV sales that soared to 2.1 million in 2019 from 450,000 in 2015, are expected to drop in 2020. Thereafter it is expected to head northwards regaining the momentum on the back of falling battery prices, improvement in energy density, better charging infrastructure, and new market entries (BloombergNEF, 2020).

According to auto industry analysts who are to forecast the timeline for EV sales to exceed ICE vehicle sales and as depicted in figure 9 new electric passenger car sales will overtake sales of ICE models by 2037 (Evarts, 2019).

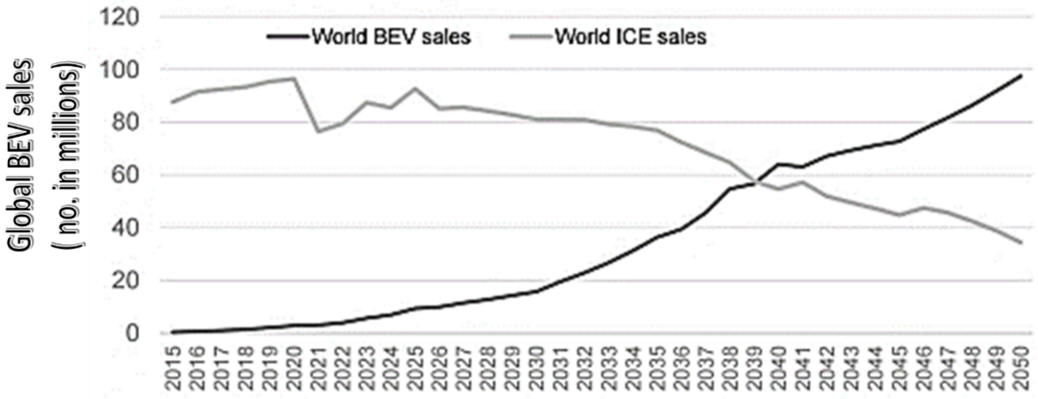

Figure 9: Projected growth in EV vs ICE

Morgan Stanley's analysts predict that more EVs will be sold in 2040 than gas-powered cars (Lambert, 2017). On a conservative basis Bloomberg Energy predicts 35% of global car sales to comprise of EV by 2040 (Lambert, 2017). In October of 2018, J.P. Morgan anticipated that EVs will comprise about 4% of global vehicle sales in 2020 and by 2025, EVs and HEVs together will comprise an estimated 30% of global vehicle sales (J.P.Morgan, 2018). According to a recent report by Cairn Energy Research Advisors, a research-based firm that focuses on EV and battery industries, there would be a spike in EV sales in 2021 as an increasing number of nations across the globe press on new campaigns with the objective of urging consumers to purchase vehicles powered by battery. The estimates published by Cairn indicate a 36% surge in the global sales of EVs in 2021 and cross 3 million for the first time ever (Le Beau, 2020). But these were estimates were made before COVID-19 virus had struck us. The world economy is now very different from what it used to be. Depending on how things pan out during the rest of 2020, EV sales are expected to constitute nearly 3% of total vehicle sales (Le Beau, 2020) even on a conservative basis and expand to over 25 million vehicles to constitute 23% of global vehicle sales by 2025. Pure-ICE vehicles will be left with approximately 70% of the market share in 2025, that is expected to fall to about 40% by 2030, primarily in emerging markets (J.P.Morgan, 2018).

Growing production of EVs means increasing demand for batteries. The global EV battery market size estimated at $23 billion in 2017 is expected to touch $84 million by 2025, reflecting a compounded annual growth rate (CAGR) of 17.2% from 2018 to 2025. Fortune Business Insights Report (2018) predicts that global EV battery market will see a CAGR of 21.1% in volume to reach at 40.6 million units by 2026 from 8.6 million units in 2018. The global EV battery market is in position to grow at a CAGR of nearly 22% (by $ 44.24 bn approximately) during 2020-2024 (Kakkar, 2020; Research & Markets, 2020). The Fortune Business Insights Report emphasized that Asia-Pacific will lead the EV battery market because of the progressively stricter regulations introduced by respective governments to cut down carbon and greenhouse gas (GHG) emissions (ETAuto, 2019)**.**

Over the last 20 years battery market growth has been fueled by the emergence of Lithium-ion technology. With the rapid growth in EV penetration, the automotive industry is looking forward to reducing its reliance on fossil fuels and lithium-ion battery manufacturers are poised to unlock access to opportunities that were unthinkable of a decade ago (Transparancy Market Research, 2019). Lithium finds its largest end-use in rechargeable batteries as shown in pie chart in figure 10 taking almost 37% (Mo & Jeon, 2018).

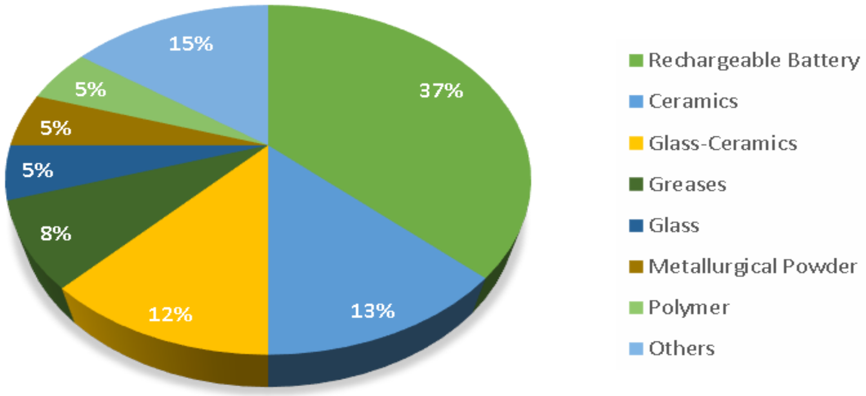

Figure 10: Uses of Lithium- Demand in 2015

Lithium-ion battery market is projected to witness volume expansion at about 11% CAGR, from 2019 to 2027 reaching 15,764.89 Million Units by 2027 (Transparancy Market Research, 2019). In terms of value, the growth is expected at about 9% CAGR during 2019-2027 to reach US$ 41.5 Bn by 2027 (Transparancy Market Research, 2019). In 2018 Asia Pacific garnered conspicuous share of the worldwide lithium-ion battery market. The charts showing Li battery demand growth in figure 11 predict a 2000 GWh capacity by 2030.

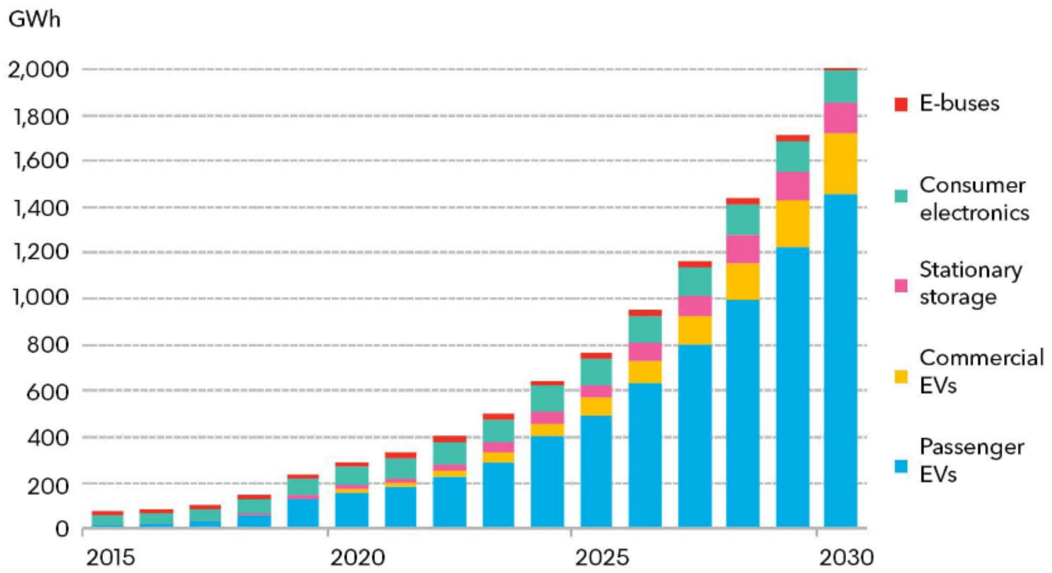

Figure 11: Annual LI battery demand

According to the World Economic Forum, keeping global warming lower than 1.5 degrees would require adding 100 million electric vehicles altogether by 2030 (Eckart, 2017). By 2025 an estimated 90% of the lithium-ion battery market would comprise batteries powering EVs. However, Li-batteries are a key element behind the possibility of EVs generating higher carbon emissions over their lifecycle (consisting of raw materials procurement, manufacturing, use and recycling) compared to petrol or diesel cars (Eckart, 2017). The huge scaling up of material demand for EV batteries necessitates increased attention to the challenges associated with raw material supply that relate mostly to ramping up production, social and environmental issues (IEA, 2020).

A key environmental issue is growing mineral crisis and consistent mining is also depleting water fast as the mining process used in South America (Lithium Triangle holds over 50% of global reserve) uses a lot of water – approximately 500,000 gallons per ton of lithium (Katwala, 2018). There is also risk of contamination of water due to leakage from the evaporation pools used during recovery (Katwala, 2018). Another big concern is waste disposal.

Considering the 2017 EV sales volume, UK researchers calculated that there will be 250,000MT, or 0.5 million cubic meters, of “unprocessed battery pack waste” when these EVs reach the end of complete their live-cycles in roughly 15-20 years, that can easily fill up 67 Olympic swimming pools (Hunt, 2019). This EV boom is expected to result in 11MT of expended lithium-ion batteries that would need recycling during 2017-2030 (Gardiner, 2017).

Cost of lithium-ion batteries plummeted 78.65% during 2010-2017 due to higher adoption of battery technology by the auto makers and the development of economical production methods by sellers (Kakkar, 2020). LIB pack price dropped 75% over 7 years from approximately $1000/kWh in 2010 to $209/kWh in 2017, and is projected to fall below $100/kWh by 2025 (BloombergNEF, 2020). This reduced cost of LIB pack makes EV price comparable to traditional vehicle resulting in an earlier tipping point for active spread of EVs (Cobb, 2015; Mo & Jeon, 2018).

In 2015 manufacturing BEVs were much costlier than comparable ICEVs, chiefly owing to the cost of manufacturing batteries which imposed a significantly higher expenditure burden on vehicle owners(Brennan & Barder, 2016), increasing the cost of ownership compared to ICEVs. Up to 50% of the cost of a typical LIB comprises raw materials cost and replacing virgin materials by recycled materials, could reduce total pack cost by up to 30% (Beaudet et al., 2020).

Recycling a battery currently entails a cost of €1 per kg. However, just one third of that is the value of raw material reclaimed. Recycling lithium costs five times as much as extracting virgin material. Hence, only about 5% of lithium-ion batteries are recycled at present (Eckart, 2017; Gardiner, 2017) (Eckart, 2017; Gardiner, 2017; Reid & Julve, 2016). However, recycling would be logical considering the huge volume of consumption of lithium-ion batteries pushing lithium demand (expected to be 350,000 MT in 2020) and supply failing to keep up which might push material prices up in future. In 2015 aggregate LIB consumption requires metals and minerals worth $2 billion (Sanderson, 2017). While lithium demand is expected to rise 4 times between 2015 and 2050 to 480,000 tons (Eckart, 2017), demand for cobalt is expected only to double (Sanderson, 2017).

V. DISCUSSION

Undoubtedly living standards in the emerging markets have significantly improved due to economic growth yet concerns remain regarding the massive volume of consumer and industrial waste generated in these markets. Several municipalities spend nearly 50% of their budgets on solid-waste management (McKinsey & Co., 2017). Studies suggest that CE can be of help here. Employing CE principles, state-of-the-art businesses are discovering ways to transform trash into cash. By accumulating volumes that are big enough to validate business investment, these businesses can establish infrastructure necessary for systematic waste supply chains management (Mc Kinsey & Co., 2017). CE approach to production is readily accepted in political and business spheres to surmount the deficiencies of conventional linear economy models of operation. Academic literature on CE is still at the embryonic stage. Adequate consideration is not given to implications of supply chain management, despite supply chain innovation's relevance in superior resource efficiency and CE (De Angelis, et al., 2017). With the UN forecasting global population to reach nearly 10 billion by 2050, Earth's natural resources will only be more strained. This emphatically underscores the environmental benefits of the circular economy - a smaller amount waste going into landfill and lower water depletion, means lower GHG emissions (Stewart, 2020). CE addresses swelling resource issues faced by business and economies and has the potential for employment generation, growth initiation, and environmental impacts diminution, including carbon emanations (MacArthur, 2015). This works well for the corporates from shareholders' and consumers' perspectives since it takes care of CSR aspect of business operations. Current study by Nielsen suggest that 81% of worldwide customers strongly believe that companies should implement environment improvement strategies (Stewart, 2020).

EVs are vital to attaining global targets of carbon emissions reduction. However, it is evident from new research that the world is unprepared to handle the LIB waste generated once EVs complete their useful life span (Hunt, 2016). LIBs being a major cost component of EVs are more expensive than lead-acid batteries or NiMH batteries (Kakkar, 2020). But Tesla's new "million miles" battery developed with China's Contemporary Amperex Technology Ltd (CATL) deploying technology developed by Tesla in collaboration with a team of academic battery experts will bring the cost of electric vehicles closer to similar ICE vehicles. (Shirouzu & Lienert, 2020). If successful, this evolution we might even see the total cost of ownership (purchase price plus running costs) of EVs dipping below those of ICEVs (Reid & Julve, 2016). So, a huge amount of battery waste can and will be generated and battery recycling technology will come to the rescue besides abating social menaces of child labor and exploitation of labor by miners and cutting down adverse environmental impacts of mining.

EVs will positively impact automotive suppliers due to batteries. New services are expected to be created and recycling/reuse players are anticipated to grow (for example Umicore) while car maintenance and fuel sectors will decline (Sietzes wolfs, 2011). It is understood that there will be

11MT of EV batter waste by 2025 without simultaneous growth of systems to handle such huge waste volume (Eckart, 2017). A pragmatic method for recycling EV batteries as also other energy repositories from EVs is essential if this transportation technology is to be successfully implemented. Several battery manufacturing technologies involve the use of toxic materials. So, when these batteries are disposed these hazardous substances are released into the environment. This necessitates regulated disposal of EV batteries in certain cases but will most likely entail substantial expenditure and moves away from the objectives of benefiting the environment using zero- emission vehicles (Jungst, 2001). Researches indicate that recycling could be the element that would, in due course, drive the sustainability of lithium-ion cells through the minimization of waste and establishment of a circular economy (Gandhi, 2020).

As batteries from the first-batch of electric cars complete their useful life auto companies will have to decide whether to recycle or to put them to alternative use, One such use is reconditioning them and reusing them in less-exhausting stationary applications where batteries usually get charged and discharged at low rates and function with in a fortified working area under restrained environment(Reid & Julve, 2016). Due to complexity and low yield of recycling currently very few (approximately 5%) of lithium-ion batteries are recycled at present. Moreover, the recovery is dependent on the nature of cathodes used with a 70% recovery in lithium cobalt oxide (LCO) and a lower recovery for non-cobalt cathodes. (Brückner et al., 2020; Harper et al., 2019b). In addition to bearing the risk of discharging toxic gases if damaged these batteries suffer from another big disadvantage. The essential components (lithium and cobalt) extraction can cause water pollution and depletion besides other environmental concerns (Gardiner, 2017). The available literatures rightly emphasize on the virtues of recycling.

2014 European Commission report estimated €600 billion annual economic gains accruing to the EU manufacturing sector with EU countries undergoing transitions to a circular economy. Following several years of speedy economic growth even China adopted the CE concept in its last two 'Five Year Plans' recognizing the need to change course in raw materials and energy use and phase out industrial processes that generate excessive waste (Valavanidis, 2018). To gain perspective into the magnitude of EV battery waste, in 2019, China recycled 60MT plus LIBs and garnered more than 70% share of the battery recycling market (Mandal, 2020). Collective effort of smartphone producers, key automakers and the government helped the republic restraint the huge battery recycling problem caused by piling up of used batteries as an increasing number of people adopted EVs(Mandal, 2020). European and Chinese markets would be the key factors driving EV demand soon and hence determining the fate of recycled battery and CE approach. China is already world's largest EV market manufacturing 1 million battery powered models in 2019 (Le Beau, 2020).

What no one is talking about the possible retaliation from oil companies. A key aspect of growth in battery driven cars is the displacement of oil as an important fuel for the transport sector. The articles that we reviewed did not shed much light on the impact that EVs and hence LIBs will have on the fossil fuel economy and the possible retaliation from countries that primarily thrive on Petro-money.

The adverse impact of passenger EVs and e-buses on global oil consumption continues to grow rapidly. Between 2011 and 2019, electric vehicles have dislodged almost 3% of the growth in global oil consumption (Murtaugh, 2019). As per Bloomberg NEF's May 2018 long-term EV outlook by 2040, EVs possibly will dislodge 6.4 million barrels/day of oil demand, while improvements in fuel efficiency will displace additional 7.5 million barrels/day, (Murtaugh, 2019). These have serious implications for both oil and electricity markets. Transport electrification, specifically by way of 2-wheelers, is already displacing approximately 1 million barrels of daily oil demand and by 2040 it will remove 17.6 million barrels daily. EVs altogether will add 5.2% to global electricity demand by 2040 (BloombergNEF, 2020). Distressed by low demand the oil producers can slash oil prices making driving ICEs further cheaper than EVs, thus making EVs unattractive to the vehicle buyers and throwing fresh challenges for the EV producers.

VI. CONCLUSION

2020 has so far been an exceptional year due to the rapid spread of corona virus that ultimately turned into a pandemic throwing the global economy out of its trajectory. The demand for EV will remain strong and is expected to pick up as soon as the global economy takes its normal course emerging out of the Corona pandemic. EVs are the key to reducing air pollution in regions with dense population. The technology has the potential to contribute towards fulfilment of objectives of energy diversification and reduced greenhouse gas emissions. While demand remains strong, waste generation has become a cause of worry. In our bid to reduce carbon footprints we are generating other toxic wastes from disposed car batteries – using evil to kill evil. There will be exponential growth in battery waste generation over the next two decades making it imperative for the environmentalists and governments to address the issue if green transport is to be implemented any time soon. This is what is urging the EV manufacturers to increasingly adopt the principles of circular economy and lean towards using recycling technologies in vehicle design and manufacturing.

In December 2019, France became the pioneer nation to pass a low towards this end, with a 20 years' timeline. We expect other countries to follow which will make it necessary to implement a circular economy framework to avoid battery waste accumulation and to eradicate the social evils associated with the mining of essential raw materials for battery. Recycling will also prove to be more economical for vehicle manufacturers. EVs can lead the way to solving, to a great extent, the problems created by the scarcity of resources even as world population continues to grow unabated. EV benefits include no tailpipe emissions, superior efficiency compared to ICE vehicles and huge potential for GHG emissions cuts, possibility of recycling and drawing benefits from a circular economy, along with growth of low-carbon electricity sector. But by far the best benefit derived from EVs is the demonstration of how recycling can be used by an industry to grow and meet growing demand. This is the key to directing nations to adopt policies supporting application of CE approach to production.

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The use of Geoelectrical Method to Investigate the Extent of Hydrocarbon Contamination in Okpare-Olomu Community, Delta State, South South Nigeria

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ABSTRACT

Two-dimensional (2D) geoelectrical survey was carried out on a suspected hydrocarbon contam- inated (oil spills) site at Okpare-Olomu commu- nity, Ughelli South Local Government Area of Delta State, to assess the intensity and extent of hydrocarbon contamination at an oil spill site. Five (5) traverses were investigated by emplo- ying a dipole-dipole array with a maximum length of 200 m. The survey was conducted during the wet season to ensure that the electrodes made good contact with the earth. Four (4) traverses (1–4) were surveyed at the contaminated site, while one traverse (5) was surveyed at a distance from the contaminated area, serving as a control traverse. Analysis of the results revealed that topsoil (sand), clayey sand, and clay make up the background subsoil within the location. This subsoil resistivity varies betw- een 43ohm-m and 554 ohm-m. The resistivity of the sand layer ranges from 292 ohm-m to 554 ohm-m, and its thickness ranges from 0 to 10 m. The clayey sand has a resistivity range of 81 ohm-m to a little over 154 ohm-m, and the depth of the clayey sand is between 10 - 20 m.

Keywords: contamination; hydrocarbon; ground- water; geometry; traverse.

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ABSTRACT

Two-dimensional (2D) geoelectrical survey was carried out on a suspected hydrocarbon contaminated (oil spills) site at Okpare-Olomu community, Ughelli South Local Government Area of Delta State, to assess the intensity and extent of hydrocarbon contamination at an oil spill site. Five (5) traverses were investigated by employing a dipole-dipole array with a maximum length of 200 m. The survey was conducted during the wet season to ensure that the electrodes made good contact with the earth. Four (4) traverses (1–4) were surveyed at the contaminated site, while one traverse (5) was surveyed at a distance from the contaminated area, serving as a control traverse. Analysis of the results revealed that topsoil (sand), clayey sand, and clay make up the background subsoil within the location. This subsoil resistivity varies between 43ohm-m and 554 ohm-m. The resistivity of the sand layer ranges from 292 ohm-m to 554 ohm-m, and its thickness ranges from 0 to 10 m. The clayey sand has a resistivity range of 81 ohm-m to a little over 154 ohm-m, and the depth of the clayey sand is between 10 - 20 m. The clay layer has a resistivity of 43 ohm-m and extends from 15 to 50 m. The results from traverses 1–4 show that the topsoil (0–10 m) is characterized by resistivity values that are generally > 4000 ohm-m (4045–10512 ohm-m) across all four traverses, the second layer (clayey sand) extends from depths of 10–25 m across all four traverses, and the resistivity value falls at 611 – 3408 ohm-m, while the third layer (clay) has resistivity values between 326 – 1940 ohm-m. These characteristic resistivity values along traverses 1 –4 show elevated values compared to the resistivity values of corresponding layers from the control traverse. These results indicate that the hydrocarbon has polluted these layers. These findings suggest that in the geometry of the contaminant plume, the contaminant is already migrating through the underlying strata (clayey sand and clay). Furthermore, the sections demonstrate that the contamination intensity is more along traverse one and particularly at horizontal distances of 40–60 m. In contrast, the least impacted zone is along traverse four (4), indicating the contaminant's lateral flow direction. The result of this investigation has once again underscored the effectiveness of the electrical resistivity method and the 2D resistivity technique employing dipole-dipole array in environmental investigations. It is recommended that Bioremediation should be embarked upon by the Government to protect the agricultural and regional groundwater system of the study area.

Keywords: contamination; hydrocarbon; groundwater; geometry; traverse.

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I. INTRODUCTION

Recent oil spills have posed a threat to human life, marine life, wildlife, and soil microorganisms. It has seriously threatened human existence in particular, that of the Niger Delta region. Statistics have shown that more than 2.4 million barrels of oil have been poured into streams and soil in southern Nigeria in the last 30 years. About 70 percent of the oil has not been recovered, while many leaks have been abandoned (The Daily

Independent, 2010). Oil spills are caused by a variety of causes, including corrosion of pipes and tanks, sabotage, and manufacturing operations. Hydrocarbon contamination has a major impact on the ecosystem into which it is released. Filtered and trapped pollutants in the non-aqueous liquid phase represent one of the biggest problems worldwide concerning the effect of biological radiation from contaminated soils and aquifers.

Oil spills are also a known source of groundwater pollution in oil-producing and developing countries. Between 2005 and 2015, Nigeria reported approximately 9,343 oil spills (NOSDRA, 2015). This gives an average of 1000 cases of oil spillage per year. Due to many factors, oil spills usually occur in Nigeria, including improper handling and maintenance of oil facilities, failure of oil infrastructure, and damage to pipelines by oil thieves.

Soil pollution caused by oil spills can be detected, mapped, and modeled using resistivity methods because oil-contaminated land usually exhibits different resistivity anomalies than equivalent but uncontaminated land (Mazac et al., 1990; De Ryck et al., 1990, 1993; Redman et al. 1994). The location of abnormal resistivity on the tomogram can indicate the location of underground contaminants. The range of resistivity anomalies can be used to predict the size and geometry of pollutant plumes and the resistivity comparison between pollutants and earth materials (Asquith and Gibson 1982; Benson et al., 1997). Atakpo (2013) used a two-dimensional dipole array resistivity map to investigate the crude oil-contaminated site in Oguhala, a coastal community in the Nigerian Delta. The study results indicate that the high resistivity value corresponds to oil contaminated soil, and the top 10 m of the area has been penetrated by oil spills.

Hydrocarbons often have much higher resistivity than water, so that smoke contamination can be recognized as a high resistivity anomaly. These traits have been reported in many studies, e.g., Endres and Greenhouse, 1996; Benson et al., 1997; Buselli and Lu, 2001. On the other hand, several studies have shown an increase in electrical conductivity in oily areas about biological degradation processes, for example, Fetter, 1993; Stuck et al., 1998; Atekwana et al., 2000. This increase in electrical conductivity may result from greater mineral wear due to acids generated by the biodegradation of organic molecules (Sauck, 2000). The time frame must be taken into account, which is also an indicator of the development of the degradation process; Recent spills should be permanent, but over time the pollutant cloud should become more conductive as biodegradation increases (Sauck, 1998; 2000).

Geophysical surveys of sites contaminated by oil are important for estimating the extent of damage caused by oil spills, designing repair methods, and evaluating the effectiveness of the repair process (Yihdego and AlWeshah 2016). Compared with traditional soil sampling and chemical analysis methods, the geophysical methods used to investigate oil-contaminated areas are cheaper, more time-saving, and nondestructive. Resistivity, Very Low-Frequency Electromagnetic (VLF-EM), induced polarization, self-generated potential, and electromagnetic induction methods have been used to assess environmental problems caused by oil spills, landfill leachate, seawater intrusion, hazardous waste, and groundwater potential (Shevnin et al., 2005; Atakpo 2013; Abubakar et al., 2014; Raji and Adeoye 2017, Elmamy et al., 2021). Among the geophysical methods, the success of the resistivity method using a dipole- dipole array for investigating environmental pollution is outstanding (Hinnell et al., 2010, Win et al., 2011). This method is particularly suitable for investigating oil spills because oil pollution is a three-dimensional environmental problem caused by a combination of decentralized and advection processes.

In this study, the 2D electrical resistivity survey, with the aid of a Dipole-dipole matrix, was used to examine the extent of oil contamination and demonstrate that high resistivity anomalies indicate oil contamination in the area of investigation.

II. DESCRIPTION OF THE STUDY AREA

A geophysical survey was carried out in Okpare-Olomu community, Ughelli South Local Government Area of Delta State located within Latitudes 05° 27’23.31’’to 05°27’28.58’ N and Longitudes

06°53’48.15’ to 06 °56’07.22 E Southern Nigeria (Fig. 1). The rainy season in the area is from April to November, and the dry season is December to March. The area has a mean annual rainfall of 2400 mm and an average annual temperature of 27°C (Ehirim and Nwankwo, 2010). It is characterized by broadly flat topography with gentle undulations and is largely drained by River Niger. Mangrove and rain forests characterize the vegetation of the study area. The spill site lies within the coastal plain of the Niger Delta Basin to the south, which consists mainly of Cretaceous sediments deposited in a high energy deltaic environment. The hydrogeological aspect of the Niger Delta has been studied by many authors (Etu-Efeotor and Odigi, 1983 and Udom et al., 1998). Its subsurface geology consists of over 90% sandstone with shale intercalations. It is coarse grained, gravely and locally fine grained, poorly sorted, sub-angular to well rounded, contains lignite streak and wood fragment. The formation has a thickness of about 2100 m (Ehirim and Nwankwo, 2010, Uko et al., 1992).

Figure 1: Map of Delta State showing the local government area of study area (Ministry of Land, survey, and urban development, Asaba, 2002)

III. METHODOLOGY AND DATA PROCESSING

Two-dimensional (2D) surveys were conducted on the affected oil spills site using Dipole-dipole array and PASI Terrameter, 16GL Model was used. The position of each survey traverse was recorded in Universal Transverse Mercator (UTM) coordinates using a GERMIN 12-channel personal navigation device (GPS). The survey was carried out during the rainy season in order to allow a good contact resistivity of the electrodes to the ground for a high conductivity of the subsoil. A total of five (5) profile lines were surveyed, covering a maximum length of 200 m. Four (4) traverses at the affected site, and one (1) traverse far from the investigated area, which serves as a control traverse. The electrode separation was 10 m apart and measurements were carried out at n=1, n=2, n=3, n=4, n=5 and constant a=5. The Dnipro software was used for the inversion of the 2D apparent resistivity data. The field data pseudo section and the 2D resistivity structure were produced after running the inversion of the raw data to filter out noise. The Diprofwin program amortizes the bulk data into a series of horizontal and vertical rectangular blocks, with each box containing several records Resistivity of each block was then calculated using the FEM (Finite Element Method) inversion model to produce an apparent resistivity pseudo section. The pseudo section was compared to the actual measurements for a good model fit. The difference between measured and observed gives the inversion resistivity model, which represents the geology of the study area.

IV. RESULTS AND DISCUSSION

The results of the inversion model show large variations in the apparent resistivity (ohm-m) of the subsurface. Due to these large resistivity fluctuations, a 10 m electrode spacing model produced very sharp images of the subsurface resistivity structure. Figure 2 shows the 2D resistivity models of the affected site, while Figure 3 shows the 2D resistivity model of the control site.

The 2D Electrical Resistivity (ER) structures along traverses 1 - 4 (Figures 2) displayed the results of the inversion of the acquired resistivity data along traverses 1 – 4. On these 2D resistivity sections, the broken white line is used to show the suspected contaminated zones. The resistivity value along traverse 1 ranges from 326 – 4045 ohm-m. The resistivity distribution along traverses 2, 3, and 4 oscillates between 1105 – 10512 ohm-m, 755 – 6458 ohm-m, and 679 – 7886 ohm-m respectively. All four traverses cover a lateral extent of 200 m, and probe 50 m depth. Generally, the background subsoils (based on resistivity distributions) include the topsoil (sand), clayey sand and clay as noticed on the control results. The topsoil (0 – 10 m) across all four traverses is characterized by a resistivity value that is generally > 4000 ohm-m (4045 – 10512 ohm-m). This shows a highly elevated resistivity value compared to the control results with the highest resistivity of 554 ohm-m. The second layer (clayey sand), which extends from a depth of 10 – 25 m across all the traverses, has resistivity values of between 611 – 3408 ohm-m, while the third layer (clay) is characterized by resistivity ranging from 326 – 1940 ohm-m. These characteristic resistivity values along traverses 1 – 4 show elevated values compared to the resistivity values of corresponding layers from the control traverse. This suggests that these layers have been contaminated by hydrocarbons. These results also show that the contaminant plume is already moving through the underlying layers (clayey sand and clay), as indicated by the geometry of the contaminant plume. Furthermore, the sections show that the intensity of contamination is highest along traverse one and especially a horizontal distance of between 40 – 60 m having a corresponding depth of 0 – 50 m while the least impacted zone is along traverse four (4); this shows the lateral flow direction of the contaminant.

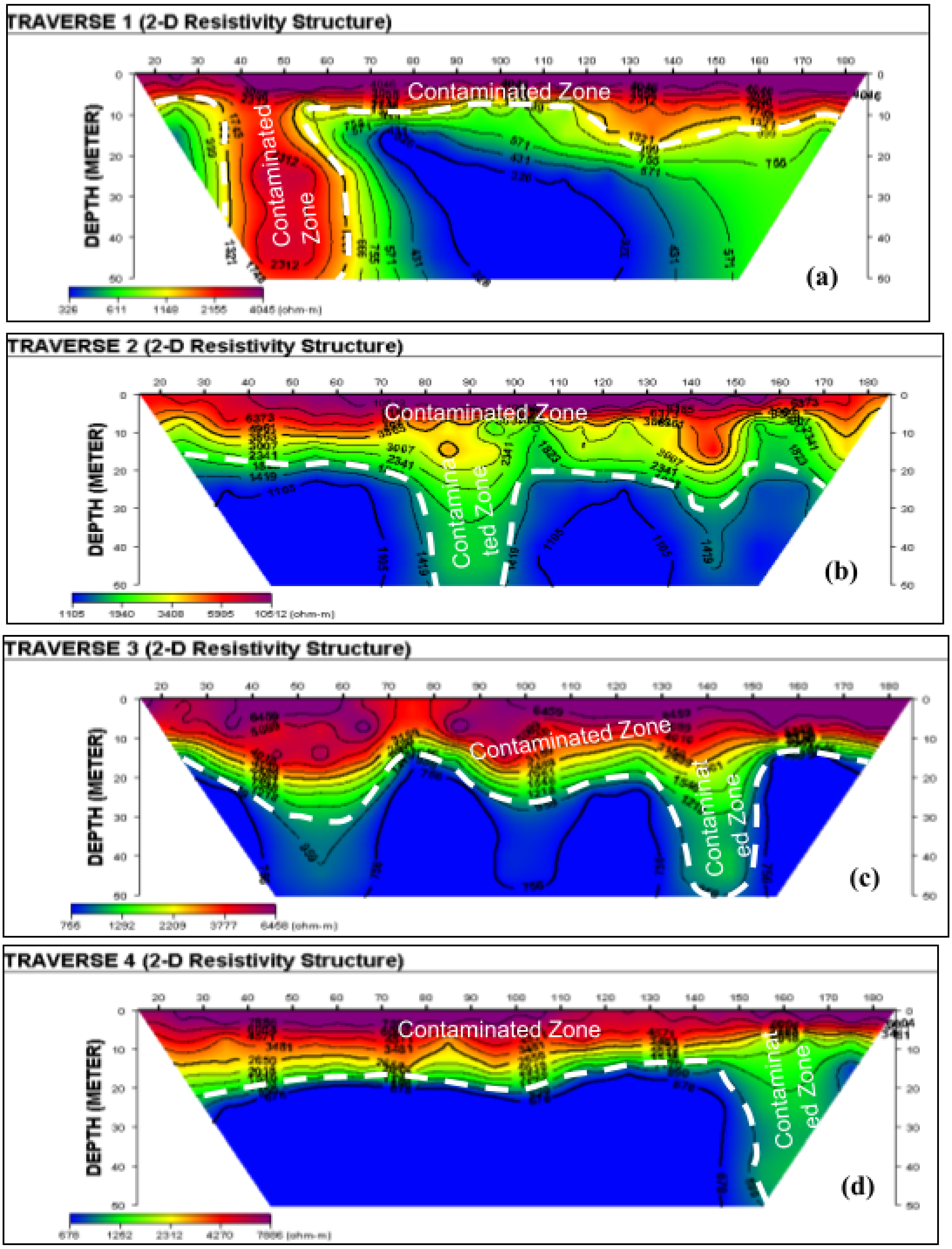

Figure 2: 2D Resistivity structure along with the Traverse 1 - 4

Figure 3 represents the control traverse. The 2D Electrical Resistivity (ER) structure was generated from the inversion of the acquired resistivity data along the control traverse (Traverse 5). The ER shows resistivity values ranging from less than 43 - 554 ohm-m. The traverse covered a lateral extent of 200 m and a total depth of penetration of 50 m. The resistivity section shows the uncontaminated ground is made of three distinct layers from the surface to a depth of 50 m. The first subsoil (red-purple) extends from the surface to a depth of about 10 m. It has resistivity values that fall between 292 ohm-m to 554 ohm-m. This is suspected to be sand. Underlying the suspected sand layer is the geoelectric layer having a resistivity value of between 81 ohm-m to a little above 154 ohm-m. This layer (green colour) extends from about 10 m to about 15 m across the traverse. This is suggestive of clayey sand. The last horizon (blue) with a resistivity value of 43 ohm-m which extends from about 15 m to beyond 50 m, is diagnostic of clay. This resistivity structure represents the background resistivity distribution within the study area.

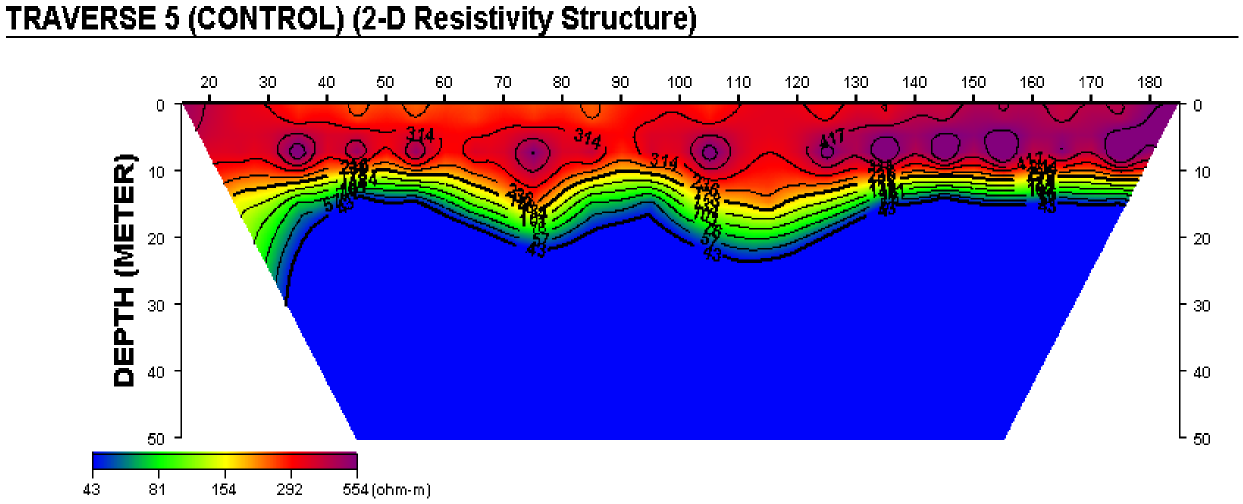

Figure 3: 2D Resistivity structure along the Control Traverse

V. CONCLUSION

Two-dimensional (2D) geoelectrical survey was conducted on a suspected hydrocarbon contaminated (oil spills) site using a Dipole-dipole array. This was aimed at delineating the geometry of the contaminated zone (if any). A total of five (5) profiles were occupied, each covering a maximum length of 200 m. The profiles were georeferenced using coordinates acquired with the aid of the GERMIN 12-channel (GPS) device. The survey was carried out during the rainy season to allow good electrode contact to the ground. Four (4) traverses (1 – 4) were surveyed at the affected site and one traverse (5) at a relatively far separation from the suspected contaminated area. This serves as a control traverse. The electrode separation was 10 m apart and measurements were carried out at n=1 to n=5.

The result of the investigation shows that the background subsoil within the location includes; topsoil (sand), clayey sand, and clay. The resistivity of these subsoils ranges from 43 - 554 ohm-m. The sand layer has a resistivity of 292 ohm-m to 554 ohm-m, and extends from 0 – 10 m. The clayey sand is characterized by resistivity of between 81 ohm-m to a little above 154 ohm-m and the depth range is from 10 – 15 m, while the clay layer has a resistivity of 43 ohm-m and extends from 15 – 50 m. The result from traverses 1 – 4 however shows that the topsoil (0 – 10 m) across all the four traverses is characterized by resistivity value that is generally > 4000 ohm-m (4045 – 10512 ohm- m), the second layer (clayey sand), which extends from a depth of 10 – 25 m across all the traverses has resistivity values of between 611 – 3408 ohm- m while the third layer (clay) is characterized by resistivity ranging from 326 – 1940 ohm-m. These characteristic resistivity values along traverses 1 – 4 show elevated values compared to the resistivity values of corresponding layers from the control traverse. These results indicate that the hydro- carbon has polluted these layers. These findings also suggest that, as indicated by the geometry of the contaminant plume, the contaminant is already migrating through the underlying strata (clayey sand and clay). Furthermore, the sections demonstrate that the contamination intensity is strongest along traverse one and particularly at horizontal distances of 40–60 m. In contrast, the least impacted zone is along traverse four (4), indicating the contaminant's lateral flow direction. The results of this investigation have once again underscored the effectiveness of the electrical resistivity method and particularly the 2D resistivity technique employing dipole-dipole array in environmental investigations. It is recommended that Bioremediation should be embarked upon by the Government to protect the agricultural and regional groundwater system of the study area.

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