ECONOMIC INPUT-OUTPUT ANALYSIS FOR BATTERY RECYCLING PROGRAMS AT THE HIGHER EDUCATION INSTITUTIONS AND REGIONAL SUSTAINABILITY PLANNING

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ECONOMIC INPUT-OUTPUT ANALYSIS FOR BATTERY RECYCLING PROGRAMS AT THE HIGHER EDUCATION INSTITUTIONS AND REGIONAL SUSTAINABILITY PLANNING

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ABSTRACT

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Economic Input-output analysis (EIOA) is a powerful technique for studying the economic behavior of a policy. Using this technique, one can study the consequences of applying a policy in a society from economic, social, and environmental perspectives. Chapters one through five of the study capture the economic impacts of recycling used dry cell batteries collected as a result of effective recycling policies at the higher education institutions (HEI) of the United States. Applied methodology modifies intermediate transactions of the input-output tables. The results show an $11,522 decrease in the gross domestic product (GDP) of the United States by applying strong recycling policies at HEI. These results support effective tax or credit incentive budget allocations in favor of recycling as the most environmentally friendly end-of-life option. Chapter 6 designs a set of policies that aim to improve quality of the environment as well as the economic growth. A framework for analyzing the EIOA results regarding implementation of the proposed policies is developed. The developed framework applies Design and Analysis of Experiments techniques and provides reasonable insight into the selection of the most effective policies, which increases the GDP as well as the quality of environment.
ACKNOWLEDGMENTS

Special thanks to my parents for their support. Indeed, their financial and spiritual support illuminated my way through the completion of the RCL program.
PREFACE

As humans dive deeper through accurate and precise contributions to increase the quality of life on the planet, decision making requires more comprehensive considerations, especially on a nationwide scale. Multidisciplinary sciences play an important role in the recent achievements of human beings. Indeed, such achievements require a combination of sciences to be evaluated for decision making. This research applies an economic input-output model to study the economic impacts of recycling dry cell batteries. In chapter six, a new inference approach for economic input-output results is developed using an analysis of said model. Hopefully, this research provides knowledge for readers who are interested in the processes of decision making as applied to macroeconomics as well as in the design and analysis of economic experiments.
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<table>
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<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEI</td>
<td>Higher Education Institutes at the United States of America</td>
</tr>
<tr>
<td>IOA (EIOA)</td>
<td>Economic Input-Output Analysis</td>
</tr>
<tr>
<td>BMS</td>
<td>Battery Manufacturing Sector</td>
</tr>
<tr>
<td>MMS</td>
<td>Metal Manufacturing Sector</td>
</tr>
<tr>
<td>RMV</td>
<td>Recovered Metal Content</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal Waste Management</td>
</tr>
<tr>
<td>LCA</td>
<td>Life Cycle Analysis</td>
</tr>
<tr>
<td>α</td>
<td>Elements of A matrix, matrix of coefficients</td>
</tr>
<tr>
<td>Z</td>
<td>Elements of Z matrix, matrix of transactions</td>
</tr>
<tr>
<td>X</td>
<td>Elements of X vector, vector of total economic output</td>
</tr>
<tr>
<td>f</td>
<td>Elements of F vector, vector of final demand</td>
</tr>
<tr>
<td>EU</td>
<td>Europe Union</td>
</tr>
<tr>
<td>$\sigma^2$</td>
<td>Variance</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Mean</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

As of March 2011, 30.4% of people over the age 25 in the United States held at least a bachelor’s degree, up from 26.2% ten years earlier [1]. The more people that participate in Higher Education Institutions (HEI), the better able these institutions will be to introduce environmental concerns to society. The proposed study is focused on the effectiveness of battery recycling facilities at HEI in the United States. Introducing the process of recycling requires an authoritative actor that can encourage and facilitate the recycling program. Also, most of the HEI already have some policies for recycling and waste treatment related to their wastes, particularly chemicals, which facilitate developing their policies to cover used batteries as well. Moreover, there are many active extracurricular organizations related to sustainability and environmental concerns at HEI, which would result in more batteries recycled than put into a landfill or incinerated. Choice of HEI as target group of the study also develops a positive attitude for recycling in students, which will result in a gradual cultural improvement.

This study performs research on the economic impacts of recovering the metal content of dry cell batteries which could be collected from HEIs in the United States by proposing effective battery recycling programs. Different HEIs have already implemented various programs. The overall result of such a variety of recycling programs would be more collected batteries. For example, Columbia University has a program that places publicly
accessible battery recycling receptacles around its campus that has resulted in 60,000 lbs of collected batteries [2]. Carnegie Mellon University accepts batteries along with the hazardous wastes that laboratories submit for waste treatment [3].

An average of eight disposable alkaline batteries are consumed per person per year in the U.S. according to the Ohio EPA [4]. With a population of roughly 305 million, this translates into approximately 3 billion batteries used per year [5]. These batteries will be thrown away after their use phase which may result in landfill toxicity and other environmental problems. Dry cell batteries contain some toxic materials including heavy metals such as mercury, lead, copper, zinc, cadmium, manganese, nickel and lithium, which have negative environmental and human health impacts [6]. Some of the potential health effects of heavy metals contamination are diabetes, pneumonia, lung and nasal cancer, blindness and anosmia [7]. Table 1 lists materials contained in Pb-acid and Ni-Cd batteries and emphasize the negative impacts for both human health and the environment. The higher the impact score, the more toxic the material is. As it is presented in the table, cadmium, lead, nickel and cobalt are associated with high health impact scores. Their leakage into an ecosystem translates to more risk.

Table 1 Relative health impact of major battery components. Higher number indicates a greater effect. (data adopted from [10], [11])

<table>
<thead>
<tr>
<th>Material</th>
<th>Health Impact Score</th>
<th>Material</th>
<th>Health Impact Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>65</td>
<td>Fluorine</td>
<td>22</td>
</tr>
<tr>
<td>Cadmium</td>
<td>57</td>
<td>Zinc</td>
<td>21</td>
</tr>
<tr>
<td>Lead</td>
<td>56</td>
<td>Aluminum</td>
<td>20</td>
</tr>
<tr>
<td>Antimony</td>
<td>51</td>
<td>Carbon Black</td>
<td>20</td>
</tr>
<tr>
<td>Nickel</td>
<td>45</td>
<td>Vanadium</td>
<td>18</td>
</tr>
<tr>
<td>Cobalt</td>
<td>35</td>
<td>Tin</td>
<td>13</td>
</tr>
<tr>
<td>Manganese</td>
<td>33</td>
<td>Sulfuric acid</td>
<td>11</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>33</td>
<td>Sulfur</td>
<td>9</td>
</tr>
<tr>
<td>Copper</td>
<td>31</td>
<td>Iron</td>
<td>8</td>
</tr>
<tr>
<td>Chromium</td>
<td>30</td>
<td>Zirconium</td>
<td>7</td>
</tr>
<tr>
<td>Lithium</td>
<td>25</td>
<td>KOH</td>
<td>5</td>
</tr>
<tr>
<td>Chlorine</td>
<td>23</td>
<td>Titanium</td>
<td>4</td>
</tr>
<tr>
<td>Sodium</td>
<td>23</td>
<td>Plastic</td>
<td>3</td>
</tr>
</tbody>
</table>
A survey revealed that an average of about 25 batteries in the sampling areas (either one retail parking lot or a few blocks of urban street) are recovered from about 1 ~ 198 littered batteries per sampling site (i.e. Cleveland, OH)[8]. Another study reported that 150 kg of used batteries are recovered from the disposal boxes at the Chulalongkorn University and the Chiang Mai University campuses in Thailand [9].

A researcher claimed that the life cycle emissions of a battery associated with all the stages up to the disposal stage are perhaps only 1% to 2% of the total potential emissions if the battery is simply discarded into the environment [10]. Three main end-of-life possible options for spent batteries are incineration, landfilling and recycling. A life cycle analysis by National Electrical Manufacturers Association (NEMA) shows that landfilling and incineration are not favorable end-of-life options, whereas recycling has a significant room for improvement [12]. Municipal waste managements (MSW) collect household and commercial wastes and after some general processes the dominant part of trashes goes to landfill. Since most of the MSWs don’t have related infrastructure to separate batteries from the wastes, used batteries goes to landfill. Thus, land filling is the most widely used option. Although there is no immediate contamination caused by landfilling, it definitely causes environmental problems by penetrating aquifers or soil in the long term [13]. For example, a study investigated that zinc-carbon batteries release significant concentrations of Mn and Zn in their leaching solutions, which is more than the US Toxic Characteristic limit [9]. Recycling is the most preferred option for the disposal of spent batteries. A study showed that the recycling option can greatly reduce any risk that may exist and conserve valuable natural resources. This study addresses the issues on the conservation of natural resource by reusing recovered metal content of batteries to produce new batteries. This will result in less demand for mining and extracting natural resources. It is supposed that recycling of used batteries prevents the entry of up to 98% of the battery’s weight into the environment after use, although energy consumption for recycling needs to be considered [11]. A study
indicated that profitability of recycling lithium-ion batteries with current technologies and economic conditions varies from $860 per ton to $8900 per ton depend on the battery type and waste stream [14]. The EU Directive 2006/66/EC recommends that at least 50% by average weight of battery waste might be recycled by 2011 into materials for their original purpose or for other purposes, excluding energy recovery [15].

In terms of economic impacts of recycling rechargeable batteries a study showed that, growing demand of rechargeable batteries have increased the demand of cobalt from 700 tons/annum in the year of 1995 to 12,000 in the year of 2005. It is estimated to account for nearly 25% of worldwide cobalt demand. It means recovering the cobalt content of used batteries not only keeps a hazardous metal away from the environment, but also decreases demand for ore material for cobalt. Moreover, this results in decreasing the price of the cobalt in the market by recycling the used cobalt content of batteries. This case is somewhat similar for other metal components of used batteries. Same authors indicated that recycling of the used rechargeable batteries results in a 51.3% natural resource savings. These savings are accrued not only by the decreased mineral ore dependency but also by the reduced fossil resources and nuclear energy demand [17].

Recycling technology is an emerging issue. Although, there are large amount of database and on-going researches are available, there are still significant amount of room for improvement in terms of the emerging issues on battery recycling technologies. A large body of research has been done on designing recycling technologies which provide both economic feasibility and environmental viability. Among the presented technologies, two main types of technologies are the pyrometallurgical processes and the hydrometallurgical processes. Pyrometallurgical processes are usually associated with the production of steel, ferromanganese alloys or other metallic alloys are operated at high temperatures. They are usually associated with a high atmospheric emissions control, since dioxins, chloride
compounds and mercury can be generated in the process. On the other hand, hydrometallurgical processes are associated with leaching steps in acid or alkaline medium and purification processes in order to dissolve the metallic fraction and to recover metal solutions that could be used by the chemical industry [10]. Table 2 shows the application of recovered metal content of used batteries based on the battery types.

Table 2 Battery types and their recovered metal application. (Data adopted from [14], [18] and [19])

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Environmental issues</th>
<th>Recovered metal Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel Cadmium (Ni-Cd)</td>
<td>Toxic cadmium</td>
<td>new Ni-Cd batteries /stiffener in materials such as cement</td>
</tr>
<tr>
<td>Lithium Ion (Li-Ion) batteries</td>
<td>Hazardous material leakage</td>
<td>new lithium-based batteries</td>
</tr>
<tr>
<td>Small Sealed Lead Acid (SSLA/Pb)</td>
<td>Lead disposal</td>
<td>The lead is used to make new batteries</td>
</tr>
<tr>
<td>Nickel Metal Hydride (Ni-MH) and Nickel Zinc (Ni-Zn)</td>
<td>Chemical handling</td>
<td>The nickel is used in stainless steel products</td>
</tr>
</tbody>
</table>
CHAPTER 2

ECONOMIC INPUT-OUTPUT ANALYSIS

2.1 Input-Output Table

Input Output Analysis is one of the macroeconomic tools that analyzes the general equilibrium of the economic impacts. This method was initially presented for the United States economy by Wassily Leontief and as a result he received the Nobel Prize of Economics [20]. With the aim of this technique governments are able to measure the economic, environmental and social impacts of their policy agendas.

Input output analysis is a system of equations which expresses the economic transactions of different sectors of an economy within each other and with the people as final receivers of the services and commodities. Results of IOA captures direct impacts of any modifications through the economic transactions in the society as well as indirect impacts. For instance, direct impacts of decrease in battery manufacturing companies demand for metals would be less production of metals or cheaper metal prices, while as an indirect effect one may point out that overall demand for energy is increased because recycling batteries rather than landfilling required more energy. In this manner, Induced effects are the impacts related to modifications of IOA, which relates to capital investments, labor costs and taxes. Therefore using same battery recycling example, regarding induced effects one may express that recycling resulted in more job opportunities. In terms of the type of data
used, IOA tables could be classified as Physical Input-Output Table (PIOT) or Monetary Input-Output Table (MIOT) based on the data utilized for constructing an input-output table.

The main part of input output analysis is input output table. Figure 2 presents a common type of IO tables. This table represents all transactions among the sectors in an economy. In this table, every inputs of each section as well as the outputs of that section, labor costs, taxes and the share of sale of each sector to the people as final consumers are presented. Different classifications of input-output economic accounts are available for different analysis and methodologies. Leontief’s demand model has been used in this study.

2.2 Leontief Model

Basically, each sector of economy imports raw material and/or products of other sectors as inputs, then processes such inputs to make certain products as outputs either for final
consumer or other sectors. Equation 1 is the mathematical expression of aforementioned procedure for an economy with n sectors.

\[ X_i = x_{i1} + x_{i2} + \cdots + x_{in} + y_i \]  

(1)

\( X_i \): Total product of sector i

\( x_{in} \): Portion of total product of sector i goes to sector n

\( y_i \): Portion of production of sector i goes for final demand

The share of production of sector \( i \) which has been used for production of one unit of sector \( j \)'s output is expressed as \( a_{ij} = \frac{x_{ij}}{x_j} \). Entry \( a_{ij} \) is named technical coefficient. Therefore, using technical coefficients Equation 1 reform as Equation 2.

\[ X_i = a_{i1}X_1 + a_{i2}X_2 + \cdots + a_{in}X_n + y_i \]  

(2)

Similarly, for all \( n \) sectors of the economy Equation 2 can be applied. The matrix form of Equation 2 for all sectors of the economy is presented in Equation 3.

\[
\begin{bmatrix}
X_1 \\
\vdots \\
X_i \\
\vdots \\
X_n
\end{bmatrix} =
\begin{bmatrix}
a_{11} & \cdots & a_{1n} \\
\vdots & \ddots & \vdots \\
a_{i1} & \cdots & a_{in} \\
\vdots & \ddots & \vdots \\
a_{n1} & \cdots & a_{nn}
\end{bmatrix}
\begin{bmatrix}
X_1 \\
\vdots \\
X_i \\
\vdots \\
X_n
\end{bmatrix} +
\begin{bmatrix}
y_1 \\
\vdots \\
y_i \\
\vdots \\
y_n
\end{bmatrix}
\]  

(3)

Or similarly it can be expressed as Equation 4

\[ X = AX + Y \]  

(4)
Since \( j \dot{X} = \dot{X} \) Equation 4 can be reformed as Equation 5

\[
X = (I - A)^{-1} Y
\]

(5)

\( X \): Vector of economy sector’s total output

\( Y \): Vector of final demand of economy

\( A: n \times n \) Matrix of coefficients

\( I: n \times n \) Identity matrix

Equation 5 has been called Leontief’s I-O model. Using this equation one can study the effect of change in each entry of \( A \) matrix or \( Y \) vector on the total output of the economy.

Input-output analysis is highly applicable in governmental research regarding economic, environmental and social impacts of their agendas. In the United States, Bureau of Economic Analysis (BEA) provides such data in yearly base for administrative decisions. Also, BEA publishes some aggregated level of IOA data for the public once every 5 years.

2.3 Ghosh Model

As it is clear from Equation (4), one can study the changes in red colored areas of an ordinary I-O table:

![Figure 2 Application area of Leontief's model.](image)
Studying the effects of changing value added section of economy on the whole economy requires another method. Also, one of disadvantages of Leontief’s model is the assumption of unlimited amount of resources to meet the effect of changes in the economy. It means Leontief’s model does not response to economic fluctuations caused by changes in prices or shortage of natural resources or rate of extracting the resources. Ghosh’s model tries to organize the IOA in order of priority in supply of commodities or services to study the consideration of resources ability to meet the changes. Following is the procedure of derivation of Ghosh’s model.

To make a cost push model A* matrix defines with entries of $a_{ij}^* = \frac{x_{ij}}{x_i}$. The entry $a_{ij}^*$ is the portion of production of sector $i$ which goes to sector $j$. Also, value added vector in the table transposes and forms $V^t$. Applying some matrix operations leads to:

$$X = V^t (I - A^*)^{-1}$$

Equation (5) is Ghosh model. Using this equation one is able to study the changes in the whole economy by changes in value added section or the ability of each sector to supply the commodities.

**2.4 Make and Use Tables**

Use table represents the intermediate and final user demand for each commodity. In this table rows are commodities and columns are intermediate sectors (or the sectors inputs) plus final user demand. Thus, using this table sum of each row results in total consumption of each commodity and sum of each column shows total input (or consumption) of each sector plus Value Added components such as taxes, surpluses and employment. Use table sometimes is referred to as recipe matrix because it includes all inputs and components of each individual sector’s production. One application of the use
table is cost push system analysis. Like make table, use table also has two standard and supplementary tables.

Make table represents a table based on the production of commodities. In this table, rows are industries and columns are commodities. Thus, the sum of each row is the total production of each industry and the sum of the columns are the total amount of each commodity that has been produced. Make table uses in demand push system analysis. Two make table usually extracts from the data, the standard make table comes from real data without any redefinition or recategorization, and the supplementary make table refers to table of data after redefinition and recategorization which is expressed below.

Make and Use tables are reverse matrixes of each other. BEA publishes these make and use tables in three level of aggregation:

1. **Detail:** it contains usually around 500 commodities and industries
2. **Summary:** Contains usually around 100 commodities and industries
3. **Sector:** includes about 15 commodities and industries

In IO accounting, each industry is associated with a commodity that is the primary product of that industry. All other commodities produced by that industry are considered secondary products. BEA provides two kinds of tables, Standard tables are collected based on each sector production of commodity without any reallocation or changing in assorting of primary and secondary products. Supplementary tables are prepared to better interpretation and more subjective sort of entries as primary and secondary product of each section. This reallocation allows to more comprehensive study in separate sectors of society and leads to more accurate results for affecting a particular sector. Three type of reallocation that implemented to prepare supplementary tables are as follow.

a- **Reclassification:** Secondary product of a sector is not like the primary one for final use. It goes to intermediate sectors. Also, a secondary product reclassifies when it is
made by more than one sector. For example, newspaper advertisement is a secondary product of newspaper but it is for intermediate and especially for business sector, so it should reclassify to advertisement section.

b- Redefinition: when secondary product of a sector is primary product of other sector.

c- Other secondary products: Rest of secondary products plus when there are same inputs as needed for primary product but there is a different process on them, like cheese as secondary product of milk production [21].

2.5 Price Model

Beside Ghosh model, Price model was presented by Dietzenbacher on 1997 as an alternative approach to overcome implausibility of cost push model. In this model the coefficients are defined to produce one dollar (or equivalent monetary value) unit of each sector. Matrix and mathematical procedure applied on equation (5) results in:

\[ \mathbf{i}' = \mathbf{i}' \mathbf{A} + \mathbf{V}_c' \]  \hspace{1cm} (7)

\[ \mathbf{V}_c' = \begin{bmatrix} \frac{V_1}{x_1}, \ldots, \frac{V_n}{x_n} \end{bmatrix} \]

\[ p^\sim = (I - \mathbf{A}')^{-1} \mathbf{V}_c \]  \hspace{1cm} (8)

Equation (6) reveals that \( \mathbf{A} \) matrix and value added components are formed in order to produce one unit of production. In equation (7) the price model form presented using index
CHAPTER 3

METHODOLOGY

This study adopts an Economic Input-Output (EIO) framework to analyze various economic impacts of recycling the used dry cell batteries in the United States. Applying proposed modifications to the Input-Output framework will provides the direct and indirect effects of such proposals or program in the economy. Figure 3 shows the inputs and outputs of the recycling facility. The process flow of Figure 3 illustrates that an increase in collection of used batteries, as long as there is no technological limit, significantly affects the inputs and outputs of the facility. Because of increasing the batteries that enters to the facility, more energy and additive chemicals ought to be consumed to recycle the surplus of inlet batteries. Although there is an increase in consumption energy and other resources like water, recycling more DCBs respectively decreases the amount of energy, water and any possible chemicals that might be used for landfilling or incineration of the collected batteries. A change in inputs and outputs of the facility results in a change in the transactions of this sector in the economy, which impacts input output table.

Figure 3 Process flow of battery recycling.
The Rechargeable Battery Recycling Corporation (RBRC), a nonprofit public organization, is the main battery recycling facility in the United States. Their Call2Recycle® program reports reveal that the most profitable product of battery recycling is reclaimed metal content [23]. The proposed study focuses on this aspect (i.e. recovery of metal contents) of recycling the dry cell batteries

Following sections are organized as follow; in order to measure the economic impacts of recovered metal content of dry cell batteries, this study estimates amount of batteries that will be collected as a result of applied recycling programs at HEIs, then calculates the equivalent price of the metals which will be recovered from the collected batteries at HEIs. Finally to the equivalent monetary value of the recovered metals modifies the related sectors of the IO table. Therefore using IOA, this study captures the economic changes caused by introducing new transactions related to demand of battery manufacturers from metal manufacturers in the economic tables of the United States.

3.1 Modification in IO Table

In this study, we assume that proposing strong recycling programs in HEIs increases recovered metal’s supply to the recycling facilities. As long as there is no technological barrier, such a supply increase results in direct increase of products of the recycling facility i.e. more recovered metal.

The increase in supply of used dry cell batteries results in more supply to the recycling facilities. As a consequence such facilities recover more metals which mean more output of recovered metal that goes to the battery manufacturers, to be used in new batteries. This study models the increase in recovered metal input of battery manufacturer as more efficient technology that battery manufacturer implemented which requires less metal for same amount of production. Although it is not a real case assumption, the aggregation of recycling facilities with battery manufacturers as one sector in the economy makes it a reasonable assumption mainly because the most important customer of battery recyclers
are battery manufacturers [10]. In fact, the battery manufacturing sector (BMS), instead of purchasing incoming materials from the metal manufacturing sector (MMS), purchases only a portion of its required metal demand from MMS. And supplies the rest of its metal requirement from the recycling facility which is aggregated to itself. Therefore, in the input-output analysis context, the decreased amount of sales from MMS to BMS can be analogously expressed as the increased amount of the supply of recovered metal from the recycling facility. Similarly, the sale of BMS to itself increases by same amount. Mathematic explanations of this methodology is expressed below:

\[ a_{MMS \rightarrow BMS} = \frac{Z_{MMS \rightarrow BMS}}{X_{BMS}} \]  \hspace{1cm} (9)

\[ a_{BMS \rightarrow BMS} = \frac{Z_{BMS \rightarrow BMS}}{X_{BMS}} \]  \hspace{1cm} (10)

\[ a_{MMS \rightarrow BMS} = \frac{Z_{MMS \rightarrow BMS-\text{RMV}}}{X_{BMS}} \]  \hspace{1cm} (11)

\[ a_{BMS \rightarrow BMS} = \frac{Z_{BMS \rightarrow BMS+\text{RMV}}}{X_{BMS}} \]  \hspace{1cm} (12)

\( a_{MMS \rightarrow BMS} \) refers to technology matrix \((A)\) element which relates to the sale of metal manufacturer sector (MMS) to battery manufacturer sector (BMS). \( a_{BMS \rightarrow BMS} \) refers to \( A \) matrix element related to sale of battery manufacturing sector to itself. \( Z_{MMS \rightarrow BMS} \) refers to the share of metal value which have been bought by BMS from MMS. RMV stands for recovered metal value, which has been calculated in the next section and \( X_{BMS} \) is the total output of BMS. \( \dot{a} \) in equation 4 and equation 5 explains the modified transaction to be replaced with \( a \) in equations 2 and 3 in IO table.
CHAPTER 4

DATA COLLECTION

4.1 National Level Battery Recycling Data

This study estimates the equivalent monetary value of recovered metal content of used batteries that have been collected as result of proposing effective recycling programs in the HEI system using the following assumptions and calculations:

HEI enrollment:

In order to estimate the number of enrolled students at HEI, the U.S. Census Bureau report on total enrollment at HEI has been used [24]. Table 3 lists the number of enrolled students in past years. Interpolating given numbers, this study estimates 2011’s enrolled students around 21,650,000 people.

Table 3 Enrolled students at HEI, million students. (Data adopted from [24])

<table>
<thead>
<tr>
<th>Year</th>
<th>Population of enrolled students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>12.1</td>
</tr>
<tr>
<td>1990</td>
<td>13.8</td>
</tr>
<tr>
<td>2000</td>
<td>15.3</td>
</tr>
<tr>
<td>2005</td>
<td>17.5</td>
</tr>
<tr>
<td>2006</td>
<td>17.7</td>
</tr>
<tr>
<td>2007</td>
<td>18.2</td>
</tr>
<tr>
<td>2008</td>
<td>19.1</td>
</tr>
<tr>
<td>2009</td>
<td>20.4</td>
</tr>
<tr>
<td>2013</td>
<td>22.9</td>
</tr>
</tbody>
</table>
Battery recycling profit:

Call2Recycle’s Annual report of 2011 states that 85% of their recycled batteries were rechargeable ones, accounting for $7.6 million. Their net revenue of proceeds due to metal content is mentioned $3.4 million. This study takes into account the same revenue for non-rechargeable batteries as well. Because only 15% of recycled batteries are non-rechargeable [23]. Therefore we have \[ \frac{3.413 \times 10^6}{7.6 \times 10^6 lb} = \frac{0.45}{lb} \]

Survey Results: University of Dayton:

In order to obtain an accurate estimate about the willingness of students to recycle their used batteries and average battery consumption of students, we have done a survey at the University of Dayton. This school has been selected because it has a diverse student body, such as part time and on-line students, as well as full time and commuter students. Figure 3 describes student’s response to the question of their willingness about dropping their used batteries on campus to the designated bins. Approximately 90% of them replied that they are willing to drop their used batteries at designated bins.

Figure 4 Survey results, student’s willingness to drop used batteries on campus designated bins.

The EPA reported that each household consumes about 10 batteries per year [4]. The survey results illustrated in Figure 4 shows that participated students believed that they
consumed approximately 7 batteries each academic year, which is about 9 months. This means 0.73 batteries per month which is close to the 0.83 batteries per month that the EPA reported.

![Graph of survey results, number of batteries that consumed each semester by students.](image)

Figure 5 Survey results, number of batteries that consumed each semester by students.

*Average weight of batteries:*

Dry cell batteries are made in different shapes and sizes to be applicable in various electronic equipment. Table 4 shows the variety and average weight of each battery type for most applicable ones. This study considers the average weight of them based on their share of sale in the market.

Table 4 Average weight of the most applicable battery types adopted from. [12]

<table>
<thead>
<tr>
<th>Type</th>
<th>Share of sale in 2007</th>
<th>weight (lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>60%</td>
<td>0.05</td>
</tr>
<tr>
<td>AAA</td>
<td>24%</td>
<td>0.02</td>
</tr>
<tr>
<td>C</td>
<td>4%</td>
<td>0.15</td>
</tr>
<tr>
<td>D</td>
<td>8%</td>
<td>0.32</td>
</tr>
<tr>
<td>9V</td>
<td>4%</td>
<td>0.10</td>
</tr>
<tr>
<td>Average Weight</td>
<td>0.07</td>
<td></td>
</tr>
</tbody>
</table>
4.2 National Level Battery Recycling Profit

Consideration of all above mentioned parameters provides with an acceptable estimate about the equivalent monetary value of recovered metal content of collected used batteries for higher education institutions. Thus we have:

\[
\text{Recovered Metal Value (RMV)} = \text{number of enrolled students} \\
\times \text{number of consumed batteries per year per student} \\
\times \text{average weight of batteries} \\
\times \text{willingness of students to recycle batteries} \\
\times \text{monetary value of recovered metal}
\]

\[
\Rightarrow \text{Recovered Metal Value} = 21,650,600 \times 7 \text{ battery/year} \times 0.0724 \text{ lb/battery} \times 0.90 \times 0.45 \text{ /lb} \equiv 4,500,000.
\]

The IO table which has been used in this study consists of 2007 economic data. The recycling facility revenue report mentioned in section 4.1 is based on the average metal prices of 2011. To overcome the error margin caused by such a time gap, this study extracted the metal values in 2007 and 2011. Comparing the different prices of metals resulted in the equivalent value of 2011’s $4,700,000 in recovered metal equivalent to $7,111,735 of same amount of such metals in 2007. Table 5 shows the prices of metals whose recovery is more profitable to battery recycling facilities in the years 2007 and 2011.

Table 5 Price value of recovered metals from 2011 and 2007. (Data adopted from [25], [26])

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td>$22,910/metric ton</td>
<td>$37,135/metric ton</td>
</tr>
<tr>
<td>Lead</td>
<td>$2,400/metric ton</td>
<td>$2,578/metric ton</td>
</tr>
<tr>
<td>Cobalt</td>
<td>$39,669/metric ton</td>
<td>$67,364/metric ton</td>
</tr>
<tr>
<td>Cadmium</td>
<td>$7,610/metric ton</td>
<td>$2,760/metric ton</td>
</tr>
<tr>
<td>Average</td>
<td>$18,147/metric ton</td>
<td>$27,459/metric ton</td>
</tr>
</tbody>
</table>
CHAPTER 5

RESULTS AND DISCUSSION

The most recent IO table during the time of this research was published by the BEA as a benchmark input-output account of the U.S. economy in year 2007[26]. These tables are presented in three levels. This study has used the most detailed available level of use table including 389 sectors. This study assumes recycling facilities are a subsector of battery manufacturers. Thus, the economic input output table is modified as discussed in chapter 3. Table 6 illustrates the transactions of BMS and MMS that are adjusted in the economic input output table in order to capture direct and indirect economic impacts of effective recycling programs at HEIs. North American Industry Classification System (NAICS) standard codes related to the study’s transactions in the IO table of 2007 are mentioned in this table as well. Table 6 shows the allocations and matching of NAICS sectors for the proposed input-output modeling [26].
Table 6 Modifications in base case of 2007 U.S. IO economic accounts (in million dollars).

<table>
<thead>
<tr>
<th>Commodity</th>
<th>NAICS code</th>
<th>Base case</th>
<th>After modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary smelting and refining of nonferrous</td>
<td>331419</td>
<td>1,809 $M$</td>
<td>+$7.1M $1,801M</td>
</tr>
<tr>
<td>metal (except copper and aluminum)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage battery manufacturing</td>
<td>335911</td>
<td>15 $M$</td>
<td>-$7.1M 22 $M</td>
</tr>
</tbody>
</table>

Table 7 shows the change of total output of economic sectors Results of the economic impacts in the IO table have been presented in Table 7. In this table, the first 20 sectors of the economy that have been affected by applying battery recycling program and the amount of change in total output of each sector is calculated.
Table 7 Major economic sectors affected by the change of inter sectorial transaction related to increase in rate of recycling batteries.

<table>
<thead>
<tr>
<th>Sector</th>
<th>NAICS Code</th>
<th>Total output change (Thousand Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage battery manufacturing</td>
<td>335911</td>
<td>7,000.22</td>
</tr>
<tr>
<td>Primary smelting and refining of nonferrous metal</td>
<td>331419</td>
<td>-7,101.02</td>
</tr>
<tr>
<td>Copper, nickel, lead, and zinc mining</td>
<td>212230</td>
<td>-2.91</td>
</tr>
<tr>
<td>Alumina refining and primary aluminum production</td>
<td>33131A</td>
<td>-1.60</td>
</tr>
<tr>
<td>Relay and industrial control manufacturing</td>
<td>335314</td>
<td>1.49</td>
</tr>
<tr>
<td>Oil and gas extraction</td>
<td>211000</td>
<td>-1.36</td>
</tr>
<tr>
<td>Petroleum refineries</td>
<td>324110</td>
<td>-1.21</td>
</tr>
<tr>
<td>Primary smelting and refining of copper</td>
<td>331411</td>
<td>-1.12</td>
</tr>
<tr>
<td>Wholesale trade</td>
<td>420000</td>
<td>0.74</td>
</tr>
<tr>
<td>Real estate</td>
<td>531000</td>
<td>-0.61</td>
</tr>
<tr>
<td>All other miscellaneous manufacturing</td>
<td>339990</td>
<td>0.50</td>
</tr>
<tr>
<td>Switchgear and switchboard apparatus manufacturing</td>
<td>335313</td>
<td>0.46</td>
</tr>
<tr>
<td>Iron and steel mills and ferroalloy manufacturing</td>
<td>331110</td>
<td>0.42</td>
</tr>
<tr>
<td>Management of companies and enterprises</td>
<td>550000</td>
<td>0.38</td>
</tr>
<tr>
<td>Truck transportation</td>
<td>484000</td>
<td>-0.38</td>
</tr>
<tr>
<td>Other electronic component manufacturing</td>
<td>33441A</td>
<td>0.35</td>
</tr>
<tr>
<td>Aluminum product manufacturing</td>
<td>33131B</td>
<td>-0.32</td>
</tr>
<tr>
<td>Ornamental and architectural metal manufacturing</td>
<td>332320</td>
<td>0.31</td>
</tr>
<tr>
<td>Nonresidential maintenance and repair</td>
<td>230301</td>
<td>-0.29</td>
</tr>
<tr>
<td>Printed circuit assembly manufacturing</td>
<td>334418</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Figure 5 illustrates the indirect economic impacts of applying effective battery recycling programs at HEIs. One of the advantages of IOA is capturing such indirect effects in the economy. For instance, total output of oil and gas extraction sector (211000 in NAICS codes) will be decreased by equivalent amount of $1,500 as a consequence of battery recycling programs at HEIs. Although, this change may be negligible compared to total output of the oil and gas extraction sector, understanding the overall consequences of such a policy and intensity of such consequences results in effective policies and designating specific tax allocations to lead the country into sustainability.
One of the results reveals that GDP decreased by $11,522 after an economy-wide proposed recycling programs are taken effect to the HEI in U.S. This result can be utilized for related tax incentive allocations in favor of recycling policies. For example as it mentioned in figure 5. Allocation of subsidies to the sectors of economy which experience a decrease in their total output by recycling batteries will make the recycling economically beneficial. When recycling batteries get profitable, free market will invest on recycling facilities. Therefore, not only technologies improves significantly for more profit, but also more batteries will be recycled instead of landfill or incineration. Furthermore, this study only captures the economic impacts of recycling used batteries at HEIs. Even though, environmental risks and hazards of contamination of ecosystem with such amount of heavy metals should be taken into account for a better decision about recycling. For instance, there is significant costs related to cleaning ecosystem from hazardous materials if in some regions such heavy metals contaminate the aquifers or soil. Also, this study only captures the recovered metal content, while recycling facilities, depending on the technology that they use, may recycle other material. For instance, Call2Recycle® organization claims that
they don’t have any residuals out of battery recycling to be landfilled. Thus, considering other sources of profit in battery recycling may make recycling batteries economically profitable.
 CHAPTER 6

A METHOD FOR DESIGNING REGIONAL ENVIRONMENTAL POLICIES

Engineering methods like many other sciences use experiments as part of the scientific procedure. Experiments are tests or series of tests to approve or deny a hypothesis. All the experiments are designed experiments; some are poorly designed and some are well designed. Design and analysis Of Experiments (DOE) refers to the process of planning an experiment so that analyzable data is collected in which results are valid and conclusions are objective. DOE develops a model that describes how the output or response of a system behaves as a function of controllable and, possibly, uncontrollable inputs. Such a model is illustrated in Figure 7. Using DOE techniques, one can define the influence of factors along with their interactions on the responses. In addition, DOE methods navigate for optimization of results in the way that engaged factors in an experiment are the ones which significantly influences the responses.

Figure 7 DOE models the relation of the system responses to input factors.
An experiment alters the inputs of a system to study the changes in the responses. After collecting the information of the experiment, DOE techniques attempt to develop a “parsimonious” approximation to the response function referred to as the empirical model. The response function – usually a polynomial model - is the best fitted formula that explains the changes caused by the alteration of some input factors. Therefore, DOE methods reduce the time to design or develop new products and processes as well as improve the performance and reliability of existing processes. Moreover, DOE facilitates evaluation of new technologies, materials, programs or any factor that alters a process with fewer resources to be consumed.

One type of designing an experiment is factorial design. Factorial design is an experiment in which all levels of each independent factor are set to all levels of the other independent factors to capture all possible conditions. Levels of factors are the actual values assigned to the factors during an experiment. Figure 8 is a two-factor factorial experiment involving type of driver and type of ball in a golf experiment. In this experiment two different drivers and two types of balls have been studied as factors. Each combination of factors has been replicated to estimate if there is any other influential factor that is not covered in this experiment. One can realize from the difference of the scores using each combination that type of driver is likely to be more important than type of ball and the differences in the score at each replicate shows that there are some other important factors that affected the scores but the experiment did not capture them as controllable factors. A factorial experiment is able to measure the interactions between factors in a systematic way that allows many simultaneous comparisons to be made. In addition, factorial experiments are computationally simple to analyze and make estimations of parameters.
Statistical hypothesis testing framework accepts or rejects a statistical hypothesis related to the samples of a normally distributed data. Figure 9 illustrates a two-sample t-test. This test is a statistic way to compare two sets of data. In this figure the means of two samples are compared against each other. Both samples should be identical except for changing one factor. If the means are different, that factor is likely to be significant. The hypothesis zero, $H_0$, represents equal sample means, and the two-sample t-test evaluates if the first hypothesis could be accepted or rejected in favor of the second hypothesis, $H_1$.

In Figure 9, $\sigma^2$ represents the variance. Variance measures how far numbers of a sample set are spread out. The square root of the variance, $\sigma$, represents standard deviation and is a quantity that calculates the extent of deviation for a sample set. The expected value or mean, $\mu$, refers to the central tendency of a sample set.

Figure 9 The sampling situation for a two-sample t-test, adopted from. [30]

One of the most applicable methods for the evaluation of means of sample sets to reject or accept a hypothesis of an experiment is the analysis of variance (ANOVA). Using the ANOVA
technique the normality of the distribution of data is evaluated. ANOVA calculates the probability of having equal means of each sample set (i.e. factor) with the mean of the data or other sample sets or even the combination of sample sets (i.e. interactions). The ANOVA results present the signal to noise ratio in order to have a better perception regarding the influential parameters in an experiment. It also measures which factors or combination of factors have probability to affect the responses. Responses are the model hypothesis.

In this study four possible scenarios for improving a society’s economic development path regarding environmental concerns and all possible combinations of such scenarios are modeled using the economic Input-Output Analysis (IOA). The response in this study is the Gross Domestic Product (GDP) of the modeled economy. The response of IOA are affected by many factors. Some policy scenarios which can improve the economic output and address the environmental concerns are modified as the inputs of the IOA system. Such a modification results in changes in the GDP of the economy [27]. Figure 10 illustrates how using DOE methods, this experiment is designed to measure the importance of each scenario and facilitate the decision making for implementations of suggested policies.

Figure 10 Schematic of Input-output analysis as a system with input factors and responses based on DOE methods.
6.1 Strategy of Experiment

One advantage of IOA is capturing indirect effects and induced effects some of them are modeled in this study.

Recognition and statement of the problem:

This analysis is designed to determine the impact of each scenario in the economy. Each scenario stands as a factor or interaction of factors and the best combination of policies have been determined for higher GDP as well as environmental efficacy. Indeed accurate and sensible results require the IOA table of Dayton, however, the data is classified. Therefore, this study develops a 5 by 5 arbitrary test model by sector that is presented in Table 9. Even though the model is arbitrary, the methodology is still the same as the real study.

6.2 Choice of Factors, Responses and Design

The GDP of the economy is the response factor in this study. DOE analysis rejects one of the following hypothesis in favor of the other one for each factor or combination of them. For example, if the $GDP_1$, which is GDP for scenario 1, is likely to be different from the base case scenario’s GDP (i.e. $GDP_{base}$), the DOE analysis will reject the hypothesis $H_0$. In addition, DOE calculates the differences of GDPs and the factor’s effect related to the residual terms. Residuals are the terms or factors that are not significantly affect the responses.

\[
H_0: GDP_1 = GDP_{base} \\
H_1: GDP_1 > GDP_{base}
\]

Four main possible policies that policy makers can suggest to lead a region toward environmental progress have been considered as variable factors of this study. Table 8 shows these factors. All possible combinations of first four main policies are referred to as policy interactions. This study captures the impacts of all possible combinations of policies as expressed in the Table 8.
Table 8 Policy descriptions and related coded factors.

<table>
<thead>
<tr>
<th>Policy</th>
<th>Code</th>
<th>Policy description</th>
<th>Applied change in the IOA table</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>Policy licensed businesses have 10% discount for transactions between themselves.</td>
<td>Sectors 1, 2 and 4 are offering and offered 10% discount to each other’s transactions.</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>Policy licensed businesses have 10% discount on their energy costs, offered by local utility company.</td>
<td>Sector 5 offers 10% discount to the policy licensed businesses, i.e. sectors 1, 2 and 4.</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>Representing policy licensed businesses in local markets and communities results in 10% increase in total sales of the businesses.</td>
<td>Share of final demand sell increases for sectors 1, 2 and 4. Same time share for non-member sectors will decrease with same percentage, here 10%.</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>Policy licensed businesses get 10% discount on their taxes.</td>
<td>Using Ghosh model, value added sector will face 10% discount for sectors 1, 2 and 4.</td>
</tr>
<tr>
<td>5</td>
<td>AB</td>
<td>Combination of policy 1 and policy 2.</td>
<td>Policy 1 and 2 changes are applied same time.</td>
</tr>
<tr>
<td>6</td>
<td>AC</td>
<td>Combination of policy 1 and policy 3.</td>
<td>Policy 1 and 3 changes are applied same time.</td>
</tr>
<tr>
<td>7</td>
<td>AD</td>
<td>Combination of policy 1 and policy 4.</td>
<td>Policy 1 and 4 changes are applied same time.</td>
</tr>
<tr>
<td>8</td>
<td>BC</td>
<td>Combination of policy 2 and policy 3.</td>
<td>Policy 2 and 3 changes are applied same time.</td>
</tr>
<tr>
<td>9</td>
<td>BD</td>
<td>Combination of policy 2 and policy 4.</td>
<td>Policy 2 and 4 changes are applied same time.</td>
</tr>
<tr>
<td>10</td>
<td>CD</td>
<td>Combination of policy 3 and policy 4.</td>
<td>Policy 3 and 4 changes are applied same time.</td>
</tr>
<tr>
<td>11</td>
<td>ABC</td>
<td>Combination of policy 1, 2 and 3</td>
<td>Policy 1, 2 and 3 changes are applied same time.</td>
</tr>
<tr>
<td>12</td>
<td>ACD</td>
<td>Combination of policy 1, 3 and 4</td>
<td>Policy 1, 3 and 4 changes are applied same time.</td>
</tr>
<tr>
<td>13</td>
<td>BCD</td>
<td>Combination of policy 2, 3 and 4</td>
<td>Policy 2, 3 and 4 changes are applied same time.</td>
</tr>
<tr>
<td>14</td>
<td>ABCD</td>
<td>Combination of policies 1, 2, 3 and 4</td>
<td>All proposed related changes are applied same time.</td>
</tr>
</tbody>
</table>

The aforementioned policies are modifying Table 9 which refers to the base case scenario in this chapter. Elements of Table 9 are arbitrarily assigned. Sectors 1, 2 and 4 are representatives of policy licensed businesses. Sector 3 is representative of independent businesses that are not willing to participate or are not local businesses. Sector 5 represents utility providers, which supply energy for the region. The value added section includes
arbitrary numbers for taxes and final demand refers to consumers or people who live in this region. The last number is total output columns refers to GDP.

Table 9 Developed IOA table for the study.

<table>
<thead>
<tr>
<th></th>
<th>Sector1</th>
<th>Sector2</th>
<th>Sector3</th>
<th>Sector4</th>
<th>Sector5</th>
<th>Final Demand</th>
<th>Total output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector1</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>23</td>
</tr>
<tr>
<td>Sector2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>Sector3</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>Sector4</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Sector5</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>Value Added</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>17</td>
<td>101</td>
</tr>
<tr>
<td>Total outlay</td>
<td>23</td>
<td>18</td>
<td>22</td>
<td>21</td>
<td>17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This study is a computational analysis. The economic input output analysis is a matrix calculation and elements of the matrices are reported numbers by authoritative organizations. Therefore, despite the errors related to the calculation of the elements and/or reporting of the data, there is no more error or nuisance factor to be considered as residual or error term. However, some higher levels of interactions between policy scenarios have been used for residuals terms. This is necessary to allocate some terms as the residual terms for constructing a significant model.

Uncontrollable factors in this study have no sensible meaning because IOA has a base case scenario and we only manipulate the base case by a controlled proposed scenario. The linear mathematical relation of the IOA matrices covers all the elements in a controllable way. Moreover, proposing some uncontrollable policies is related to dynamic economic systems, which control, for example, imports / exports, natural disasters, and other factors that are beyond the scope of this study.

Choice of experimental design:

This study has used analysis of variance to illustrate the impacts of each factor on the response. Screening main factors as characterization or preliminary tests has been done to
learn which factors have the most influence on the response. Using results of characterization test, $2^4$ factorial design has been applied to the study. Using factorial design, we can capture the interactions of policies using categorical levels of -1 as “policy not present” and 1 as “policy has been applied”. ANOVA has been used to study the significance of factors and interactions.

6.3 Screening Factors

In order to screen the factors and to have an estimate about differences in GDP by each policy, a preliminary test has been done. This test covers main factors and two level interactions. Results of IOA have been presented in Table 10. All the proposed steps have been taken for two cases of 10% and 20% policy suggestions as mentioned in Table 8. The reason to capture effects by 20% change as well as 10% change is to cover the nuisance effect linearity of analysis. Analyzing two differences in percent change helps us to study and understand whether or not economic changes are linear.

<table>
<thead>
<tr>
<th>Scenario (GDP)</th>
<th>Total Economic Output</th>
<th>Percentage of change from base</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10% change</td>
<td>20% change</td>
</tr>
<tr>
<td>Base</td>
<td>101</td>
<td>101</td>
</tr>
<tr>
<td>Scenario 1 (GDP1)</td>
<td>98.38</td>
<td>95.77</td>
</tr>
<tr>
<td>Scenario 2 (GDP2)</td>
<td>99.35</td>
<td>97.67</td>
</tr>
<tr>
<td>Scenario 5 (GDP5)</td>
<td>96.70</td>
<td>92.29</td>
</tr>
<tr>
<td>Scenario 3 (GDP3)</td>
<td>108.03</td>
<td>115.07</td>
</tr>
<tr>
<td>Scenario 4 (GDP4)</td>
<td>97.50</td>
<td>94.01</td>
</tr>
<tr>
<td>Scenario 14 (GDP14)</td>
<td>106.79</td>
<td>111.60</td>
</tr>
</tbody>
</table>

Screening results:

Figure 11 and Figure 12 reveal that considering two levels of changes in the IOA is not likely to be important. It is obvious from the location of the mean in both graphs.
Moreover, based on this test, the range of changes in GDP can be extracted in order to calculate the best fitted sample size. The residuals vs. fitted values graph shows that there is a gap between the responses. The main reason is the discrete level of percent changes. Since there are only two levels of percent changes in factors, we might have discrete responses in a linear model. R-Square and R-Square adjusted have reasonable values and it reveals that our sample factors are describing the model appropriately. In fact, these factors are likely to have a significant effect.

Figure 11 Residual plots for preliminary test, C2 refers to GDP changes using Minitab software.
Figure 12 Box plot for one way ANOVA, C2 refers to GDP changes using Minitab software.

Figure 13 ANOVA for preliminary test using Minitab software.
6.4 Optimization of DOX Analysis

Blocking:

Based on the discussion of our results in the last section, a consideration of two levels of changes as two blocks is not likely to be important. Nevertheless, in a real situation we might perform a more accurate analysis which converts blocks into factors.

IOA results for all applicable policies:

Table 11 includes GDP related to all applicable scenarios mentioned in Table 8. This table’s information has been used for further DOE analysis.

Table 11 Policy scenarios impact on the whole economy modeled as the changes in GDP.

<table>
<thead>
<tr>
<th>Policy Scenario</th>
<th>GDP</th>
<th>delta GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>98</td>
<td>-2.6</td>
</tr>
<tr>
<td>2</td>
<td>99</td>
<td>-1.6</td>
</tr>
<tr>
<td>3</td>
<td>108</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>97</td>
<td>-3.5</td>
</tr>
<tr>
<td>5</td>
<td>97</td>
<td>-4.3</td>
</tr>
<tr>
<td>6</td>
<td>105</td>
<td>4.2</td>
</tr>
<tr>
<td>7</td>
<td>102</td>
<td>0.8</td>
</tr>
<tr>
<td>8</td>
<td>106</td>
<td>5.3</td>
</tr>
<tr>
<td>9</td>
<td>103</td>
<td>1.8</td>
</tr>
<tr>
<td>10</td>
<td>111</td>
<td>10.5</td>
</tr>
<tr>
<td>11</td>
<td>103</td>
<td>2.4</td>
</tr>
<tr>
<td>12</td>
<td>109</td>
<td>7.6</td>
</tr>
<tr>
<td>13</td>
<td>110</td>
<td>8.7</td>
</tr>
<tr>
<td>14</td>
<td>107</td>
<td>5.8</td>
</tr>
<tr>
<td>15</td>
<td>100</td>
<td>-1</td>
</tr>
</tbody>
</table>

6.5 Results

Using DesignExpert™ software, a $2^4$ factorial design has been performed. Table 12 shows the ANOVA results of the optimized analysis. In this table, each of the policy scenarios and the combinations of scenarios, which was likely to be significant in the GDP changes, are presented. The model consists of 10 degrees of freedom for factors and 5 degrees for residuals. Residuals of the optimized analysis are the scenarios that have negative or negligible positive effect on the base case GDP. The allocation of degrees of freedom
between factors and residuals is significant. According to Douglas Montgomery, “P-value is the smallest level of significance that would lead to rejection of H₀” [27, page 40]. Therefore, in the table 12, P-Value column represents the probability of equal numbers for altered GDP and the base case GDP. F value relates to the ratio of each scenario’s effect on GDP to the residuals overall impact. F value could be interpreted as signal to noise ratio as well. By rule of thumb, the F values of more than 4 are likely to reject the H₀. This means the higher the F value is, the higher the impact of related scenario to GDP is.

Table 12 ANOVA results after optimization.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F Value</th>
<th>p-value</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>303.31</td>
<td>10</td>
<td>30.33</td>
<td>9.93</td>
<td>0.0103</td>
<td>significant</td>
</tr>
<tr>
<td>A-A</td>
<td>14.65</td>
<td>1</td>
<td>14.65</td>
<td>4.80</td>
<td>0.0799</td>
<td></td>
</tr>
<tr>
<td>B-B</td>
<td>2.91</td>
<td>1</td>
<td>2.91</td>
<td>0.95</td>
<td>0.3734</td>
<td></td>
</tr>
<tr>
<td>C-C</td>
<td>240.09</td>
<td>1</td>
<td>240.09</td>
<td>78.67</td>
<td>0.0003</td>
<td></td>
</tr>
<tr>
<td>D-D</td>
<td>26.35</td>
<td>1</td>
<td>26.35</td>
<td>8.63</td>
<td>0.0323</td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>3.18</td>
<td>1</td>
<td>3.18</td>
<td>1.04</td>
<td>0.3538</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>3.80</td>
<td>1</td>
<td>3.80</td>
<td>1.24</td>
<td>0.3148</td>
<td></td>
</tr>
<tr>
<td>AD</td>
<td>2.71</td>
<td>1</td>
<td>2.71</td>
<td>0.88</td>
<td>0.3888</td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>3.49</td>
<td>1</td>
<td>3.49</td>
<td>1.14</td>
<td>0.3333</td>
<td></td>
</tr>
<tr>
<td>BD</td>
<td>3.02</td>
<td>1</td>
<td>3.02</td>
<td>0.99</td>
<td>0.3652</td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td>3.05</td>
<td>1</td>
<td>3.05</td>
<td>1.00</td>
<td>0.3632</td>
<td></td>
</tr>
<tr>
<td>Residual</td>
<td>15.25</td>
<td>5</td>
<td>3.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cor Total</td>
<td>318.56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13 presents the R-squared numbers. R-squared measures the proportion of variation of results using the regression model [29]. The higher the R squared to 1, the better the regression model fits. Clearly, adding more factors to the model will increase the R-squared term. However, added factors may not add any value. Thus, R squared adjusted is defined as a statistic that is adjusted related to the size of the model. Therefore, adding more factors in the model does not necessarily increase the R squared adjusted term. The
closer the R squared adjusted is to R squared the better the model is designed. Predicted R squared defines how well the model will predict new data.

Table 13 R squared, Adjusted-R squared and Predicted-R squared after optimization.

<table>
<thead>
<tr>
<th></th>
<th>Std. Dev.</th>
<th>R-Squared</th>
<th>Adj. R-Squared</th>
<th>Pred. R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>103.6</td>
<td>0.95</td>
<td>0.85</td>
<td>0.5</td>
</tr>
<tr>
<td>C.V. %</td>
<td>1.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRESS</td>
<td>156</td>
<td>Adeq. Precision</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Figure 14 illustrates the residuals versus the predicted value of each scenario. This graph is an illustrative way to see if the model is correct and assumptions are satisfied. In fact, if residuals follow any specific pattern versus factors, it means there are likely to be some significant impacts from the residual terms that the model have not captured. Thus, structureless pattern of residuals versus predicted values of the factors is what we expect from a significant model.
Figure 14 Residuals versus predicted values of factors, structureless plot illustrates that our model is likely to be correct and assumptions are likely to be satisfied.

Figures 15 to 18 are the effects of each scenario in the GDP. In this figure level 1 represents the base case scenario while level 2 is related to GDP after applying the policy in the IOA table. Scenarios of A, B, C, and D are presented in Table 8.
Figure 15 Impacts of Scenario A on the GDP.

Figure 16 Impacts of Scenario B on the GDP.
Figures 19 to 24 present the changes in GDP of the economy by applying two policies in same time. In each plot, levels 1 and 2 respectively represent lack or presence of the first policy. Similarly, red and green colors are two levels of the second policy. The following graphs clarify the interactions that applying two policies may have in the economy.
model. Using such graphs for real economic tables one can evaluate the impacts of applying two scenarios in a society. Thus selection of the best two policies for an economy with respect to any indexes such as GDP of the economy is possible. For instance, using the arbitrary table of this study, the combination of scenarios C and D (Figure 24) is likely to be more effective regarding the growth in GDP. Nevertheless, later in this chapter the scenario C is selected as the best option in this case.

Figure 19 GDP changes by applying two scenarios of A and B at same time.
Figure 20 GDP changes by applying two scenarios of A and C at same time.

Figure 21 GDP changes by applying two scenarios of A and D at same time.
Figure 22 GDP changes by applying two scenarios of B and C at same time.

Figure 23 GDP changes by applying two scenarios of B and D at same time.
Figure 24 GDP changes by applying two scenarios of C and D at same time.

Figure 25 illustrates the half-normal graph. Half-normal plots the absolute value of factors against their cumulative normal probabilities. In this graph important effects appear to be in right-top side of the plot. In contrast the effects in left down of the plot are expressing the factors that are not likely to be important. The line in the graph starts at origin and represents the normal distribution of data with mean zero and variance equal to the range of data. The closer the effects are to the line the less important they are.
Figure 25 Half-Normal plot of the factors and their two-level interactions, factors closer to the line are likely to be less important.

According to the above results, one can decide that the best possible policy in this case is policy of scenario C. In addition scenario D is likely to be important as well. Therefore, if the budget required for applying both policies is available or there are not any other constraints, the combination of scenarios C and D is the best policy solution that not only addresses the environmental concerns but also results in approximately 10% growth in GDP. Figure 26 shows the share of policies C and D relative to the GDP. This graph can lead the decision makers to use the results of this analysis as preliminary analysis for another EIOA modeling with emphasis on policy scenarios C and D. In fact following graph draws the road ahead for improving the accuracy of results.
Finally, the regression model that is carried out by DOE experiment is:

\[
\text{GDP} = + 103.58 - 0.96 \times A - 0.43 \times B + 3.87 \times C + 1.28 \times D - 0.45 \times A \times B - 0.49 \times A \times C + 0.41 \times A \times D - 0.47 \times B \times C + 0.43 \times B \times D + 0.44 \times C \times D
\]

This model expresses the significance of each policy scenario. Using this model decision maker’s find out how each scenario affects the total output of the economy.
CHAPTER 7

CONCLUSION

This study presents the economic impacts of introducing effective battery recycling policies in the higher education institutions of the United States. Recycling used batteries is important in two main aspects. First, used batteries dumped into the ecosystem or landfills contain toxic material that contaminate the environment and may result in many diseases for human. Second, recycling used batteries reduce the demand for extracting some metals. This not only leads the society toward sustainability and save the natural resources for next generations, but also reduces the amount of energy that is consumed for extraction, purification, and transportation of such metals.

Higher education institutions have been selected as the target group in this study because HEIs have feasible ready infrastructure to apply battery recycling policies. Even many of the universities have already applied some battery recycling programs on their campuses. In fact, ready infrastructure of the HEIs as well as the share of citizens that participate in the HEIs are two considerable factors that led the study to select HEIs as target group.

This study presented that capturing recycling impacts using input-output analysis for HEIs results in negligible -$11,000- decrease in the GDP of the United States. The IOA results can lead the government through effective tax reductions or subsidies in the economic
sectors that may experience significant decrease in their output by proposing nation-wide recycling programs such as this study.

Chapter 4 of this research proposes an effective method that one can interpret the IOA results for a set of policies. This chapter proposes four main policies that can be applied in a region’s economy in order to not only address the environmental concerns of the region but also to result in the economic growth of the community. The study uses an arbitrary table of data to express the methodology. Using real data one can evaluate the impacts of each policy as well as impacts of applying all possible combinations of policies in an economy. Because there is no previous information related to chapter 6’s methodology, this study is the first in presenting the methodology.
REFERENCES


