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A System Dynamics Costing Model for The Refurbishment of Electric Vehicle Batteries

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Abstract

Electric vehicle batteries (EVBs) are produced from rare earth metals and they get retired from electric vehicles in just 8 years, there are several options for them to be reused as their useful life can be extended for a couple of years. This research presents an opportunity for businesspersons to carry out the business of refurbishing EVBs and selling them. The present research was conducted to develop a system dynamics model to assess the dynamic behavior of various variables involved in the refurbishment of Electric vehicle batteries (EVBs).To serve this purpose, data was collected by conducting an in-depth literature review and the system dynamics model was developed in Anylogic PLE version. The model was then initialized by using collected secondary data and analysis was conducted in three scenarios; scenario1 (EVBs` sales locally), scenario2 (EVBs` sales regionally), and scenario3 (EVBs` sales nationally). After the simulation of the model, its output was downloaded in Microsoft Excel 2016 from Anylogic. Origins softwarewas used for plotting the graphs. It was concluded that therefurbishing cost of batteries per kWh was $59.82, $55.47, and $76.67 in scenarios 1, 2, and 3 respectively, which was still affordable when compared to other new batteries. Estimation of required capital investment and EVB recycling are still unexplored areas. Moreover, this research provides a detailed business model to investors along with a comprehensive feasibility analysis.

Keywords: Electric vehicles; electric vehicle batteries; repurposing of batteries; reusing of batteries.

1. Introduction

With the superior electrochemical characteristics and relatively long service life of LIBs, they are increasingly becoming power sources due to the gradual popularity of consumer electronics and electric vehicles [1]. One of the energy storage technologies used to deliver some of the expected power grid functions is batteries[2].Furthermore,Lithium-ion batteries (LIBs)are used in the majority of commercialized electric vehicles. These batteries reach their end-of-life (EOL) when their capacity is reduced by 20%, or when their capacity reaches 80% of its original capacity, which is known as a status of health (SOH) [3]. In this instance, it was recommended that electric vehicle batteries be recycled while they still had 80% of their original capacity [4]. South Korea, China, and the United States have all started research programs in the last decade to promote circular economies by encouraging and reusing[5]. There is also the possibility of repurposing electric vehicle batteries.EV batteries that have been reproduced can be utilized for large, centralized battery storage systems or many small, distributed storage systems. The battery's second life has a wide range of options [6]. There is a wide range of possibilities for the second life of the battery. Batteries can be repurposed in a less demanding application Before being recycled andincreasing the total lifetime value by upto ten years by generating economic revenue through second use alternative uses and reducing the battery's initial cost [7].In this context, the current research will build a commercial model for the usage of reused batteries utilizing circular economy and system dynamics approaches, so that the EV batteries can be used as much feasible option before being recycled.

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2. Literature Review

2.1. Electric Vehicles, Electric Vehicle Batteries, and Circular Economy

Automobile sector plays a significant role in the national economy [8]–[10]. Electric vehicles were invented before gasoline-powered automobiles, and it has been argued that the electric vehicle era began at the turn of the 20th century. Electric vehicles disappeared around 1920 for a variety of reasons, including large-scale oilfield discoveries and the introduction of mass production of the Ford Model T [11]. The first electric vehicle (EV) was exhibited in 1828[12]and the first electric vehicle was introduced in 1884. These EVs had distinct advantages over steam andgasoline–powered vehicles, such as the lack of the loud noise of an unmuffled internal combustion engine and the difficult starting procedures that in early vehicles required the involvement of specialized staff to bring the engines upto operating temperature [13]. According to the world economic Forum 2018 report, car manufacturers have planned to transition away from the production of internal combustion engines in response to these requirements (ICEs). BMW intends to mass-produce electric vehicles by 2020, with 12 variants available by 2025.The number of electric vehicles has increased steadily over the last several decades. According to projections, more than 125 million electric vehicles will be on the road worldwide by 2030[12]. According to the world economic Forum 2018 report, car manufacturers have planned to transition away from the production of internal combustion engines in response to these requirements (ICEs). BMW intends to mass-produce electric vehicles by 2020, with 12 variants available by 2025.Renault plans to develop 20 electrified vehicles by 2022, including eight pure electric vehicles. Volkswagen plans to invest up to $84 billion in battery and electric vehicle technologies by 2030, electrifying all 300 of its vehicles. Volvo has pledged to equip all of its vehicles with electric or hybrid engines by 2019[14].

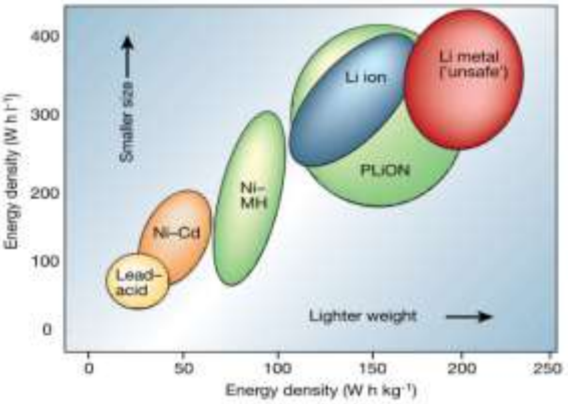


Figure 1. Various battery technologies as presented in Ragone Plot (Source: [15]).

There are various types of batteries, and as new systems become economically feasible, they are being used to solve the challenge of electrified transportation [12]. Figure 1shows a Ragone plot of several of the more common battery technologies. Early electric applications relied on Gaston Plantes' rechargeable lead-acid battery, which he invented in 1859 [11].Waldermar Jungner created the nickel-cadmium battery in 1899, which improved storage capacity significantly but had certain downsides, including a voltage reduction issue known as the memory effect that occurs as the battery ages [16]. Although, research proceeded during the first half of the 20th century, the first Lithium-ion (Li-ion) batteries were not developed until 1985. It took a further six years of research before they were developed [16], [17]. Meanwhile, EVs with ZEBRA and Nickle-Metal Hydride batteries have been created. In the meantime, EVs using ZEBRA batteries and Nickel-Metal Hydride batteries were developed [18]. SONY was the first to commercialize the Li-ion battery (LIB)[12], [15].

Because of its high energy density, extended life cycle, and ease of manufacture, the Lithium Cobalt Oxide battery has been the battery of choice for most personal devices (tablets, laptops,cameras, and so on)[19]. The Li-ion battery is now the most used energy storage technology for electric vehicles[12].When an electric vehicle's Lithium-ion battery reaches the end of its usable life, it can no longer charge to more than 80% of its original capacity[20]. EV batteries currently have a range of 100,000 to 200,000 miles of life. While warranties vary by the manufacturer, most are between five and 10 years, and while capacity will deteriorate over time, the battery will most likely [21]. According to Hirst et al. (2021), an electric vehicle (EV) has a range of 100-250 miles (160-400km) with a fully charged battery, but the plug-in hybrid electric car (PHEVs) have a range of 25-55 miles (40-90), and hybrids have a range of few miles in electric mode [21]. Although the number of EVs approaching end–of–life is currently limited, the EV market is rising, which will result in more batteries reaching the end of their on-vehicle life.Forexample, 14 GWh of batteries (102, 2000 tonnes) are expected to reach the end of their first life by 2020. [22]. However, the current spike in EV sales, along with an even larger expected market growth over the next decade, might result in 2020 GWh of batteries reaching their end of life on vehicles globally [23].Due to the restricted operating range, EV batteries are replaced before they reach their physical end of life, often when they reach 70-80 percent of their initial capacity [24]. After their automotive EOL, electric vehicle batteries can be used in energy storage applications as part of their life cycle. Many researchers have attempted to assess ESS (energy storage system) technology and issue in the electric grid [25].

Furthermore, according to Heymans etal., (2014), reusing EV batteries can be divided into two business choices. The first is to build arrays of packs for larger applications like energy leveling for renewable energy sources like solar and wind. The second alternative is to employ reused batteries in smaller applications such as offices, houses,buildings, and retail outlets for peak-time energy shifting. The growing market sizes and the number of packs required are two important differences between these solutions[26].A circular waste management system, on the other hand, advises looking at this as an opportunity to investigate the best tactics and policies for enabling the reuse of batteries in these EOL EVs [27]. The circular economy (CE) is increasingly being viewed as a solution to several issues, including resource scarcity, waste creation, and long-term economic benefits [28]. It is now widely accepted that corporate strategies should focus on both business models (BM) and product design (PD) for the circular economy (CE) to grow at the firm level [29]. The circular economy is seen as a promising strategy for alleviating global sustainability pressures. [30]. A lake is analogous to a circular economy. Reproducing goods and materials creates jobs and saves energy while reducing estate and resource usage. In 1990, the word circular economy was introduced [5]. One of the first uses of the term "circular economy" came in 1990. According to [31], in 1990, authors Pearce and Turner built an economy that looks into account a materials balance and followed the first and second laws of thermodynamics. The circular economy has been defined in a variety of ways since its initial conception.The circular economy, in general, is a solution that balances economic expansion with environmental conservation [32].From the well-known 3R concepts of reuse, reduction, and recycling to the less utilization ofremanufacturing circulatory may be demonstrated in a variety of applications [31]. Remanufacturing, in general, entails recovering value to create new energy than comparable virgin products [33]. It aims to eliminate waste through the superior design of materials, and within this business model. It replaces the end-of-life concept with restoration, shifts toward the use of renewable energy, and eliminates the use of toxic chemicals that impede reuse [34].

The core of CE is the circular (closed) movement of materials (seeFigure 2). After the EVBs are manufactured from raw materials, they are installed in EVs and when the battery reaches its 80% capacity, EVBs are taken out from EVs; some of EVBs are sent directly for recycling, and the rest of them are refurbished to be reused in different applications: the decision of refurbishment and recycling depends on their condition. This whole process is demonstrated in Figure 2.Moreover, when the refurbished batteries are retired at last, then they are sent for recycling so that the reusable materials can be extracted from them and utilized in the manufacturing of new EVBs.When the EVBs and the utilization of raw materials and energy passthrough several phases [32], [36]. In conjunction with the 3R principles (reuse,reduction, and recycling). The 3R-based CE method offers a model for long-term economic growth that decouples economic growth from rising resource usage (such as energy, land, materials, water and forest, and so on) and the resulting service ecological and environmental harm [37].

2.2. Related Research and Research Gaps

The dynamics of cost,Tactical, earnings, and regulative judgments were designed using a system dynamics (SD)technique in the research conducted by [38]. The system dynamics technique was utilized to build a business model in which various required human resources and costs were calculated in the current study. The model was built on the recovery, refurbishment, and resale of EVBs; in this scenario, the generated model was utilized to forecast revenue and profit statistics. Furthermore, remanufacturing and repurposing process promise a large Market capacity for the recovery of electric vehicle batteries shortly[38]. For the creation of the model, Alamerewa and Brissauda (2018) employed system dynamics modeling and analyzed product recovery options [39]. Farel (2013) proposed a model to investigate the potential costs and advantages of ELV glazing recycling for all stakeholders in the value chain [40]. Guan (2011) proposed a dynamic combination approach of SD geographical information system (GIS) to simulate and assess city expansion in Chongqing, China, which is experiencing resource depletion and environmental damage [41]. Alamerew, Y. A. and Brissaud, D. (2020) proposed a model to reflect the complex system of reverse logistics used to recover post-used objects at their end-of-life (EoL) stage [38]. Tang et al. (2019) developed a systematic video game academic model to examine the social,economic, and environmental implications of reusing retired EV batteries under the reward penalty mechanism [42]. Wang et al. (2014) used a system dynamic approach and simulated the Chinese vehicle parts industry to investigate the impact of incentive policies on the development of the recycling and remanufacturing business in China [43].

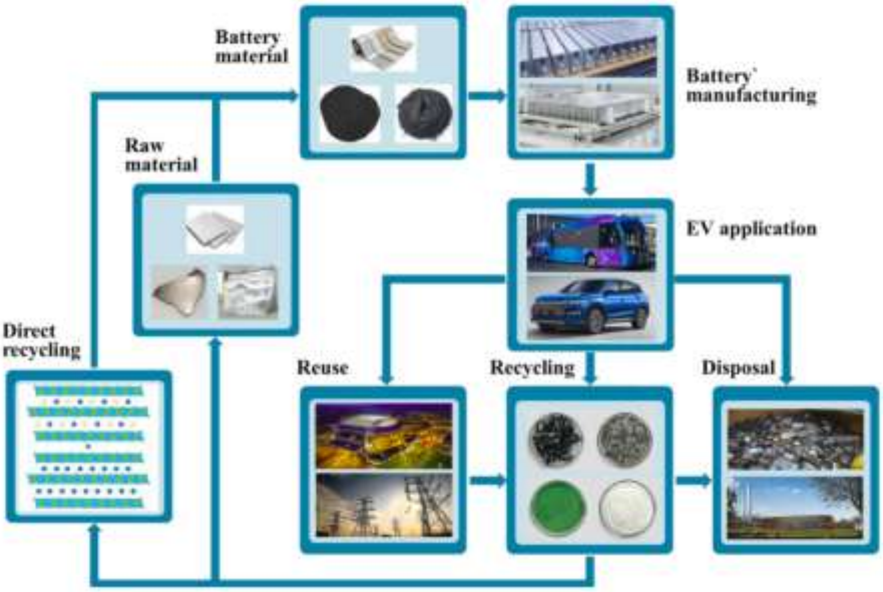


Figure 2. Approaches for treating retired EVBs (Source: [35])

In this paper, the problem of the second life of electric vehicle batteries (EVBs) has been discussed and a model (The data used in the model was collected from a literature review) has been suggested for their refurbishment so that their life can be extended for several years. Their recycling can harm our environment because their dismantling can cause the emission of greenhouse gases. During the literature review, we studied various models on the second life of EVBs but this model covers various variables. This work is significant contribution because a detailed model provides several costs (refurbishing cost, transportation cost, human resources cost, and various other costs that are supposed to incur during the EVBs` refurbishment) which would be involved in the refurbishment of EVBs. Most importantly, the highlighted contribution of the present research is that it provides the detailed feasibility of EVBs refurbishment business model.

3. Research Methodology

The present research paper is based on the modeling and simulation of system dynamics (SD) model but before the model development, it was necessary to highlight the relationship among the various variables, and this was done by making the causal loop diagram (CLD).After the in-depth review of the literature, a causal loop diagram (CLD) (seeFigure 3)was developed in the Vensim PLE version. The development of a stock and flow diagram was the next step, which was carried out in the Analogic PLE version; whereas, several researchers have used Vensim [38], [40], [41], [43]–[47], Stella [48], Powersim Studio [49], and Dynaplan Smia [29] for the development of SD model. Moreover, the model was then initialized by putting the data collected from NREL, it was then simulated, and validated by using the collected secondary data; furthermore, its sensitivity analysis was also conducted as discussed in the below-given headings in detail.

3.1. Causal Loop Diagram

CLD, according to Alamerew, 2020, is first built from a literature assessment of three basic approaches. The developed model is then validated by testing it with businesses. Based on feedback from the case study companies, the model has been updated. Each diagram is made up of five key steps. (step 1: define the theme; step 2: place the variables and identify the focus variable; step3: determine the casualty and the feedback; step4: determine the polarity, and step 5: refine the model) [45]. The causal loop diagram is used to create a stock and flow diagram [43]. A causal loop diagram is used to show the relationship between elements and the systems feedback process [43]. The creation of a causal loop diagram (CLD) is regarded as the most important stage in SD [47]. Proactive decision-makers, on the other hand, anticipate changes by spotting casual loops early and adequately adjusting their business models before the competition [50]. Diagram presented in Figure 3 is the causal loop diagram of the present research, based on which the system dynamics model was developed.

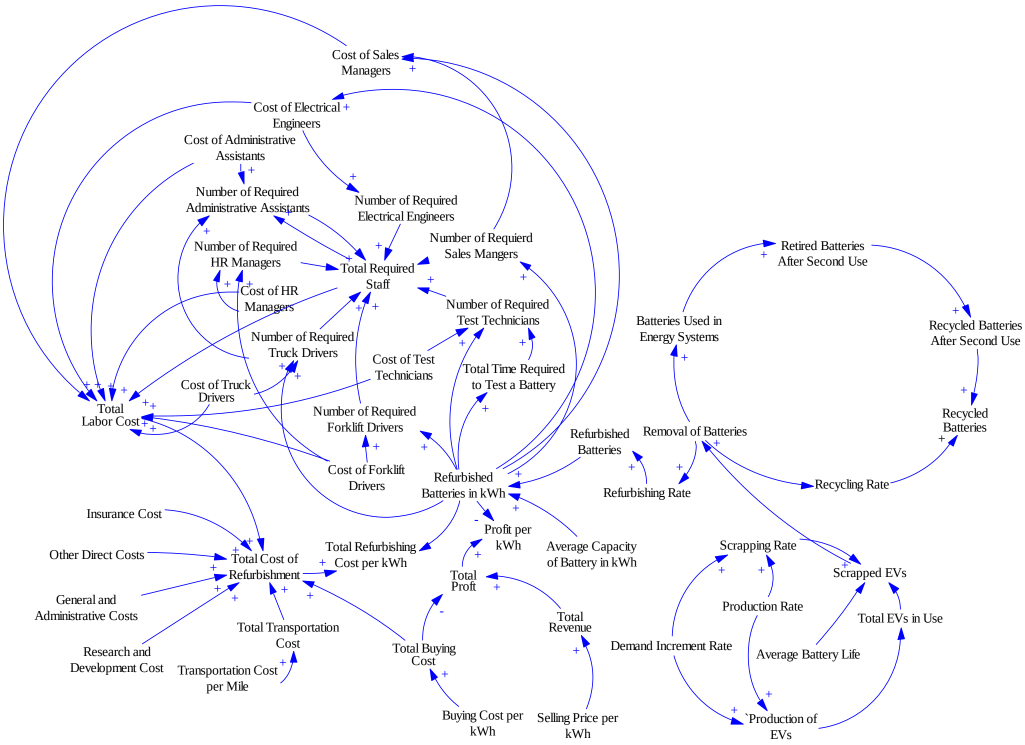


Figure 3. Causal loop diagram as developed after reviewing the literature

3.2. Data Collection

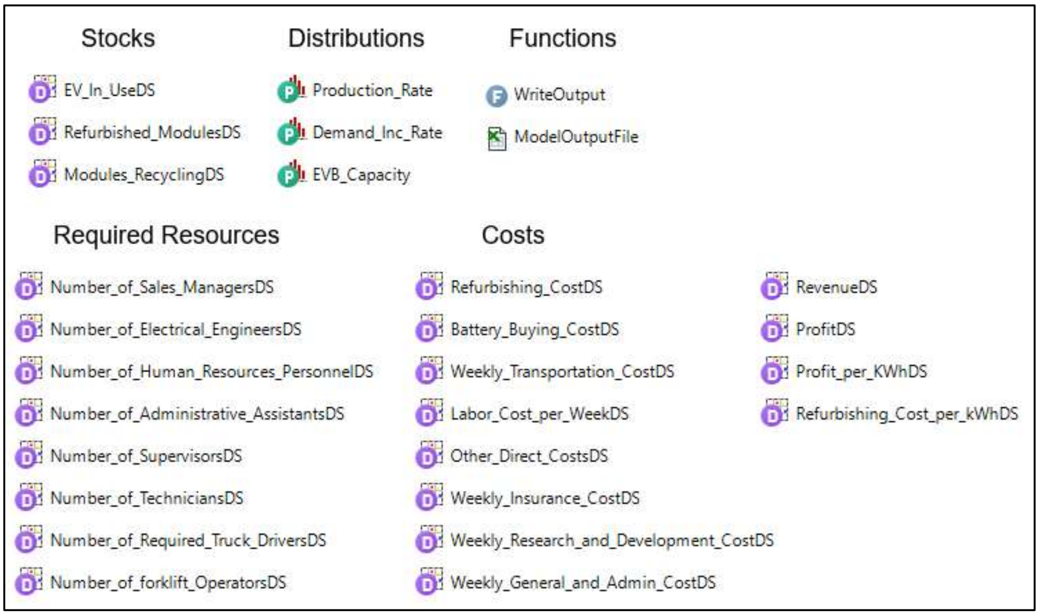
The data regarding the production of EVs at tesla was collected from the Statista website [51]; the distribution function for the production rate of EVs, their production increment rate, and the capacity of EVs (kWh) was used (seeFigure 4). moreover, the data regarding the various costs, module handling and transportation, and requirement of human resources was obtained from NREL [52] and various other sources (see table 1 to 4).The completely collected data was secondary in nature. The model was then initialized and a simulation was conducted in three scenarios i.e. scenario1 (selling batteries locally), scenario2 (selling batteries regionally), and scenario3 (selling batteries nationally).

During the model development, datasets were used for storing the simulation data and the Microsoft Excel function (ModelOutputFile) was used to link Microsoft Excel (seeFigure 4) with Anylogic, and the WriteOuput function was used to download that data into Microsoft Excel (seeFigure 5). After downloading the data, it was organized and transferred to the origin software for plotting graphs.

3.3. Model Development

3.3.1. Stock and Flow Diagram

Initially, EVs are manufactured (with the production rate given in eq. 1) and after their specified lifetime (w = 416 weeks), they are scrapped and are separated from EVs. After dismantling, some batteries are recycled and some of them are refurbished for second use as indicated in CLD and stock and flow diagram in Figure 3 and Figure 6 respectively. Refurbishment needs several resources i.e. work force (technicians, engineers, administrative personnel, drivers, sweepers, etc.), testing equipment, and vehicles for transportation within and outside the refurbishing facility.



Stocks
EV_In_UseDS
Refurbished_ModulesDS
Modules_RecyclingDS

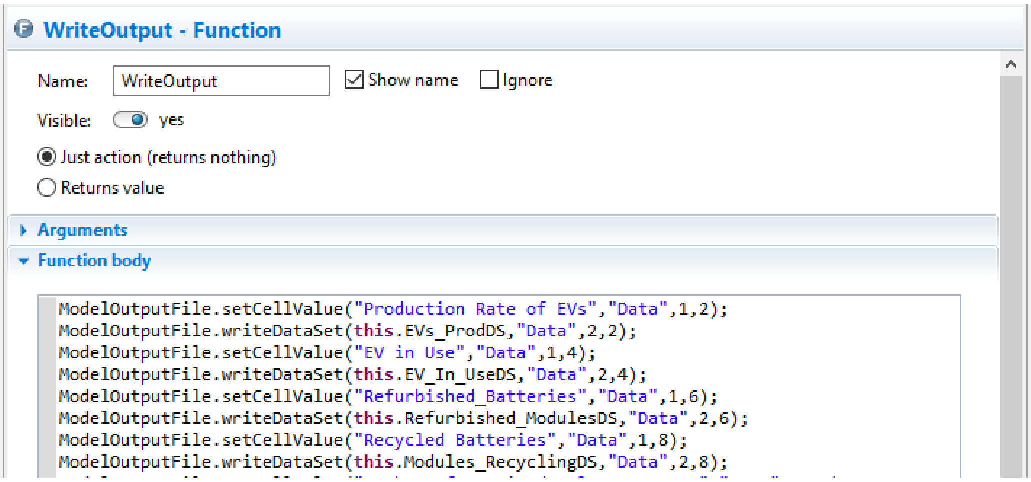
Distributions
Production_Rate
Demand_Inc_Rate
EVB_Capacity

Functions
WriteOutput
ModelOutputFile

Required Resources
Number_of_Sales_ManagersDS
Number_of_Electrical_EngineersDS
Number_of_Human_Resources_PersonnelDS
Number_of_Administrative_AssistantsDS
Number_of_SupervisorsDS
Number_of_TechniciansDS
Number_of_Required_Truck_DriversDS
Number_of_forklift_OperatorsDS

Costs
Refurbishing_CostDS
Battery_Buying_CostDS
Weekly_Transportation_CostDS
Labor_Cost_per_WeekDS
Other_Direct_CostsDS
Weekly_Insurance_CostDS
Weekly_Research_and_Development_CostDS
Weekly_General_and_Admin_CostDS
RevenueDS
ProfitDS
Profit_per_KWhDS
Refurbishing_Cost_per_kWhDS

Figure 4. Used elements in Anylogic software for storing data and downloading it in Microsoft Excel



WriteOutput - Function

Name: WriteOutput ☑ Show name ☐ Ignore

Visible: yes

● Just action (returns nothing)
○ Returns value

```
ModelOutputFile.setCellValue("Production Rate of EVs","Data",1,2);
ModelOutputFile.writeDataSet(this.EVs_ProdDS,"Data",2,2);
ModelOutputFile.setCellValue("EV in Use","Data",1,4);
ModelOutputFile.writeDataSet(this.EV_In_UseDS,"Data",2,4);
ModelOutputFile.setCellValue("Refurbished_Batteries","Data",1,6);
ModelOutputFile.writeDataSet(this.Refurbished_ModulesDS,"Data",2,6);
ModelOutputFile.setCellValue("Recycled Batteries","Data",1,8);
ModelOutputFile.writeDataSet(this.Modules_RecyclingDS,"Data",2,8);
```

Figure 5. Write Output function, which was used for downloading the simulation data from Anylogic to Microsoft Excel

$$\varphi_p = P_w(1 + D_w)$$
Eq. 1

$$E(w) = \int_{w_0}^{w} [\varphi_p - \varphi_{rb}]\, dw + E(w_0)$$
Eq. 2

$$R(w) = \int_{w_0}^{w} \varphi_{rb}\, dw + R(w_0)$$
Eq. 3

$$R_m(w) = \int_{w_0}^{w} \varphi_r\, dw + R_m(w_0)$$
Eq. 4

$$M_u(w) = \int_{w_0}^{w} [\varphi_{2u} - \varphi_{r2u}]\, dw + M_u(w_0)$$
Eq. 5

$$M_{r2u}(w) = \int_{w_0}^{w} [\varphi_{r2u} - \varphi_{fr}]\, dw + M_{r2u}(w_0)$$
Eq. 6

$$M_r(w) = \int_{w_0}^{w} [\varphi_{fr} + \varphi_{cy}]\, dw + M_r(w_0)$$
Eq. 7

It was found by the researchers that the quality of solution can be made better by its integration with optimization algorithm[53]–[55].The flow of production rate is the summation of average weekly production as calculated by given distribution and the demand increment rate as presented by eq. 1.After the batteries are refurbished, they would be supplied to the customers, and finally, when they would be retired after second use they are supposed to be recycled as indicated in Figure 3 and Figure 6. The equations representing the various stocks (see Figure 6) are given in the above equations from eq. 2 to 7.The equations from eq. 2 to 7 are the equation of stocks (rectangle shapes) as given in Figure 6; these are adapted from the standard formulations of stocks as per SD modeling.

3.3.2. Properties of Batteries

After the definition of production rate, refurbishing rate, and recycling rate, the properties of the battery and its components were initialized by using variables and parameters (see Figure 7). Properties (length, width, height, capacity, footprint, and volume of module) were used for the calculation of handling and transportation costs of EVB modules inside and outside the refurbishing facility. When the EVBs are dismantled from EVs, they are further disassembled and the unit is known as the EVB module.

$$M_m = \frac{M_{ne}}{M_{nse}} 1000$$
Eq. 8

$$M_v = \left[\frac{M_{ne}}{M_{ned}} 1000\right] 1000$$
Eq. 9

$$M_h = \left(\frac{M_v}{2}\right)^{\frac{1}{3}}$$
Eq. 10

$$M_w = M_h$$
Eq. 11

$$M_l = \frac{M_v}{M_w M_h}$$
Eq. 12

$$M_f = M_l M_w$$
Eq. 13

$$M_b = \frac{EVB_{ac}}{M_{ne}}$$
Eq. 14

$$N_{cim} = \frac{M_{ne}}{0.074}$$
Eq. 15

To model the refurbishment of batteries and their costs, it is necessary to look at their properties. From the literature review, The formulae given in equations from eq. 8 to eq. 15 are about the calculation of the mass of the module of battery (M_m) by using eq. 8 and its various geometrical characteristics of EVB module. For instance, length (M_l) was calculated by using eq. 12, and width (M_w) by eq. 11, height (M_h)by eq. 10, volume (M_v) by eq. 9, footprint (M_f) by eq. 13, number of cells in the module (N_{cim}) by eq. 15, and number of modules in the battery (M_b) by eq. 14. These were necessary to be calculated so that number of batteries to be transported in a truck could be estimated. All the equations from eq. 8 to eq. 15 are used in dynamic variables given in Figure 7.

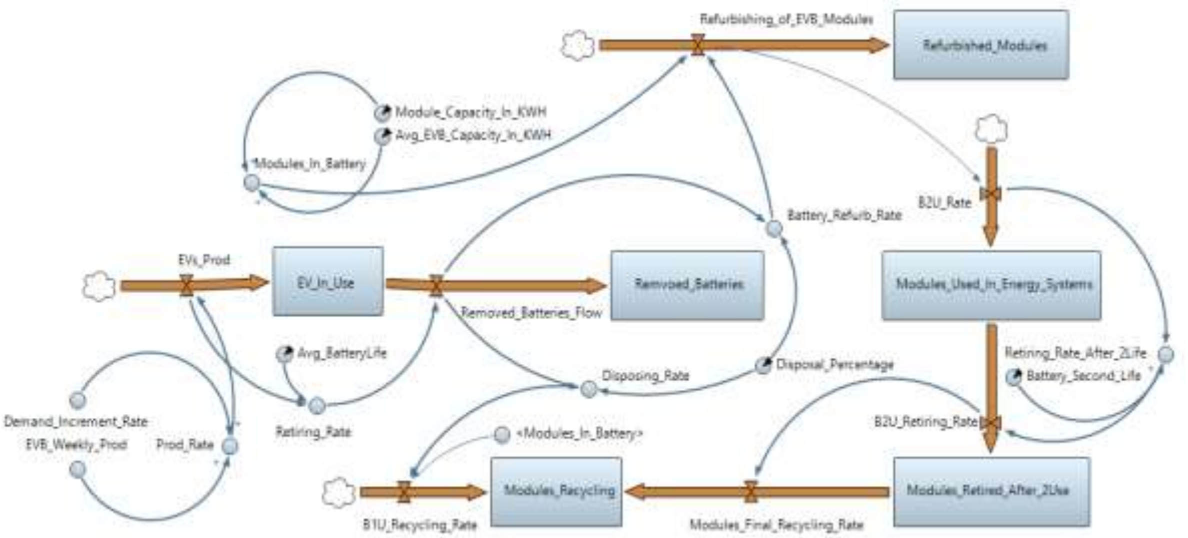


Figure 6. Stock and Flow Diagram of the model

3.3.3. Transportation of Batteries Within and Outside the Refurbishing Facility

When the modules are taken out from batteries, they are moved by the use of forklifts to the testing stations where they are tested, refurbished, and transported to the selling point via trucks. Figure 8 is incorporated with all the variables necessary for the calculation of transportation cost and module testing cost, and module handling cost.Total technician handling time (t_{tht}) as given in eq. 16 is the summation of connection to and initiation of electrical equipment (t_{ciete}), receiving inspection and handling time (t_{rih}), disconnection time of electrical test equipment (t_{dee}), and final inspection and packaging time (t_{fip}).According to the estimated total technician handling time (t_{tht}), modules per technician per week (M_{ptpw}) were estimated as given in eq. 17; to estimate the time of forklift operator per day (t_{fopd}) as given in eq. 19, it is necessary to calculate the number of receiving palletsmoved per day (P_{rmpd}) as shown in eq. 18. These variables are based on the time study of various operations carried out to transport and inspect the EVB modules. The estimation of the capacity of a truck to transport the modules (M_{tc})was calculated by using in eq. 20, trips per truck per week (T_{pw}) by eq. 21 were calculated accordingly to the refurbished volume of EVBs. In this way, the number of required shipping containers (S_{rc})was calculated by eq. 25, the number of truck drivers (N_{td}) was calculated by eq. 23, and total miles traveled per week (D_{mtpw}) were estimated by using eq. 24. These variables depend on the volume of refurbished batteries transported. Variables that were used for the calculation of costs associated with module handling are represented by the below-given equations from eq. 16 to 19.

$$t_{tht} = [t_{rih} + t_{ciete} + t_{dee} + t_{fip}] \qquad \text{Eq. 16}$$

$$M_{ptpw} = \frac{(d_{wpw}t_{wpd})60}{tht} \qquad \text{Eq. 17}$$

$$P_{rmpd} = \frac{M_{pw}}{d_{wpw}} M_{pp} \qquad \text{Eq. 18}$$

$$t_{fopd} = \frac{(t_{lmp}P_{rmpd})2}{60} \qquad \text{Eq. 19}$$

$$M_{tc} = \frac{T_{cm}}{M_m} \qquad \text{Eq. 20}$$

$$T_{pw} = \frac{M_{pw}}{M_{tc}} \qquad \text{Eq. 21}$$

$$t_{ct} = T_{pw}t_{trc} \qquad \text{Eq. 22}$$

$$N_{td} = \frac{t_{ct}}{d_{wpw}t_{wpd}} \qquad \text{Eq. 23}$$

$$D_{mtpw} = D_{trc}T_{pw} \qquad \text{Eq. 24}$$

$$S_{rc} = \frac{N_{td}M_{tc}M_{ne}}{10} \qquad \text{Eq. 25}$$

Transportation cost calculation is based on the set of variables, which are represented by the various equations given above from eq. 20 to 25.The mentioned range of equations were used in the dynamic variables that were inserted in the part of model as given in Figure 8.

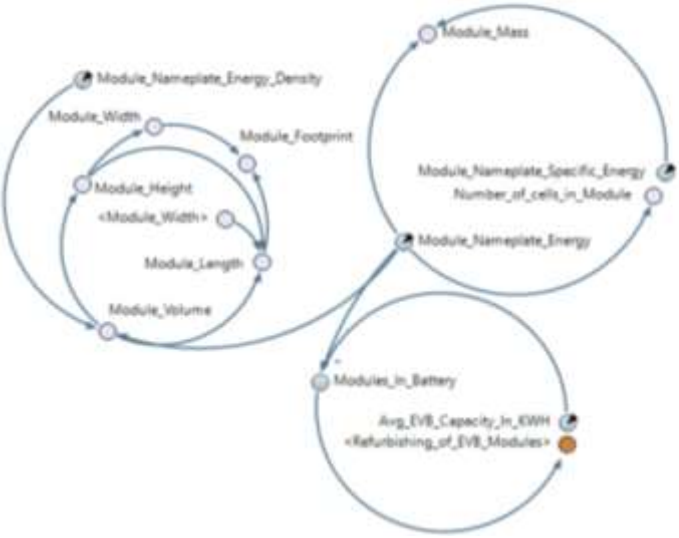


Figure 7. Properties of dismantled modules of the battery

Figure 8. Variables included in the model for handling and transportation of modules

3.3.4. Costs and Financial Variables Associated with Refurbishing of EVBs

Since the EVBs in such a greater quantity are expected to be found in the market in near future and they would require the workforce resources, equipment, vehicles (forklifts and trucks), and most importantly, the space to set up a refurbishing facility. In the model given inFigure 9, the number of required resources (number of electrical engineers, technicians, forklift drivers, truck drivers, human resource assistants, administration personnel, supervisors, etc.), their cost, and overheads are incorporated in detail.

The base of the equations used in the model was a time study of every single operation required in the refurbishment of EVBs and that data was collected from NREL as discussed in the research methodology section. The number of required technicians (N_t) per week was estimated by using eq. 26; in which the received number of modules of EVBs (M_{pw}) was divided by the modules per technician per week (M_{ptpw}). $M_{ptpw}$was estimated after the collection of time study data fromNREL. Similarly, the number of required forklift operators (N_{fo}), number of required truck drivers (N_{td}), number of required supervisors (N_s), number of sales managers (N_{sm}), number of required electrical engineers (N_{ee}), number of required administrative assistants (N_{aa}), and number of human resource personnel (N_{hrp}) were calculated by using equations from eq. 27 to 33 respectively.

$$N_t = \frac{M_{pw}}{M_{ptpw}} \qquad \text{Eq. 26}$$

$$N_{fo} = \frac{t_{fopd}}{d_{wpw} t_{wpd}} \qquad \text{Eq. 27}$$

$$N_{td} = \frac{t_{ct}}{d_{wpw} t_{wpd}} \qquad \text{Eq. 28}$$

$$N_s = \frac{N_t + N_{fo} + N_{td}}{10} \qquad \text{Eq. 29}$$

$$N_{sm} = \frac{M_{pw}}{4000} \qquad \text{Eq. 30}$$

$$N_{ee} = \frac{M_{pw}}{4000} \qquad \text{Eq. 31}$$

$$N_{aa} = \frac{N_t + N_{fo} + N_{td} + N_s + N_{sm} + N_{ee} + N_{ceo}}{30} \qquad \text{Eq. 32}$$

$$N_{hrp} = \frac{N_t + N_{fo} + N_{td} + N_s + N_{sm} + N_{ee} + N_{ceo}}{30} \qquad \text{Eq. 33}$$

The number of required human and non-human resources was estimated by using the above-given equations (from eq. 26 to 33).All below-given equations were used in the dynamic variables in the part of the SD model given in Figure 9.

After all the equations associated with the operation of the refurbishment facility, it was required to conduct its financial analysis and it was conducted by putting the below-given equations in the SD model. The cost of human resources was calculated plainly by multiplying the number of human resources by their salary. For instance, the cost of required human resource personnel (C_{hrp}) was calculated by eq. 34; it was calculated by multiplying the required number of human resource personnel (N_{hrp}) to the salary of one human resource personnel (S_{hrp}). In this way, the cost of required electrical engineers (C_{ee}), cost of required sales managers (C_{sm}), cost of required technicians (C_t), cost of required truck drivers (C_{td}), cost of required forklift operators (C_{fo}), cost of required supervisors (C_s), cost of required administrative assistants (C_{aa}), and cost of chief executing officer (CEO) (C_{ceo}) were calculated from eq. 34 to 42. Total labor cost (C_{tl}) was calculated by using eq. 43 by summing up the cost of all human resources as discussed above. Moreover, the battery purchasing cost (C_{bb}), other direct costs (C_{od}), insurance cost (C_i), general and administrative expenses (C_{ga}), research and development cost (C_{rd}), and toal cost of refurbishment were calculated by using the range of equations from eq. 44 to 49 respectively. Moreover, transportation cost (Ctr) and refurbishing cost of batteries per kWh was calculated by using eq. 50 and 51. The range of equations from eq. 34 to 51 were used in the dynamic variables inserted in the part of the SD model given in Figure 9.

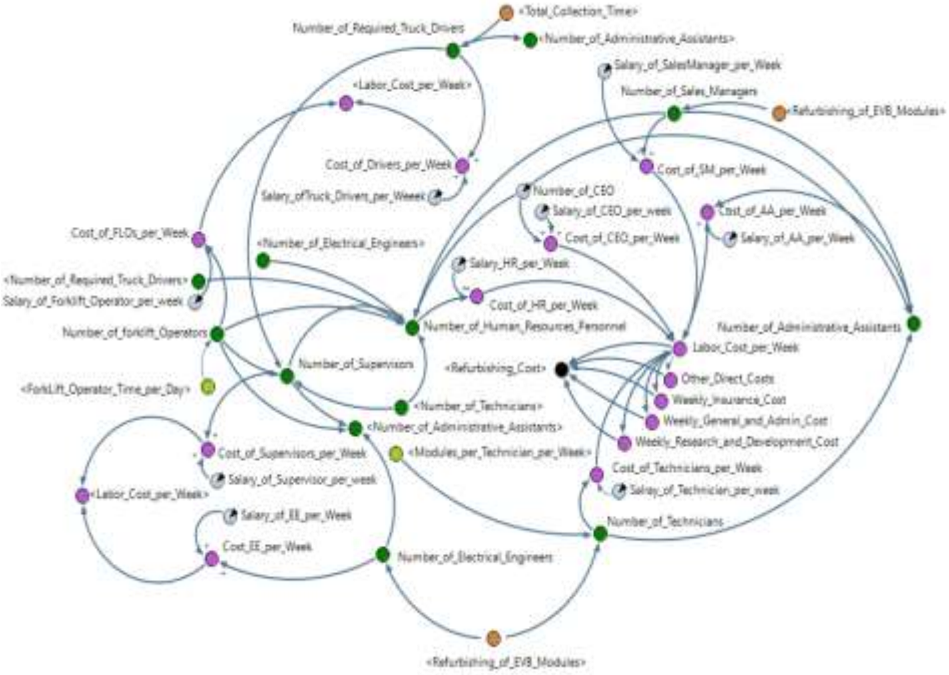


Figure 9. Cost included in the model by the use of variables

$$C_{hrp} = N_{hrp}S_{hrp} \qquad \text{Eq. 34}$$

$$C_{ceo} = N_{ceo}S_{ceo} \qquad \text{Eq. 35}$$

$$C_{sm} = N_{sm}S_{sm} \qquad \text{Eq. 36}$$

$$C_t = N_tS_t \qquad \text{Eq. 37}$$

$$C_{td} = N_{td}S_{td} \qquad \text{Eq. 38}$$

$$C_{fo} = N_{fo}S_{fo} \qquad \text{Eq. 39}$$

$$C_s = N_sS_s \qquad \text{Eq. 40}$$

$$C_{aa} = N_{aa}S_{aa} \qquad \text{Eq. 41}$$

$$C_{ee} = N_{ee}S_{ee} \qquad \text{Eq. 42}$$

$$C_{tl} = [C_{aa} + C_t + C_{ee} + C_{hrp} + C_{ceo} + C_{sm} + C_{td} + C_{fo} + C_s] \qquad \text{Eq. 43}$$

$$C_{bb} = C_{bbk}M_{ne} \qquad \text{Eq. 44}$$

$$C_{od} = \frac{2C_{tl}}{100} \qquad \text{Eq. 45}$$

$$C_i = \frac{3C_{tl}}{100} \qquad \text{Eq. 46}$$

$$C_{ga} = \frac{5C_{tl}}{100} \qquad \text{Eq. 47}$$

$$C_{rd} = \frac{3C_{tl}}{100} \qquad \text{Eq. 48}$$

$$C_{refurb} = [C_{tl} + C_{od} + C_i + C_{ga} + C_{rd} + C_{bb} + C_{tr}] \qquad \text{Eq. 49}$$

$$C_{tr} = t_{ct}C_{toc} \qquad \text{Eq. 50}$$

$$\boldsymbol{C_{refurbk}} = \frac{C_{refurb}}{\varphi_p M_{ne}} \qquad \text{Eq. 51}$$

The objective behind the establishment of any business is the multiplication of money. InFigure 10, the variables for the calculation of cost per kWh, revenue, profit, and profit per kWhwere included in the SD model.

Table 1 describes the purpose of each figure from Figure 6 to Figure 10 and links them to the set of mathematical equations that are used in the specific part of the model.

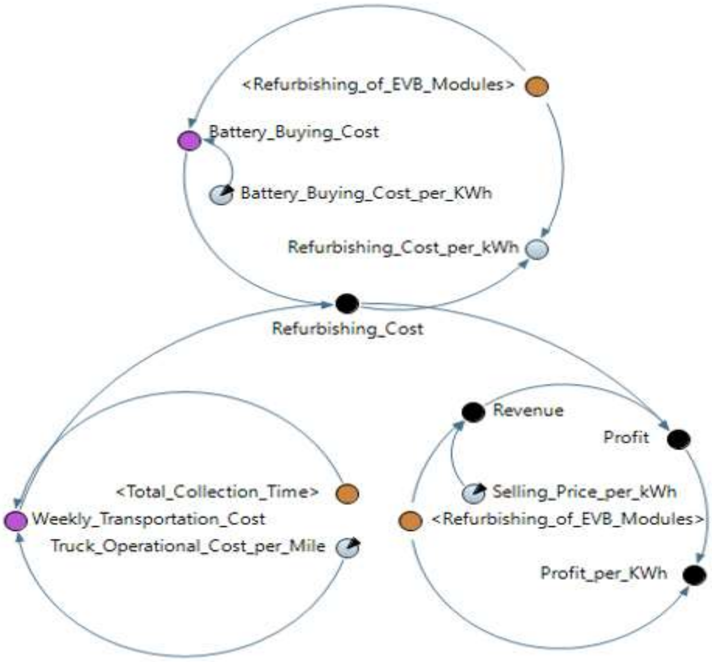


Figure 10. Overall revenues, refurbishing cost, cost per kWh, and profit per kWh

Table 1. Figures and the range of used equations

Figure #	Used Equations	Purpose
Figure 6	Eq. 1 to Eq. 7	The part of the model given in Figure 6 was developed to initiate the flow of EVs production per week and after 8 years; EVBs are retired and are received to the refurbishing facility and then transported to the customer destinations after refurbishment.
Figure 7	Eq. 8 to Eq. 15	The part of the model given in Figure 7 was developed for the estimation of truck capacity needed could be conducted from the geometrical measures of dismantled modules of EVBs including their mass, weight, and volume.
Figure 8	Eq. 16 to Eq. 25	The part of the model given in Figure 8 was used for the estimation of assets i.e. equipment (forklifts, pallets, trucks) so that magnitude of hiring could be set accordingly in the model.
Figure 9	Eq. 26 to Eq. 33	The part of the model presented in Figure 9 was developed for the estimation of overall needed human resources as per the received EVBs. Moreover, the cost of every human resource was calculated according to 8 hours shifts and 5 workdays. The cost of human resources included truck drivers, administrative assistants, HR personnel, technicians, supervisors, electrical engineers, managers, general managers, CEOs, and overheads
Figure 10	Eq. 34 to Eq. 51	Overall revenues, refurbishing cost, cost per kWh, and profit per kWh were calculated by adding the equations of mentioned desired financials in dynamic variables as given in Figure 10.

3.3.5. Model Validation

Since most of the OEMs are not working on refurbishment, practices (seeTable 2); this was the one of main reasons that the data from OEMs could not be collected. This was the reason that the data was collected from various published sources as cited in the present research. Since the companies are striving to come up with a solution to this big problem; thus the availability of the data was rare; in this regard, the present model was not validated with the real-time collected data.

3.4. Initialization of the Model

The developed system dynamics model was initialized by putting the values, which are discussed in the below-given headings.

3.4.1. Model Initialization Using Distribution Function

The data regarding the production of electric vehicles by tesla was collected (seeTable 3). Quarterly production details were collected [51]; the obtained data was organized and Microsoft Excel and the weekly production rate was calculated accordingly; at the same time, the demand increment rate of the production was also calculated.

The simple average and standard deviation of production donot bring that much variation during the simulation of the model. Thus,three custom distribution functions were used in the model in anylogic for the production rate and demand increment rate and power capacity of EVBs (see Figure 4). The graphs of frequency distribution for production rate and production increment rate are given in Figure 11and Figure **12**respectively. By doing this, the real vicissitudes in the production of EVs were possibly brought into the simulation of the model.

Table 2. Circular economy practices being carried out at original equipment manufacturers (OEMs). X in the table indicates that there is no availability of information regarding the type of activity (Source: [56])

Company/Group	Intensifying Use	Repair	Refurbish	Remanufacturing	Repurpose	Closed-Loop Recycling
ADL	X	X	X	X	X	X
BAIC	X	X	X	X	Yes	X
BMW	X	X	X	X	X	Investigations
BYD	X	X	X	X	X	X
DAF	X	X	X	X	X	X
Daimler AG	X	Yes	Yes	Yes	Yes	Investigations
Ford	X	X	X	X	X	X
Honda	X	X	X	X	Investigations	Investigations
Hyundai	X	X	X	X	Yes	X
Irizar	X	Yes	Yes	X	Yes	X
Jaguar Land Rover	X	X	X	X	Yes	X
LEVC	X	X	X	X	X	X
Mitsubishi	X	X	X	X	Yes	X
Nissan	C	X	X	X	Yes	X
PSA Group	X	X	Unclear	X	Investigations	X
Renault Group	Yes	Yes	Yes	No	Yes	Yes
Solaris Bus and Coach	X	X	X	X	Investigations	Unclear
Street scooter	X	X	X	X	X	X
Tazzari	X	X	X	X	X	X
Tesla	X	X	X	X	No	Envisioned

Table 3. Quarterly production of EVs (Source: [51])

Year	Quarter	Quarterly Production	Weekly Production
2016	1	15510	1193.08
	2	18345	1411.15
	3	25185	1937.31
	4	24882	1914.00
2017	1	25148	1934.46
	2	25708	1977.54
	3	25336	1948.92
	4	24656	1896.62
2018	1	34494	2653.38
	2	53339	4103.00
	3	80412	6185.54
	4	86555	6658.08
2019	1	77100	5930.77
	2	87048	6696.00
	3	96155	7396.54
	4	104981	8075.46
2020	1	102672	7897.85
	2	82272	6328.62
	3	145036	11156.62
	4	179757	13827.46
2021	1	180338	13872.15
	2	206421	15878.54

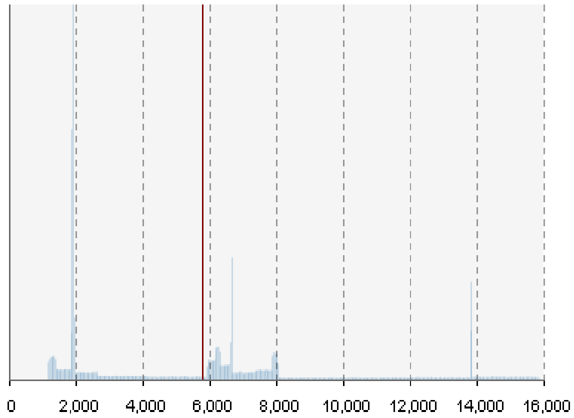


Figure 11. Distribution of production rate (from the data given inTable 3): screenshot from Anylogic.

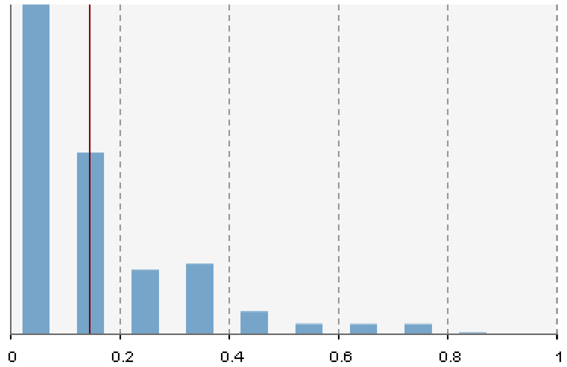


Figure 12. Distribution of demand increment rate (from the data given in Table 3): screenshot from Anylogic.

The power capacity of several models of tesla was collected from the database of electric vehicles as can be seen inTable 4.In the collected data, the power capacity of vehicles from various companies was there but due to the scope of present research, which is limited to Tesla; this is the reason, power capacity of only Tesla EVs was put in the distribution function of the model.

Table 4. Useable Capacity of the electric vehicles produced by Tesla (Source: [57])

Electric Vehicle Model	Useable Capacity (KWh)
Tesla Model S Long Range	90
Tesla Model S Plaid	90
Tesla Model X Long Range	90
Tesla Model X Plaid	90
Tesla Model 3 Performance	76
Tesla Model Y Performance	76
Tesla Model 3 Long Range Dual Motor	76
Tesla Model 3 Long Range Dual Motor	70
Tesla Model Y Long Range Dual Motor	70
Tesla Model 3 Standard Range Plus LFP	52.5
Tesla Model 3 Standard Range Plus	51

Instead of initializing the model with the average power capacity via using a parameter, a distribution function for the power capacity of EVs was used;the graph of the frequency distribution of the power capacity of EVs is given inFigure 13.

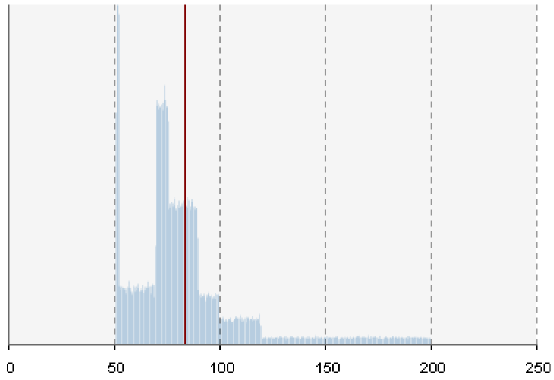


Figure 13. Distribution of power capacity of tesla models (from the data given inTable 4): screenshot from Anylogic

3.4.2. Model Initialization Using Parameters

The values that are entered into the parameters of the model were collected from several sources. At the same time, there were some values in the model that were assumed i.e. second battery life, disposal percentage, and battery refurbishment rate (seeTable 5). Moreover, the model initialization phase comes after the verification of formulae entered in the dynamic variables of the SD model, and the links between them were verified from every aspect. This verification was necessary because on entering the wrong equation in a dynamic variable, the result i.e. model output will not be correct.The values as given in Table 5were put in the parameters that have been used in the SD model.

The data regarding costs were collected from published sources i.e. research papers. As other direct costs were used by Cready et al., (2003) as 2% of the labor cost; furthermore, insurance (3%), warranty (4%), and general and administrative costs (16%) were included in indirect costs as cited by [7]. In the present research, 18% of the price of a new battery was considered as the buying cost ($39/kWh) of an EVB [60]; whereas, 24$/kWh as the cost of retired batteries was considered by NREL [61]; since this cost was 6 year old thus was not considered in the present research. Alamerew (2020), used remanufacturing cost/kWh (60 €), price of remanufactured EVB per kWh (60% of the original price of battery), price of new EVB (800 € with 10% Reduction/year), treatment cost of remanufacturing EVBs per kWh (32 €), transportation cost per kWh (10 €) [45]; the authors did not find any concrete justification of the mentioned cost, thus were not considered in the present research.

3.5. Sensitivity Analysis

Since the main input of the present model is the production rate and demand/production increment rate (see eq. 1), with the increase and decrease in the production of EVs, the number of required resources and costs vary accordingly. There are no feedback loops in the model; this is the reason the model is not sensitive to production rate and demand/production increment rate. Moreover, with the change in business level i.e. local/regional/national, the requirement for trucks, drivers, supervisors, administrative assistants, and HR personnel vary in a justified manner as can be seen in Figure 17,

Figure 18, and Figure 19. Moreover, with the change in business level, the labor cost and transportation costs vary as can be seen inFigure 21.

3.6. Scenario Analysis

In scenario analysis, three different marketing scenarios were considered i.e. local, regional, and national as used by [52]. For each scenario, a simulation experiment was set up in Anylogic software and the values of four parameters (typical round trip collection distance, typical round trip collection time, operational cost of truck, and truck cargo mass) as given in Figure 14 below-given were put accordingly.

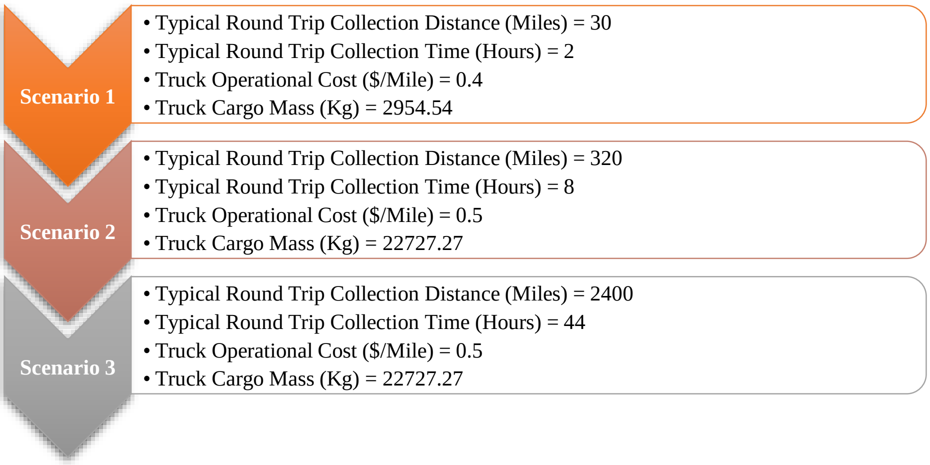
4. Results and Discussion

4.1. Production of EVs, EVBs` Retirement, and EVB Recycling

The number of electric vehicles in use increases until the retirement of EVs after 8 years from their production date (seeFigure 15). When the EVBs are dismantled from EVs, 80% of them were refurbished and the rest were recycled as per the dynamics of the developed model. It can be seen in Figure 15 that after eight years, the number of recycled batteries gradually increases and after 16 years, a significant increase can be seen in the number of recycled EVBs.This is because those EVBs are also received for recycling that were refurbished eight years ago. This is the reason for a highly increased quantity of EVBs after 16 years.

Table 5. Values of parameters as initialized in the system dynamics model

Sr. #	Parameter	Value
1	B_{al}	8 years [58]
2	B_{2l}	8 years (Assumption)
3	D_p	20% (Assumption)
4	B_{rr}	80% (Assumption)
5	EVB_{ac}	75.59 [57]
6	M_{ne}	5.3 kWh [59]
7	M_{nse}	115 [52]
8	M_{ned}	150 [52]
9	T_{cm}	22727.27 Kg [52]
10	D_{trc}	320 Miles [52]
11	t_{trc}	$0.5 [52]
12	T_{oc}	8 Hours [52]
13	B_{bc}	18% ($39) of the new battery price [60]
14	t_{ciete}	10 minutes [58]
15	t_{rih}	60 minutes [58]
16	t_{dee}	10 minutes [58]
17	t_{ftp}	25 minutes [58]
18	M_{pp}	7 [52]
19	t_{lmp}	15 minutes [52]
20	St	$728.08 [52]
21	S_{ee}	$1795.77 [52]
22	S_{fo}	$628.08 [52]
23	S_{hrp}	$1938.46 [52]
24	S_{td}	$644.04 [52]
25	N_{ceo}	1 [52]
26	S_{ceo}	$3430.77 [52]
27	S_{sm}	$1646.35 [52]
28	S_{aa}	$635.85 [52]
29	B_{sp}	$100



Scenario 1

- Typical Round Trip Collection Distance (Miles) = 30
- Typical Round Trip Collection Time (Hours) = 2
- Truck Operational Cost ($/Mile) = 0.4
- Truck Cargo Mass (Kg) = 2954.54

Scenario 2

- Typical Round Trip Collection Distance (Miles) = 320
- Typical Round Trip Collection Time (Hours) = 8
- Truck Operational Cost ($/Mile) = 0.5
- Truck Cargo Mass (Kg) = 22727.27

Scenario 3

- Typical Round Trip Collection Distance (Miles) = 2400
- Typical Round Trip Collection Time (Hours) = 44
- Truck Operational Cost ($/Mile) = 0.5
- Truck Cargo Mass (Kg) = 22727.27

Figure 14. Values of parameters for several parameters included in the model (Source: [52])

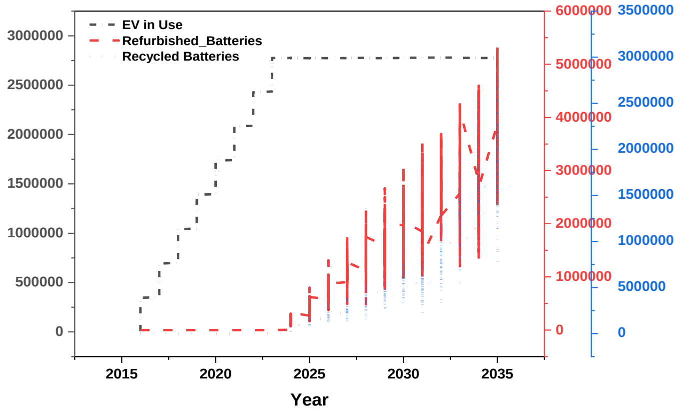


Figure 15. Number of produced EVs, refurbished and recycled EVBs

4.2. Estimation of Human Resources

The average number of electrical engineers and sales managers decrease in scenario2 and scenario3 as compared to scenario1; a look at Figure 16indicates no significant decrease. Whereas, the significant variation can be seen in the number of forklift and truck drivers(seeFigure 18) across various scenarios. This variation is due to the requirement of truck capacity; in scenario1 (local transportation), the required trucks` capacity is 2854.54 kg and the round trip time and distance are 2 hours and 30 miles respectively. For regional transportation (scenario2), trucks of larger capacity (22727.27 kg) are required and at the same time, round trip distance (320 miles) and time (8 hours) are greater as well: due to the longer trip, the company would need more drivers (see Figure 18) and trucks to transport the EVBs regionally. In scenario3 (national transportation), round trip distance and time would increase to 2400 miles and 44 hours respectively, this is the reason that required human resources would be more. In this way, the number of supervisors and administrative assistants, and human resource personnel also increase which can be seen inFigure 19.

4.3. Transportation Cost and Labor Cost

When the required truck drivers and forklift drivers vary across the scenarios, the variation in the transportation cost is certain as can be observed inFigure 20. Since the transportation levels are directly affecting the magnitude of the required workforce then labor costs will also vary in each scenario, as can be seen in Figure 20.

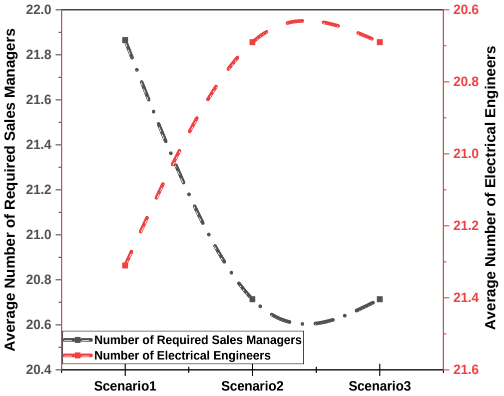


Figure 16. Estimation of the average number of required sales managers and electrical engineers

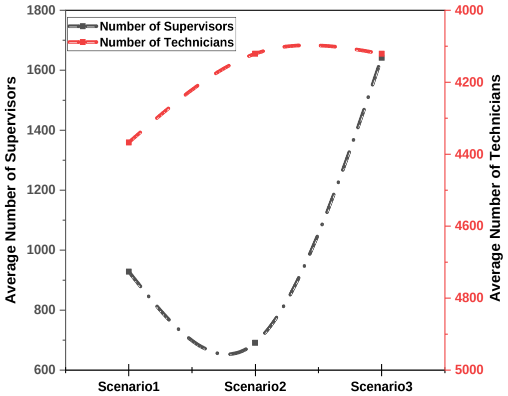


Figure 17. Estimation of the average number of required supervisors and technicians across

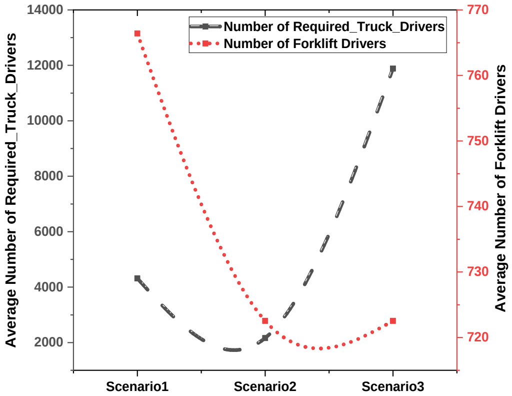


Figure 18. Estimation of the average number of required truck and forklift drivers

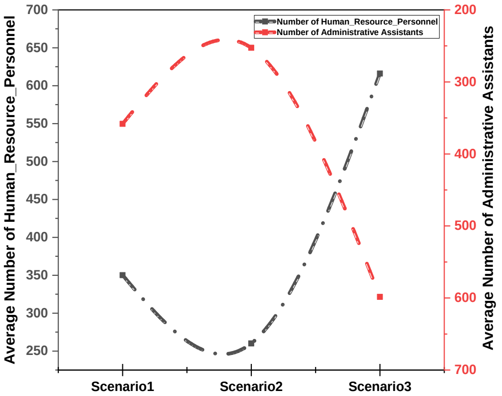


Figure 19. Estimation of the average number of human resource and administrative assistants

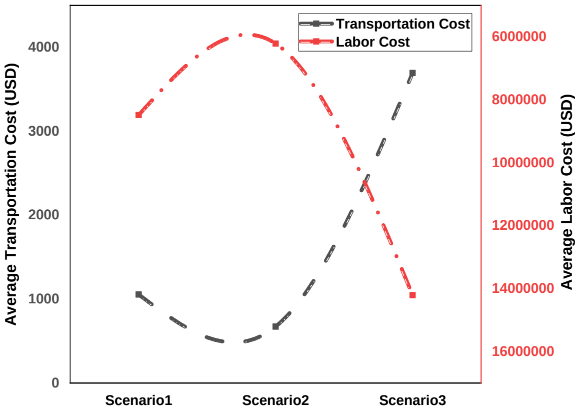


Figure 20. Estimation of average labor and transportation costs across all the scenarios

4.4. Other Costs

The costs i.e. general and administrative expenses, insurance costs, and other direct costs are associated with the labor cost; thus, rate of change of curve in all the mentioned costs can be observed to be similar as can be seen inFigure 21. Because of the increase and decrease in the number of human resources required, labor cost increases/decreases across all the scenarios; vicissitudes in the labor cost cause fluctuations in general and administrative expenses, insurance costs, and other direct costs. Since round-trip collection distance and time vary across the scenarios (see Figure 21); this causes an increase/decrease in the transportation cost. Due to variations in these costs, the refurbishing cost of batteries varies as can be seen in the graphs given in Figure 21. Neubauer et al. (2015) reported that buying cost (76%) of retired EVBs exceeded the yearly operating cost and it was calculated to be 45% of the cost per year [61]. In the present research, the contribution of battery purchasing cost was found to be greater i.e. scenario1 (65.48%), scenario2 (62.51%), and scenario3 (62.51%).

4.5. Financial Analysis

A look at Figure 22indicates that the revenue and profit were found to be maximum in scenario 1 and minimum in scenario 2. It can be seen in Figure 23that the refurbishing cost per kWh was maximum in the third scenario and the profit per kWh was calculated to be minimum.

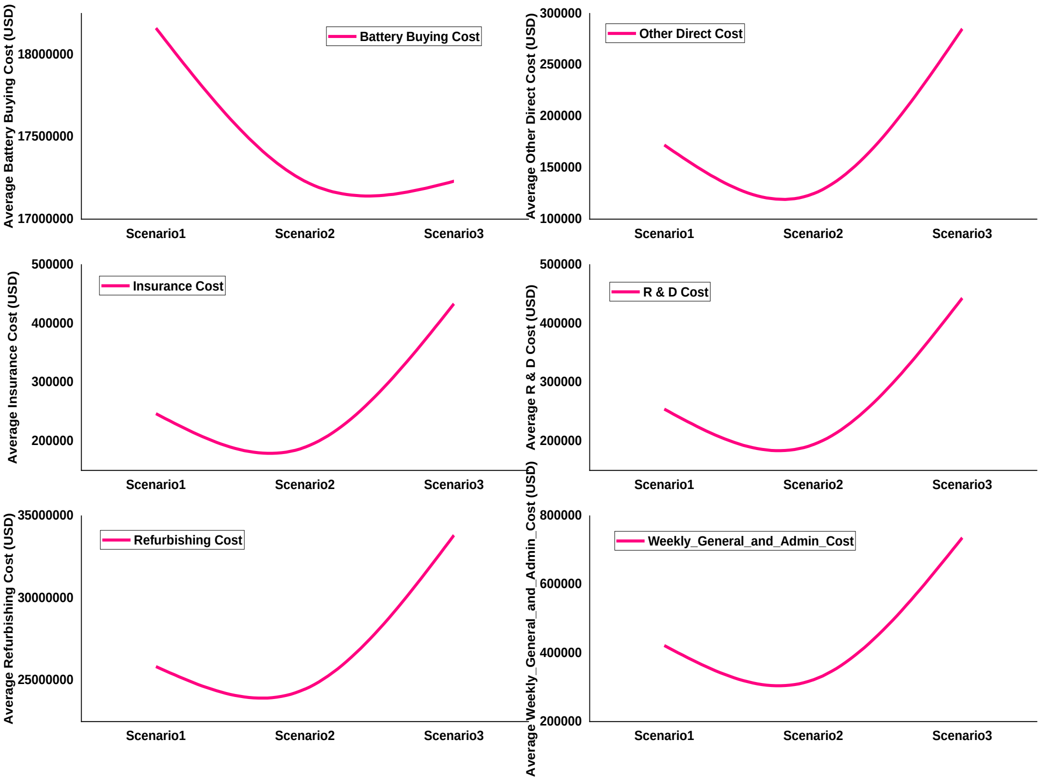


Figure 21. Estimation of all the associated average costs across 3 scenarios

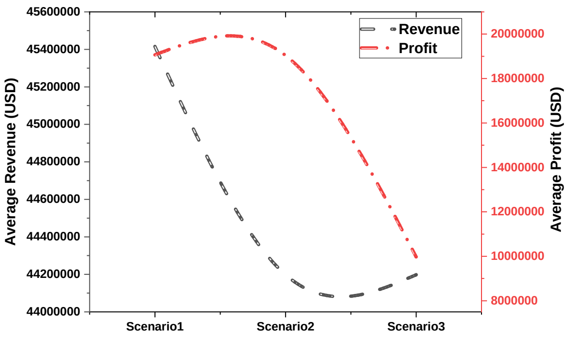


Figure 22. Estimation of the revenue and profit per week across 3 scenarios

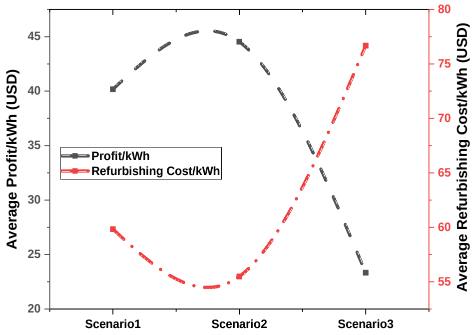


Figure 23. Estimation of the refurbishing cost and profit per kWh across 3 scenarios

Sustainable practices are highly considered in our society these days. In this regard, the present model was developed to suggest the **establishment** of a facility where the retired batteries can be refurbished and sold in the market at a reasonable price. Conclusively, as per the possible maximum generation of revenues and profits and minimum refurbishing cost in scenario2 (regional levels), thus it can be highlighted as a profitable option (seeFigure 22 and Figure 23).

There are several options for end-users to select one of the options (seeFigure 24) for their homes. The price of batteries is quite high as can be seen in Figure 24. Moreover, the price of $50/kWh (with a tight profit margin) was considered by Rayes and he suggested that the arrival of EVs in bulk would benefit the business of repurposing and refurbishing [7]. Whereas, in the present research, the price was set to $100/kWh, and the cost was different in each scenario**.**

4.6. Several Options for EVBs to be utilized

After the establishment of the refurbishing facility, EVBs will be received and refurbished in greater quantity. According to the present research, the installed business would certainly sustain itself in the market. It can be seen in Figure 25that there are various applications for utilizing EVBs at different levels i.e. industrial, commercial and residential.

The energy utilization has been the issue of concern these days [63], [64].There are still a lot of areas with unpredictable grid connections; where there are many people who live without power [7]. In such cases, a simple system is used i.e. a solar panel of 50 watts with a Li-ion battery for powering the small devices and lights for several hours in a 12-volt DC system [65]. This mechanism is not costly and can be developed fast in those areas [7]. It is valuable to reuse EVs if they are integrated with renewable energy sources (RES) rather than the procurement of new batteries of other ESSs [66].

5. Conclusion and Future Work

The production of EVs in the greater number has already been done and it is continued even after; the problem will start when they`ll get retired from EVs, where they were installed. It is a big challenge for automotive companies to deal with a big quantity of retired batteries that are harmful to the atmosphere when they would be recycled. In such a scenario, in the present research, it was suggested to refurbish them and extend their life for some more years so that they could be usefully utilized. The automotive companies are not working on refurbishing batteries (seeTable 2) but by the present research, they can be made to see this useful context of using the EVBs so that the damage to this environment can be postponed for the greater good.In the present research, the limited areas were covered i.e. the required resources` estimation, and the refurbishing cost of EVBs; for future research, the recycling of EVBs and the possibly recoverable materials can be the issue to be focused on. A model can be developed for the recovery of raw materials from EVBs and the number of EVBS that can be produced from that recovered material can be estimated.

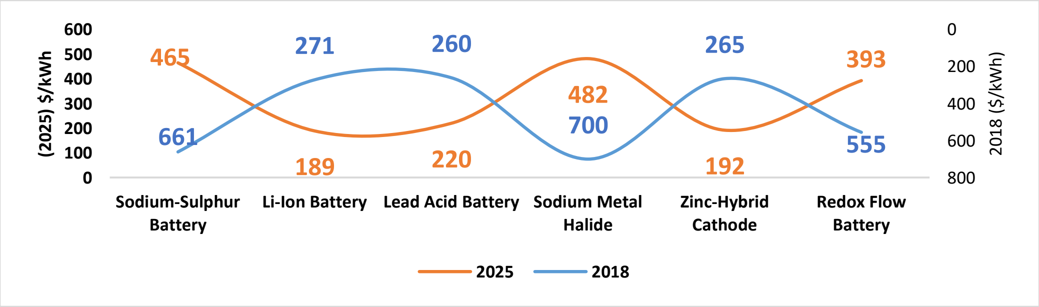


Figure 24. The price comparison of various batteries available in the market (Source: [62])

Figure 25. Most common battery applications (Source: Reid et al. 2016 as cited by [7])

6. Limitations

In the present research the estimation of capital investment is not considered; which is a gap for future research; Moreover, the recycling of EVBs is also an area being explored these days. The estimation of the quantity of possibly recoverable material from EVBs can be studied along with the required capital cost, required human resources, and time required for recycling.

7. Acknowledgment

The authors of the present research would like to thank NREL for the data it has published regarding the refurbishing of EVBs. The accessed data by NREL was very helpful in the initialization of the developed system dynamics model.

8. Conflict of Interest

There was no conflict of interest among the authors of the present research paper.

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Appendix

Notations

Stocks

E = EV in Use
R = Removed Batteries
M_r= Modules Recycling
R_m= Refurbished Modules
M_u = Modules Used in Energy System
M_{r2u}= Modules Retired After Second Use

Flows

φ_p = EVs` production rate in time w
φ_{rb} = Flow of removed batteries in time w
φ_r= Flow of refurbished batteries in time w
φ_{cy}= Flow of recycled batteries in time w
φ_{2u}=Second use rate of batteries in time w
φ_{r2u} = Batteries retiring after the second use in time w
φ_{fr}= Final recycling of modules in time w
P_w= Production rate
D_w = Demand increment rate

Variables and Parameters

B_{al} = Average battery life
B_{2l} = Battery second life
D_p = Disposal percentage
B_{rr} = Battery refurbishment rate
EVB_{ac} = Average capacity of EVB
M_m = Module mass
M_v = Module volume
M_l = Module length
M_w = Module width
M_h = Module height
M_f = Module footprint
M_b = Module in a battery
N_{cim} = Number of cells in a module
M_{ne} = Module nameplate energy
M_{nse} = Module nameplate specific energy (Wh/Kg)
M_{ned} = Module nameplate energy density (Wh/L)
T_{cm} = Truck cargo mass
D_{trc} = Typical round trip collection distance
D_{mtpw} = Total miles travelled per week
S_{rc} = Required shipping containers
t_{trc} = Typical round trip collection time
T_{oc} = Truck operation cost per mile
B_{bc} = Battery buying cost per kWh/Battery residual value per kWh
t_{ciete} = Connection to and initation of electrical test equipment
t_{rih} = Receiving inspection and handling time
t_{dee} = Disconnection time of electrical test equipment
t_{fip} = Final inspection and packaging time
t_{tht} = Total technician handling time
t_{lmp}= Time to load and move one pallet
t_{fopd} = Forklift operator time per day
t_{wpd} = Working time per day
t_{ct} = Total collection time
d_{wpw} = Working Days per week
M_{pp} = Modules per pallet
M_{tc} = Truck module capacity
M_{pw} = Modules per week
P_{rmpd} = Receiving pallets moved per day
M_{ptpw}= Modules per technician per week
S_t = Salary of technician per week
S_{ee} = Salary of electrical engineer per week
S_{fo} = Salary of forklift operator per week
S_{hrp} = Salary of human resource personnel per week
S_{td} = Salary of truck drivers per week
S_{ceo} = Salary of CEO per week
S_{sm} = Salary of sales manager per week
S_{aa} = Salary of administrative assistant per week
B_{sp} = Battery selling price
T_{pw} = Trip per week
N_{td} = Number of required truck drivers
N_t = Number of technicians
N_{fo} = Number of forklift operators
N_s = Number of supervisors
N_{ceo} = Number of CEO
N_{sm} = Number of sales managers
N_{ee} = Number of electrical engineers
N_{aa} = Number of administrative assistants
N_{hrp} = Number of human resource personnel
C_{td} = Cost of required truck drivers
C_t = Cost of technicians
C_{fo} = Cost of forklift operators
C_s = Cost of supervisors
C_{ceo} = Cost of CEO
C_{sm} = Cost of sales managers
C_{ee} = Cost of electrical engineers
C_{aa} = Cost of administrative assistants
C_{hrp} = Cost of human resource personnels
C_{tl} = Total labor cost
C_{bb} = Battery buying cost
C_{bbk} = Battery buying cost
C_{od} = Other direct costs
C_{ga} = General and administrative expenses
C_i = Insurance Cost
C_{rd} = Research and development cost
C_{tr} = Transportation cost
C_{refurb}= Refurbishing Cost
$C_{refurbk}$= Refurbishing Cost per kWh
C_{toc} = Truck operational cost per mile