An Examination of the Scale of Evolution of Electric Vehicles

A Project Report of

System Dynamics

Submitted To

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Submitted by

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Abstract

In this report, we analyze the progress and evolution of electric vehicles over time. The study examines the key factors that have contributed to the growth of the electric vehicle industry, including advancements in technology, government policies, and consumer attitudes. It also assesses the challenges that the electric vehicle industry faces, such as range anxiety, high upfront costs, and limited charging infrastructure. The paper provides an overview of the current state of the electric vehicle industry and offers insights into its future potential.

In addition to analyzing the factors that have contributed to the growth of the electric vehicle industry, our report also explores the concept of charging stations and their importance in facilitating the widespread adoption of electric vehicles. The study highlights the need for a robust and reliable charging infrastructure to overcome range anxiety, which is one of the primary concerns of potential electric vehicle buyers.

Furthermore, the paper compares the prices of electric vehicles with conventional vehicles, highlighting the challenges of higher upfront costs associated with purchasing an electric vehicle. The paper provides insights into the evolving pricing structures of electric vehicles and how they may impact the future adoption of this technology.

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Chapter 1

Problem statement

1.1 Problem statement

The widespread adoption of EVs confronts a number of difficulties, including high initial costs, a short range, a lack of infrastructure for charging, and customer acceptance. A thorough understanding of the dynamic interactions among important components, such as technology, policy, market, and societal aspects, is required to solve these issues and assist the switch to a sustainable transportation system.

1.2 Introduction

In recent years, the popularity of electric vehicles has continued to grow, driven by advances in battery technology, declining costs and increasing concern over the environmental impacts of fossil fuels showing that there is a significant impact of emission-optimal-on-road power management of EVs on the CO2 emission levels [Kopfer and Vornhusen, 2017]. Today, EVs are offered by a growing number of automakers and are becoming increasingly mainstream as a way to reduce emissions and help mitigate the effects of climate change [Xiang et al., 2017].

But there are many problems standing in the way of adopting EVs globally from a technical and socio-economical viewpoint. Also, with the mass production of electric vehicles, there grows a new issue of the development of charging stations which puts a huge burden on the energy systems or grids [Zhou et al., 2014].

In recent years, researchers and policymakers have been exploring various approaches to overcome these challenges and scale up the EV industry. One such approach is the use of system dynamics modeling, which allows stakeholders to simulate the complex interactions among different variables and identify potential strategies for scaling up the industry. Figure 1.1 shows a causal link diagram showing the dynamics of the problems pertaining to EVs.

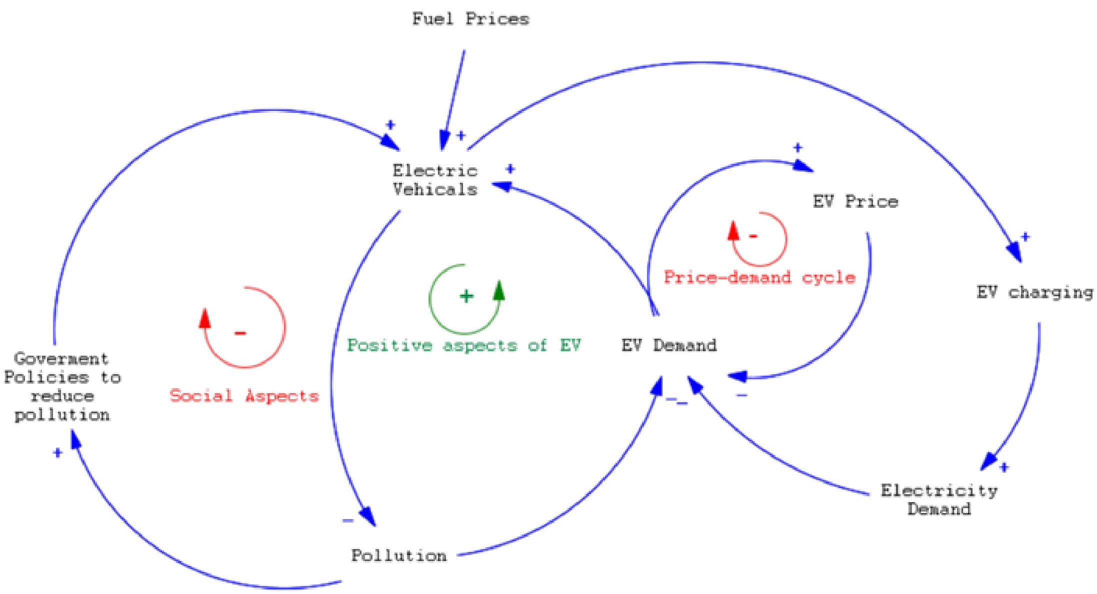

Figure 1.1: Causal Link Diagram to represent the problems pertaining to EVs

1.3 Remaining structure of the Report

In Chapter 2, we describe about the analysis of the different aspects of EV using Causal Loop Diagrams. Then, in Chapter 3, we transform those CLDs in Stock Flow Diagrams along with all the assumptions and the results that we got from our analysis. Finally we conclude in Chapter 4 along with the challenges faced and possible future works.

Chapter 2

Analzing the different aspects of EV using CLD

In this chapter, we discuss the different areas/domains that are impacted by Electric vehicles either directly or indirectly and vice versa. We have considered three major domains:

- **Environmental Domain:** In this we study the various factors that affect the production of Evs like mining of raw materials, carbon emission, load on power plants, burning of non-renewable resources etc.
- **Financial Domain:** In this area, we study about the financial factors like fuel prices, EV price, CV price etc. that are going to affect the demand of EVs which will eventually affect their production.
- **Individual Domain:** In this domain, we study about how the EVs affect the lives of a common person and how their interests affect the demand of EVs which affects their production.

2.1 Environmental Impact of Electric Vehicles

The Environmental effect of electric vehicles is studied in this section. Here we will see how the growth of EVs' affects our environment and whether will there be any change in pollution rate if the use of EVs increases or if that is not the case. Here we looked into the following main aspects of EVs and pollution: Carbon Emission of EVs, the Power supply needed for EVs and the electricity production and how it affects the environment, the effect on tires as using EVs rather than fuel-powered vehicles, how the manufacturing of EVs batteries affect the environment, and more such factors. The CLD is shown in figure 2.1

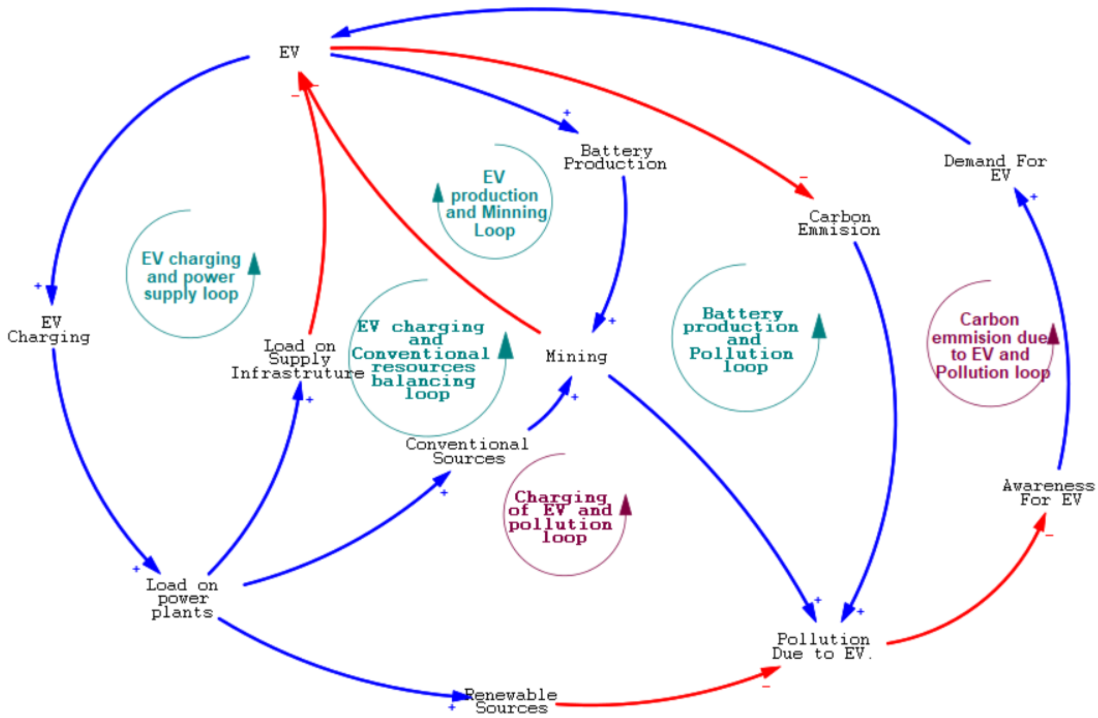

Figure 2.1: CLD representing the interdependence of environmental factors in EV dynamics

2.1.1 Loops in CLD

Loop B1 (Effect of EV charging and power supply infrastructure):

(EV—EV charging —Load on power plants—load on supply infrastructure—EV)

The loop shows how the increase in electric power demand will affect the EV market. As the number of EVs increase in the market, we will require more power to charge those vehicles. Assuming the same power supply infrastructure, it will increase the load on power plants and supply infrastructure. But as the demand increases beyond a threshold, current infrastructure will not be able to cope up with this demand and we will see a decrease in supply which will force the population to avoid the EVs due to short supply. But again as the number of EVs decreases, supply becomes more than demand and again the number of EVs on the road should increase, and so on.(Nature : Balancing Loop)

Loop B2 (Effect of EV charging and conventional resources) :

(EV—EV charging —Load on power plants—Conventional sources—Mining- EV)

As the Evs charging require more electricity the load on power plants will increase, and as the conventional power planet results in more pollution and requires more mining(mainly coal), as the availability of Coal decreases the power supply will not meet the demand. And hence EV users have to avoid the Evs due to less power supply.

Loop B3 (Effect of battery production on pollution) :
(EV—Battery Production—Mining — Pollution due to EV—Awareness of EV—Demand of EV—EV)

As the mining of resources required to manufacture batteries for Ev result in environmental pollution, implying that manufacturing Ev increases the pollution, resulting in negative awareness for Ev. So the mining and manufacturing will go down, hence the pollution. Now as with time these negative effects are not seen for a while, the negative awareness will go down and hence the usage of EV will start to increase again.(Nature : Balancing Loop)

textbfLoop B4 (Effect of EV charging on power supply) :
(EV— EV charging-Load on power plants-load on supply infrastructure—EV)
As the EV's increases the power required to run those vehicle is also increased, hence we require more power, which adds load on power plants and power supply infrastructure. Which results in less power supply then demand, hence less power for EV charging. As a result number of EV will reduce and load on power plants and supply infrastructure decreases which gives enough power as requirement .(Nature : Balancing Loop)

Loop R1 (Effect of EV) :
(EV—EV charging —Load on power plants—Renewable Sources—Pollution due to EV—Awareness of EV—Demand of EV—EV)

As the renewable power rescues results in very very low or zero pollution while producing the electric power, if we use these sources to generate power that is used in EVs, the overall pollution will decrease, as a result of low pollution from EV and renewable resources power production. Hence it will increase the awareness for EV resulting in more demand of Ev. Again the increase in Ev result in more power generation from these sources, and the system will fall in a reinforcing loop. (Nature: Reinforcing Loop)

Loop R2 (Effect of EV's carbon emission) :
(EV— Carbon Emission—Pollution due to EV—Awareness of EV—Demand of EV—EV)

It is well known that the Evs have zero cannon emission while running , resulting in very very low or can say zero pollution. So as the use of Ev increases the pollution will go down due to low carbon emission, resulting in increase in awareness of Ev for the general public, and demand of Ev. And as Ev increases the fuel engines go down, resulting in fall in pollution due to transport vehicles Hence more and more people will be attracted to use Ev and save their environment. (Nature: Reinforcing Loop)

2.2 Impact of EV on the financial aspect of a nation

The different elements that can influence the economic impact of electric vehicles are depicted in the causal loop diagram (CLD) (EVs). Reduced fuel prices, increased EV adoption, government incentives, consumer preferences, grid capacity, the supply chain for electric vehicles, secondary markets for used EVs, energy storage and global supply and demand are among the factors represented in the diagram. Because of their interdependence and potential for complex interactions, these factors emphasize the necessity for a thorough and systems-based approach to comprehending the economic impact of EVs. The CLD in figure 2.2 can assist in strategic planning for the adoption and expansion of EVs by helping to visualize these relationships.

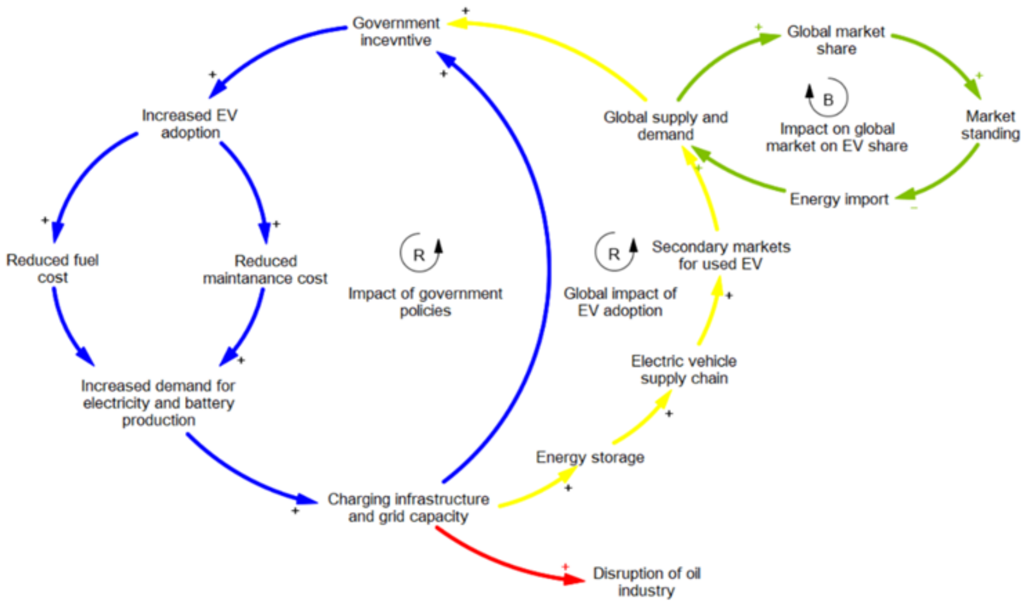

Figure 2.2: CLD representing the interdependence of environmental factors in EV dynamics

2.2.1 Loops in the CLD:

Loop 1 (Impact of government policies): Government incentives for popularising EVs will result in increased EV adoption and reduction in fuel and maintenance costs increasing the demand for electricity and battery production which will create a better charging infrastructure and grid capacity and will require more changes to meet the growing needs hence will pave the path for further government incentives. (Nature: Reinforcing loop).

Loop 2 (Global Impact of EV adoption): This loop inculcates the previous loop and shows how a change in infrastructure will result in the adoption of techniques for better energy storage and an efficient supply chain for electric vehicles opening grounds for a secondary market for used EVs (for instance in goods transportation). This will impact the global supply chain (abstract quantity) and will require the government to take measures to counter or regulate the arising changes. (Nature: Reinforcing loop).

Loop 3 (Impact on Global Market share of EV): This loop depicts how global supply and demand will increase the global market share of a nation and will increase its standings in the global market. This will reduce the global imports into the nation. (Nature: Balancing loop)

2.3 Impact of EVs on the lives of individuals

The introduction of Electric Vehicles in the market has had a profound impact not only on the environmental aspects but also on the lives of the people as well. Aspects like the livelihood of an individual, operation cost of vehicles, decentralization of power consumption, etc., for whom it looks like they don't affect each other but they do indirectly. A systematic study is required to observe the interaction among these aspects. Figure 2.3 is a CLD to represent the interactions.

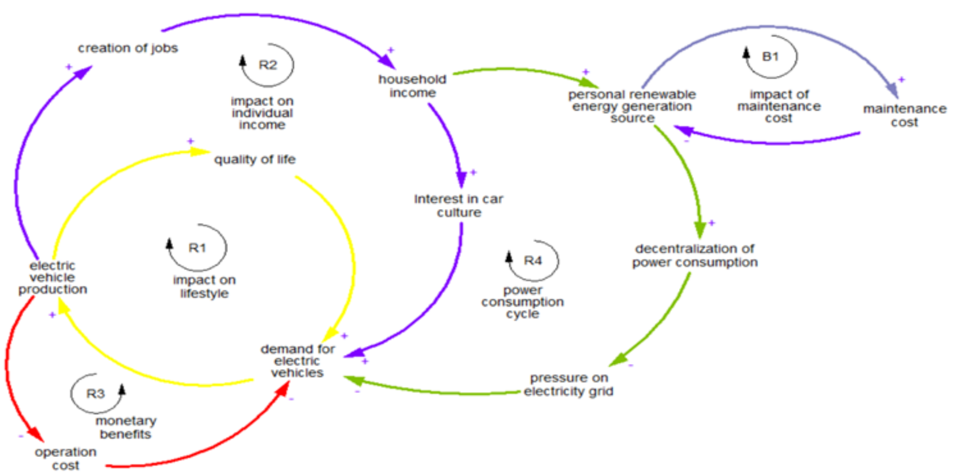

Figure 2.3: Impact of EVs on the lives of individuals

2.3.1 Loops in CLD

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Loop R1 (Impact on lifestyle): Since EVs not only reduce air pollution but also produce far less noise than traditional vehicles, the increased production of EVs will help improve the quality of life available for individuals which will in turn increase the demand for EVs and thus, their production. (Nature: Reinforcing loop)

Loop R2 (Impact on individual income): With the increased production of EVs, there will be a creation of a lot of job opportunities, especially in the area of research for making EVs more efficient and cheaper which will in turn help the people with increased income and thus, help in the creation of a car culture among the car enthusiasts. This will in turn increase the demand for EVs and thus, in EV production. (Nature: Reinforcing loop)

Loop R3 (Monetary benefits): EVs have far less operation cost than traditional vehicles. Thus, decreased operation cost is a contributing factor to increase in EV demand. (Nature: Reinforcing loop)

Loop R4 (Power consumption cycle): With the increased income, people can invest in personal energy generation sources like solar panels which will help in the decentralization of power consumption and thus put less pressure on the central electricity grid. This increases the EV demand and thus EV production. (Nature: Reinforcing loop)

Loop B1 (Impact of maintenance cost): With the increase in investment in personal energy generation, the cost of maintenance will also increase which can negatively impact the demand of EVs. (Nature: Balancing loop)

Chapter 3

Conversion of CLDs to Stock Flow Diagrams

In this chapter, we have converted the initial CLDs into Stock Flow Diagrams and have used various submodels to model EV dynamics more vividly. The various dynamics of EV modeled using the SFDs are as follows :

3.1 Initial SFD

In this section, we describe the stocks, flows, and auxiliary variables that have been used in the SFD along with the assumptions that we have made with respect to them. We made this model without doing much literature survey and considered a very simple one that is described below.

3.1.1 Assumptions made

The following assumptions have been made while modeling the initial SFD of EV:

- The manufacturing of EVs only depends upon the number of families in India and the demand for EVs.
- Demand variable takes fractional values which are calculated from the previous 8 years of sales data of EVs[aut,].
- the number of years over the years remains constant.

3.1.2 Model explanation

This is a simple model that was made from the basic knowledge of SFDs construction that was taught in class. The Stock that we have considered for this SFD is *Electric*

Vehicle stock and the flow variables associated with them are *manufacturing* as in-flow and *degradation* as outflow. Figure 3.1 represents the initial SFD.

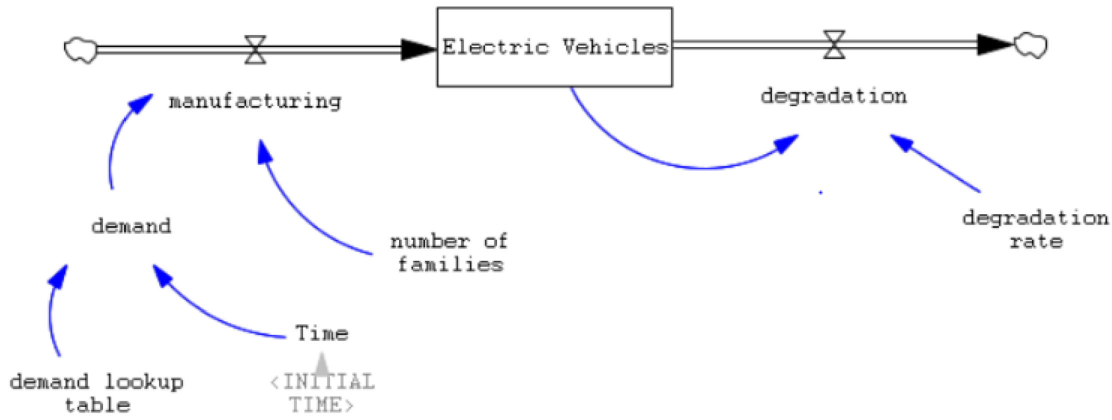

Figure 3.1: SFD representing EV dynamics

3.1.3 Graphs

Figure 3.2 represents the variation of EV stock with respect to time.

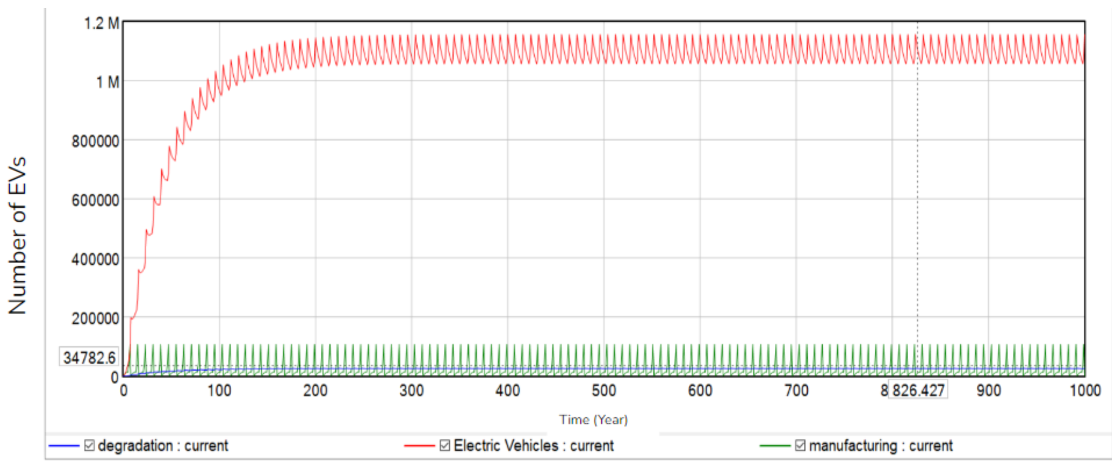

Figure 3.2: Graph of EV stock w.r.t time from our initial SFD

3.1.4 Results

From the graph in figure 3.2, we can infer the stock will initially rise but eventually saturate after some point in time. Specifically talking with respect to this graph, this kind of result can be attributed to the fact that after a certain point in time, the number of EVs degraded every year matches the number of EVs manufactured every year, and thus, the saturation in stock value comes. The cyclic fluctuations that we see in the graph are because of the introduction of periodicity for the values in the *demand lookup table*.

3.2 Price Dynamics

This section describes the price dynamics of our model along with the assumptions that we made for it and the results that we got from our analysis.

3.2.1 Assumptions made

The following assumptions have been made while modeling the price dynamics of EV :

- The price of EV and CV can increase by at most 10 percent of the price of an EV last year.
- The price of EV and CV are affected by lot of factors but considering only these two we introduce a repelling nature between the stock of EV and AV.

3.2.2 Model explanation

The SFD in figure 3.3 models the price dynamics of electric vehicles and conventional vehicles. The motivation to model the Price dynamics has been taken from the *Romeo - Juliet model* taught in class. The model showcases a reverse nature relationship between the price of an EV and the price of a CV thus when one of the vehicle's price grows the other one decreases and vice versa. The stock *EV Price Fluctuation* is used to represent the fluctuation in the price of EV and another stock *EV price* is used to actually represent the price of EV. The initial price of EV is taken as 5 million rupees and that of CV is taken as 2 Million rupees.

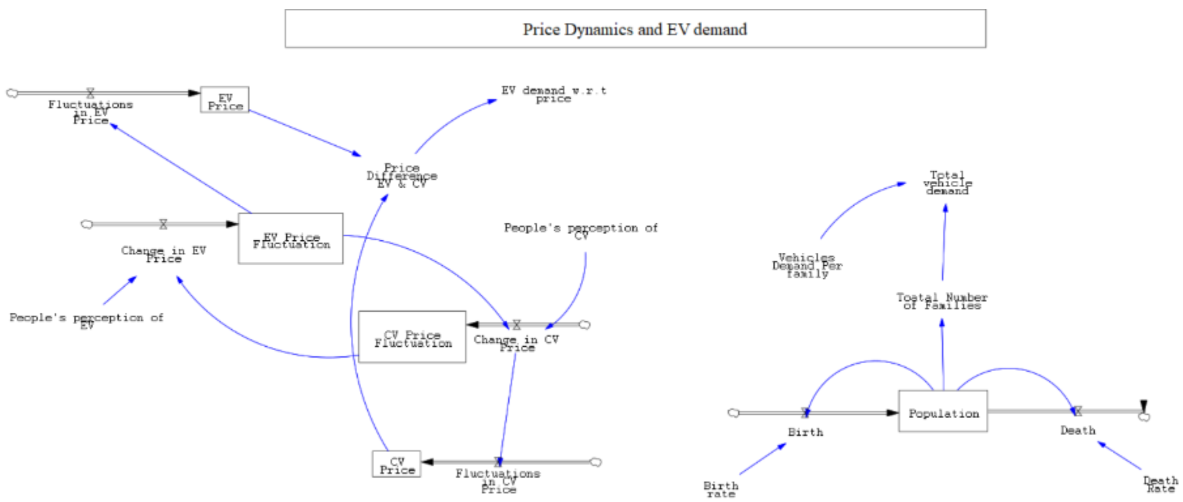

Figure 3.3: SFD for Price dynamics and EV demand

3.2.3 Graphs

In this section, we present the graph of *EV demand*, *EV price*, and *CV price* with respect to time which is shown in figure 3.4.

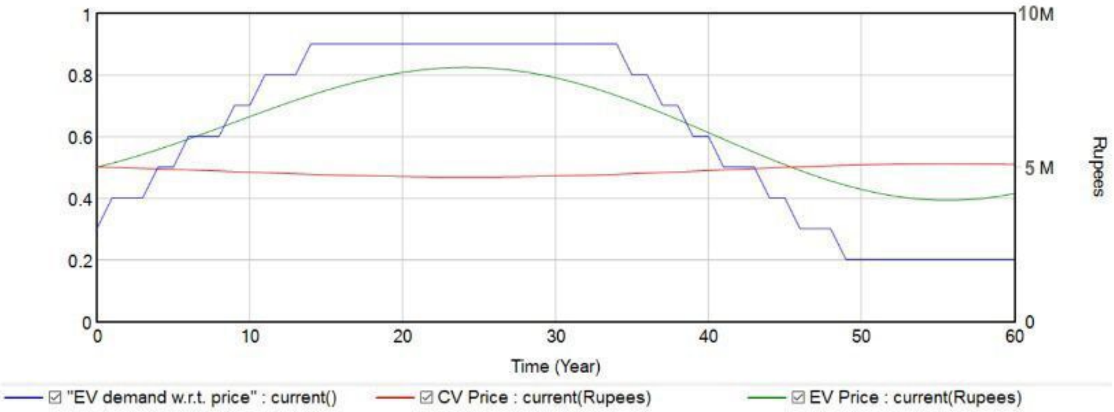

Figure 3.4: Graph of EV demand, EV price, and CV price w.r.t time

3.2.4 Results

From the graph in the figure 3.4, we can see that as the demand for EVs increases the price of EVs also increases but later starts dropping as the demand for EVs decreases. This dynamics can be attributed to the attempt of manufacturing companies for retaining their customers. The price of CV also keeps fluctuating (impacted by the price of EV) which is in accordance with the dynamics that we studied in the *Romeo - Juliet model* that we were taught in class.

3.3 Energy Dynamics

This section describes the SFD of the Energy dynamics that we have described before.

3.3.1 Assumptions made

The following assumptions have been made while modeling the Energy Dynamics of EVs:

- Electricity consumption of other sources remains constant, w.r.t production i.e. 80% of total production.
- The number of charging stations built is w.r.t. total EVs, and we build one charging station per 100 vehicles.

- Both the degradation rate and repair rate of charging stations are constant at 10% and 70% respectively.

3.3.2 Model explanation

The SFD in figure 3.5 shows how the power supply will be affected by EVs. And what can be the architecture of charging stations over time. The *electricity* stock shows the total electricity production, *charging stations* shows the number of charging stations build over time and are currently working, similarly *degraded stations* shows the number of charging stations that are not working .The model shows that the number of EVs will directly affect the consumption of electricity, which alters the production, and as production increases the consumption due to other sources also increases as they see an increase in supply. Also, the number of EVs affects charging stations built over time, that's simple relation that EVs directly affect the number of charging stations.

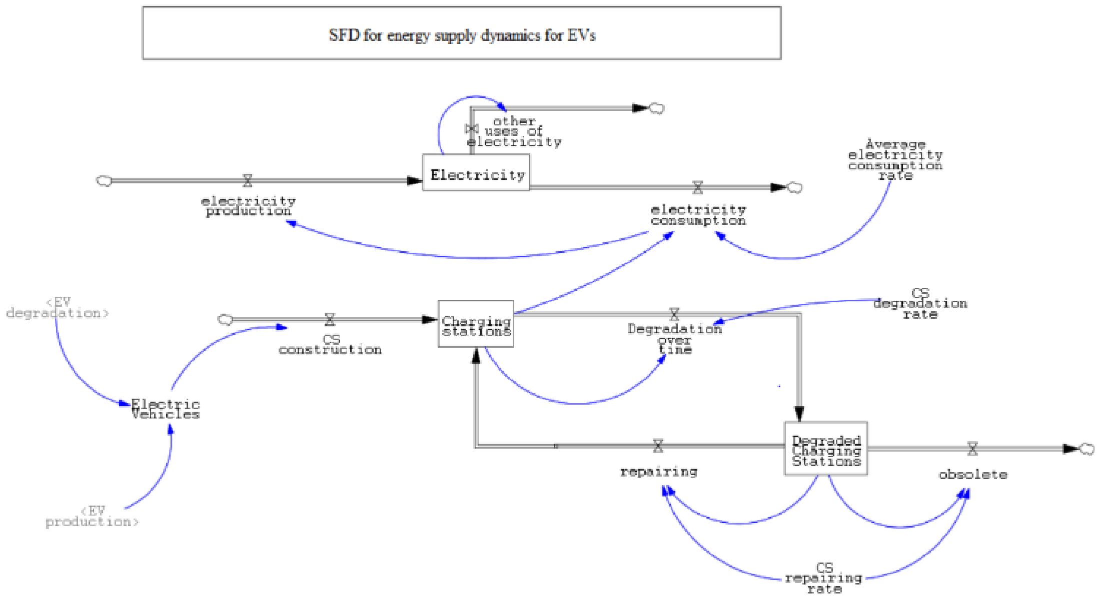

Figure 3.5: Energy Supply Dynamics

3.3.3 Graphs

This section presents the graphs obtained from the study of the energy dynamics of the model. The graph is shown in figure 3.6

3.3.4 Results

From the graphs in figure 3.6 we can see that the increase in the number of EVs increases the consumption of power, which results in increased production. As production increases

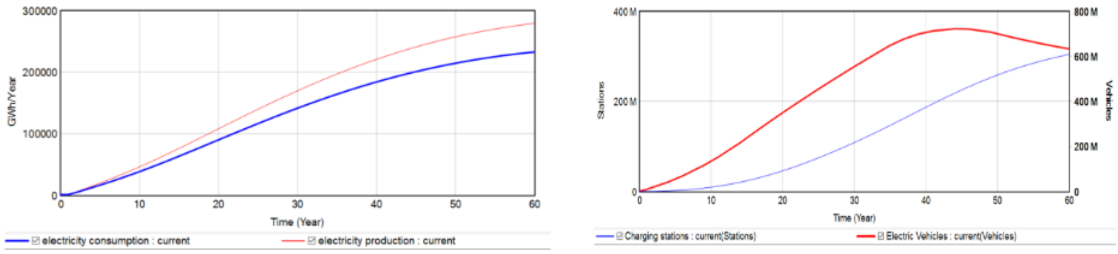

Figure 3.6: Graph for Energy dynamics: (a) represents the Electricity production and consumption graph w.r.t time; (b) represents Graph of the number of charging stations and EVs w.r.t time

the consumption due to other sources also increases resulting in more demand.
Also the number of EVs affects the number of charging stations, and as the number of Ev grows the number of stations grows, and if the number of Ev goes down, the number of stations also goes down.

3.4 Production Dynamics

This section describes the Price Dynamics of the system that we have made the CLD for in the previous chapter. We describe the assumption made, the model and explain the results that we got from our analysis.

3.4.1 Assumptions made

The following assumptions have been made while modeling the Energy Dynamics of EVs:

- Raw materials are supplied at a constant rate, and production does not increase over time.
- Raw materials used for both EV and CV are the same.
- Degradation rates, recycling rate, and weights of EV and CV remain the same, and are assumed to be constant.
- EV and CV define the number of vehicles of that class, on the road.

3.4.2 Model explanation

The SFD given in figure 3.7 shows how the production of EVs will be affected by demand and how the number of CVs will affect EVs. We define recycling and scraping as means of reusing the material used for building an EV and CV.

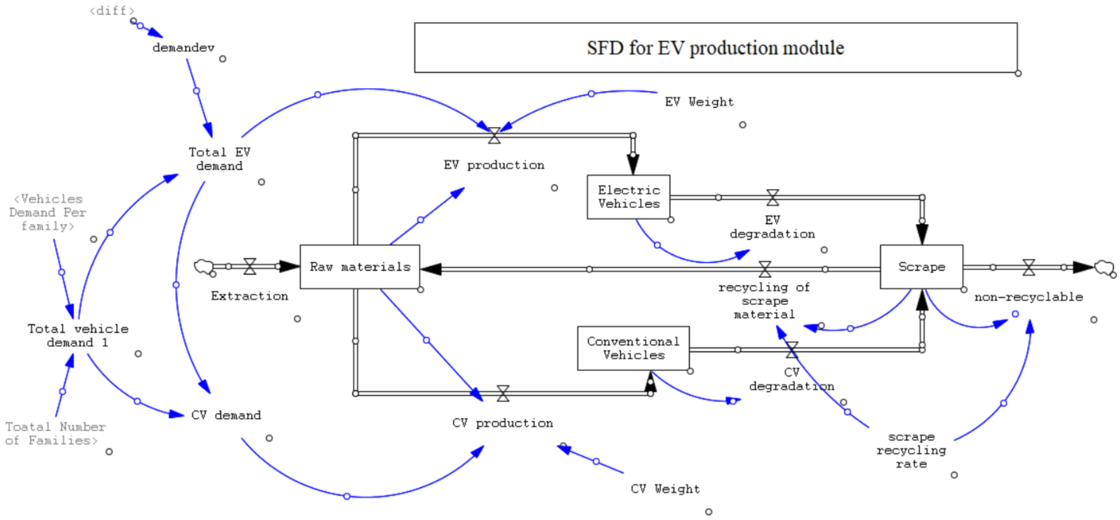

Figure 3.7: SFD for the Production module

3.4.3 Graphs

This section gives the graph of the results obtained from analyzing the production dynamics of EVs. It is given in the figure 3.8.

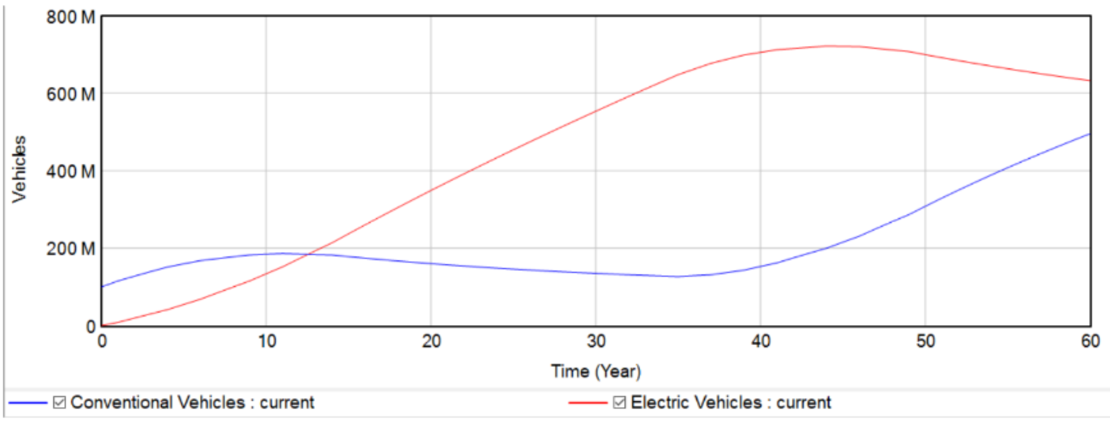

Figure 3.8: Graph of EV and CV production w.r.t time

3.4.4 Results

Here we see that initially, the number of EVs increases which results in decreased number of CVs. But as the price of EVs increases due to high demand the customer base shifts towards the CV, and results in an increased number of CVs. This demand price loop changes the number of vehicles of both classes, as one class's demand increases its price increases which increases the demand in other classes, resulting in lowered prices, and again high demand, and so on. As recycling rate and scrapping rates are constant, they do not play a much role, but as production is limited by the material available, recycling helps in increased production.

Chapter 4

Challenges faced and Conclusions

In this chapter we look at the challenges faced while making the SFDs/CLDs and we give the conclusions that we made in this analysis of EVs.

4.1 Challenges faced

Some of the major challenges that we faced while making the CLDs and SFDs during our analysis are as follows:

- Selection of the important variables which have a major impact on the future of EVs.
- Quantification of various soft variables involved in the model.
- Gathering necessary and sufficient data is always a difficult task. It was especially difficult in this case as data on EVs in India is not readily available.
- Building a comprehensive model that captures most of the dynamics involved with EVs was difficult.

4.2 Conclusion & Future Work

Here we present the overall conclusion that we have derived from our analysis of the dynamics involved with EVs.

- The number of EVs will surpass the number of CVs after a few decades.
- The number of charging stations increases as the number of EVs increases and starts saturating after a steep drop in the demand for EVs.

- As the demand for EV increases the price of EVs also increases which starts dropping as the demand for EV decreases to retain customers. The price of CV also keeps fluctuating(impacted by the price of EV)

Some of the possible areas where we can work to improve our model is as follows:

- Incorporation of Lithium dynamics in our system as the amount of lithium available for making the batteries of the EVs will impact the number of useful EVs available.
- Increasing the granularity level for the electricity demand generated by the increasing number of EVs as not every person can afford private energy sources for charging the EVs.
- Incorporation of a pollution module that will depict the impact of EVs on the environment as that will help shape the mass psychology towards its acceptance by the mass.

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