Global temperatures are increasing due to global warming that is caused by CO_2 emissions [1]. It is predicted that global temperatures will increase between 1.1° Celsius to 5.4° Celsius by the year 2100. Hence to combat rising global temperatures it is necessary to reduce CO_2 emissions. Vehicular transportation is the largest contributor to CO_2 emissions in India. Traditional cars use fuels like petrol and diesel while emitting CO_2 emissions. Electric vehicles don't emit any substances [2]. They run on electric power and not directly on fossil fuels. However, the mileage offered by electric vehicles is not comparable to that of traditional vehicles [3].

Three-wheeled vehicles provide more mileage as compared to their four-wheel counterparts, as they are lighter and more aerodynamic [4]. Designing an energy-efficient and stable structure for three-wheeled electric vehicles would ensure considerable mileage along with long battery life. Additionally, three-wheeled vehicles allow the use of innovative structures such as Tadpole and Delta that maximize the speed and stability of such vehicles. By using such electric vehicles, global warming can be slowed down by reducing CO_2 emissions.[5]

Electric vehicles may be traced back to the early 19th century when inventors such as Robert Anderson and Thomas Davenport created rudimentary electric vehicles driven by batteries. These vehicles were the first step in the development of electric vehicles. However, in 1884, a British inventor named Thomas Parker produced the first functional electric vehicle. He designed an electric automobile that could run up to 100 miles on a single charge and built an electric car that he built in 1884.[6]

1.1 Historical Development of Electrical Vehicle

In the early part of the 20th century, electric vehicles began to gain favor as a mode of urban transportation, particularly for use as taxis and delivery trucks. On the other hand, electric vehicles fell out of favor and were mostly abandoned after the invention of the internal combustion engine and the widespread availability of inexpensive petrol.[7]

Concerns over air pollution and reliance on foreign oil led to a resurgence of interest in electric vehicles towards the end of the 20th century. The first electric vehicle to be manufactured on a large scale in the modern period was the General Motors EV1, which was introduced in 1996. Other car manufacturers quickly followed suit, beginning production of electric and hybrid vehicles similar to the Toyota Prius and the Honda Insight, amongst others.[8]

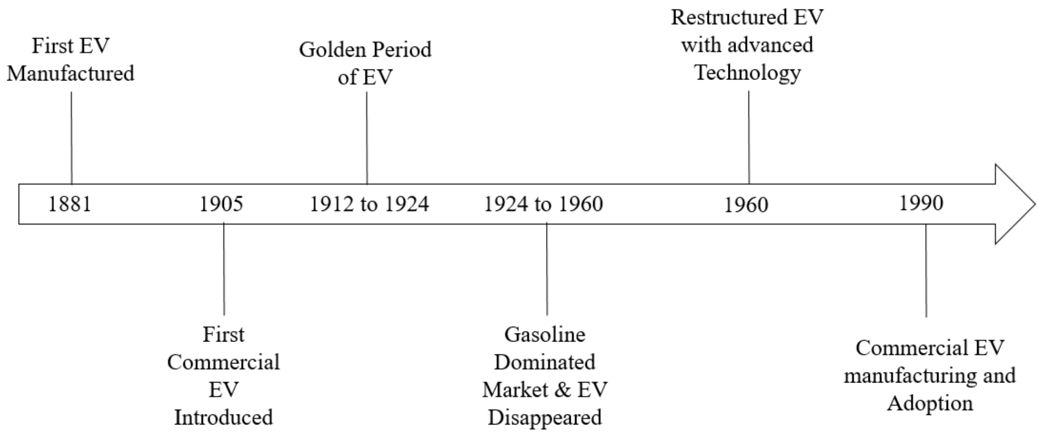

Fig. 1 : Historical Development of EV

Early on in the 21st century, improvements in battery technology and financial incentives offered by the government contributed to a rise in the demand for electric vehicles. Roadster, Model S, and Model X helped propel Tesla Motors to the forefront of the electric vehicle industry soon after the company's founding in 2003. Other major automakers, like as Nissan, BMW, and Chevrolet, have also started developing electric vehicles, and many nations have established policies, such as tax incentives and subsidies, to inspire the implementation of electric vehicles.[9]

To this day, electric vehicles continue to advance thanks to developments in battery technology, charging infrastructure, and technology that allows them to operate without human intervention. Electric vehicles are being increasingly recognized as a critical component of the evolution towards a transportation system that is both more sustainable and less harmful to the environment as people become increasingly concerned about issues such as climate change and air pollution.[10]

Three-wheeled automobiles have existed for an extended time, even predating the Patent Motor Wagen design. For example, in the 15th century, Leonardo da Vinci sketched a simple three-wheeled car driven by a spring-operated mechanism similar to a clock. In 1769, French engineer Nicolas Cugnot developed a sizable, tricycle-like automobile equipped with a steam-powered motor. As the twentieth century progressed Three-wheelers became popular as affordable and lightweight vehicles, but their popularity declined in the late 1920s with the increasing dominance of four-wheeled cars. However, things changed once more after WW II.[11]

In war-torn countries like England, France, Germany, and Japan, gasoline and other auto parts were hard to come by, but people still needed a way to get around. Most of the time, they couldn't afford or couldn't get full-sized four-wheel cars, and a motorbike was too small for their needs. Bond Cars Ltd. did well in England after the war by making small three-wheeled cars with motorbike engines that only had one cylinder. People on motorcycles who wanted to be protected from the weather liked these small cars. As an added plus, you didn't need an auto driver's license to drive one. In addition, they were very helpful because they could get more than 100 miles per gallon (42.5 km per liter) when fuel was expensive and sources were limited.[12]

There were three-wheelers made by Bond Cars until the 1970s. In the 1950s, BMW started selling a funky, egg-shaped microcar called the Isetta with three wheels. And once more, the three-wheeled form of this car was very popular in the UK, where you could drive one with a motorbike license. Japan's car companies, like Daihatsu, made three-wheelers that were often used as cabs, light trucks, and other service vehicles. For the second time, a lot of them were small and driven by cheap motorbike engines. The English have made the fiberglass microcar Reliant Robin on and off for more than 30 years. It is thought to be one of the most famous three-wheelers of all time.[13]

1.2 Definition of an Electrical Vehicles

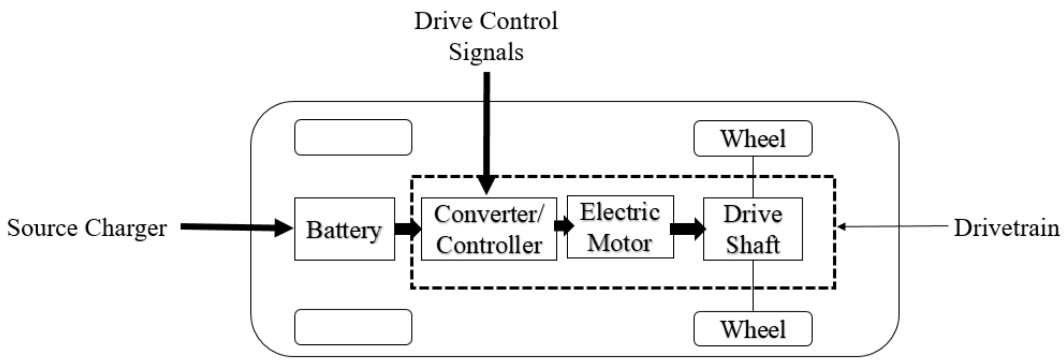

Fig. 2 : General Configuration of EV

An electric vehicle (EV) is a car that uses electricity as its primary source of propulsion, as opposed to a fossil fuel like petrol or diesel. Electric vehicles (EVs) run on either hydrogen fuel cells or rechargeable batteries, and they don't release any pollutants from their exhaust pipes. [14] These three categories best describe EVs:

1.2.1 Battery Electric Vehicles (BEVs)

The batteries in these automobiles may be recharged by connecting them to a standard wall socket or charging station.

1.2.2 Hybrid Electric Vehicles (HEVs)

These automobiles are powered by both electricity and conventional fuels like petrol or diesel. The electric motor helps the petrol or diesel engine out and charges the batteries, but the petrol or diesel engine takes over when going faster or when the batteries are low.

1.2.3 Plug-In Hybrid Electric Vehicles (PHEVs)

Like HEVs, these automobiles are equipped with both an electric motor and a petrol or diesel engine. However, plug-in hybrid electric vehicles (PHEVs) have larger battery packs that may be recharged by connecting the car to a standard electrical outlet or charging station. PHEVs may travel short distances solely on electric power before switching to the petrol or diesel engine.[15] on electric power before switching to the petrol or diesel engine.[15]

1.3 Configurations of Electric Vehicles

In the past, most electric vehicles were based on existing ICEVs; the main difference was that ICEVs had internal combustion engines and fuel tanks that were replaced with electric motor drives and battery packs. This kind of electric vehicle's popularity has waned because of its cumbersome design, lack of maneuverability, and diminished performance. [16]

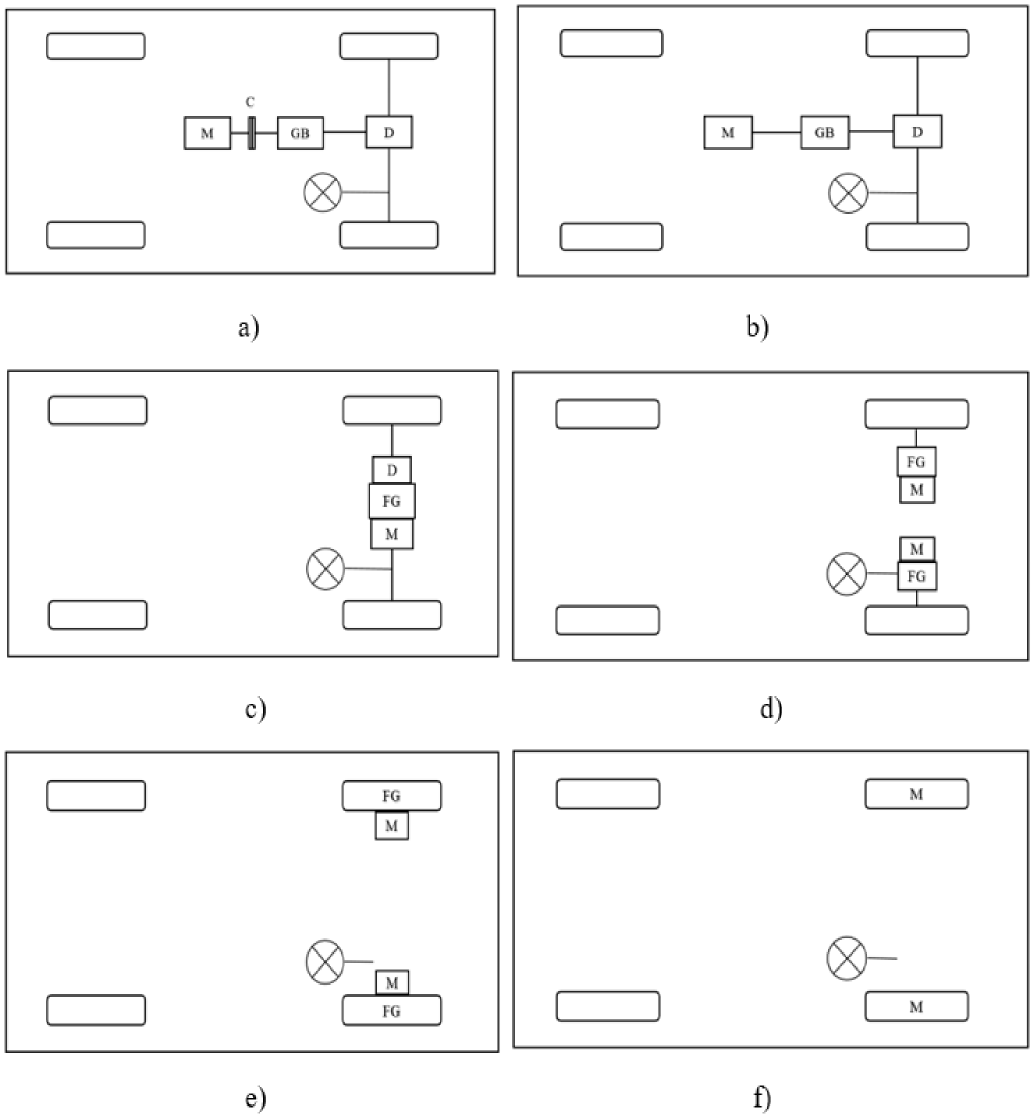

Figure 3 : EV Configurations

Modern EVs use original body and frame designs. This meets EV structural standards and makes electric propulsion versatile. Due to features of electric propulsion and sources of energy, Figure 3 shows many EV setups.

Figure 3 (a) shows the first option, which doesn't use an IC engine but instead makes use of electric power. A clutch, an electric motor, a gearbox, and a differential. Clutches can be swapped out for automatic gears. The clutch lets you connect or disconnect the electric motor from the wheels. The gearbox has the right gear ratios for the load's speed-power (torque) formula. When the car turns, the differential (usually planetary gears) sends different speeds to the wheels on each side.

An electric motor that has steady power over a wide speed range can be used instead of the multispeed gearbox and the clutch. This set-up, shown in Figure 3(b), makes the mechanical transmission smaller and lighter, and it makes controlling the drive train easier by getting rid of the need to change gears.[17] With both hubs directed at both moving wheels, the electric motor, set gears, and differential can all be built into a single unit. Making the engine shown in Figure 3 (c) simpler and smaller. In Figure 3 (d), the mechanical differential has been replaced by two drive motors. Each person drives one side wheel at a different speed when the car turns.

A traction motor inside a wheel simplifies the drive train indicated in Figure 3 (e). Thin planetary gear sets can lower motor speed and increase torque. The thin planetary gear set has a high-speed reduction ratio and an integrated input/output shaft.[18] In-wheel (Hub Motor) drives can directly connect the out-rotor of a low-speed electric motor to the driving wheel by eliminating mechanical gearing shoed in Figure 3 (f). The electric motor controls wheel speed and vehicle speed. To start and accelerate the car, the electric motor needs more torque.

1.4 3-Wheeled & 4-Wheeled Vehicles

Table 1.1 : Comparison of Three-wheel and Four-wheel Vehicles

Three-wheeled	Four-wheeled
Less number of friction points	More number of friction points
More aerodynamic	Less aerodynamic
Can tip over at high cornering speeds	Can’t tip over at higher cornering speeds
Supports less number of passengers	Supports more number of passengers

1.4.1 3-Wheeled Vehicles

A three-wheeled car also called a tri-car, has either one front wheel for steering and two back wheels for power, two front wheels for steering and one rear wheel for power, or any other combination. The front-steering "tadpole" or "reverse trike" is becoming popular due to its handling.[19]

Three-wheeled cars are triangular. This implies the car either has two front wheels or two rear wheels, depending on where the travelers sit, the engine's location, and other key mechanical components. Steering and engine drive can be done anyway.

1. **Delta Structure:** Delta layout has one front wheel and two back wheels. Reliant Robin and Karl Benz followed this setup. The Mazda-Go, the first three-wheeled Mazda, had a pickup truck bed in the back. Delta is cost-effective. The engine drives the back wheels and steers the front in most cars. One-wheel steering is cheap and straightforward to build.[5]

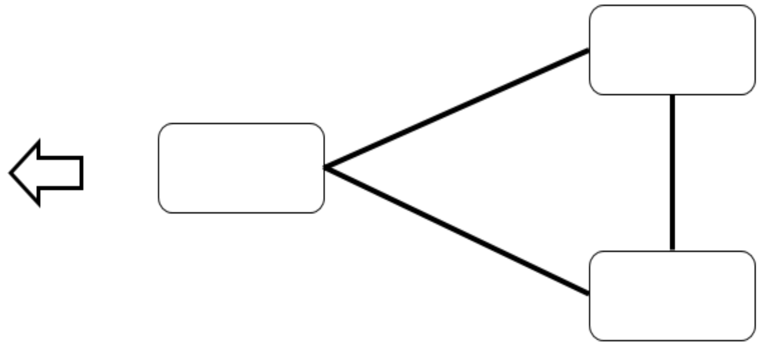

Fig. 4 : Delta Structure

2. **Tadpole Structure:** Tadpole trikes are backward trikes. This arrangement has two front wheels and one back, unlike the delta. Tadpole designs exhibit greater stability compared to delta designs due to the presence of a back-wheel drive and two front wheels for steering. The vehicle's teardrop form makes it aerodynamic. Air flows readily over the vehicle's bodywork. For its stability, aerodynamics, and fuel efficiency, auto designers are favoring tadpole design. Many hybrid and electric concept cars feature a three-wheel configuration. Three-wheelers may become increasingly common as cars become eco-friendlier.[20]

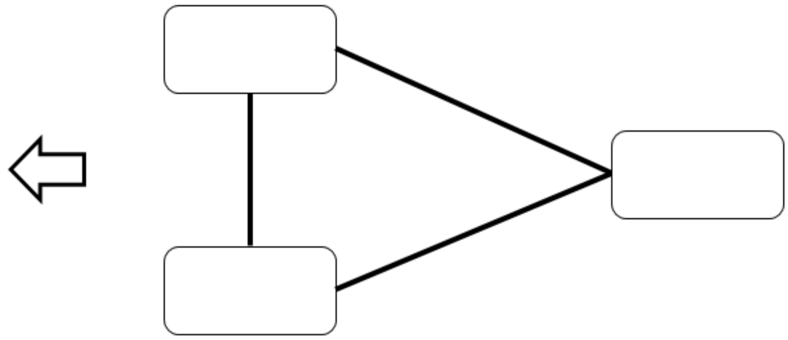

Fig. 5 : Tadpole Structure

1.4.2 Advantages of Tadpole over Delta structure

- **Turning:** two front wheels offer better stability and higher turning speeds.
- **Weight distribution:** Higher in the front providing improved steering and braking.
- **Center of gravity:** Lower and near the steering axis providing higher speeds.
- Simpler drive mechanism.
- Lighter in weight.
- Not prone to tip over while turning on high speeds.

1.5 Types of Tadpole structure Vehicle

1.5.1 Solar-Powered Tadpole

The tadpole-based three-wheeled electric vehicles offer better aerodynamics which reduces air drag and provides better mileage as compared to their four-wheeled counterparts. However, the tadpole design limits the size of the batteries that can be used to power the vehicle. Hence, Tahjib et al. [7] have proposed a tadpole-based electric vehicle that is powered via solar panels. Their design specifically focuses on battery charging circuits, suspension systems, and motor control circuits. They have also designed a data logging system to evaluate the performance of the proposed design. The designed vehicle is of type rear-wheel drive and uses a Brushless Direct Current (BLDC motor). The data logger is attached to the rear wheel to read the speed of the vehicle, current, voltage, and power received by the motor. The solar panel array was connected to a solar charge controller, which is in turn connected to a motor controller. The accelerator and the BLDC motor were connected to the motor controller. The suspension system is situated on the two front wheels, with the free length of the springs being 250 mm and the compressed length being 180 mm. The data coming in from the voltage and current sensors are passed through a signal conditioning process to remove noise. The filtered signal was then passed through an Analog-to-Digital (ADC) converter to produce digital signals. [21]

1.5.2 Hybrid Tadpole

Auto rickshaws are Delta-based three-wheeled vehicles which are commonly used in Asian countries like India and Pakistan to ferry passengers over short to medium distances. In contrast, Tadpole-based three-wheelers generally seat only one passenger. As they are designed to carry a single person they have better aerodynamics. At the cost of being lesser aerodynamic, more passengers can be added. However, designing a single-seater vehicle affects its large-scale adoption as people would rather have multi-passenger vehicles. Hence, to address this issue Reddy et al. [5] have proposed a hybrid two-seater Tadpole-based vehicle. The proposed design has a low center of gravity situated near the rear wheel and high ground clearance. They have also designed a unique powertrain for the proposed design. The vehicle consists of a mechanical drive design that requires the users to pedal to drive the vehicle. Additionally, an electric drive mechanism can also be attached to the rear wheel. Hence the proposed vehicle is a hybrid electric vehicle. They have designed a transmission system that is easy to manufacture and utilizes a single motor to drive the vehicle as well as charge the battery through regenerative braking. Considering only the roll cage, the weight of the vehicle is 16 Kg. Its simple design allows for quick and straightforward manufacturing.[22]

1.6 Current State of Electrical Vehicle Technology

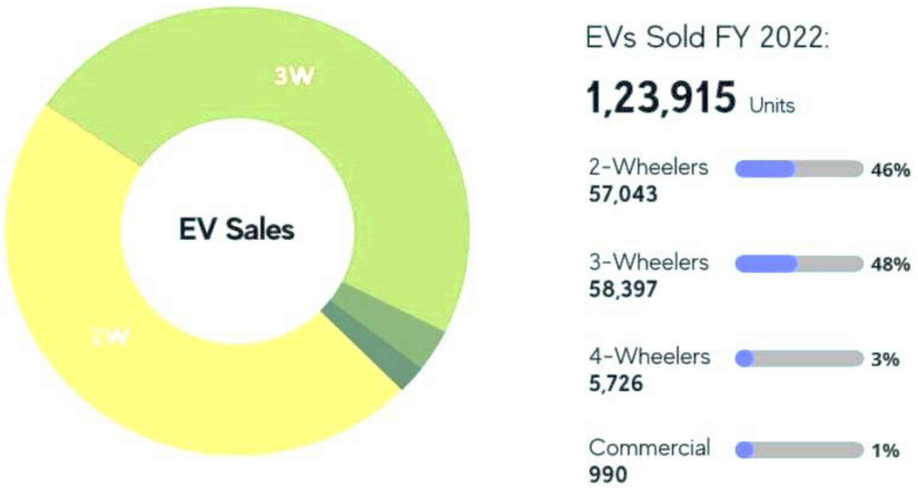

Fig. 6 : Current Electric Vehicle Scenario in India (ecogears.in)

Battery technology, power electronics, and electric motor design are all seeing tremendous advancements, which is driving the quick evolution and improvement of the current level of electric vehicle (EV) technology. Electric vehicles are gaining popularity because they have cheaper running costs, have less impact on the environment, and are eligible for government incentives.[23] The following is a list of significant advances in EV technology:

At the moment, lithium-ion batteries are the most prevalent form of battery that is utilized in electric vehicles (EVs). Because of advancements in battery technology, batteries now offer a higher energy density, a greater range, and a shorter time to charge. There is ongoing research and development into other battery chemistries, such as lithium-sulfur and solid-state batteries, with the goals of further enhancing performance and lowering costs.[24]

The electric motors that are used in EVs are becoming more efficient and compact, which enables them to provide more power in a smaller size. EVs are expected to hit the market in the next few years. In addition, developments in the algorithmic control of motors have led to improvements in both performance and efficiency.

The availability of charging infrastructure is growing, as more public charging stations are being created and as prices for home charging systems continue to fall. The technology behind rapid charging is also advancing, which will cut the amount of time needed to charge an electric vehicle and make it more convenient to use.

Electric vehicles are currently undergoing the process of integrating with autonomous driving technology, which will allow for increased fuel efficiency and safety. Some manufacturers of electric vehicles (EVs) are already introducing features that allow for partially autonomous driving, such as adaptive cruise control and lane-keeping assistance.[25]

1.6.1 Lightweight Materials

In order to reduce the overall weight of electric vehicles (EVs) and boost their fuel efficiency, automobile manufacturers are turning to lightweight materials like carbon fiber and aluminium. This may result in an increase in performance and range, in addition to a reduction in the amount of energy required for operation.[26]

In general, the current level of electric vehicle technology is progressing at a quick pace, and there is a substantial amount of space for growth and improvement in the years to come.

1.7 Energy-Efficient Structures

The increased availability of charging infrastructure and the environmentally benign character of electric vehicles (EVs) are two factors that are contributing to the rise in the popularity of EVs. However, one of the most significant obstacles that stand in the way of the general adoption of electric vehicles is the restricted range of their batteries, which is partly controlled by how efficiently they use energy.[27]

In the context of electric vehicles (EVs), "energy-efficient structures" refers to designs and technical processes that cut down on the amount of energy needed to run the vehicle. This can be accomplished by reducing the overall weight of the vehicle, enhancing its aerodynamics, maximizing the performance of its powertrain, and minimizing the amount of energy that is lost as a result of friction and other reasons.

Creating structures for electric vehicles (EVs) that are both energy efficient and lightweight involves multidisciplinary knowledge in fields such as mechanical engineering, materials science, electrical engineering, and computer science. Research in this field focuses on discovering novel materials and manufacturing techniques, as well as improving the efficiency of already existing components like motors, batteries, and power electronics, in order to meet the growing demand for these technologies.[28]

Increasing the energy efficiency of electric cars (EVs) can assist to extend their driving range and lower their operating costs, which in turn makes EVs more competitive with conventional automobiles that use internal combustion engines. In addition, electric vehicles that are efficient in terms of energy use can contribute to the reduction of greenhouse gas emissions and the improvement of air quality, which makes them an important instrument for the mitigation of the effects of climate change.[29]

1.7.1 Parameters of Energy-Efficient Structure

- **Materials with a Low Specific Gravity:** Lightweight materials are one technique to increase the energy efficiency of an electric vehicle (EV). This is something that can be accomplished by the utilization of lightweight materials like carbon fiber, aluminium, or high-strength steel. These materials have the potential to help minimize the amount of energy necessary to accelerate, brake, and climb slopes.[30]
- **Aerodynamic Drag:** The reduction of aerodynamic drag is another method that may be used to increase energy efficiency through the use of aerodynamic design. This can be accomplished in a variety of ways, including streamlining

the design of the body, improving the underbody panels, and taking additional steps. If there is less drag, then there will be less need for energy to maintain a certain speed, which will result in an increase in the vehicle's range.[31]

- **Energy-efficient accessories:** Electric vehicle (EV) accessories such as air conditioning, heating, and lighting can use a large amount of energy. Energy-efficient accessories can help reduce this consumption. The utilization of designs that are more energy-efficient for these components can contribute to the total reduction of energy usage.

There are many alternative energy-efficient structures and technologies that may be utilised to improve the efficiency of electric vehicles, and manufacturers are always inventing new methods to increase the range of EVs while simultaneously reducing the amount of energy they require to operate.[32]

1.7.2 Benefits of Energy-Efficient Structures

In general, buildings that are efficient in their use of energy can confer a number of advantages on electric vehicles. These advantages might vary from enhanced range and performance to decreased running costs and less of an impact on the environment. As a consequence of this, manufacturers are consistently working on the development of innovative technologies and designs in order to enhance the effectiveness of EVs and make them more suitable for day-to-day use.[33], [34]

1.7.3 Challenges Involved in Designing an Energy-Efficient Structure

The task of developing a framework that is both energy-efficient and suitable for electric vehicles (EVs) can be difficult. The following are some of the most important problems that need to be solved:

Constructing that is both energy efficient and aesthetically pleasing frequently necessitates making compromises between various competing objectives. For instance, reducing weight can enhance energy efficiency, but this often comes at the expense of other considerations like as safety, durability, or cost.

The integration of several components is typically required for energy-efficient constructions. These components can include things like lightweight materials, aerodynamic designs, and efficient powertrains. To ensure that these parts can function efficiently together after they have been integrated, careful planning and engineering are required.

Due to the usage of specialized materials and manufacturing processes, energy-efficient structures sometimes have a higher production cost than conventional designs. This is because of the increased demand for these buildings. This may cause EVs to be more expensive for customers, which in turn may slow the adoption of EVs.Producing structures that are efficient with energy typically requires the use of specialized manufacturing methods and equipment. This can add complexity to the production process, which can in turn lead to a rise in prices.

Energy-efficient structures are held to the same stringent safety requirements as conventionally designed buildings. However, the vehicle's safety performance and crashworthiness can be negatively impacted by either reducing its weight or making changes to its aerodynamics.

In order to be considered energy efficient, a building must also have a long lifespan and be able to resist the rigors of regular use, such as vibration, impact, and being exposed to the elements. To ensure that anything will last for a long time, it is generally necessary to use specialized materials and production methods.[35]

1.8 Problem Statement

The Delta structure for three-wheeled vehicles could be replaced with more efficient structures like Tadpole. The tadpole structure is optimized to reduce weight and increase strength. Also, the crashworthiness of the vehicle will be optimized to increase driver safety. To reduce toppling, rollover, etc. the design of these vehicles can be optimized by varying parameters like wheel suspension and steering geometry. This tadpole vehicle is integrated with level-one autonomy for maximizing performance.

1.9 Aim

This project aims to design a tadpole structure for three-wheeled electric vehicles as an energy-efficient structure. The chassis of the vehicle is designed and optimized for parameters such as weight, strength, and crashworthiness. Also, parameters of suspension and steering geometries like wheel diameter, wheelbase, Track width, Camber, Caster, KPI, etc, would be optimized and tested to identify the most efficient combination. The best-performing structure and geometries will be chosen to manufacture a prototype. Pilot testing of the prototype will be performed to assess its performance.

1.10 Objectives of the Proposed Study

1. To design an electric vehicle with an innovative tadpole structure by considering parameters wheel diameter, wheelbase, track width, steering geometries, suspension geometries, weight, crashworthiness, etc.
2. To design a prototype of an electric vehicle and conduct pilot testing on city roads. Its characteristics such as air drag, cornering stability, energy efficiency, acceleration, braking performance, driver comfort, etc. will be evaluated.

1.11 Scope

The scope of this project is to design an electric vehicle with a Tadpole structure that can achieve maximum mileage and battery life while ensuring stability during cornering. The Tadpole structure will be optimized by testing the combinations of varying wheel diameter, vehicle weight, vehicle height, location of the center of gravity, tumbling speed, etc. A 3D model of the proposed design will be prepared. Various types of roads will also be simulated with varying friction co-efficient.

The most efficient combination of suspension and steering mechanism will be identified by evaluating various parameters for front-wheel and rear-wheel. Testing of the proposed design on a simulated cement road will be performed. The optimal structure design and steering-suspension geometries will be used to manufacture a prototype. Pilot testing of the prototype will be performed on the streets and parameters such as drag coefficient, maximum speed, maximum acceleration, braking efficiency, and driver comfort will be observed.

1.12 Hypothesis

H0: Optimization of wheel diameter, wheelbase, track width, vehicle height, vehicle weight, and location of the center of gravity will affect the performance of the vehicle.

H1: Variation of suspension and steering parameters affects the performance of the electric vehicle.