# SUSTAINABLE TECHNOLOGIES FOR EV CHARGING INFRASTRUCTURE

**Abstract**

This study provides the different sustainable technologies that could be used for EV charging infrastructure. With the increasing adoption of e-vehicles globally, the importance of adhering to sustainable developmental goals while adopting newer technologies is imminent for the automotive sector.

**Keywords**: smart grids, charging station, virtual power plants, smart pricing, algorithms for EVs.

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## I. INTRODUCTION

Fast adaptation to electric mobility is necessary to have a sustainable future for all. Electric vehicles (EV) are considered a sustainable or green technology compared to the existing Internal Combustion (IC) engine-based transportation sector. Similarly, the EV chargers and EV charging infrastructure should be too. EVs do not generate unnecessary emissions such as $CO_2$, $NO_x$, CO, etc. Like IC engine-based vehicles while driving, they are not completely emission-free considering the complete EV ecosystem. Some emissions are generated in the process of manufacturing, powering, and producing the infrastructure to charge the EVs. Still, e-mobility will help promote cleaner transport and sustainability efficiency.

Recently, the automobile sector is evolving with increased use and sales of pure EVs. Governments are also providing incentives and subsidies for EVs. This is one of the major ways to limit $CO_2$ emissions.

The government of India (GoI) has supported accelerating the adoption of electric vehicles through several policy initiatives such as the National Electric Mobility Mission Plan (NEMMP), Faster Adoption and Manufacturing of (Hybrid) and Electric Vehicles (FAME) Scheme, etc. With the demand for EVs increasing accordingly, there is also an equal increase in the requirement for supporting infrastructure.

To meet this increasing demand, the GoI is actively formulating policies at various levels, such as Energy guidelines for setting up EV charging infrastructure, Modification of the model building regulations (MBBL-2016) for the charging infrastructure for electric vehicles by the Ministry of Housing and Urban Development, etc.

The private sector also supports government initiatives with technological innovations, improving battery density, reducing operation and maintenance (O&M) costs, improving charging time, etc. Therefore, efforts such as incentivizing EVs and introducing new policies, campaigns, and initiatives by private companies are playing a catalytic role in boosting the adoption of electric vehicles and associated infrastructure.

Electric vehicles (EVs) are the upcoming transition in the transportation sector, which are sustainably better than conventional vehicles that run on fossil fuels such as petrol, diesel, natural gas, etc.

The major advantages of using EVs are the non-usage of fossil fuels, low running cost, zero-emission (no pollution), and reduced emission of greenhouse gases (GHGs), use of fewer components, low noise while running, and use of a recyclable battery. The scope of this paper is limited to battery-based EVs but could be extended to fuel cell-based EVs and other technologies in the coming future.

One of the most pre-requisite items for using EVs is the EV charging infrastructure (EVCI). EVCI is a set of individual components such as EV supply equipment (EVSE), power supply source with/without a transformer, communication technology, and installation location.

EVCI is defined as a system that is used to charge the EVs safely when the batteries inside the EVs get depleted, using intelligent communication and protection technology.

In this case of EVCI, the essential technology in place is the EVSE, and other technologies involved are electrical power supply, installation and commissioning aspect, software and communication factors, type of EV charger, services offered, the material used, type of semiconductor technology used, type of ownership, area/location of stakeholders, governance, and supporting institutions.

Sustainable technology is defined as the system of knowledge, techniques, skill, ability, processes, and organization that will transform the resources effectively into a usable form of goods and services considering the economic, social, and environmental outcomes that are sustainable. Figure 1 shows the multi-dimensional aspects of sustainability.

Under the context of sustainability, the technologies help transform the available natural capital into useable goods and services adhering to sustainability norms. Both soft and hard technologies are important for sustainable economic development by contributing to economic growth, meeting the social needs and equitable distribution of resources, improving the quality of life, balancing ecological growth, meeting lifestyle and livelihood needs, etc. Example- Software help in reducing the manpower work in automated car manufacturing by using controlled robots. Hardware, such as instruments and equipment, are used to measure and analyze the efficiency of a product. These make the life of humans easy, the quality of life is improved, etc. For example, plant-based solar power is a sustainable technology for EV charging infrastructure.

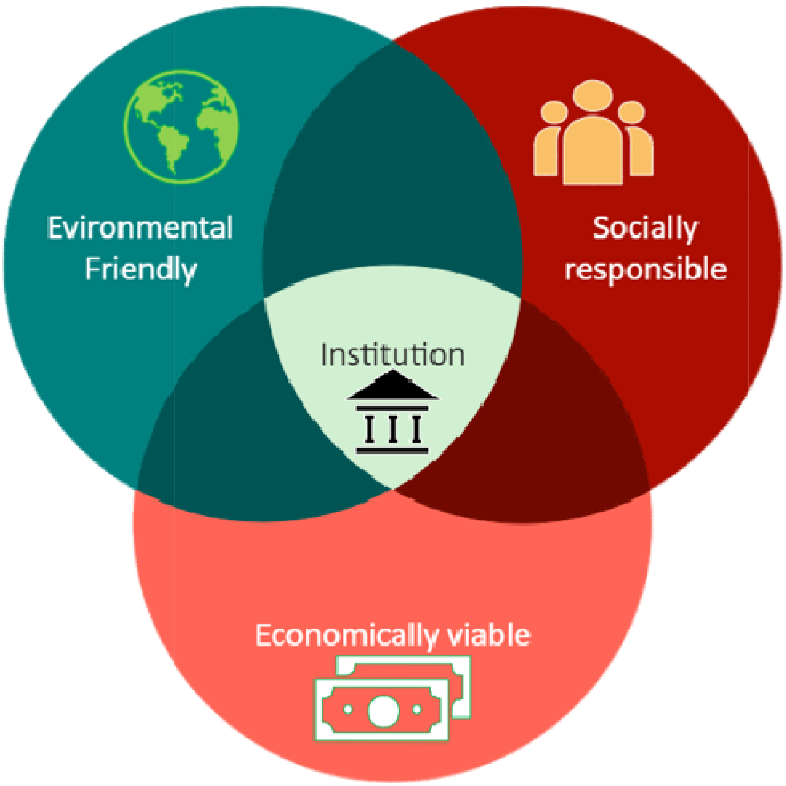


**Figure 1:** The Four Pillars of Sustainability Dimensions

To enable the decarbonization of the automotive sector and support the global EV30 campaign, sustainable, accessible, and robust charging infrastructure for EVs is an essential prerequisite. To encourage EV adoption, the availability of charging infrastructure is a key requirement, and it is reported that EV adoption in India would require 4,000 charging stations by 2026. The government has also planned to set up charging stations every 3km in cities every 25km on both sides of the highways to improve accessibility.

1. **The objective of Sustainable Mobility:** Sustainable mobility's objective is to allow people to move freely without sacrificing environmental or human values. This includes reducing harmful emissions from transport, protecting pedestrians and cyclists, and providing universal access to important places through public transport.Sustainable mobility is a challenge that needs to be addressed in order to improve social, economic, and environmental well-being in cities. It requires investment in electric vehicles, car sharing, and public transport, as well as green mobility policies that support the green fleet, restrict polluting vehicles in urban areas, and construct roads and circuits for non-motorized vehicles.By promoting and using public transport, and non-motorized vehicles, and reducing private cars, we can create a more sustainable automotive sector that is better for the environment and human health.Here are some specific examples of how sustainable mobility can be achieved:

   - Invest in electric vehicles and charging infrastructure. Electric vehicles produce zero emissions, making them a cleaner and more sustainable option than gasoline-powered vehicles.
   - Promote car-sharing and ride-hailing services. These services can help to reduce the number of cars on the road, which can also help to reduce congestion and pollution.
   - Improve public transportation. Make public transportation more affordable, convenient, and accessible. This will make it a more attractive option for people looking to reduce their environmental impact.
   - Create more walkable and bikeable communities. Make it easier for people to get around without a car by designing communities with a focus on pedestrians and cyclists.
   - Promote sustainable transportation policies. Implement policies that encourage sustainable transportation, such as congestion pricing and parking fees.

   With the increasing use of EVs across the country and globally, the efficient contribution to the economic, social, and environmental aspects must be considered in the EV ecosystem, especially for the EV charging infrastructure. Such infrastructures that contribute to greener economic growth are environment-friendly, socially inclusive, and sustainable infrastructures. The EV charging infrastructures that follow sustainable norms and help contribute to climate change, efficient use of smart technologies and resources, greener economic growth, and making socially habitable and inclusiveness sustainable EV charging infrastructures.This means the infrastructure is environmentally friendly from end to end, including economic, financial, social, and institutional factors. These factors form the 4 dimensions of sustainability and sustainable development. Technology is the main factor that converts essential resources efficiently into useful outcomes for consumption. This paper discusses the sustainable technologies, advantages, disadvantages, and challenges of EV charging infrastructure (EVCI).

2. **The Ecosystem of EV Charging Infrastructure:** The infrastructure required to support battery-based EVs to charge their batteries is called EV charging infrastructure. Such infrastructure is used only for battery EVs (BEVs). In the near future, the possibility of using hydrogen as a fuel will be adopted with the integration of fuel cell systems and such infrastructure will be entirely different from battery-based electric vehicles. To understand the EVCI completely, understanding the ecosystem is required. The ecosystem of EVCI consists of the type of EV supply equipment (EVSE), type of power supply usage, land use area (location specific), installation and commissioning aspects of EVSE, type of services offered such as communication and software used, and operation and maintenance of EVCI. To enable the ecosystem of EVCI, the institutions, proper governance, and stakeholders play a significant role. There are 3 types of EVCI's, which are detailed in Table 1. The differences mainly arise concerning the usage type, location of use, type of ownership, and operation. Public EVCI can help in faster EV adoption, followed by semi-public and private, respectively. With the adoption rate in the nascent stage, the public EVCI can help promote the use of EVCI's and EVs, help create awareness among the society, and reach a large audience as most people use public transport systems, etc. The technologies related to different types of EVCI may be common or different with respect to the location of use, type of ownership, etc.

**Table 1: Types of EV Charging Infrastructure**

| Type of EV Charging Infrastructure | Factors affecting the EV charging Infrastructure | | | |
|---|---|---|---|---|
| | Usage | Location | Ownership | Operation |
| **Private** | Dedicated charging for personal EV or EV fleet owned by one entity | Independent homes, dedicated parking spots in apartments/offices; for fleets- any location with land availability | Individual EV owners, EV fleet owners/ operators | Self-operated or CPO-managed (for EV fleet charging) |
| **Public** | Open for all EV users | Public parking lots, on-street parking, charging plazas, petrol pumps, highways, metro stations | Municipal authorities, PSUs, CPOs, host properties | CPO-managed |
| **Semi-public** | Shared charging for a restricted set of EV users | Apartment complexes, office campuses, gated communities, shopping malls, hospitals, universities, government buildings, etc. | Host properties, Original Equipment Manufacturers (OEMs) & Charge Point Operators (CPOs) | CPO-managed |

For example, the technology used for private EVCI will be wall mounted type, whereas, in the case of public charging, it will be floor mounted type. The differences may be many depending on other factors such as type of usage (personal purposes or shared usage, or high-power usage) and location of the charger. Secondly, another major factor that depends on technology will be the type of services offered, such as smart charging, intelligent communication systems, fast charging, better connectivity, etc. The whole ecosystem is dependent on the type of technologies used and their influence on their operation. Thirdly, the type of EVSE and its specification is another factor of the ecosystem that is considered during the installation and commissioning process for the EVCI. The EVSE can be either conductive or non-conductive type EVSE and are of 2 typesviz. DC charging (fast charging) and AC charging (slow charging). The institutions such as the Ministry of Road Transport and Highways of India and the Department of Heavy Industries play an important role in the faster adoption of EVs and the development of EV charging infrastructure across the country. If the institutions can make proper policies, regulations, and guidelines for the public, the impact will be larger. The process of forcing the adoptionof certain technology using rules and regulations are called the top-bottom approach, which is the practical way of living, rather than the bottom-top approach, which is the ideal way. Similarly, the stakeholders viz. Government, private, and public representatives are important in formulating the necessary guidelines, rules, and regulations that lead to policymaking. The common services offered by EVCI are payment options, a mobile app for connectivity between the charging points, fast charging options, security, safer energy transfer, proper and reliable energy supply, etc. The general power supply is through the normal electricity supply from state utilities or distribution companies (DISCOMS) that is supplied from fossil fuel-based generating power plants.

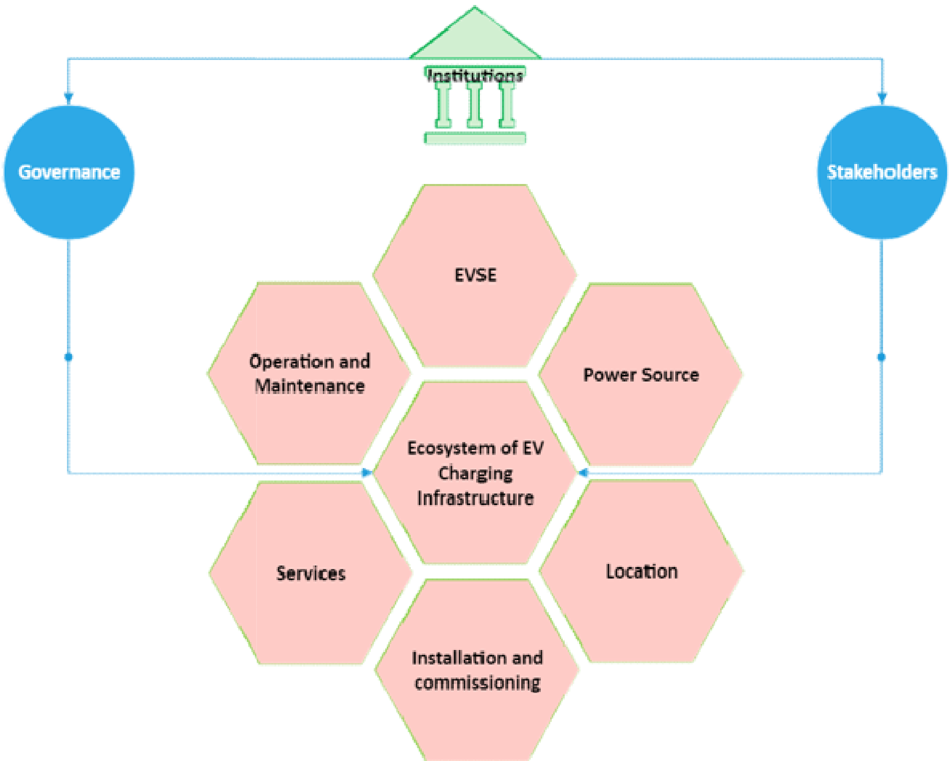


**Figure 2:** A Typical Ecosystem of EVCI

**Key Drivers for Charging Infrastructure Development:**

- **Location:** Location is one of the critical factors when considering range anxiety and EV charging time. Therefore, a mix of home charging, public charging, and destination charging (workplace/commercial) is required to increase range and improve charging access.

- **Charger Type:** To increase utilization at the charging site by installing the most appropriate mix of chargers, i.e., H. Charger type (slow/fast) and charging standards, to ensure interoperability within the EV ecosystem.

- **Electricity:** Large-scale EV charging requires a proper power distribution system and grid infrastructure planning to ensure power availability at the charging locations.

- **Technology:** Applying the right technology will make the operation of the charging infrastructure ecosystem more efficient and further improve the seamless customer experience.

3. **Technologies Involved in EVCI:** Technology is driven by energy and the use of resources. Technology is a tool, skill, process, etc., that improves the system's quality and life. The major technological factors in EVCI are the material technology, power electronic semiconductor technology, EVSE technology, software and communication technology, technologies involved in the type of electricity supply, technologies involved in the operation and maintenance, the technology used in infrastructure development, technology variations based on the ownership type and usage pattern, and the technological mechanism of the stakeholders. The complete ecosystem of EVCI depends on various technologies, and Figure 3 shows the technologies involved in the EVCI ecosystem.Various EV charging technologies are available, each with advantages and disadvantages.Some of the most common EV charging technologies include slow chargers, fast chargers, and battery swapping stations.Slow chargers are the most affordable option but take the longest to charge a vehicle. These chargers are the most common type of EV charger. They typically take several hours to charge an EV battery fully.Fast chargers are more expensive but can charge a vehicle much faster than slow chargers.These chargers are faster than slow chargers but are also more expensive. They can typically fully charge an EV battery in less than an hour.Ultra-fast chargers are the fastest type of EV charger. They can typically fully charge an EV battery in less than 30 minutes. The different types of electricity that can be used to power EV chargers are:

   - **Grid Electricity:** This is the most common type of electricity used to power EV chargers. The electricity is generated by power plants and distributed to homes and businesses.

   - **Solar Power:** This renewable energy source can be used to power EV chargers. Solar panels can be installed on homes, businesses, or EV charging stations to generate electricity.

   - **Wind Power:** This is another renewable energy source that can be used to power EV chargers. Wind turbines can be installed to generate electricity.

 

**Similarly, the Different Stakeholders Involved in the EV Charging Industry are:**

- **Governments:** Governments can play a role in the EV charging industry by providing financial incentives for EV charging infrastructure. They can also set regulations for EV chargers.

- **Utilities:** Utilities can play a role in the EV charging industry by providing electricity to EV chargers. They can also install and maintain EV chargers.

- **EV Manufacturers:** EV manufacturers can play a role in the EV charging industry by designing and manufacturing EV chargers.

- **EV Charging Station Operators:** EV charging station operators can play a role in the EV charging industry by installing and operating EV chargers.

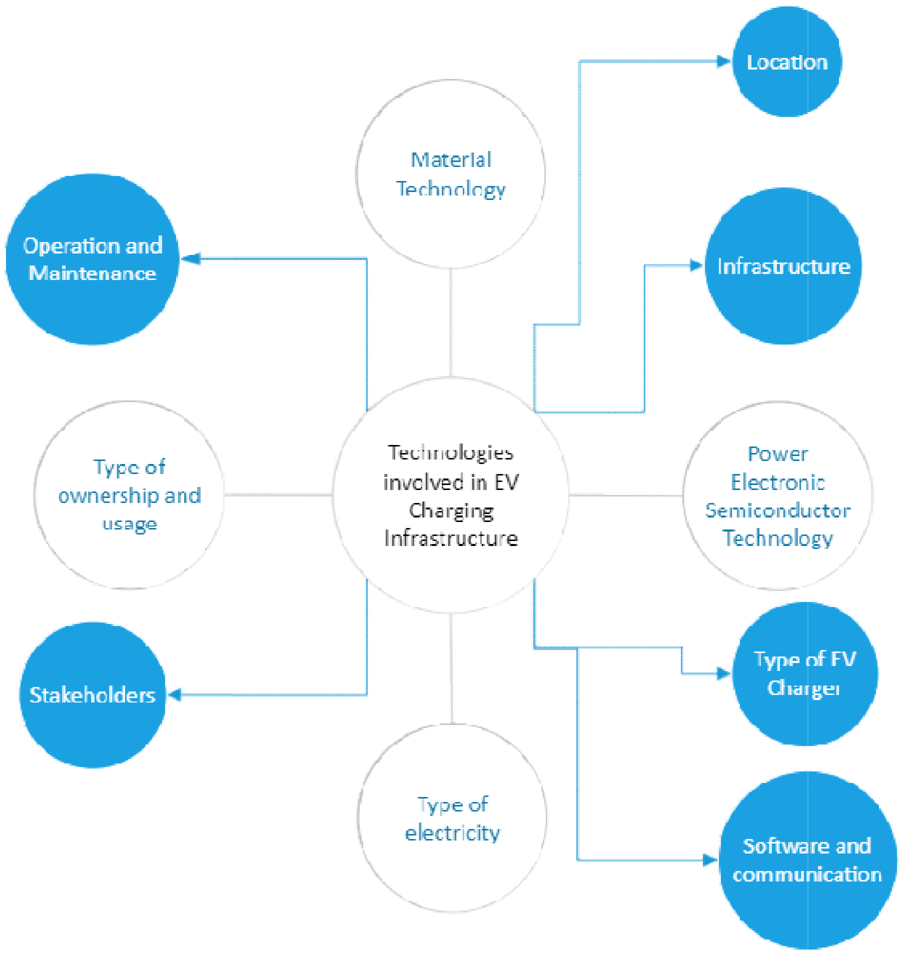


**Figure 3:** Typical Technologies Involved in EVCI

Battery swapping stations allow drivers to swap out their depleted batteries for fully charged ones quickly.The challenges of EV charging include the high cost of infrastructure, the limited availability of chargers, and the long charging times for some technologies.The benefits of EV charging include reduced emissions of greenhouse gases, improved air quality, and increased energy independence. Figure 4 highlights the importance of sustainability in the EV charging industry. Different EV charging technologies have different environmental impacts, and choosing the most sustainable option for a particular application is important.The figure provides a good overview of the EV charging industry and its challenges and opportunities.The figure shows that the government, private entities, and public/individuals all have a role to play in developing EV charging infrastructure. It also shows that the type of electricity used, the location of the chargers, and the type of ownership and usage all have an impact on the sustainability of EV charging and concludes by highlighting the importance of stakeholder collaboration in the development of sustainable EV charging infrastructure.

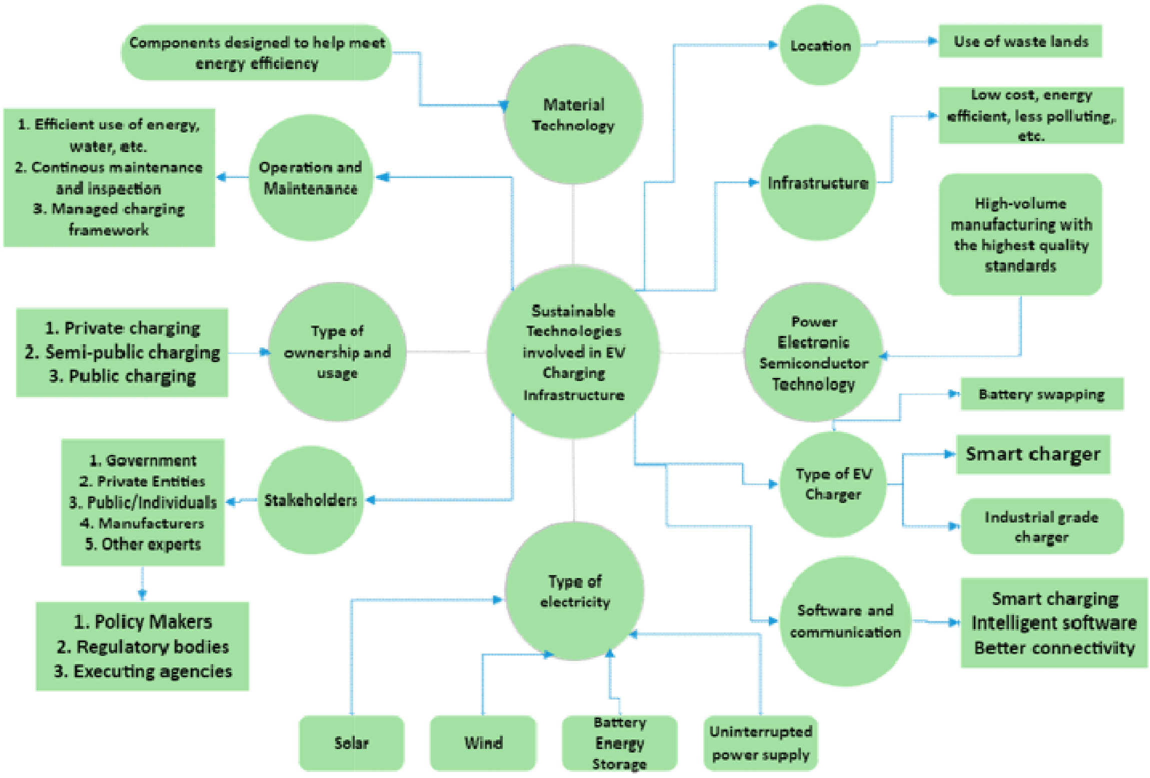


**Figure 4:** Sustainable Technologies Involved in SEVCI

**The Following are the Methods to be adopted For SEVCI to be Sustainable:**

- **Material Technology:** using less energy-intensive materials and energy-efficient components can reduce GHG emissions in manufacturing the raw materials used in EVCI.

- **Power Electronic Semiconductor Technology:** good quality manufacturing with low waste output and high-volume production are more sustainable than low-quality products.

- **Type of Electricity Used**: using renewable energy resources such as solar power, wind power, biomass, etc., instead of natural gas, coal, etc., are sustainable as they contribute positively to environmental development. The use of solar or wind power-based energy supply will help reduce GHG emissions and help climate change aspects positively. To ensure a reliable power supply, usingan uninterrupted power supply (UPS) and battery energy storage systems are encouraged to contribute to social-economic development.

- **Location or Land use Planning:** using wasteland or barren land is best compared to useful land for developing the EVCI. This contributes to environmental sustainability.

- **Infrastructure:** Using low-cost, energy-efficient, and low polluting in nature.

- **Type of EV Charger or EVSE:** Using an industrial-grade charger, smart charger, and battery swapping system is much better for economic, social, and environmental sustainability.

- **Operation and Maintenance:** The efficient use of land, water, energy supply, etc., along with continuous maintenance and managed to charge network, is a sustainable system.

- **Software and Communication:** The adoption of smart charging and intelligent communication system with better connectivity is socially sustainable but may not be economically sustainable.

- **Type of Ownership and Usage:** The public EVCI is the most preferred and needed type of ownership that should be supported by the institutions and good governance that contribute to socio-economic sustainability. Adopting shared usage instead of private usage of EVCI is sustainable but not comfortable to adopt practically.

- **Stakeholder Mechanism:** This technological aspect comprises 5 components viz. Government organizations/entities/institutions, private entities, manufacturers, individuals, or public, and expert peoples. The outcome of partnerships between these components can help provide better policy-making decisions, proper rules, regulations, and guidelines, and better implementations. Hence, contributing to inclusive economic, social, and environmentally sustainable growth.

4. **Sustainable EVCI:** The infrastructure that focuses on and follows sustainable practices and norms is called sustainable infrastructure. Using sustainable technologies can help make the existing system into a sustainable EV charging infrastructure. The most fundamental difference between EVCI and SEVCI is the source of power supply (electricity) which is coal-based and solar-based, respectively. The other options for SEVCI are the use of wind-power-based and battery-based. The second important difference is using less energy-intensive and energy-efficient materials or components for manufacturing the various technologies involved in creating the product SEVCI, such as aluminum, silica, silver, etc. Figure 5 is a good representation of the four pillars of sustainable development. It suggests that sustainable development is not a single goal, but rather a complex system of interconnected goals.

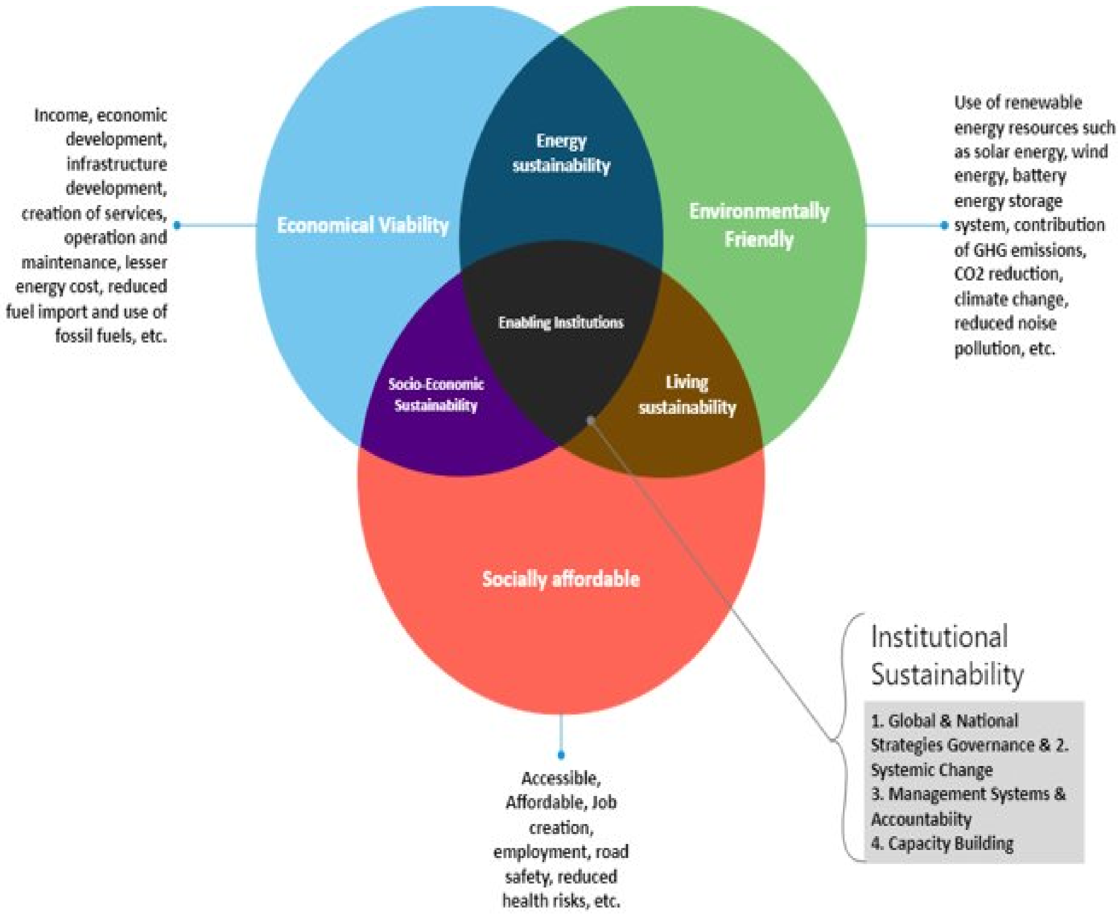


**Figure 5:** Dimensions of Sustainable EVCI

It also suggests that sustainable development cannot be achieved overnight but rather a long-term process that requires the cooperation of all stakeholders.There are 17 Sustainable Development Goals (SDGs) detailed by the United Nations (UN) for inclusive growth in terms of economic, environmental, and social development on a global scale. Figure 6 provides the 17 SDGs. The most direct way of understanding the effect and contribution of certain technology on sustainability is by relating to the SDGs. For example, the country or city with a better sustainability index is having better sustainable mobility ecosystem. By adopting SEVCI, the following goals can be achieved directly:

1. **Goal 3 (SDG 3):** Adopting a sustainable mobility ecosystem can promote well-being, ensure healthy lifestyles among the community, and contribute to inclusive social development. The use of SEVCI will indirectly ensure healthy living by reducing the release of GHG emissions as they use renewable energy-based energy sources (majorly solar energy), which are much cleaner than conventional sources of electricity (from fossil fuels such as coal, hydrocarbon, and natural gas, etc.).

2. **Goal 7 (SDG 7):** We know that renewable energy-based power sources are not reliable with their operating characteristics. With the increased use of renewable energy-based sources of electricity such as solar power, the intermittency or fluctuations in the solar radiation during the daytime can be supported by the SEVCI wherein the option of the vehicle to grid power is possible, especially during the peak

hours and fluctuating hours. This option is advanced and still in the global research stage but has proven successful in certain countries. Therefore, adopting SEVCI with the vehicle-to-grid (V2G) technology option can help ensurea reliable energy supply for all, which is both sustainable and affordable.

3. **Goal 8 (SDG 8):** With the recent move by the Government of India (GoI), any private entity can start setting up EVCI to encourage small-scale start-ups and business companies. The SEVCI is an existing equivalent of petrol/diesel stations that can act as a source of income and a decent employment opportunity for the owners of SEVCI. With the transition towards using EVs in the next 50 years, this business can act as a productive employment opportunity and decent work. This ensures sustainable economic growth.

4. **Goal 9 (SDG 9):** The use of battery swapping station (a special type of EV charging solution), adoption of solar/wind/battery/UPS integrated electricity supply, optimal use of energy resources, use of less energy intensive and energy efficient materials/components in manufacturing, use of intelligent software solutions (smart charging), sustainable charging framework (operation and maintenance), less polluting or less GHG emissions, usage of the optimal land area without compromising environmental surrounding (protecting biodiversity), etc., based EV charger is said to be SEVCI. If such an infrastructure is adopted, it can positively impact socio-economic and environmental development and lead to sustainable industrialization.

5. **Goal 11 (SDG 11):** The use of SEVCI in smart cities is considered safer, resilient, and sustainable. Sustainable cities adopting SEVCI are more socially sustainable.

6. **Goal 13 (SDG 13):** The SEVCI does not have many GHG emissions as they use a cleaner source of energy supply, thereby contributing to climate change. This positively impacts on environmental sustainability.

7. **Goal 15 (SDG 15):** Using efficient land for establishing SEVCI (like the use of wasteland) can help contribute to environmental sustainability.

**Goal 1. End poverty in all its forms everywhere**
**Goal 2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture**
**Goal 3. Ensure healthy lives and promote well-being for all at all ages**
**Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all**
**Goal 5. Achieve gender equality and empower all women and girls**
**Goal 6. Ensure availability and sustainable management of water and sanitation for all**
**Goal 7. Ensure access to affordable, reliable, sustainable, and modern energy for all**
**Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all**
**Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation**
**Goal 10. Reduce inequality within and among countries**
**Goal 11. Make cities and human settlements inclusive, safe, resilient, and sustainable**
**Goal 12. Ensure sustainable consumption and production patterns**
**Goal 13. Take urgent action to combat climate change and its impacts**
**Goal 14. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development**
**Goal 15. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation, and halt biodiversity loss**
**Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels**
**Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development**

**Figure 6:** Sustainable Development Goals (SDGs)

**Table 2: Advantages and Disadvantages of Battery EV Charging Through BSI**

| Sl. No | Advantages | Disadvantages |
|---|---|---|
| 1 | Faster recharging: Battery swapping can fully recharge an electric vehicle in minutes, compared to hours for conventional charging. | Lack of standardization: There is currently no standardization among EV batteries, which makes it difficult to develop and deploy battery swapping systems. |
| 2 | Greater flexibility in setting up swap stations: Batteries can be charged away from the swapping point, which gives more freedom in the location of swap stations. | Unsuitable battery pack design: Some battery pack designs are not suitable for easy swapping, due to factors such as weight, dimensions, and ergonomics. |
| 3 | Lower upfront cost: Battery swapping can reduce the upfront cost of an electric vehicle, as battery ownership is replaced by battery leasing. | Greater number of batteries needed: A greater number of batteries are needed to power the same number of EVs if battery swapping is used, due to the need to have a spare battery available for each vehicle. |

| | | |
|---|---|---|
| 4 | Improved battery life: Controlled charging conditions can help to improve the predictability of battery life. | Shorter commercial life of battery packs: Battery packs typically have a shorter commercial life than the rest of an electric vehicle, due to customer preference for new batteries with higher ranges.Slow adoption by OEMs: Some original equipment manufacturers (OEMs) are hesitant to adopt battery swapping, due to concerns about the cost and complexity of the technology.Higher costs of battery leasing: Battery leasing can be more expensive over the lifetime of an electric vehicle than battery ownership.Higher GST on separate battery: In some countries, there is a higher Goods and Services Tax (GST) on a separate battery than on a battery sold with an electric vehicle. |

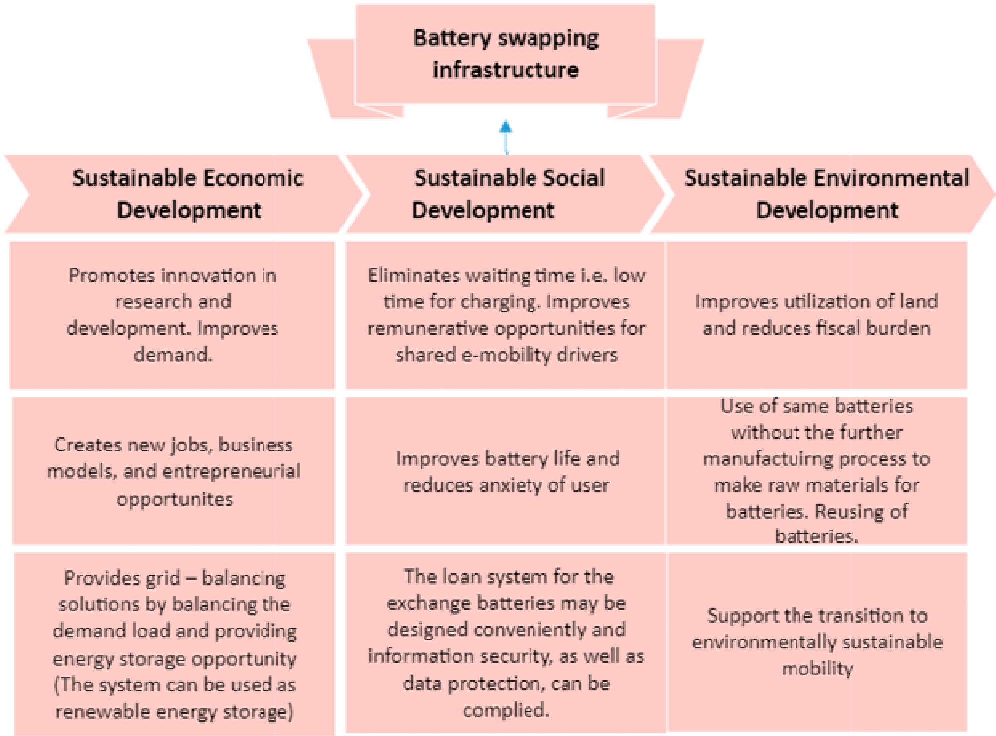


**Figure 7:** The Sustainability Aspect of BSI

Battery swapping infrastructure (BSI) is an alternative method of charging batteries for electric vehicles (EVs). In BSI, a discharged EV battery is removed from the vehicle and replaced with a fully charged one. This technology is being trialed for various EV segments; including electric two-wheelers (E-2Ws), electric three-wheelers (E-3Ws), electric cars, and electric buses.There are two main types of BSI: manual BSI and autonomous BSI.

1. **Manual BSI:** In manual BSI, the battery charging station is a stand-alone device in which batteries are inserted and removed manually from the individual slots. These stations are modular and occupy a minimum amount of space. They are used for E-2Ws and E-3Ws as battery pack sizes are smaller and can be handled by one or two people.

2. **Autonomous BSI:** A robotic arm removes and replaces the batteries in autonomous BSI. These stations are semi- or fully automated. They are used for electric cars and buses as battery packs are larger, heavier, and require mechanical assistance. Autonomous BSI stations are more expensive and require more space but are more efficient.

   Changing the battery has some distinct advantages over its Plug-in store but will also face several Challenges in its development as a mainstream Charging method (see Table 2). Changing the battery is currently a Feasible Solution for commercial EV fleets, especially in the e-2W and e-3W segments. The Ministry of Roads Transport and Highways (MoRTH) made this possible Sale and registration of electric vehicles without batteries, thusproviding a tremendous boost for battery swapping solutions and the development of BSIs across the country. In addition, industry interest groups make big Investments in the development of the battery replacement ecosystem. This indicates that battery replacement is in progress to emerge as an independent component of charging networks for electric vehicles in India in the coming years. BSI is currently the best type of SEVCI. Using batteries as part of a BSI also can be a lower-impact method of providing a vehicle with the potential to store the batteries in an optimum environment. Figure 7 shows the sustainability contribution of BSI in three dimensions.

**The Different Benefits of Battery Swapping Infrastructure for Each of these Three Dimensions of Sustainability are as Follows:**

1. **Sustainable Economic Development**

   - **Promotes Innovation in Research and Development:** Battery swapping infrastructure can help to promote innovation in research and development of new battery technologies. This can lead to the development of more efficient and affordable batteries, which can help to reduce the cost of electric vehicles (EVs).

   - **Improves Demand:** Battery swapping infrastructure can help to improve demand for EVs. This is because it can make EVs more convenient to own and operate, as drivers do not have to wait for their batteries to be charged.

   - **Creates New Jobs, Business Models, and Entrepreneurial Opportunities:** Battery swapping infrastructure can create new jobs, business models, and entrepreneurial opportunities. This is because it requires the development of new technologies and services, such as battery swapping stations and battery leasing programs.

   - **Provides Grid-Balancing Solutions:** Battery swapping infrastructure can provide grid-balancing solutions. This is because it can help to balance the demand load and provide energy storage opportunities. The system can be used as renewable energy storage.

**2. Sustainable Social Development**

- **Eliminates Waiting Time:** Battery swapping infrastructure can eliminate waiting time for charging. This is because drivers can quickly swap their depleted batteries for fully charged ones.

- **Improves Remunerative Opportunities for Shared E-Mobility Drivers:** Battery swapping infrastructure can improve remunerative opportunities for shared e-mobility drivers. This is because it can make it more convenient for drivers to pick up and drop off passengers.

- **Improves Battery Life and Reduces User Anxiety:** Battery swapping infrastructure can improve battery life and reduce user anxiety. This is because drivers do not have to worry about their batteries running out of power.

- **The Loan System for the Exchange Batteries May be designed conveniently:** Battery swapping infrastructure can make the loan system for the exchange batteries convenient. This is because it can be done quickly and easily without having to wait for the batteries to be charged.

- **Information Security and Data Protection can be Complied with:** Battery swapping infrastructure can comply with information security and data protection regulations. This is because the data collected from battery-swapping stations can be encrypted and protected.

**3. Sustainable Environmental Development**

- **Improves Land Utilization and Reduces Fiscal Burden:** Battery swapping infrastructure can improve land utilization and reduce fiscal burden. This is because it does not require as much land as traditional charging stations.

- **Use of the Same Batteries Without the Further Manufacturing Process to Make Raw Materials for Batteries:** Battery swapping infrastructure can use the same batteries without the further manufacturing process to make raw materials for batteries. This can reduce the environmental impact of battery production.

- **Support the Transition to Environmentally Sustainable Mobility:** Battery-swapping infrastructure can support the transition to environmentally sustainable mobility. This is because it can help to reduce emissions of greenhouse gases.

## II. ADVANTAGES AND DISADVANTAGES OF SEVCI

Sustainable infrastructure is infrastructure that is designed to minimize its environmental impact and promote economic growth. It can include energy-efficient buildings, renewable energy sources, and public transportation systems.There are many benefits to sustainable infrastructure, including:

1. **Reduced Environmental Impact:** Sustainable infrastructure can help to reduce greenhouse gas emissions, improve air quality, and conserve water.
2. **Promoted Renewable Energy:** Sustainable infrastructure can help promote using renewable energy sources, such as solar and wind power.
3. **Created Green Jobs:** The construction and maintenance of sustainable infrastructure can create jobs in the renewable energy sector and other related industries.
4. **Driven Green Economic Growth:** Sustainable infrastructure can help to drive economic growth by creating jobs and stimulating investment.
5. **Equalized Inequalities:** Sustainable infrastructure can help to equalize inequalities by providing access to essential services, such as clean water and transportation, to all people.

The transition to sustainable infrastructure will require significant investment, but it is an investment that will pay off in the long run. Investing in sustainable infrastructure can create a cleaner, healthier, and more prosperous future for all.

**Here are Some Specific Examples of Sustainable Infrastructure:**

- **Energy-Efficient Buildings:** Energy-efficient buildings use less energy to heat and cool, which reduces greenhouse gas emissions.
- **Renewable Energy Sources:** Renewable energy sources like solar and wind power do not produce greenhouse gas emissions.
- **Public Transportation Systems:** Public transportation systems reduce the number of cars on the road, which also reduces greenhouse gas emissions.
- **Green Spaces:** Green spaces, such as parks and gardens, help to improve air quality and reduce noise pollution.

Investing in sustainable infrastructure can make our cities and communities more livable, healthier, and sustainable.

**Table 3: Advantages and Disadvantages of SEVCI**

| Sl. No. | Advantages | Disadvantages |
|---|---|---|
| 1 | Reducing our environmental and carbon footprint | Pollution due to production and manufacturing activities remain at large |
| 2 | Fostering renewables | Capital cost is high |
| 3 | Creating green employment | Existing jobs will be lost, and it will takes more time to learn new skills for the SEVCI |

| | | |
|---|---|---|
| 4 | Driving green economic growth | Very poor economic growth but a healthy version |
| 5 | Evening out inequalities by providing Accessibility, affordability, transparency, and effectiveness | Accessibility, affordability, and effective reach to rural areas are difficult |

## III. CHALLENGES

1. **Short Lifespan, High Waste:** The lifespan of charging stations is often shorter than advertised, which can lead to waste and environmental problems. Some chargers only last 5-7 years, even though manufacturers claim they should last a decade. This is not only wasteful but also makes no economic sense, as the infrastructure is supposed to last for a long time.

2. **Making Charging Infrastructure Out of Recycled Materials:** Using recycled materials can make charging infrastructure more sustainable. The carbon cost of manufacturing most of the materials used in chargers is close to zero, as they have already been manufactured. For example, charging stations can be made from recycled tires and plastics. This reduces the need to mine new materials, which can help to conserve resources and protect the environment.

3. **Using Charging Infrastructure to Encourage Green Behaviors-** Charging infrastructure can encourage green behaviors, such as smart charging on the street or at work. Smart charging allows cars to be plugged in for long periods of time, such as overnight or at work. This can help to minimize stress on the grid and batteries, and it can also extend battery life. Charging on the street or at work makes electric vehicles more accessible to people who do not have a driveway, and it can also help to reduce traffic congestion.

4. **Charging Should be Green, too:** As part of our efforts to promote electric vehicles, we should also make sure that the charging infrastructure is as green as possible. This means using recycled materials, designing chargers to minimize materials and electronics, and ensuring the infrastructure lasts for a long time. We should also design infrastructure that encourages green charging behavior, such as smart charging on the street or at work.

## IV. CONCLUSION

The sustainability of the charging process for electric vehicles (EVs) is a challenge as the adoption of EVs grows. Infrastructure viability can be achieved by understanding the needs of key ecosystem players, including consumers, government, and private operators.On the consumer side, the accessibility and availability of supporting infrastructure must be provided to increase user confidence in purchasing EVs. On the operator side, additional privileges may be offered to operators when EV traffic on the road is limited, such as the availability of land at subsidized rates for infrastructure creation, provision of additional revenue from commercial activities, etc.The enabling policy environment and promotion of private sector involvement by original equipment manufacturers (OEMs) and operators to develop supporting infrastructure are also important. The interaction of all these factors will make the infrastructure sustainable in the long term.

Five key EV charging infrastructure areas that must be considered critical to sustainable development are energy, transport, waste management, land use planning, and governance. Battery swapping technology is the most sustainable technology for EV charging infrastructure. Currently, over 90% of vehicles in India are two-wheelers (2W). 2W electric batteries can be charged from any single-phase outlet. Battery swapping can be successful for 2W vehicles. A new business model of 2W vehicles sold without batteries and a battery leasing agency that owns and rents charged batteries in a city is worth exploring. Battery replacement is yet to be feasible for cars and buses (although trials are ongoing). Innovative models for battery swapping stations (BSSs) must be explored to make them successful. Given the current scenario of the EV landscape in India, EV consumers will like the idea of BSSs as replacing the battery is much easier than charging it. However, as fast-changing technology advances every day, EV range increases, and faster charging of EV batteries decreases, battery swapping could become obsolete over the years. Ultimately, battery swapping has the potential to become a successful business model for commercial electric vehicles. Fleet operators, such as buses, taxis, etc., would swap their battery packs at their facilities and distribute battery changes across electric vehicles. International collaboration is essential for faster EV adoption in India.

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