

# **A Study on Connected and Autonomous Electric Vehicles**

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**ABSTRACT:** Connected and Autonomous Electric Vehicles (CAEVs) will play a vital role in emerging eco-friendly automobile revolution. CAEVs have great potential to operate with higher vehicle efficiency and if they are charged using renewable energy sources that will significantly reduce emissions and dependency on fossil fuels. Autonomous technology integrates better with electric engines. Most Electric Vehicles are built with drive-by-wire systems that replace traditional mechanical control systems with electronic controls, and these systems create a more compatible and flexible platform for autonomous driving technologies. CAEVs offer many potential advantages in terms of sustainable development for environment friendly urban mobility like less environmental pollution, improved safety. This study aims to enumerate the concept, levels of automation, benefits and challenges associated with Connected and Autonomous Electric Vehicles. A shift to Connected and Autonomous Electric Vehicles would not just reshape the entire transportation industry, but also our daily lives. Experts refer to this future as zero crashes, zero emissions, and zero fatalities. Presumably, Connected and Autonomous Electric Vehicles will become smart enough to avoid all collisions, eliminating over 1.25 million traffic fatalities around the world each year. Their battery powered-nature would significantly reduce air pollution, particularly in cities where car density and air pollution are at their highest. Traffic congestion would become a thing of the past, as networked cars would communicate with each other and local infrastructure to seamlessly choreograph traffic movements. The value of such developments is virtually unquantifiable, as people would likely be able to live longer, healthier lives, with more free time.

**KEYWORDS:** Connected and Autonomous Electric Vehicles, levels of automation, vehicular automation, vehicle electrification, vehicular connectivity, shared mobility.

## **I. INTRODUCTION**

Connected and Autonomous Electric Vehicles (CAEVs) are complex automotive systems, combining basically connected vehicles (CV), autonomous vehicle (AV) and electric vehicle (EV). The automotive industry is at the verge of the Autonomous Vehicles (AVs) era and Electric Vehicles are already into the market. These vehicles are envisioned to dominate the roads by 2030 creating substantial economic benefits manifested in the form of safer roads, improved equity and accessibility to transportation, significantly reduced Greenhouse emissions, and reduced congestion. Connected and Autonomous Electric Vehicle technology aims to reduce crashes, energy consumption, pollution, and congestion while at the same time increasing transport accessibility. This technology can change the existing transportation system due to advanced communication and sensing capabilities, enhanced travel convenience and lesser environmental impact. The powerful capabilities of Connected and Autonomous Electric Vehicles will make it a popular provider of a wide range of services, including mobility, sensing, computing, traffic control, and energy management. CAEVs definitely transform existing mobility paradigm. It can be observed that technological advancements in driving assistants and network connectivity yield further opportunities and services, and meet the sustainable development for cleaner, safer, and smarter mobility.

## II. THE CONCEPT OF CONNECTED AND AUTONOMOUS ELECTRIC VEHICLE

Connected and Autonomous Electric Vehicle inherits the capabilities of the three underlying technologies, Connected Vehicle, Autonomous Vehicle and Electric Vehicle.

**Connected Vehicle:** It is a vehicle that has communication devices that communicates with other devices within the same vehicle and within its surroundings. Internally, these communication devices can be connected using wired or wireless communications technologies; while externally, they are connected using wireless communications technologies (e.g., LTE and 5G). Wireless connectivity is used to share safety information and for infotainment and Internet access.

**Autonomous Vehicle:** It is a vehicle capable of manoeuvring roads unattended and without human intervention or back-end control centre. This is achieved using a combination of sensing and actuation networks supported by computer vision and learning capabilities. Autonomous Vehicles rely primarily on on-board sensors for decision-making and use safety information from surrounding environment as guidance. To run the autonomous driving algorithms, it is equipped with strong computational power and large data storage.

**Electric Vehicle:** It is a vehicle that uses electric motors for propulsion instead of internal combustion engines used in conventional vehicles. EVs store electricity in an energy storage device, such as a battery. The electricity powers the vehicle's wheels via an electric motor. Electric vehicles are different from fossil fuel-powered vehicles in that they can receive their power from a wide range of sources, including fossil fuels, nuclear power, and renewable sources such as tidal power, solar power, and wind power or any combination of those. However it is generated, this energy is then transmitted to the vehicle through use of overhead lines, wireless energy transfer such as inductive charging, or a direct connection through an electrical cable.

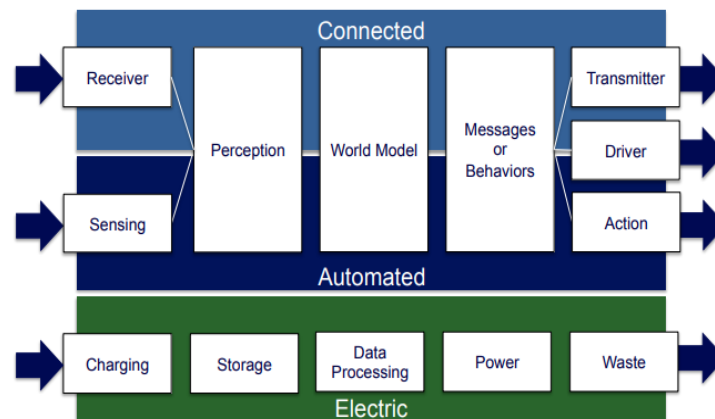


Fig. 1 Connected and Automated Electric Vehicle System

CAEVs bring forth significant benefits by optimal integration of the concepts of CV, AV and EV. CAEV is an electric vehicle that is capable of sensing its environment and navigating with little or no human input. CAEV senses its environment using various sensing devices including Radar, light detection and ranging (LiDAR), image sensors, 3D camera, etc. Basically, CAEV is composed of five major components:

1. Perception system which is responsible for sensing the environment to understand its surroundings.
2. Localization and mapping system that enables the vehicle to know its current location.
3. Driving policy refers to the decision making capability of a CAEV under various situations, such as negotiating at roundabouts, giving way to vehicles and pedestrians, and overtaking vehicles.
4. Communication system: As CAVs will be connected to the surrounding environment such as vehicles with vehicle to vehicle connectivity (V2V), to the infrastructure with vehicle to infrastructure (V2I) and to anything else such as the Internet: vehicle to anything (V2X), through wireless communications links.

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- Storage battery system: This system includes charger and battery packs in the vehicle. Basically state of charge (SoC) level determines the amount of charge stored in the battery.

## III.LEVELS OF AUTOMATION

The Society of Automobile Engineers (SAE) defined five levels of autonomous driving, as summarized below. Level zero is no automation, Level 1 to Level 3 requires a licensed driver, but levels 4 and 5 allow driverless operation, which is necessary for many predicted benefits.

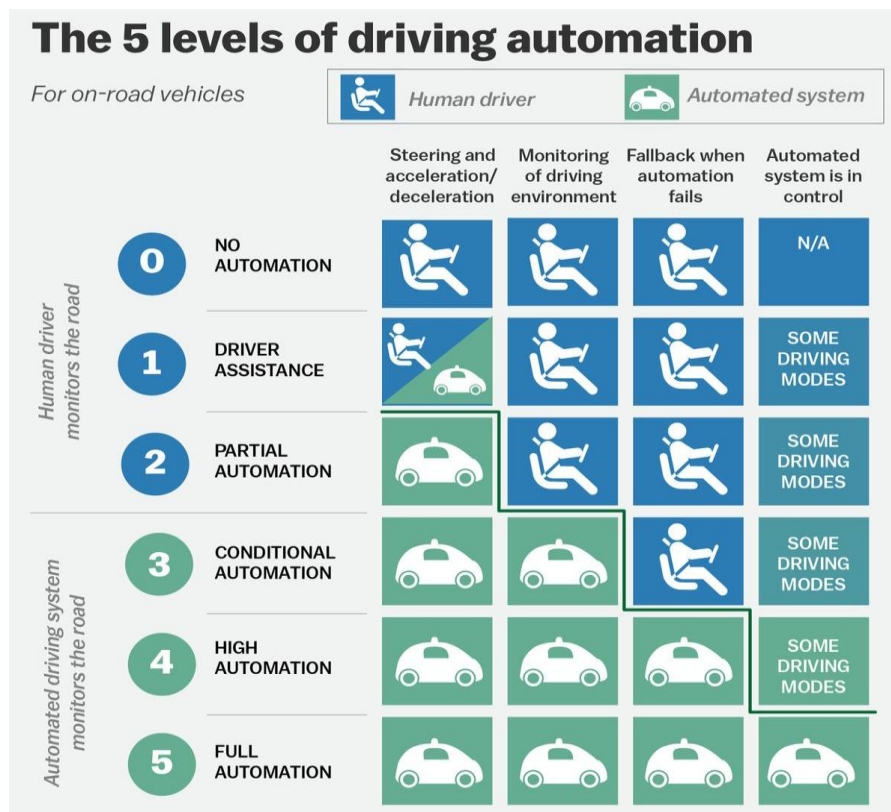


Fig. 2 Levels of Automation

- Level Zero(No Automation): At Level 0 Autonomy, the driver performs all operating tasks like steering, braking, accelerating or slowing down, and so forth.
- Level One(Driver Assistance):At this level, the vehicle can assist with some functions, but the driver still handles all accelerating, braking, and monitoring of the surrounding environment. Think of a car that brakes a little extra for you when you get too close to another car on the highway.
- Level Two( Partial Automation): Most automakers are currently developing vehicles at this level, where the vehicle can assist with steering or acceleration functions and allow the driver to disengage from some of their tasks. The driver must always be ready to take control of the vehicle and it still responsible for most safety-critical functions and all monitoring of the environment.
- Level Three (Conditional Automation): The biggest leap from Level 2 to Levels 3 and above is that starting at Level 3, the vehicle itself controls all monitoring of the environment (using sensors like LiDAR). The driver’s attention is still critical at this level, but can disengage from “safety critical” functions like braking and leave it

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to the technology when conditions are safe. Many current Level 3 vehicles require no human attention to the road at speeds less than 37 miles per hour.

5. Level Four (High Automation): At Levels 4 and 5, the vehicle is capable of steering, braking, accelerating, monitoring the vehicle and roadway as well as responding to events, determining when to change lanes, turn, and use signals. At Level 4, the autonomous driving system would first notify the driver when conditions are safe, and only then does the driver switch the vehicle into this mode. It cannot determine between more dynamic driving situations like traffic jams or a merge onto the highway.
6. Level Five (Complete Automation): This level of autonomous driving requires absolutely no human attention. There is no need for pedals, brakes, or a steering wheel, as the autonomous vehicle system controls all critical tasks, monitoring of the environment and identification of unique driving conditions like traffic jams.

## IV. PRESENT SCENARIO OF AUTOMATION

The leaders in autonomous driving have achieved Level 4 technology, but only along pre-defined routes under specific circumstances (daytime, good weather). These companies are offering campus shuttles or employee buses only, and always with human safety drivers on board. Self-driving cars that the public can actually buy and use themselves are still firmly at Level 3 technology, with [Cadillac's Super Cruise](#) system the [widely-recognized leader](#). This system works on pre-mapped highways, but it is the only hands-free system available to the general population. Currently there are no companies that are able to offer a fully autonomous ride in any conditions, on any road, with no human overseer. Auto Original Equipment Manufacturers, start-ups and others are touting the benefits of the autonomous vehicles and in a highly advertised race to see who will be the first to market at each level. Unfortunately, while autonomous vehicles are currently possible, they require an extensive and expensive set of sensors and software along with exemptions from standard regulations. So far, their use is mostly limited to pilots within geo-fenced areas. The major players include Tesla, Cadillac, Uber, Waymo etc.

## V. ELECTRIC VEHICLES AND AUTOMATION

Autonomous technology integrates better with electric engines. The convergence of the electric propulsion systems and AVs are, in many ways, perfectly aligned. Electric vehicles (EVs) have inherent advantages when it comes to fuel savings and reducing the impact on the environment. , it is also [easier](#) for computers to drive electric vehicles. According to Securing America's Future Energy (SAFE), 58 percent of autonomous, light-duty vehicle retrofits and models are built over an electric power train, while a further 21 percent utilize a hybrid power train. Electric vehicles (EVs) are strongly contributing to the widespread advancement and adoption of autonomous vehicles because:

- Technology-focused early adopters want both innovations in the same car.
- It is easier to implement autonomous features on EVs (e.g. fewer moving pieces).
- Wireless charging integrates seamlessly with autonomy.
- More efficient self-driving extends range, which is an EV pain point.

## VI. IMPORTANT ASPECTS IN DEVELOPMENT OF CONNECTED AND AUTONOMOUS ELECTRIC VEHICLE

Mainly, due to four revolutions namely vehicular automation, vehicle electrification, vehicular connectivity and shared mobility, CAEVs can offer great possibilities in expanding mobility and accessibility, and can play a leading role in achieving eco-friendly mobility. As Vehicular automation involves the use of AI, and multi-agent system (MAS) to assist the vehicle operation, CAEVs can be referred as a smart or intelligent. Vehicular automation includes automated vehicle dynamics control such as adaptive cruise control (ACC) and automated power train operations that can improve vehicle energy efficiency and reduce carbon emissions. Automated driving would allow to reduce unnecessary accelerations as well as decelerations so that energy efficiency can be improved. Consequently, Vehicular automation

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may result in optimized efficiency, increased safety, smooth traffic flow, few accidents as well as less pollution due to completely automated fuel control.

Vehicle electrification, which is referred as zero emission, is one of the appealing ways to reduce transportation related fossil fuel consumption, which in turn, minimize carbon emissions and other pollutions. Due to the vehicle electrification, dependence on fossil fuel oil as well as vulnerability to volatile fuel prices is greatly reduced. Electric vehicles are significantly energy efficient than conventional ICE vehicles, thus, the formers have drastic reductions in long-term operation costs.

Vehicular connectivity accommodates communication systems equipped within the vehicles that allow them to communicate with other vehicles and roadside units (RSUs) to provide a wide range of information such as traffic, infotainment. Motivation for vehicular communication systems is safety and reducing traffic collisions. Advancement of vehicular communication technologies (i.e., V2V, V2I) has not only revolutionized intelligent transportation system (ITS) but also furnishes various promising applications such as collision avoidance, dynamic traffic light. Efficient use of the vehicular communications shall improve eco-driving and encourage more energy efficient driving.

Shared mobility is referred to Mobility-as-a-Service (MaaS), which can be described as a shift away from personally-owned modes of transportation toward mobility solutions that are considered as a service. Shared mobility is evolving rapidly and can take several forms including ride-sharing, shared CAEVs. The shared mobility services shall allow increase in roadway capacity by reducing number of vehicles on the road, thus reducing traffic congestion and tailpipe emissions as well as reducing vehicle miles travelled, and vehicle energy consumption. Due to enabling technologies including mobile and wireless, CAEV in conjunction with shared mobility have the potential to increase the viability of shared transportation services.

## VII. BENEFITS OF CONNECTED AND AUTONOMOUS ELECTRIC VEHICLE

The following are the main advantages of CAEVs

1. **Reduced Accidents:** CAEVs have the potential in the future to reduce deaths and injuries from car crashes, particularly those that result from driver distraction. With 94 percent of fatal vehicle crashes attributable to human error, CAEVs have the potential to reduce accidents, saving 30,000 lives a year.
2. **Reduced Traffic Congestion:** Under normal circumstances, human drivers naturally create stop-and-go traffic, even in the absence of bottlenecks, lane changes, merges or other disruptions. This phenomenon is called the phantom traffic jam. University of Illinois researchers found that by controlling the pace of the autonomous car in the study, they were able to smooth out the traffic flow for all the cars. According to US Energy Information Administration (EIA), even decreasing the number of accidents could reduce congestion, because up to 25% of congestion is caused by traffic incidents.
3. **Reduced Co2 Emission:** The use of fully electric engines and reduction in congestion will most likely result in a reduction of CO<sub>2</sub> emissions as well. Software driven CAEVs can be programmed to reduce emissions to the maximum extent possible. The transition to CAEV is expected to contribute to a 60% fall in emissions.
4. **Increased Lane Capacity:** CAEVs could increase highway capacity by 100 percent and increase expressway travel speeds by more than 20 percent. An even more aggressive estimate, taking into account the possibility of CAEVs platooning in a hypothetical continuous train, could raise capacity even further, to 8,000 vehicles per hour at 60 mph, or 10,000 vehicles per hour at 80 mph. The ability to constantly monitor surrounding traffic and respond with finely tuned braking and acceleration adjustments should enable CAEVs to travel safely at higher speeds and with reduced headway (space) between each vehicle.
5. **Lower Fuel Consumption:** CAEV technology can improve fuel economy, improving it by 4–10 percent by accelerating and decelerating more smoothly than a human driver. A platoon of closely spaced CAEVs that stops or slows down less often resembles a train, enabling lower peak speeds (improving fuel economy) but higher effective speeds (improving travel time). Over time, as the frequency of crashes is reduced, cars and trucks could be made much lighter. This would increase fuel economy even more.

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6. First/Last Mile Services: CAEVs are well-positioned to provide first/last-mile services to connect commuters to public transportation. Larger cities have the problem of providing adequate public transportation. Many lack the appropriate infrastructure to support the needs of their residents, a void that could partially be filled by self-driving cars.
7. Transportation Accessibility: Many seniors and people with disabilities cannot currently drive, even with vehicle modifications that help others drive safely. CAEVs could provide many people an access to the open road and to independence. With self-driving cars, tasks like commuting to work, going to the doctor, and visiting family across town could become easier for seniors and those with disabilities.
8. Reduced Travel Time and Transportation Costs: CAEVs may cut travel time by up to 40 percent, recover up to 80 billion hours lost to commuting and congestion, and reduce fuel consumption by up to 40 percent in traffic congested cities.
9. More Effective and Affordable Taxis: The waiting time and cost for a cab will come down as connectivity enables the taxi to reach quickly and autonomous feature combined with electric engine brings down the running cost.
10. More Efficient Parking: CAEVs remove commuter's demands for street and lot parking. Some cities devote a third of their land to parking and CAEVs could free up significant real estate for other uses, from parks to residences to office space. For personal CAEVs, commuters may be dropped at a location and the vehicle would park itself away from the destination, where space is available. Cutting back on the land used for parking might even reduce real estate costs. With self-driving cars, vehicles can be stacked right next to each other. Urban areas facing acute space shortage will gain from the transition to driverless cars.
11. Minimized environmental impact and better quality of urban life: As CAEVs run on electric engines, the environmental impact is considerably less. Minimized environmental pollution would improve quality of life, particularly in urban areas.
12. Relaxed drivers: CAEVs can be designed in different levels of automation. As the level of automation increases, drivers can rest, work, or entertain themselves during a trip safely.
13. Less fuel costs: Fossil fuel will not be consumed to run CAEV with fully electric engine. Even in case of CAEV's with hybrid engines, the amount of fossil fuel consumed will be considerably less and thus fuel cost is significantly reduced.

Wider adoption of the CAEVs is expected to improve road safety, optimize traffic flow, help reduce fuel consumption, and minimize CO<sub>2</sub> emissions in the urban environments. Overall energy efficiency and environmental implications of CAEVs in future will depend on following influencing mechanisms:

1. Energy-saving algorithms and vehicle design.
2. Vehicle operation (i.e., eco-driving).
3. Platooning.
4. Electrification using renewable energy resources.
5. Vehicle utilization.
6. Travel-cost implications
7. Congestion mitigation.
8. Information and communication technology (ICT) infrastructure.
9. Government policies and laws.

### VIII. CHALLENGES ASSOCIATED WITH CONNECTED AND AUTONOMOUS ELECTRIC VEHICLE

The technical challenges associated with CAEVs includes

1. Safety Standards: Safety is the most fundamental requirement of autonomous cars. There are several standards, such as the ISO 26262, that specify the safety standard for road vehicles. For self-driving cars standards are under development. Google Car tests show one million kilometres without any accident. Testing of present-day cars should demonstrate the compliance of their behaviour with legislative norms. In CAEVs both software and hardware plays an important role in assuring safety. Software of the car may get advanced even when the vehicle is already on the street, testing should account for this new challenge. When it comes to hardware and hardware-

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software systems, there comes a situation where choice is to be made. Laser radars are very expensive, but deliver high quality data in diverse weather conditions. Ultra-sonic sensors or cameras are less accurate and sensitive under weather conditions like rain. If a car manufacturer choose a cheap over an expensive sensor the likelihood of errors/faults/accidents increases.

2. Security: For autonomous cars, security is of paramount importance, and software security is a fundamental requirement. The following eight basic principles should be followed: (1) Organizational security is owned, governed, and promoted at board level; (2) Security risks are assessed and managed appropriately and proportionately, including those specific to the supply chain; (3) Organizations need product aftercare and incident response to ensure systems are secure over their lifetime; (4) All organizations, including sub-contractors, suppliers, and potential 3rd parties, work together to enhance the security of the system; (5) Systems are designed using a defence-in-depth approach; (6) The security of the software is managed throughout its lifetime; (7) The storage and transmission of data is secure and can be controlled; (8) The system is designed to be resilient to attacks and respond appropriately when its defences or sensors fail.
3. Privacy: The more information taken into consideration for the decision making, the more it might interfere with data and privacy protection. For example, a sensor that detects obstacles, such as human beings in front of the car is based on visual information. Even the use of a single sensor could invade privacy, if the data is recorded/reported and/or distributed without the consent of the involved people. At most care should be taken to avoid breach of privacy.
4. Trust: Trust is an issue that appears in various forms in CAEVs e.g. in production (when assembled, trust is the requirement for both hardware and software components) as well as in use of the car. A human might define where the car has to go, but the self-driving car will make the decisions how to get there, following the given rules and laws. However the self-driving car might already distribute data like the target location to a number of external services, such as traffic information or navigation data, which are used in the calculation of the route. Thus ensuring trust worthiness of data sources (e.g., GPS, map data, external devices and other vehicles) becomes important.
5. Transparency: The transparency is of central importance for many of the previously introduced challenges. Without transparency none of them could be analysed, because the important information would be missing. Transparency is a prerequisite for ethical engagement in the development of autonomous cars. There can be nothing hidden, no cover-ups, no withholding of information. It is a multidisciplinary challenge to ensure transparency, while respecting e.g., copyright, corporate secrets, security and other concerns and many other related topics. It is to be ensured that right amount of information/data are disclosed at right time on right places
6. Reliability: In connected vehicles there are different levels that should be considered for reliability purposes. First, the diagnostic of the vehicle that might be subject to failures. Then, the vehicle sensors that enable the vehicle to sense the surrounding environment of the vehicle. Finally, the data coming from external entities, like other vehicles and road infrastructures. Reliability approaches should consider all these levels.
7. Responsibility and Accountability: In the case of autonomous cars, responsibility will obviously be redefined in case of incidents and accidents. Redefining of accountability and responsibility is a complex task as all possibilities should be taken into account and legality should be maintained. Regarding ethical aspects of responsibility, a lot can be learned from the existing Roboethics.
8. Quality Assurance Process: Detailed Quality assurance programs covering all relevant steps must be developed in order to ensure high quality components. One part of the Quality Assurance (QA) process regards assembling of components. All parts of a vehicle are designed, fabricated and then assembled to the overall car. A standard non-autonomous premium vehicle today has more than 100 electronic control units that are responsible for the control of e.g., the engine, the wipers, the navigation system or the dashboard. For self-driving cars, the number will be increased. Parts are usually built by not one, but a multitude of suppliers. This requires an extensive design and development process, which again involves various disciplines, such as requirements engineering, software engineering or project management. All this makes quality assurance a huge challenge.

Apart from above mentioned technical challenges, there are several social and legal challenges associated with CAEVs. Self-driving cars will influence job markets, as for example for taxi drivers, chauffeurs or truck drivers. The perception

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of cars will change and cars might be seen as a service that is used for transportation. The idea of having a vehicle that is specialized for the specific use, e.g. off road, city road, long travels might become attractive. This might impact the business model of car manufacturer and their market. It is expected that the accident frequency will decrease rapidly, so car insurances may become less important. This may affect insurance companies in terms of jobs and the business. Many job opportunities related to CAEVs like that of Artificial Intelligence and Programming would increase. Present-day regulatory instruments for transportation systems are based on the assumption of human-driven vehicles. It has been recognized that present state regulatory instruments for human-controlled vehicles will not be adequate for self-driving cars. The existing legislation, standards and regulations are likely to be insufficient to meet the needs of the time and reap the full benefits of automation technology. Authorities need to be updated to recognize the challenges autonomous vehicles pose. The legislation frameworks should consider the aspects of use of data, liability, exchange of knowledge and cross-border testing for the emerging technology. For an effective communication between the technological and political spheres, categorization and terminology are being developed which define different levels of vehicle automation.

## IX. CONCLUSION

The Connected and Autonomous Electric Vehicles will be an important part of the coming automobile revolution which is driven by the need for sustainable, eco-friendly and smart mobility. The CAEVs have the great potential to operate with even higher vehicle efficiency, if they are charged using the electricity generated from renewable energy sources and that will significantly reduce emissions as well as dependency on fossil fuels as well. CAEVs combine the abilities of connectivity, automation and e- mobility and are capable of sensing its environment and navigating with little or no human input. The potential impact of CAEV technology is vast and it is being hailed by many as the fourth industrial revolution. While the automotive sector stands to be radically altered, it is not alone. The possible applications of this technology straddle a variety of different sectors and will change not only the way people travel but the way that we live our lives. While disruption on such a broad scale presents a wide range of opportunities, the speed at which this technology is developing, combined with the evolving regulatory landscape poses a number of novel and challenging issues. Efficient addressing of the associated challenges would enable easy transition to CAEVs which on the other hand is expected to improve road safety, optimize traffic flow, reduce fuel consumption, and minimize environmental pollution.

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