IAES Journal of Electrical and Electronics Engineering
Vol. 9, No. 2, December 2022, pp. 26~30
ISSN: 2338-7432, DOI: 10.11591/jeee.v9i2.pp26-30

Smart and sustainable automotive technologies: a review of vehicle electrification, autonomous driving, and vehicle-to-everything communication

Tole Sutikno[1], Watra Arsadiando[2], Anggit Pamungkas[2]
[1]Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Embedded Systems and Power Electronics Research Group, Yogyakarta, Indonesia

Article Info

Article history:

Received Aug 18, 2020
Revised Jan 27, 2021
Accepted Feb 13, 2021

Keywords:

Advanced driver-assistance systems
Autonomous driving
Electric vehicles
Smart grid
Sustainable mobility
Vehicle-to-everything
Vehicle-to-grid

ABSTRACT

The transition toward sustainable mobility is reshaping the relationship between automobiles, communication infrastructure, and electric power systems. Battery electric vehicles (EVs) reduce tailpipe emissions and enable new energy services, while advanced driver-assistance systems (ADAS) and autonomous driving can improve traffic safety and operational efficiency. Vehicle-to-everything (V2X) communication extends vehicle awareness through vehicle-to-vehicle and vehicle-to-infrastructure information exchange, whereas vehicle-to-grid technology enables bidirectional interaction between electric vehicles and smart grids. Despite these opportunities, the three technology domains are often developed independently, creating challenges involving charging demand, renewable-energy coordination, communication reliability, cybersecurity, data interoperability, and lifecycle impacts. This review synthesizes research published through 2021 on vehicle electrification, autonomous driving and ADAS, V2V/V2I/V2X communication, and V2G-enabled smart-grid integration. It compares their functions, enabling technologies, benefits, and deployment barriers, and examines the system-level dependencies between mobility and energy infrastructures. The review identifies a key research gap in the coordinated design of intelligent transport and energy systems, particularly under uncertain driving patterns and variable renewable generation across urban and regional transportation networks. An integrated framework and future research priorities are proposed to support sustainable, connected, and energy-aware mobility.

This is an open access article under the CC BY-SA license.

1. INTRODUCTION

The automotive sector is undergoing a major transformation driven by environmental concerns, advances in digital technology, and the increasing demand for safer and more efficient transportation. Vehicle electrification is reducing dependence on conventional fossil-fuel powertrains, while autonomous driving and advanced driver-assistance systems (ADAS) are changing how vehicles perceive and respond to their surroundings. At the same time, vehicle-to-everything (V2X) communication enables information exchange between vehicles, infrastructure, networks, and other road users. These developments indicate that future automotive systems will operate as interconnected components of both intelligent transportation and energy infrastructures [1]–[4].

Despite their potential, these technologies introduce challenges that cannot be solved independently. Electric vehicle (EV) adoption increases electricity demand and requires appropriate charging infrastructure, while uncontrolled charging may create distribution-grid congestion and additional peak loads. Autonomous vehicles depend on reliable sensing, computing, and communication, whereas V2X applications require low-latency connectivity, interoperability, and cybersecurity. The environmental benefits of electrification also depend on electricity generation, battery production, charging behavior, and end-of-life management [5]–[9].

Previous studies have examined EV technologies, autonomous driving, vehicular communication, and vehicle-to-grid (V2G) integration as separate research areas. However, the interactions between these domains remain important because mobility patterns determine charging demand, communication supports coordinated transportation and energy services, and grid conditions influence the sustainability of electric mobility. This review addresses this gap by synthesizing research published through 2021 and examining the technical relationships among electrification, autonomous driving, V2X communication, and smart-grid integration. Its objective is to identify an integrated direction for developing intelligent automotive technologies that are environmentally responsible, operationally reliable, and compatible with future energy systems.

2. VEHICLE ELECTRIFICATION AND SUSTAINABLE POWERTRAINS

Vehicle electrification is a central pathway toward reducing the direct emissions associated with road transportation. Battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs) use different combinations of electric machines, batteries, power converters, and conventional power sources. BEVs rely primarily on stored electrical energy, whereas HEVs and PHEVs combine electric propulsion with internal combustion engines to varying degrees. Their performance depends on battery characteristics, powertrain configuration, motor efficiency, energy management, and charging infrastructure [1], [2], [10].

The development of electric powertrains has improved the efficiency and flexibility of automotive propulsion systems. Permanent-magnet synchronous motors, induction motors, and other electric machine technologies offer different combinations of power density, efficiency, cost, and control complexity. Power electronic converters regulate energy transfer between batteries and traction motors, while regenerative braking recovers part of the vehicle's kinetic energy during deceleration. Improvements in converter topologies, semiconductor devices, and motor control can increase driving efficiency and reduce energy losses [3], [4], [11].

Charging infrastructure is equally important because it determines the practicality and scalability of electric mobility. Conductive charging remains widely adopted, while wireless power transfer offers the possibility of convenient stationary or dynamic charging. Charging systems differ in power level, conversion topology, efficiency, installation requirements, and communication capability. Fast charging can reduce charging time, but high charging demand may affect power quality, distribution-network loading, and battery degradation [6]–[8], [12].

The sustainability of EVs must therefore be evaluated across their entire lifecycle rather than through tailpipe emissions alone. Battery manufacturing, material extraction, electricity generation, vehicle operation, reuse, and recycling all influence environmental performance. EVs can provide substantial environmental benefits when powered by low-carbon electricity, but these benefits vary with the regional energy mix and battery supply chain. Sustainable electrification consequently requires coordinated progress in clean electricity, efficient charging, responsible material sourcing, and battery circularity [1], [5], [9].

3. AUTONOMOUS DRIVING AND ADVANCED DRIVER-ASSISTANCE SYSTEMS

Autonomous driving represents a major development in intelligent automotive technology because it enables vehicles to perceive their environments and make driving decisions with reduced human intervention. ADAS functions, including adaptive cruise control, automatic emergency braking, lane-keeping assistance, blind-spot monitoring, and parking assistance, provide varying levels of automated support. Higher automation levels require increasingly sophisticated perception, localization, decision-making, planning, and vehicle-control capabilities. These functions rely on integrated hardware and software platforms that process information from multiple sensors in real time [13]–[16].

Environmental perception is a critical requirement for autonomous driving and ADAS. Cameras provide visual information for lane detection, traffic-sign recognition, and object classification, while radar measures object distance and relative velocity. LiDAR can generate detailed three-dimensional representations of the surrounding environment, and ultrasonic sensors support short-range detection. Sensor fusion combines complementary measurements to improve perception reliability, although adverse weather, occlusion, sensor failure, and inconsistent data can still affect performance [13]–[15].

Autonomous driving systems generally combine perception, localization, prediction, planning, and control. Perception identifies road users and environmental features, while localization estimates the vehicle's position using maps and sensor information. Prediction estimates the future behavior of surrounding road users, and planning determines an appropriate trajectory under road and traffic constraints. Vehicle-control algorithms then translate the planned trajectory into steering, braking, and acceleration commands [14]–[16].

Although autonomous driving can improve traffic efficiency and reduce certain human-related driving errors, its deployment remains constrained by technical and operational limitations. Complex road environments, unpredictable human behavior, sensor uncertainty, and rare traffic scenarios can challenge the reliability of automated systems. Communication with other vehicles and road infrastructure may improve situational awareness, but connected information cannot replace reliable onboard perception and safety mechanisms. Therefore, ADAS and autonomous driving should be developed with rigorous testing, functional-safety considerations, and clearly defined operational boundaries [13], [15], [16].

4. VEHICLE-TO-EVERYTHING COMMUNICATION: V2V AND V2I

V2X communication provides a framework for exchanging information between vehicles and their surrounding environment. V2V communication allows vehicles to share information such as position, speed, acceleration, and potential hazards. V2I communication connects vehicles with roadside infrastructure, traffic signals, road sensors, and traffic-management systems. These communication capabilities can support cooperative awareness, intersection management, hazard warnings, traffic optimization, and selected autonomous-driving applications [17]–[20].

V2X communication can be implemented through dedicated short-range communication technologies, cellular V2X systems, and emerging 5G networks. These technologies differ in communication range, latency, reliability, spectrum use, network architecture, and deployment requirements. Cellular V2X and 5G-based approaches offer opportunities for broader connectivity and advanced cooperative applications, while interoperability with existing communication systems remains essential. The selection of communication technology must reflect the safety requirements and operating conditions of each application [18]–[21].

Communication security and reliability are particularly important because vehicles may use exchanged information to support safety-related decisions. False messages, identity spoofing, replay attacks, and unauthorized access can compromise the integrity of cooperative driving applications. Authentication, message integrity, privacy protection, intrusion detection, and secure communication protocols are therefore necessary elements of V2X deployment. Research has identified cybersecurity and interoperability as continuing challenges for connected and autonomous transportation systems [19], [20], [22].

5. VEHICLE-TO-GRID AND SMART-GRID INTEGRATION

Vehicle-to-grid technology extends the role of EVs beyond transportation by enabling bidirectional energy exchange with the electricity grid. In conventional charging, electricity flows from the grid to the vehicle, whereas V2G-capable systems can also export stored energy from vehicle batteries to the grid. This capability allows aggregated EVs to provide services such as peak shaving, frequency regulation, load balancing, and support for renewable-energy integration. The concept transforms participating vehicles into flexible distributed energy resources, provided that suitable chargers, communication systems, and grid-interconnection arrangements are available [23]–[26].

Smart charging is an important first step toward vehicle-grid integration because it coordinates charging schedules with electricity demand, energy prices, renewable generation, and user requirements. Uncontrolled charging may increase peak demand, whereas coordinated charging can shift energy consumption toward periods of lower demand or greater renewable-energy availability. V2G adds bidirectional power flow and can provide additional grid flexibility, but its implementation requires consideration of battery degradation, user mobility requirements, charger cost, and compensation mechanisms. These factors demonstrate that technical feasibility alone does not guarantee widespread commercial adoption [8], [23]–[26].

The integration of EVs with smart grids also requires effective communication and interoperability between vehicles, charging stations, aggregators, and grid operators. Open communication protocols can support information exchange concerning charging schedules, power availability, user preferences, and grid requirements. Bidirectional onboard chargers and appropriate power electronic interfaces are essential for controlling energy flow between the vehicle and the grid. In addition, distribution-network operators must consider transformer loading, voltage regulation, power quality, and the location of charging infrastructure when planning large-scale EV deployment [7], [8], [24]–[26].

6. INTEGRATED ASSESSMENT OF SMART AND SUSTAINABLE AUTOMOTIVE TECHNOLOGIES

The reviewed technologies perform different but complementary functions within a connected automotive ecosystem. Vehicle electrification provides the electrical powertrain and energy-storage capability, while ADAS and autonomous driving improve perception, decision-making, and vehicle

operation. V2V and V2I communication extend the information available to vehicles and infrastructure, whereas V2G connects vehicle energy storage with smart-grid services. Table 1 summarizes these relationships and identifies the principal technical challenges associated with each technology.

Table 1. Functional comparison of smart and sustainable automotive technologies

Technology	Main function	Potential contribution	Key challenges
EVs	Electrified propulsion and energy storage	Reduced tailpipe emissions and improved energy efficiency	Battery cost, charging access, lifecycle impacts
ADAS	Driver assistance and partial automation	Improved driving safety and situational awareness	Sensor reliability and operational limitations
Autonomous driving	Automated perception, planning, and control	Potential improvements in mobility and traffic efficiency	Safety validation and complex environments
V2V	Direct vehicle-to-vehicle information exchange	Cooperative awareness and collision warnings	Latency, reliability, and cybersecurity
V2I	Vehicle interaction with road infrastructure	Traffic coordination and infrastructure-based warnings	Deployment cost and interoperability
V2G	Bidirectional vehicle-grid energy exchange	Grid flexibility and renewable-energy support	Battery degradation, standards, and economic incentives
Smart-grid integration	Coordinated management of EV charging and grid operation	Better load management and renewable-energy utilization	Grid capacity, communication, and regulation

As shown in Table 1, the greatest benefits emerge when these technologies are coordinated rather than deployed independently. For example, autonomous and connected EV fleets can potentially optimize routes and charging schedules using traffic information, charging-station availability, and electricity-price signals. V2I communication can provide information about congestion and charging infrastructure, while V2G aggregation can coordinate the energy services of vehicles connected to the grid. Such coordination requires common data interfaces, reliable communication, secure control, and compatibility between mobility and electricity-system objectives.

7. RESEARCH CHALLENGES AND FUTURE DIRECTIONS

A major research challenge is the lack of integrated frameworks that simultaneously consider vehicle operation, communication, and energy management. Many EV studies focus on battery performance and charging infrastructure, while autonomous-driving research emphasizes perception, planning, and control. V2X research often concentrates on wireless communication performance and cybersecurity, whereas V2G research emphasizes grid services and charging coordination. Future studies should develop system-level models that combine mobility demand, vehicle availability, communication quality, battery constraints, and grid operating conditions [17], [23]–[27].

Another important challenge concerns the reliability and security of connected automotive systems. Autonomous vehicles may depend on information received from other vehicles and roadside infrastructure, but communication failures or malicious messages can lead to incorrect decisions. Similarly, smart charging and V2G services rely on secure data exchange between vehicles, charging equipment, aggregators, and grid operators. Future architectures should therefore incorporate cybersecurity, privacy protection, fault tolerance, and functional-safety requirements from the early design stage [18]–[22].

The environmental performance of future automotive technologies also requires more comprehensive assessment. Electrification alone does not guarantee sustainability if battery production, electricity generation, and end-of-life processes remain carbon-intensive. Autonomous driving and connected mobility may improve traffic flow, but additional computing, sensing, communication, and vehicle travel could introduce new energy demands. Research should therefore evaluate lifecycle emissions, battery reuse, renewable-powered charging, efficient traffic management, and the overall energy consumption of connected vehicle systems [1], [5], [9], [12].

8. CONCLUSION

Smart and sustainable automotive technologies are transforming vehicles into interconnected mobility and energy platforms. Electrification provides efficient propulsion and battery storage, while ADAS and autonomous driving introduce advanced perception and automated control. V2V and V2I communication support cooperative transportation, and V2G enables EVs to contribute to smart-grid operation through bidirectional energy exchange. These technologies offer complementary opportunities to improve transportation efficiency, road safety, energy flexibility, and environmental performance. However, their full

potential depends on coordinated technical development and system-level integration. Battery lifecycle impacts, charging infrastructure, communication reliability, cybersecurity, interoperability, grid constraints, and economic incentives remain important barriers. Future research should focus on integrated mobility-energy architectures that coordinate vehicle operation, connected services, renewable electricity, and grid flexibility while maintaining safety and user requirements. Such integration provides a practical direction for developing intelligent, connected, and genuinely sustainable automotive systems.

REFERENCES

[1] J. A. Sanguesa, V. Torres-Sanz, P. Garrido, F. J. Martinez, and J. M. Marquez-Barja, "A review on electric vehicles: Technologies and challenges," *Smart Cities*, vol. 4, no. 1, pp. 372–404, Mar. 2021, doi: 10.3390/smartcities4010022.

[2] M. Ehsani, K. V. Singh, H. O. Bansal, and R. T. Mehrjardi, "State of the art and trends in electric and hybrid electric vehicles," in *Proceedings of the IEEE*, Jun. 2021, pp. 967–984. doi: 10.1109/JPROC.2021.3072788.

[3] W. Cai, X. Wu, M. Zhou, Y. Liang, and Y. Wang, "Review and development of electric motor systems and electric powertrains for new energy vehicles," *Automotive Innovation*, vol. 4, no. 1, pp. 3–22, Feb. 2021, doi: 10.1007/s42154-021-00139-z.

[4] J. L. Afonso *et al.*, "A review on power electronics technologies for electric mobility," *Energies*, vol. 13, no. 23, p. 6343, Dec. 2020, doi: 10.3390/en13236343.

[5] M. S. H. Lipu *et al.*, "Review of electric vehicle converter configurations, control schemes and optimizations: Challenges and suggestions," *Electronics (Switzerland)*, vol. 10, no. 4, p. 477, Feb. 2021, doi: 10.3390/electronics10040477.

[6] S. M. Arif, T. T. Lie, B. C. Seet, S. Ayyadi, and K. Jensen, "Review of electric vehicle technologies, charging methods, standards and optimization techniques," *Electronics (Switzerland)*, vol. 10, no. 16, p. 1910, Aug. 2021, doi: 10.3390/electronics10161910.

[7] M. Brenna, F. Foiadelli, C. Leone, and M. Longo, "Electric vehicles charging technology review and optimal size estimation," *Journal of Electrical Engineering and Technology*, vol. 15, no. 6, pp. 2539–2552, Nov. 2020, doi: 10.1007/s42835-020-00547-x.

[8] S. Kumar, A. Usman, and B. S. Rajpurohit, "Battery charging topology, infrastructure, and standards for electric vehicle applications: A comprehensive review," *IET Energy Systems Integration*, vol. 3, no. 4, pp. 381–396, Dec. 2021, doi: 10.1049/esi2.12038.

[9] M. Ashfaq, O. Butt, J. Selvaraj, and N. Rahim, "Assessment of electric vehicle charging infrastructure and its impact on the electric grid: A review," *International Journal of Green Energy*, vol. 18, no. 7, pp. 657–686, May 2021, doi: 10.1080/15435075.2021.1875471.

[10] L. Wang, Z. Qin, T. Slangen, P. Bauer, and T. Van Wijk, "Grid impact of electric vehicle fast charging stations: Trends, standards, issues and mitigation measures - an overview," *IEEE Open Journal of Power Electronics*, vol. 2, pp. 56–74, 2021, doi: 10.1109/OJPEL.2021.3054601.

[11] F. Gonzalez Venegas, M. Petit, and Y. Perez, "Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services," *Renewable and Sustainable Energy Reviews*, vol. 145, p. 111060, Jul. 2021, doi: 10.1016/j.rser.2021.111060.

[12] B. K. Sovacool, J. Axsen, and W. Kempton, "The future promise of vehicle-to-grid (V2G) integration: A sociotechnical review and research agenda," *Annual Review of Environment and Resources*, vol. 42, no. 1, pp. 377–406, Oct. 2017, doi: 10.1146/annurev-environ-030117-020220.

[13] F. Mwasilu, J. J. Justo, E. K. Kim, T. D. Do, and J. W. Jung, "Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration," *Renewable and Sustainable Energy Reviews*, vol. 34, pp. 501–516, Jun. 2014, doi: 10.1016/j.rser.2014.03.031.

[14] M. Sarp and N. Altin, "Review on vehicle-to-grid systems: The most recent trends and smart grid interaction technologies," *Gazi University Journal of Science*, vol. 33, no. 2, pp. 394–411, Jun. 2020, doi: 10.35378/gujs.554206.

[15] N. Naik and C. Vyjayanthi, "Optimization of vehicle-to-grid (V2G) services for development of smart electric grid: A review," in *2021 International Conference on Smart Generation Computing, Communication and Networking, SMART GENCON 2021*, IEEE, Oct. 2021, pp. 1–6. doi: 10.1109/SMARTGENCON51891.2021.9645903.

[16] M. Yilmaz and P. T. Krein, "Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles," *IEEE Transactions on Power Electronics*, vol. 28, no. 5, pp. 2151–2169, May 2013, doi: 10.1109/TPEL.2012.2212917.

[17] A. Triviño, J. M. González-González, and J. A. Aguado, "Wireless power transfer technologies applied to electric vehicles: A review," *Energies*, vol. 14, no. 6, p. 1547, Mar. 2021, doi: 10.3390/en14061547.

[18] M. N. Ahangar, Q. Z. Ahmed, F. A. Khan, and M. Hafeez, "A survey of autonomous vehicles: Enabling communication technologies and challenges," *Sensors (Switzerland)*, vol. 21, no. 3, p. 706, Jan. 2021, doi: 10.3390/s21030706.

[19] C. Badue *et al.*, "Self-driving cars: A survey," *Expert Systems with Applications*, vol. 165, p. 113816, Mar. 2021, doi: 10.1016/j.eswa.2020.113816.

[20] E. Yurtsever, J. Lambert, A. Carballo, and K. Takeda, "A survey of autonomous driving: common practices and emerging technologies," *IEEE Access*, vol. 8, pp. 58443–58469, 2020, doi: 10.1109/ACCESS.2020.2983149.

[21] J. Jeong *et al.*, "A comprehensive survey on vehicular networks for smart roads: A focus on IP-based approaches," *Vehicular Communications*, vol. 29, p. 100334, Jun. 2021, doi: 10.1016/j.vehcom.2021.100334.

[22] H. (Harrison) Jeong, Y. (Chris) Shen, J. (Paul) Jeong, and T. (Tom) Oh, "A comprehensive survey on vehicular networking for safe and efficient driving in smart transportation: A focus on systems, protocols, and applications," *Vehicular Communications*, vol. 31, p. 100349, Oct. 2021, doi: 10.1016/j.vehcom.2021.100349.

[23] A. Alalewi, I. Dayoub, and S. Cherkaoui, "On 5G-V2X use cases and enabling technologies: A comprehensive survey," *IEEE Access*, vol. 9, pp. 107710–107737, 2021, doi: 10.1109/ACCESS.2021.3100472.

[24] M. Hasan, S. Mohan, T. Shimizu, and H. Lu, "Securing vehicle-to-everything (V2X) communication platforms," *IEEE Transactions on Intelligent Vehicles*, vol. 5, no. 4, pp. 693–713, Dec. 2020, doi: 10.1109/TIV.2020.2987430.

[25] M. R. Khalid, I. A. Khan, S. Hameed, M. S. J. Asghar, and J. S. Ro, "A comprehensive review on structural topologies, power levels, energy storage systems, and standards for electric vehicle charging stations and their impacts on grid," *IEEE Access*, vol. 9, pp. 128069–128094, 2021, doi: 10.1109/ACCESS.2021.3112189.

[26] J. Yuan, L. Dorn-Gomba, A. D. Callegaro, J. Reimers, and A. Emadi, "A review of bidirectional on-board chargers for electric vehicles," *IEEE Access*, vol. 9, pp. 51501–51518, 2021, doi: 10.1109/ACCESS.2021.3069448.