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SYSTEMATIC REVIEW OF SOLAR PHOTOVOLTAICS AND AUTOMOTIVE APPLICATIONS

Zach Schreiber, Anne Lucietto, Ph.D.
School of Engineering Technology
Purdue University, West Lafayette, IN, United States

Abstract— **Photovoltaic (P.V.) solar cells convert sunlight into electricity. The conversion of available sunlight to electricity leads to investigations focused on technologies that reduce reliance on fossil fuels and reduce carbon emissions. Investigative work in this area leads to several improvements, increasing efficiencies, cleaner processes, new materials, and reduces cost. With increasing awareness and growing need for sustainable development, P.V.'s have made their way into various applications in the Energy, Industrial, Commercial, Residential, and Transportation sectors of the world. The migration of P.V.'s is reducing reliance on fossil fuels for energy while combating carbon emissions and climate change.**

The oil embargo of the 1970s led many governments and researchers to investigate alternative and cleaner technologies of vehicle propulsion in the transportation industry, including hydrogen, ethanol, natural gas, methane, and various forms of electric vehicles (E.V.'s). Of these technologies, electric vehicles have gained popularity in the market with improvements continuing to advance the field in energy efficiency, storage, and management with a potential of energy generation using P.V.'s mounted to vehicles. The utilization of vehicle integrated P.V. solar cells presents possibilities for improving the range of electric vehicles demonstrated throughout various solar race challenges worldwide. Many of these solar electric vehicles (S.E.V.'s) were on the individual, research-based scale, and little use of this technology has made it to market vehicles. Further improvements and investigations in P.V. and E.V. technology continue to improve consumer level adoption to address their challenges and limitations.

As a result of examining these facts, the researchers present a summary systemic review of existing research on the use of solar energy to power an automobile. It will lightly cover solar energy collectors and then provide a more in-depth examination of existing literature.

Keywords— **Photovoltaics (P.V.), Electric Vehicle (E.V.), Solar Electric Vehicle (S.E.V.)**

I. INTRODUCTION

The discovery of the photovoltaic effect converting sunlight into electricity in the 1800s sparked interest in P.V. technologies. After World War II, the space race led to more massive research and development in P.V. technologies worldwide for extra-terrestrial applications. New research identified materials and manufacturing processes that improved solar P.V. panels' performance, ultimately leading to the extensive adoption of P.V.'s for terrestrial applications in many energy sectors.

The oil shortages of the 1970s incentivized research into alternative propulsion technologies in the transportation industry. Engineers and scientists developed new concept vehicles powered by alternative energy sources, including E.V.'s resurrection and a new concept of S.E.V.'s. After the end of the oil shortage, these concepts struggled to gain attention and slowly faded to a small market sector due to the return of cheap oil.

Due to increasing concern for climate change and improvements in technology, E.V.'s and solar P.V.'s began to gain popularity in the early 21st century. Decreasing costs, government subsidies, and improvements in technology, infrastructure, and performance led to greater adoption by consumers, industry, and businesses of E.V.'s and P.V.'s to transition to more efficient and sustainable technologies. This article discusses the history, trends, applications, impacts, costs, and challenges associated with P.V.'s and E.V.'s and presents P.V. and E.V.'s utilization to benefit society while addressing climate change and other environmental concerns.

II. LITERATURE REVIEW

A. Solar Energy

Solar energy is the most readily available, free energy source that contributes to our planet’s sustainment. Solar heating along with the earth’s rotation and terrain contribute to various climates and weather patterns, driving winds, waves, and precipitation. Capturing these different solar energy forms can be seen today using renewable energy applications, including wind, hydroelectric, solar thermal, and solar photovoltaic applications [1]. Wind and hydroelectric applications are indirect forms of capturing solar energy that are driven by weather. Solar thermal and solar photovoltaics are direct forms of capturing solar energy since both rely on direct radiation from sunlight and require sunny days for capturing energy.

Solar thermal and solar photovoltaic applications are the most common forms of capturing solar energy. Solar thermal and P.V. technologies can be seen in many energy sectors worldwide, differing in application [2]. Solar thermal technologies capture the Sun's radiant heat energy, heating a fluid, such as a liquid or gas, for heating and cooling applications. Solar P.V.'s capture the Sun's energy through the photovoltaic effect, converting the Sun's photon energy directly to electricity. By utilizing solar energy technologies, buildings can generate electricity and heat, consuming little electricity or other fuel sources external to the building. The practice of consuming as much energy as produced by equipment dedicated to a building is called net-zero. The adoption of both solar technologies is key to achieving net-zero energy buildings producing clean, free energy [3].

Solar Thermal

High efficiencies and the ability to capture the Sun's energy in the form of heat increased solar thermal collectors' popularity. Fluids such as liquids and gases capture heat from the Sun for heating and cooling applications, thermal storage, or electricity generation [4]. Different applications require different styles and quantities of solar thermal collectors. Standard solar thermal collectors include flat plate, evacuated tube, parabolic dish, compound parabolic concentration, parabolic trough, heliostat field, and linear Fresnel [5]. Many of these collectors can be defined as concentrated vs. non-concentrated, glazed vs. unglazed, and fixed vs. tracking [4]. A concentrated collector uses concentrators such as mirrors to increase solar intensity. A glazed collector uses a glass covering on an absorber surface and insulation. A tracking system moves the collector or concentrator to stay perpendicular to the Sun to collect the most energy possible and increase solar intensity [5]. Flat plate and evacuated tube collectors are for low to medium temperature applications below 100 C for domestic water heating and storage. Concentrated collectors such as parabolic dish, compound parabolic concentration, parabolic trough, heliostat field, and linear Fresnel are for higher temperature applications above 100 C for heating and energy generation [5]. Each type of solar thermal collector has a specific purpose and benefit associated with it. All solar thermal collectors require pumps, fans, piping, ductwork, and other equipment necessary for operations, making them less ideal for small applications and impossible for vehicles. Due to the universal usability of electricity, decreasing costs, and low operation and maintenance compared to solar thermals, solar P.V.'s adoption has continued to increase worldwide while solar thermals have stalled.

Solar Photovoltaics (P.V.'s)

The discovery of the photovoltaic effect created new opportunities for harvesting energy and creating electricity. The photovoltaic effect was first observed in 1839 by Alexandre Becquerel using an "electrode in solution" to convert sunlight into electricity. Becquerel's work led to various scientists' research and the creation of the first solar cell in 1883 by Charles Fritts, with a 1% efficiency [6]. Due to limits in technology, little improvements were made to P.V.'s for almost 70 years until the space race after World War II between the U.S. and U.S.S.R. for extra-terrestrial applications. Bell Laboratories is attributed to discovering the modern-day crystalline silicon P.V. cell in the 1950s, paving the way for P.V.'s of today. During the first ten years, performance efficiencies increase from 2 to 14 % [6]. As the space race progressed, scientists continued research to improve performance by discovering new materials and manufacturing methods. By the 1980s, researchers identified new P.V. materials, including amorphous silicon and thin-film solar cells. While these materials did not perform as well as traditional silicon cells, they were a lower-cost solution. Near the end of the cold war, solar cell efficiencies began to peak for these staple materials that have remained consistent to this day [6]. These materials currently dominate the market due to their cost-effectiveness and continue to decrease in price, prompting adoptions in many markets.

Automotive Application of P.V.

Many researchers have proposed using solar P.V. mounted to electric vehicles to help with charging and provide clean energy. This idea is known as solar electric vehicles (S.E.V.'s), was initiated during the oil shortages of the 1970s when many scientists looked for alternative energy sources. Several solar race challenges began in the 1980s conducted in both Australia and the U.S. to increase awareness, research interest, and publicity. These races covered thousands of miles and several different terrain and climates as a proof of concept to push and test the limits of the technology [7]. Today, solar vehicles remain mainly at a sport level, with colleges competing in races to continually push the technology. Teams have achieved speeds of 75 mph and a range of 75 miles with a 5-kilowatt-hour battery pack [8]. However, researchers and industry are continually researching and developing new designs, materials, and processes to implement P.V.'s into many energy markets.

P.V. Material and Manufacturing Discoveries

Researchers continued experimenting with alternative materials and processes to achieve greater performance over longer life expectancies. Newer materials, including organic materials, dyes, thermphotonics, and thermophotovoltaics, pose great potentials for future use and performance of P.V. cells [9]. Organic dyes provide a way of mimicking nature's use of chlorophyll to create energy flow. Additionally, the dyes create the potential to achieve 15% efficiencies at a much lower cost than silicon. Organic materials also show a potential for lower-cost P.V. cells with moderate performance. However, the newer technologies using organic materials have unknown life expectancies compared to silicon. [9]. Thermophotovoltaics convert thermal wavelength energy such as heat into electricity, such as thermoelectric materials. Thermophotonics, similar to thermophotovoltaics, use heat to generate photons through diodes. The photons emit energy to break the bandgap energy of electrons in solar P.V. cells. Thermophotonics have been modeled but not realized in a laboratory. These materials possess different properties than standard P.V. panels that can improve cost, durability, performance, and manufacturing [9].

Research in the manufacturing and assembly of P.V. panels has also improved P.V. cell performance. Initially, cutting silicon with diamond wire was required to create P.V. cells, creating enormous costs and material losses. By switching to block casting, the material was able to be salvaged while reducing cost. Recently, laser cutting has also been introduced, creating further manufacturing improvements and cost [10]. Multiple junction cells increase performance by creating parallel circuits inside P.V. panels, creating fewer energy losses while increasing voltage output [9]. The use of materials with different bandgap energy requirements provide different amounts of energy to capture and break electrons free from materials in P.V. cells. Using materials with higher bandgap requirements requires and generates more energy for a given area, improving performance [9]. Sunlight concentrators increase the solar intensity using mirrors, lenses, and other means to focus sunlight on a specific area. Concentrators increase the available energy, increasing the energy output of cells, creating performance improvements in the assembly and installation of P.V.'s [9]. These discoveries and improvements continue to lead to record-breaking efficiencies, with the most recent performance improvement made in 2019 by the National Renewable Energy Laboratory (NREL), achieving a solar cell efficiency of 47% [11]. These discoveries continually contribute to P.V.'s performance improvements, however, the cost-effectiveness of higher-performing technologies and materials continue to be a challenge.

P.V. Market Adoption

The benefits of P.V. systems are useful and are known to achieve goals such as reducing carbon emissions and slow climate change. P.V. cost and performance have inhibited the adoption of these technologies into mainstream use throughout the world. In 1955, commercial solar P.V. cells were 2% efficient with a cost of $1785 per Watt [6]. Over time, performance and manufacturing process improvements made them more ideal and cost-effective. However, government incentives and subsidies were still needed to encourage P.V.'s adoption to reduce the upfront costs and capital [12]. Incentives played a vital role in P.V. systems' life cycle costs, making them more economical based on cost and performance. By 2005, P.V.'s started to grow in countries like Japan and Germany due to government incentives and low-interest loans to reduce cost and increase awareness. Along with incentives and policies, public education and awareness were critical to P.V.'s rapid adoption [9]. With modern societies needing more electricity to sustain daily life and government incentives reducing costs, P.V.'s continued to grow in popularity.

P.V. can be found in all energy sectors globally due to the universal need for electricity. Companies have installed large solar fields near airports [13] and unused, uninhabited lands such as deserts to generate electricity for customers through the grid [14]. P.V. panels can also be found on residential and commercial buildings, producing electricity for direct use or feeding electricity into the grid [3]. Conceptual vehicles have integrated P.V.'s into the body to run small applications such as radios [15]. Street lights and road signs use P.V. panels to generate electricity and provide energy for direct use or storage [16].

Energy Storage

Energy storage is a growing research topic for P.V. systems in a variety of applications. In the transportation industry, P.V. systems with battery storage allow for mobility operations, such as construction signs and highway lights. Battery storage can also remove the need to connect to electricity grids, allowing for operation in remote locations outside urban areas [17]. While less common, buildings may have battery storage systems charged by a P.V. system, providing power in the event of power outages or when solar energy is unavailable, just like a generator [12].]. In Australia, Tesla constructed a solar farm with battery storage in 2017 to provide electricity all day and night. Tesla’s battery storage proved successful, reducing cost and providing energy at all hours of the day through cleaner technologies while reducing carbon emissions from fossil fuels [18]. The amount of energy stored and used is ultimately dependent on the application and available solar energy.

Solar Forecasting

Solar forecasting is another growing topic of research interest to predict weather patterns that are key to many renewable energy systems' performance and integration. Many renewable technologies like P.V.'s are reliant on weather patterns to produce energy. Weather patterns such as clouds and storms reduce available solar energy, hindering P.V. electricity generation [19]. Predicting wind and solar power variability is a significant challenge for successful grid integration and transformation from fossil fuel to renewable energy [20]. Several modeling methods for solar forecasting [19] utilize sensors, satellite imaging, climatology, and historical data [21]. When renewable energy is unavailable, other sources such as power plants must supply people and businesses with energy to sustain operations. Implementing and improving solar forecasting methods can identify weather patterns critical to the grid integration of renewable energy systems and their performance [21].

Performance

Location and orientation affect the performance of P.V. systems. While everywhere on earth experiences solar radiation, it is not equally distributed. Some locations experience variability in weather patterns and solar irradiation more than other places [22]. The intensity and exposure to sunlight affect P.V. systems' performance as well as the temperatures and orientation of the P.V. panels relative to the Sun [23]. P.V. panels can be oriented to the Sun using three systems: fixed, single-axis tracking, and two-axis tracking structures. The rule of thumb for achieving the best performance for a fixed system is to orient a panel facing parallel to the equator and tilted at an angle equal to the location's latitude [24]. However, more optimal angles can be determined using mathematical modeling to achieve the best performance based on latitude location [25]. For a single-axis tracking system, the P.V. system's orientation or angle can move with the Sun to obtain better performance than a fixed system and collect more energy over a day [26]. A two-axis tracking system can adjust both orientation and angle over a day, leading to the best performance. Location analysis usually determines the implementation of a tracking system due to space, complexity, weather, cost, and benefits of adding tracking systems [27]. Tracking systems are typically more costly but can increase performance resulting in more significant energy generation and savings.

Savings

P.V. systems are large investments that can create savings over time. The average cost of a P.V. system depends on the size and location of the system. As of 2018, the average cost of a P.V. system was less than $3 per Watt, including the cost of the panels, installation, and equipment. Generally, larger systems are more cost-effective, despite the considerable upfront cost [28]. Once installed, the electricity generation from these systems is provided by the Sun at no cost or fuel input, contributing to energy savings annually with minimal operation and maintenance. Over time, the system will produce enough savings in electricity to eventually pays for itself [29]. Beyond this point, savings continue to occur for the rest of the P.V. system's life.

Solar P.V. systems can reduce and offset carbon emissions from fossil fuels used to generate electricity overtime. P.V. panels and equipment utilize material extraction techniques, transportation, and manufacturing, that require energy generated from fossil fuels. Thus, this equipment's production results in carbon emissions [30]. After production, P.V. systems must be transported, sold, and installed, using more energy and contributing to more emissions. Once installed, clean energy generation compared to fossil fuels' burning begins to offset these emissions. Over time, the emissions created before installation will be offset from clean energy generation, known as energy payback time. P.V.'s continue to offset more carbon emissions until the system's end of life, spanning over 25 years [29]. At the end of a P.V.'s life, there are opportunities to recycle much of the material, saving some emissions from producing virgin material and disposal in landfills [31]. Depending on the manufacturing process, transportation, and other factors, the total emissions and waste contributions to the environment will vary.

B. Electric Vehicles

In the transportation sector, several sources of vehicle propulsion technologies are integral to the automobile market. The two primary forms of propulsion have been through combustion and electrification. The internal combustion engine (I.C.E.) has been the popular form of vehicle propulsion since the early 1900s, [32] using gasoline as a combustion fuel source. Over time, researchers and companies have introduced new fuel sources such as diesel, ethanol, alcohol, vegetable oil, and compressed natural gas as alternate combustion sources, providing different performance [33]. While gasoline has remained the popular fuel, these other fuel sources hold smaller shares of the I.C.E. vehicle market. Electric motors are the second popular form of propulsion that use batteries or onboard generators such as hydrogen fuel cells and solar P.V. panels to provide electricity for electric motors [34, 35]. E.V.'s can provide cleaner, better performing forms of propulsion as an alternative to combustion engines and continue to grow in the market.

Electric and I.C.E. vehicles have competed in the transportation market for roughly the same amount of time. The electric vehicle first appeared in the late 1800s before increasing in popularity during the early 1900s, the same as I.C.E. However, the increased durability, performance, range, cost-effectiveness, and popularity of the I.C.E.'s slowly led to the disappearance of the E.V.'s from mainstream markets [32]. It was not until the oil crisis of the 1970s that pressured engineers and scientists to find alternative energy sources for propulsion that brought back to the idea of E.V.'s and the use of other alternative energy sources [7]. Some of these alternative technologies included biomass fuels, hydrogen fuel cell vehicles, E.V.'s, and S.E.V.'s with recent P.V.'s. None of the automotive companies considered the alternatives feasible until 1993 when General Motors made a serious attempt to include these technologies. They incorporated EV1, a 100% electric vehicle reaching speeds of 80 mph and achieving a driving range of nearly 100 miles [36], perfect for many city commuters. Due to uncertainty, liability, and limitations of the technology, EV1's were leased rather than sold to consumers due to their experimental nature. After some time, EV1's eventually disappeared like previous generations, with only hobbyists, researchers, environmentalists, and small shops creating or modifying vehicles to be electric.

Increased Adoptions of E.V.'s

A decade after the launch of the EV1, more companies began to create and sell more alternative energy vehicle options and push towards E.V.'s. Hydrogen fuel cell vehicle, hybrid-electric vehicle (H.E.V.’s), and pure E.V.'s such as the Honda Clarity, Toyota Prius, Nissan Leaf, and Tesla Roadster were part of a new revolution in vehicles transportation, shifting from internal combustion provided by oil byproducts to other energy sources [34]. Government incentives and subsidies for these new technologies improve research and adoption of these new vehicles, forcing engine manufactures to search for efficiency improvements for I.C.E.'s, which continue to be achieved [37]. However, the push towards E.V.'s continues with H.E.V.’s gaining momentum in the market, utilizing the combined power of electric and internal combustion engines to achieve greater efficiencies and performance. Plug-in hybrid electric vehicles (P.H.E.V.s), vehicles that allow drivers to run on electric power only for a limited range, are growing in popularity and continuing to be produced by automakers as they push towards pure E.V.'s worldwide [38, 39]. It appears that E.V. technologies and infrastructure may eventually replace gasoline and I.C.E. in the transportation market once energy storage and infrastructure is improved.

Energy Storage

E.V.'s use of energy storage in batteries combines with electric motors to provide propulsion. For many years, E.V.'s relied on lead-acid batteries to electric power motors for propulsion [32]. With limited space and weight capacity in vehicles, energy storage capacity still is the limiting factor for all vehicles’ driving range. Over time, battery technologies have improved with discovering new chemical combinations that can store more energy for less weight, known as energy density. Today, lithium-ion (Li-ion) batteries are the popular form of battery storage for E.V.'s, providing greater energy density, range, and performance [34]. The improvement in energy storage continues to improve the automotive market's adoption and transition from I.C.E.'s to E.V.'s.

Transitions to E.V.'s

Significant automakers and racing organizations are transitioning to E.V.'s around the world. By 2020, many significant automakers sold a pure E.V. with more models projected and new concepts emerging. Furthermore, new companies are springing up with new E.V.'s to address the market gap, bringing more competition and options for consumers [40]. In the racing world, Formula E has been a significant promoter of E.V. racing with new competitions for rallycross, GT3, and other fields of racing, creating or transitioning to electric racing divisions [41]. Ultimately, motorsports like racing help push the envelope of technologies to address challenges with automotive technologies for implementation into everyday consumer vehicles [42]. The continued competition of both motorsports and industry automakers will continue to push for technology improvements that will lead to E.V.'s increased performance and adoption.

E.V. Performance

E.V.'s can provide different and potentially better performance compared to I.C.E. vehicles. Power from electric motors is instant compared to I.C.E.'s, providing better performance for racing applications. Electric motors are also much more efficient in converting potential energy into kinetic energy, roughly 85% compared to I.C.E.'s 30 %, depending on the model [43]. Additionally, E.V.'s can have fewer energy losses when transmitting energy to the wheels. Electric motors can be installed at each wheel rather than one location in the I.C.E., reducing the need for transmitting energy through driveshafts and transmissions across the vehicle. Installing motors at each wheel can also distribute weight and power for better balance [44, 45].

Furthermore, these electric motors can be used for regenerative braking to slow the vehicle down and capture some of the energy used to propel it too [43, 46]. Another critical efficiency improvement has been using high voltage electric motors to provide power, reducing energy losses from current and improving efficiency [47]. Electricity power is the result of voltage and current, and by providing more voltage, less current is needed for constant power output. Current is dependent on voltage and resistance in a circuit—the more current used results in more energy losses [48]. Discoveries and improvements made by researchers, industry, and motorsports will continue improvements in E.V.'s and overcome challenges, increasing their adoption in the transportation market.

E.V. Challenges

E.V. still faces many challenges, including range, infrastructure, life expectancy, and cost. Vehicle range depends upon individual driving performance, terrain, and energy storage capacity. For I.C.E. vehicles, energy storage is dependent on the size of the fuel tank. For E.V.’s, energy storage is dependent on the number of batteries installed in the vehicle. In both cases, storage is limited by space and weight, limiting the driving range. More fuel can be obtained for I.C.E. vehicles at gas station pumps, providing quick and easy refilling. For E.V.’s, batteries require a charge with electricity. However, due to small amounts of infrastructure, charging becomes more difficult and gives some consumers “range anxiety” for fear of being stranded.

Additionally, E.V. charging can take longer than refilling a fuel tank for I.C.E. vehicles, making them less ideal for long trips [49, 50]. Tesla, an E.V. company, has implemented an interstate network of supercharging stations across the U.S., improving E.V. charging infrastructure, charging time, and travel range. The supercharging network has led to larger adoptions of Tesla vehicles with fast supercharging stations near many cities along interstates [51]. However, fast charging is still slower than filling a fuel tank, and fast charging can degrade battery life, requiring a change of batteries sooner than desired, making them less cost-effective [52]. Another challenge for E.V.'s is the cost to own and operate. E.V.'s cost more than the average citizen can or is willing to pay over its life due to its drawbacks. Compared to a conventional gasoline vehicle, the average cost of an E.V. can be $15,000 more, and the life cycle cost $4,000 more [53]. While E.V.'s still have challenges to overcome, they do provide some benefits compared to I.C.E. vehicles.

E.V. Savings

E.V.'s are a financial investment that can reduce carbon emissions over time. E.V.'s like P.V.'s are considered a clean form of energy due to zero tailpipe emissions. However, E.V. components must be produced in manufacturing plants like other vehicles, requiring the extraction of raw materials, transportation, manufacturing, and wastes associated with all processes [53]. Manufacturers suggest that once a vehicle is in use with an end consumer, it may still not be clean depending on the source of its' charging. For example, if an E.V. obtains electricity generated from renewable energy sources such as P.V.'s, the vehicle is not causing as much harm and emissions as I.C.E.'s. However, if electricity is from a coal-fired power plant, the E.V. is still contributing to carbon emissions, just not out of a tailpipe [53]. In the E.V.'s defense, the electrical and mechanical systems' greater efficiencies may produce fewer emissions and waste than I.C.E.'s. For example, if two identical vehicles, one with an I.C.E. and one with an electric motor, drove 100 miles, this would require the same amount of energy for both vehicles.

However, the energy source for each differs in extraction and burning processes, creating different amounts of emissions. For gasoline, crude oil must first be extracted and shipped to a refinery, processed into gasoline, shipped to gas stations, and then burned in the combustion engine process. For electricity, coal, as a worst-case scenario, must be extracted and burned to create electricity and transmitted over the electricity grid with associated losses, stored and used [53]. While E.V. charging appears to have fewer processes, the difference in carbon emissions may not be so clear. This article aims not to investigate this topic in-depth; however, it is essential to highlight this. Due to differences in fuel and electricity prices and maintenance and operation, saving can occur depending on each energy source cost as they vary. At the end of a vehicle's life, there is a need for disposal, which creates further emissions from transportation, disposal, and recycling. However, some value may be acquired through the reuse or recycling of components, saving money, carbon emissions, and addressing some challenges with E.V.'s. In standard vehicles, the recycling of metal for scrap can be used for other purposes, saving carbon emissions from producing virgin material and receiving the materials.

Additionally, the charging systems and batteries of E.V.'s have the potential for reuse in other markets such as P.V.'s to store energy [54]. This potential reuse can improve some challenges associated with both P.V.'s and E.V.'s that can improve their adoption to the market. For instance, battery integration with P.V.'s can provide clean charging stations for E.V.'s that are also grid-connected [55]. Additionally, wind power can improve these charging stations for additional energy production [25].

C. Solar Electric Vehicles

Given today's technology advancements, the use of P.V.'s for both E.V.'s and H.E.V.'s are increasing in designs. Automakers such as Toyota experiment with P.V. panels on the roof of vehicles to power smaller components such as radios and air conditioning [15]. Researchers are building on past S.E.V. designs to be used in all environments, capable of independent and grid charging and on-road and off-road capability [35]. Researchers also assess S.E.V. designs for urban environments and short commuting, comparing life cycle cost and savings to I.C.E. vehicles [56]. The benefits of having solar P.V. incorporated into E.V.'s can charge a vehicle while driving, known as dynamic charging, potentially increasing range, sustaining battery charge, controlling charge rate, and eliminating the need to stop and recharge. Honda has researched other potential forms of dynamic charging systems for E.V.'s using contacting and non-contacting methods. Both proving possible; however, the implementation of both would be difficult due to cost, infrastructure, and operation [57].

Along with dynamic charging, S.E.V.'s can become stationary generators of electricity when parked and fed into the electricity grid, similar to stationary powered P.V. charging stations [55]. S.E.V.'s serving as generators come from smart grid's aspirations where E.V.'s serve as energy storage and generation mediums for electricity during peak demand loads [58]. S.E.V.'s charging and energy storage could provide more significant amounts of energy during peak electricity loads and provide cost savings for customers. Ultimately, the use of P.V.'s and E.V.'s both individually and in combination can significantly benefit society while addressing climate change and other environmental concerns.

III. CONCLUSION

P.V.'s show great potential for providing savings for all energy sectors worldwide. The increased use and implementation of P.V.'s can reduce energy costs and dependence on fossil fuel electricity generation, consequently reducing and offsetting carbon emissions and electricity costs over time. While P.V.'s still face challenges with grid connectivity, weather predictability, and energy storage, improvements in technology and cost will aid in the continued adoption of P.V. systems in all energy sectors as the world shifts to a more sustainable future.

The use of cross-integrating P.V. and E.V. technologies shows excellent potential for a sustainable future in all energy sectors. E.V. batteries can be recycled to provide energy storage for P.V. utility systems. In contrast, P.V.'s can provide clean charging for E.V.'s at charging stations and potentially improve performance through direct integration into vehicles to provide dynamic charging. Both technologies can complement and benefit each other, making them more cost-effective, improving performance, and reducing carbon emissions over time.

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