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Energy Harvesting Technologies in Electric Vehicles and Applications in Sustainable Agricultural Transportation: A Review

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ABSTRACT

The increasing challenges of energy depletion, environmental pollution, climate change, and agricultural transportation costs demand innovative solutions. Electric vehicles (EVs) offer a promising solution towards mitigating these issues through renewable energy sources. However, limited driving range remains a crucial barrier to their widespread adoption, particularly in environmentally friendly agricultural transportation. This review paper comprehensively analyzes energy harvesting technologies in electric vehicles and their application in agricultural transportation. The focus is on their potential to improve driving range and address the specific needs of farmers in terms of maximizing their income. Very few review articles have been published on maximum number of possibilities of harvesting energies in electric vehicles, application in agricultural transportation and future prospects for improvement. Existing and current literature was systematically reviewed on various energy harvesting techniques applicable to EVs, including solar energy harvesting, regenerative braking, aerodynamic (wind) energy recovery, and vibration energy harvesting through suspension systems which are all renewable energy sources. Their advantages, working principle, limitations, and recent advancements were critically discussed. All explored energy harvesting methods show the ability to extend EV driving range. However, solar energy and wind or aerodynamic energy harvesting in EVs are theoretically possible but still under research for practical applications due to lots of limitations. Regenerative braking and vibration energy harvesting show the most promising current applications. The Electrical or electromagnetic vibration energy harvesters produce better results over mechanical (hydraulic and pneumatic harvesters). When optimization is employed, better results were achieved. Research on the application of artificial intelligence based computer algorithms to optimize and produce the best amount of harvested energy in EVs will play a significant contribution in the adoption of EVs for sustainable agricultural transportation.

Keywords: *Artificial Intelligence**,** Electric Vehicles, Energy Harvesting Systems, Farmers' Income, Sustainable Agricultural Transportation.*

INTRODUCTION

The automobile industry has played a very crucial role in economic development. It has thus become a high research area of focus because of its importance in transporting humans and agricultural transportation (Caban et al., 2023). According to the British Columbia Ministry of Agriculture (2014), transportation of produce and farm equipment is very important for all farm activities. Amongst various modes of transport such as air, water and land, land transport by vehicles is the commonest. Transportation in farm operations is required to move farm inputs and materials, working tools, planting, harvesting materials, fertilizers, feeds, pesticides and seeds. Agricultural transportation also helps to transport humans such as farm workers (managers and laborers) and visiting customers to the farm as well as farm by-products such as manure. Semi-finished, finished processed products and general farm yields are also transported as part of farm operation processes (Lun et al., 2010). However, Gao et al. (2019) reported that transportation demands in agriculture have significantly increased operations cost, thereby having a negative impact on the revenue of farmers. Consumption of fuels by farm transportation equipment has the greatest percentage of transportation cost (Savić et al., 2020). It therefore greatly reduces profits earned by farmers. Thus, there is a great need to well manage the energy consumption of farm transportation vehicles to enhance the gross profits of agricultural businesses.

Sanguesa et al. (2021) related the impacts of transportation vehicles on the environment. The high demand for transportation vehicles however has led to a very high number of transportation vehicles on road paths. The increase in the number of gasoline internal combustion engines on roads has increased greatly, the amount of greenhouse gases (GHGs) such as oxides of carbon, with carbon dioxide contributing 97 % of the total global warming in the atmosphere (Environmental Protection Agency, 2018). The European Union reported that over 28 % of the total amounts of carbon dioxide emissions to the air is caused by the sector of transportation including the various modes while at least 70 % of this amount is caused by road transportation (Ballou, 1999). In 2019, this amount of emissions by road vehicles has been reported to increase to 83 % of the total emissions by the sector of transportation (Chad & Ron, 2022).

Furthermore, Alamili (2019) reported that the non-sustainability and depletion of natural transportation fuels, coupled to their negative impacts on the environment, contribution to the emission of greenhouse gases that cause global warming and climate change has aroused interest in renewable energy sources of energy which are environmentally friendly (Ehsani et al., 2009; Erdinc & Uzunoglu, 2012). Therefore, different institutions, governments and non-governmental organizations interested in sustainable development have recommended and fostered the use of Electric Vehicles which are powered by renewable energy sources with zero or negligible greenhouse gas emissions. This is to curb air pollution from the use of gasoline vehicles with internal combustion engines that emit GHGs to the air like carbon dioxide (CO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO). Electric vehicles have been said to reduce the total amount of carbon dioxide emissions in the United States by 20 % (Chad & Ron, 2022). Authorities encourage the use of EVs through various initiatives such as tax policy and free parking (Sonali et al., 2021). In this perspective, more tax is placed on enterprises in sectors of activity that produce gasoline vehicles while zero or minimum tax is placed on enterprises producing EVs. Electric vehicles also produce less noise and less frequent maintenance due to their less complex structures and moving parts, hence less friction between parts compared to conventional vehicles (Siang & Chee, 2013).

Despite the advantages of the electric vehicle on the environment, Sonali et al. (2021) reported that the biggest challenge and limitation of electric vehicles is their driving range. They have a limited driving range compared to conventional gasoline internal combustion engine vehicles. Because of limited battery energy density and limited charging stations like fuel stations for conventional vehicles, the most feasible solution to the problem is the adoption of systems that enhance the effective usage of the energy from batteries of electric vehicles. Harvesting devices are needed to collect and convert small amounts of wasted energies to useful forms for reuse, thereby increasing the efficiency and reducing losses in vehicles (Briand et al., 2015). Energy harvesting is thus currently the most effective way of increasing the driving span of electric vehicles with the goal being to make the vehicle self-powered. Self-powered devices have the advantage of minimal maintenance with a high reliability (Zhu, 2011).

Effective capture of wasted energies in electric vehicles helps to boost the efficiency of the vehicle. Some of the energy harvesting technologies in electric vehicles include regenerative braking, vibration energy harvesting, aerodynamic energy harvesting, flywheels kinetic energy and solar photovoltaic panels.

Siang and Chee (2013) reviewed on the use of electric vehicles as a good sustainable and environmentally friendly replacement for internal combustion engine vehicles. The work emphasizes on energy harvesting technologies in electric vehicles but fails to review on other important energy sources like aerodynamic and solar energy harvesting technologies in

EVs. Xiaoli et al. (2020) reviewed the emergence of research on electric vehicles and reports the trend to have grown tremendously since the beginning of the 21st century. Puma-Benavides et al. (2021) analyses the different control methods and management of harvested energies in electric vehicles. Caban et al. (2023) reports devices that collect energy or harvest energy as having a crucial role in increasing the driving range of electric vehicles.

While these works review various individual approaches to harvest wasted energies, little or no work has been done on the holistic approach that considers all the design parameters of the harvesting device, using artificial intelligence based algorithms to optimize or get the best values of harvested energies. This involves comparing energy or power harvested from non-optimized and optimized energy harvesting devices. Furthermore, transportation cost forms a large part of the variable costs of an enterprise and involves the use of vehicles and fuel with fuel cost justifying for as much as 40 to 50 % of the total transport cost (Savić et al., 2020). Thus, in managing agribusinesses, the financial implications of transportation should be highly considered in decision making (Brian et al., 2018). However, little or no reviews have been done on methods of harvesting energies in electric vehicles to increase their driving range for applications in agricultural transportation. This review paper examines recent developments and technologies used to minimize the biggest challenge of electric vehicles which is limited driving range compared to internal combustion engines. This will go a long way to improve on farmers' net profits and income in a sustainable way.

This article delves into the exciting world of energy harvesting technologies for electric vehicles (EVs) for applications in sustainable agricultural transportation. To navigate this landscape effectively, the review has been structured into sections. Section 1 establishes the current energy challenges faced by agricultural EVs, highlighting dependence on grid-based electricity, limited range and impacts on the income of farmers and the environment. The methodology for the survey and selection of papers for this review paper is highlighted in section 2. Section 3 looks into the different types and advances in EVs. In section 4, various energy harvesting technologies, their operating principles and potential energy yields are discussed in detail. Section 5 discusses and compares the various technologies, their implementation, challenges or limitations and environmental benefits. Section 6 concludes on how energy harvesting can empower agricultural EVs, paving the way for a sustainable and efficient future of rural transportation and perspectives.

METHODOLOGY FOR THE SURVEY

There has been a sharp increasing number of articles published on energy harvesting technologies in electric vehicles. Fig. 1 shows the number of articles published on energy harvesting technologies in electric vehicles from 2010 to 2023. The increasing trend of published articles portrays a growing interest to increase the fuel economy of vehicles in general or the driving span of electric vehicles. Emphasis is placed on recovering or harvesting wasted energies from vibrations through regenerative dampers, regenerative braking, aerodynamic and solar potentials. Counting from 2010 to 2023, it is observed that a total of 1262 articles were published. From the total number of published articles, 329 of the total were published in the preliminary seven years (2010-2023) whereas the remaining 933 were published in the last seven years (2017-2023). In this last seven years, 73.93 % of the articles were published. This amount is 47.93 % more than the percentage of articles published in the preliminary seven years (26.07 %).

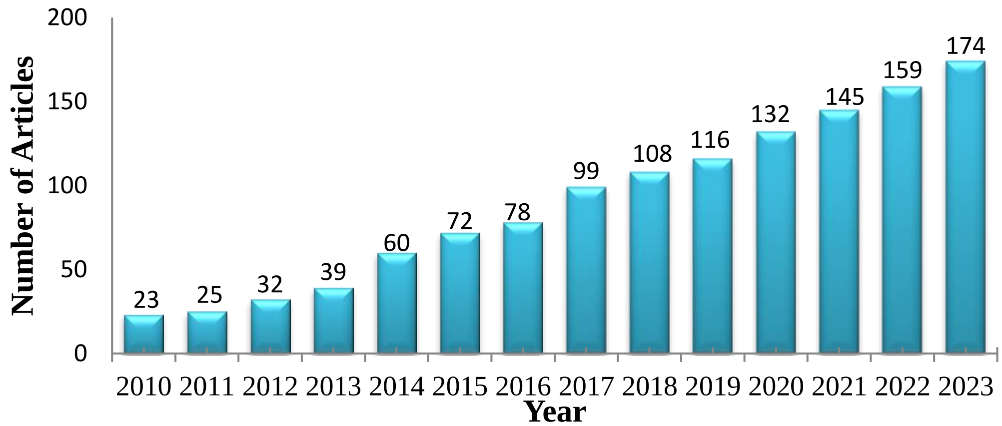

Figure 1: Number of articles published per year from 2010 to 2023 on energy harvesting technologies in electric vehicles

The main aim of this review is to collect and assemble all the most current information on electric vehicles and their application in sustainable agricultural transportation. The limitation of EVs in terms of limited driving span compared to conventional internal combustion engine vehicles is also discussed. Detailed advances in the various approaches and technologies to solve this limitation are discussed critically, revealing their working principle, possible output power generated, limitations and prospects for future enhancements or research.

The approach firstly involves the exploration of popular databases like Google Scholar, Science Direct, MDPI, IEEEXplore and others to see studies or published articles related to energy harvesting technologies in electric vehicles and application of electric vehicles in sustainable agricultural transportation. These databases are chosen because of their reputation and engineering content. Secondly, using the contents of papers, their keywords, abstracts and publishing dates, the initially identified articles were closely observed to see their relation to the topic of this research as well as their citations, impact factor and novelty.

The outcome of the survey of articles published in relation to the topic of this review generated the contents and results of the review as presented in Fig. 2. Fig. 2 summarizes the two phases of this review process and the sections of the article highlighting their main points of discussion.

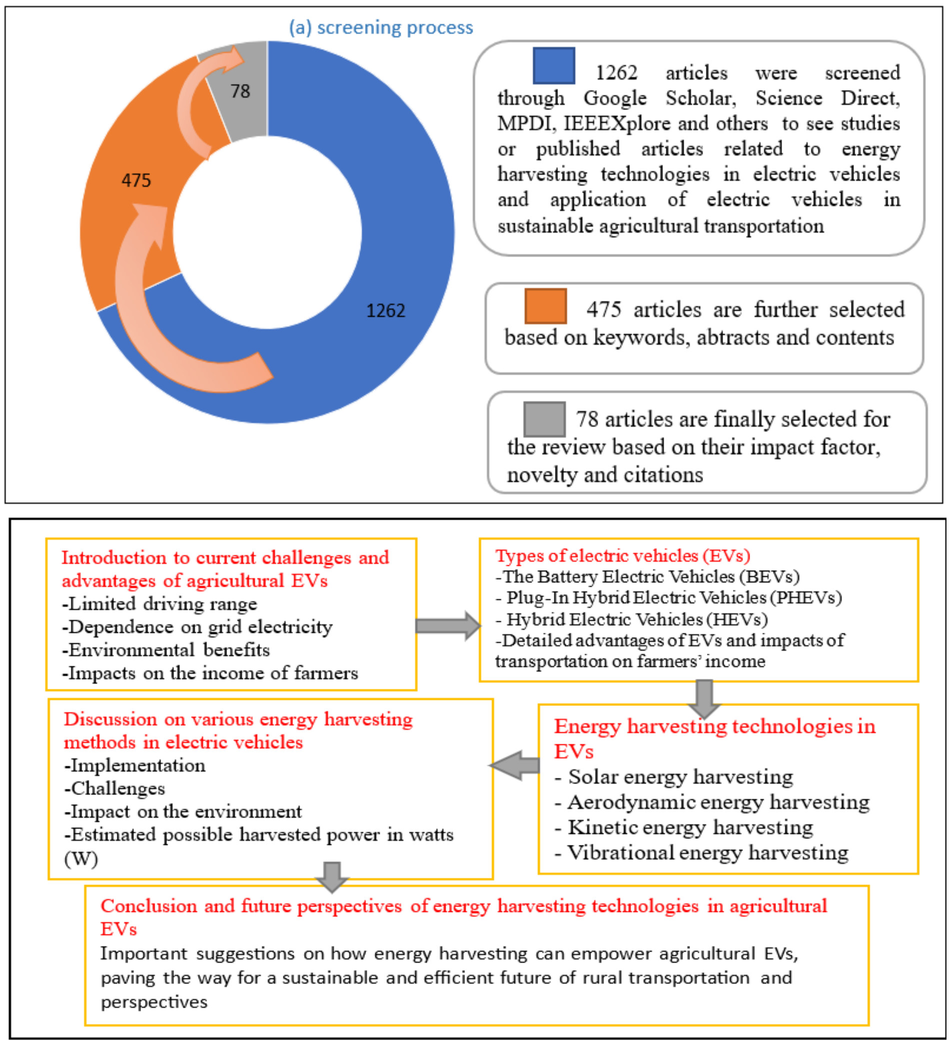

Figure 2: Diagrammatic representation of the method of survey (a) and the general results of the review and (b) the general results of the review

2.1 Screening process and method of selection of articles

- A total number of 1262 articles were screened through Google Scholar, Science Direct, MPDI, IEEEXplore and others. The aim of this exercise is to come up with studies or published articles related to energy harvesting technologies in electric vehicles and application of electric vehicles in sustainable agricultural transportation.

- Using keywords, abstracts and contents, 475 articles were selected for the review.
- Finally, a total of 78 articles were selected based on their impact factor, citations and novelty. This involves journals, conference proceedings, government documents and reputable web pages.

2.2 General survey outcomes

- Electric vehicles were introduced, their advantages, limitations and applications in sustainable agricultural transportation.
- Advances in electric vehicles and the different types were discussed.
- Different energy harvesting technologies in electric vehicles were explained including their operating principle, estimated harvested power outputs and limitations.
- Important suggestions were made on how energy harvesting can empower agricultural EVs, paving the way for a sustainable and efficient future of rural transportation and perspectives.

ADVANCES IN ELECTRIC VEHICLE TECHNOLOGY

There are principally three types of electric vehicles, distinguished based on their engine configurations and drivetrain (Crisostomi et al., 2018).

3.1 The battery electric vehicles (BEVs) or fully electric vehicles

These electric vehicles are wholly moved by electrical energy. The autonomy of these vehicles is completely given by an assembly of battery packs usually connected in series. Thus, unlike conventional gasoline internal combustion engines that use liquid fuels, BEVs do not use fuel. BEVs have large battery packs to store energy for driving and require plugging into an external power source to recharge. They have the smallest driving range compared to the other types of electric vehicles. This kind of electric vehicle is the most environmentally friendly and least expensive to operate since it relies completely on electrical energy from batteries which is less expensive compared to the cost of buying fossil fuels for gasoline engines (Aziz et al., 2018; Kriukov & Gavrilas, 2019; Kurtz et al., 2020; Malek et al., 2020). An example of a BEV is the Nissan Leaf. Its battery capacity is 62 kWh supplying for a range of up to 350 km (Inside EVs. Nissan Reveals LEAF e-Plus, 2019). Meanwhile some BEVs will have ranges of up to 450 km; BEVs generally have ranges of 150 to 200 km (Ntombela et al., 2023).

3.2 Plug-In hybrid electric vehicles (PHEVs)

Plug-in hybrid electric vehicles are moved by two engines; one being the gasoline engine and the other being the electric motor drive that can be charged by an external pluggable electric source(Singh et al., 2021). The ability of PHEVs to store sufficient amounts of electrical energy from the grid in synergy with gasoline curbs their consumption of fuel during propels (Ntombela et al., 2023). With a battery capacity of 12 kWh, the Mitsubishi Outlander plug-in hybrid electric vehicle supports a driving distance of up to 50 km with just the electrical motor. However, the PHEV produces more GHG emissions than BEVs but lesser emissions than corresponding gasoline vehicles (Mitsubishi Motors, 2018).

3.3 Hybrid electric vehicles (HEVs)

Just like PHEVs, HEVs also make use of a combination of two engines. That is the internal gasoline combustion engine working in synergy with an electric engine. They thus have smaller battery packs since the battery energy only complements the gasoline engine energy. They mostly charge their batteries through regenerative braking and not external plugging. There are many phases of energy generation, conversion and storage in HEVs (Huang et al., 2021). HEVs are distinguished from PHEVs from the fact that they cannot be plugged in for recharge from the grid. The gasoline engine plays a significant role not only in propelling the vehicle but also to charge the batteries that power the electric motor drive. Because of its complex build-up, it produces noise and vibrations. It also emits quantities of greenhouse gases to the atmosphere but the concentrations are smaller compared to complete gasoline operated internal combustion engines. An example of an HEV is the hybrid Toyota Prius model with a battery capacity of 1.3 kWh. While being 100 % powered by the electrical drive train, its autonomy is observed to support up to 25 km of travel distance (Plötz et al., 2020).

3.4 Advantages of electric vehicles (EVs) over internal combustion engine road vehicles

Based discussed literature so far, EVs have numerous advantages over gasoline internal combustion engines. This information is summarized in Table 1. The numerous advantages of EVs indicate why they are a better sustainable alternative in agricultural transportation since they help to maximize the farmers' income and profits.

Table 1: Advantages of EVs over conventional internal combustion engine vehicles

	Electric vehicles (EVs)	**Internal combustion engine road vehicle**
GHG emissions	EVs emit zero or lesser quantities of GHGs to the atmosphere such as carbon dioxide and nitrogen dioxide. Their manufacturing processes and testing produces minimal air pollution.	Emits over 83 % of the total greenhouse gas emissions from the sector of transportation (Chad & Ron, 2022)
Complexity of structure	Components of the electric vehicle drivetrain are very simple with fewer complexes compared to gasoline drivetrains with heavy engines, gear boxes, clutching and cooling systems with high noise levels from engine action	Has a more complex structure
Fuel/operating cost	The cost savings per kilometer of energy consumption by transportation vehicles for Gasoline, Ethanol, Hybrid, Diesel oil, Biodiesel, Liquefied Petroleum Gas, Natural Gas Vehicle, and Electricity are 0 %, 1 %, 20 %, 23 %, 27 %, 33 %, 38 % and 75 % respectively (Blázquez & Martín, 2010; Sanguesa et al., 2021). Thus EVs have lesser operating cost compared to internal combustion gasoline engines. The cost of electricity used to power the EVs is lesser than the cost of chemical fuels such as diesels and petrol	More of the farmers' income is spent on fuel using conventional vehicles than EVs
Maintenance	Due to less complex structures in EVs, they produce less noise and vibrations leading to lesser breakdowns and maintenance compared to internal combustion engines. They thus have a higher reliability and less frequent maintenance schedules unlike gasoline engine vehicles	More moving parts lead to more frequent maintenance
Effect on farmers' income	Less operating and maintenance cost imply less effect on the reduction of farmers' revenue or gross profits (Savić et al., 2020)	More income spent on fuel and maintenance leads to bigger negative impact on gross profits earned by farmers.
Efficiency	Converts 70-80 % of chemical energy in the battery to mechanical energy at the wheels due to the high efficiency electric machines (Vodovozov et al., 2021)	Converts just 12-30 % of chemical energy in gasoline to mechanical energy

Reports from most of the 78 articles reveal that the number of electric vehicles purchased around the world keep increasing and this increment is expected to duplicate in the nearest five years since many countries around the world have firmly demonstrated their desires to completely ban gasoline powered engine vehicles and transition to the complete use of electric vehicles. A typical example of a country that has demonstrated a transition to electric vehicles is Norway that has stated that all vehicles traded in its territory should emit zero greenhouse gases to the atmosphere. Increasing interest in electric vehicles has also caused India, Netherlands and Israel to state that all vehicles traded in their territory should all be electric vehicles by 2030. California, the United Kingdom and Germany have also expressed their interest to ban gasoline internal combustion engine vehicles by 2040. Some cities in Germany have already announced the ban of diesel engine vehicles by 2024 and vehicles with internal combustion engines by 2030. From 2025, gasoline combustion engines will be banned in Mexico City, Athens and Madrid. Despite the high purchase and trading of electric vehicles round the world, it has been observed from statistics that over 95 % of the vehicles were purchased by Canada, the United Kingdom, USA, France, Sweden, Netherlands, China, Norway and Japan. This therefore implies that the use and application of electric vehicles technology in Africa and Sub Saharan Africa is still underdeveloped. (CNN, 2017; Elec trek, 2018; Newsweek, 2017; NL Times, 2017; The Guardian, 2018; The Times of Israel, 2018).

Despite the numerous advantages of EVs and their progressive adoption by many countries today over internal combustion engines, they have a relatively limited range of drive compared to internal combustion engines. The span of drive has been reported to limit to 200 km for one complete charge, though the Tesla model can attain 500 km (Tesla Official Website, 2019). Thus, rigorous research is being done on developing theories, concepts and methods to increase the driving span of electric vehicles. Some of these approaches are discussed further in the subsequent sections. Before discussing the energy harvesting technologies for application in agricultural EVs, it will be extremely important to discuss the impacts of transportation costs on the income of farmers while proposing a sustainable solution to optimize the income of farmers.

3.5 Effects of transportation fuel on the income of the farmer

The components of transport cost involve cost of acquiring vehicles, means of transport depreciation cost, salaries of personnel that carry out the operations of transport, maintenance, transportation fuel or energy consumption cost, loading of vehicles, payment of taxes and fees of transportation when external transport services are hired. These transportations related costs are mainly classified into fixed and variable cost (Krakowiak-Bal & Sokora, 2016).

Fixed cost refers to the component of transportation costs that does not vary irrespective of the size of activities or tasks carried out (Chivu et al., 2015). Examples of fixed transport cost are depreciation cost, taxes, insurance and transport means cataloging. The knowledge of fixed cost helps in determining the break-even point, which is the point that indicates the amount of products or services that must be produced and sold for the enterprise to begin making profits. On the other hand, variable cost of transportation varies depending on transport operations executed.

Examples include fuel or energy cost, maintenance cost, lubricant cost, loading and unloading. It has been reported that fuel cost account for 40 to 50 % of the total cost while maintenance accounts for over 25 % of the total transport cost and transport employees cost represent 20 % of the total cost. Fuel and maintenance cost thus represent the greatest part of the overall transport cost and thus their optimization can enhance the benefits and profits of enterprises. Knowledge of the variable cost gives opportunity of reviewing and selecting alternative transportation options or solutions as recounted by Nielsen et al. (2015).

A study conducted by Richard et al. (2013) reveals that the marketing cost and wholesale prices of agricultural produce are considerably increased by transportation cost. Factors such as transportation method, characteristics of transported produce (like perishability) and the distance between the supply location and the demand location of customers determine the effects of fuel on the prices of produce. World oil prices have been further reported to be on an increase since 2004, though some stability of prices of fuel had been observed from 1990. The research further affirms that cost of fuel increases with increase in distance from the supply location of produce, which then has a significant impact on the sales price of the agricultural produce. Although the magnitude of this impact also depends on method of transportation employed, seasonal related concerns and degree of perishability of the produce, these factors all contribute to the increase in fuel consumption for agricultural transportation vehicles, thereby increasing the cost of produce sold and the income of producers is highly affected negatively if buyers do not conform to increased prices. Another effect of high fuel consumption is that farmers will have limited capital for quality farm inputs, investments and acquisition of infrastructure for higher productivity.

The prices of fuel play an important role in the differences that occur between prices of produce already at the consumption location and prices of those still at the farm level. The distance travelled from the supply source of produce is proportional to the fuel consumption or price which determines the price of produce sold in the market.

The price of fuel has shown an increasing trend in 2021 (Junyi, 2022). Fig. 3 shows the prices of Brent crude oil and West Texas Intermediate (WTI) crude oil according to the international oil prices.

Figure 3: Trend of World oil prices (nominal dollars), 2021 (U.S. Energy Information Administration, 2021)

It can be seen from Fig. 3 that fuel prices have been increasing. This increase in fuel prices as earlier discussed affects the price of products in the market due to transportation and hence the income of farmers. The significant geographic disparity in the prices of agricultural produce is caused by a change in fuel prices. The effects of fuel price on the prices of produce relates to transportation rates that increase with increase in fuel prices. The rates of transportation vehicle sensitivity to the prices of fuel increase linearly with the distance covered.

Ultimately, in view of the high share of transport related cost in the total logistics cost and cost of production, it is very important to dedicate substantial consideration to ameliorating or optimizing the effectiveness of transportation activities and operations. This approach solves the problem of minimizing fuel consumption cost which has a significant impact on the income of farmers. When farmers spend huge sums on transportation, their total revenue or gross margins are affected negatively.

3.6 Effects of the internal combustion engine vehicle's maintenance cost on the income of food producers and processors

Abhishek and Ajinkya (2016) presented the structure of internal combustion engine drivetrain of a gasoline or conventional vehicle. The presentation shows the complex system of the vehicle transmission system from the engine crankshaft through the input shaft, system of gears to drive various mechanisms and components in the vehicle including tires. The complex nature and involvement of many moving parts in the conventional vehicle drive system explains the reason why maintenance cost account for as much as over 25 % of the total transportation cost for conventional vehicles. Thus transportation is greatly affected by maintenance cost which affects the income of food producers, consequently reducing their profit margin (Savić et al., 2020).

3.7 Approach to solve the problem of negative impacts of transportation cost on farmers' income

The intensive review of literature on impacts of agricultural transportation on the reduction of gross profit margins of farmers has revealed the significant contribution of transportation and its overall cost in logistics and farm operations. Therefore, for profitability and sustainability, agricultural ventures and agribusinesses require the efficient management of transportation costs.

Voortman (2004) recounted that efforts should be done for the optimization of transportation cost, reducing them to minimum and recommends the determination of the effective vehicle design, structure or efficiency as a substantial means to optimize or enhance the reduction of transportation costs. This thus reiterates the importance of using electric vehicles with minimal energy cost and less complex structures requiring less frequent maintenance compared to internal combustion vehicles. The subsequent sections of this paper will discuss various energy harvesting technologies used in electric vehicles and their applications in agricultural transportation.

ADVANCES IN ENERGY HARVESTING TECHNOLOGIES IN ELECTRIC VEHICLES (EVS)

One of the most cost-effective methods of energy recovery in the automotive industry is kinetic energy recovery which is done through regenerative braking (Long et al., 2014). Due to many losses, automobiles have a fuel economy of less than 75%. Irreversible or unavoidable losses in the engine sector, such as partial combustion, friction, pump, and heat losses, account for a large portion of the vehicle's overall energy loss. Additional areas of interest for study include lowering engine energy losses and raising engine efficiency (Deulgaonkar et al., 2011; Harkude & Malagi, 2015; Mohamad et al., 2015). The following data summarizes the power delivered to different elements of an average car used for urban transportation, together with the known energy losses: Heat losses: 63.5%, pumping losses: 5%, inefficiency in combustion: 3.4%, friction losses: 3.3%, auxiliary: 2.3%, alternator: 2.3%, power to wheels: 22.5%, vehicle inertia: 5.7%, aerodynamic drag: 3.8%, rolling resistance: 3.8%, torque converter: 1.7%, other drag: 1.7%, transmission: 1.4 %, differential 1.2 %, others 3.2 % (Lafarge et al., 2016).

The energy needed to drive and control an automobile makes up 22.5% of the overall energy use. The energy required to drive the wheels against different road and weather resistances, power utilized at the powertrain, and other losses are added up to this amount (Lafarge et al., 2016). Investigations have been done to minimize energy losses at the vehicle's powertrain, even for very small amounts, in light of the significance of fuel economy and energy efficiency. These research efforts specifically focus on solar energy collecting, aerodynamic energy harvesting, regenerative braking systems, and energy harvesting suspension systems in electric vehicles intended for use in agricultural transportation.

The several energy collecting systems seen in electric cars are covered in this section. The primary objective of energy harvesting in electric cars (EVs) is to address the driving range constraint of EVs in relation to internal combustion engine vehicles in an environmentally friendly and sustainable manner. The section elaborates on their principle of operation, challenges and implementation.

4.1 Solar Energy Harvesting in EVs

The most effective and realistic alternative renewable energy source is solar power (Spina, 2012; Wei et al., 2021). Experiments have been conducted to find ways that solar energy may support electric automobiles. As of right now, a few auto manufacturers want to include solar panels to their next electric car models. Regarding solar uses in electric cars, the most important and challenging subject is still how much energy can be supplied by solar panels mounted on vehicles. It is now well known that obtaining enough solar energy to power a car is quite difficult. Consequently, solar panels have very little effect on electric vehicles when it comes to resolving the issue of restricted driving range. Additionally, silicon serves as the basic ingredient for solar panel production. Because silicon is so costly, it is not a material of choice for making electric vehicles because the cost of the vehicle will increase significantly (Tesla, 2019). Due to their high cost, insufficient energy, and inadequate power density, solar-powered electric vehicles (SPEVs) are not yet practical in the real world as further reported by Hu et al. (2017). It should be mentioned that farmers' profit margins are negatively impacted by high transportation costs. However, research into integrating solar panels into electric vehicles is still ongoing, with Toyota being one of the leading businesses in this field. Smaller electric car parts like cooling systems and lights can be run by solar energy. This significantly lowers the energy burden on the engine, boosting the EV's efficiency in the process (Tesla, 2019).

Theoretical models have been provided on the use of solar energy to power electric vehicles. Mandakuriti et al. (2022) used MATLAB to model and analyze the solar-powered electric vehicle (SPEV) as the key to solving the downside of fuel and pollution. In this model of an electric vehicle (EV), a battery is utilized to produce and supply electricity. This battery is charged by photovoltaic (PV) panels, which collect solar radiation and convert it into electrical power. The highest power is tracked using a maximum power point tracker (MPPT) controller. A three-phase voltage source inverter (VSI) receives the boosted output from a buck-boost converter, which is used to increase the DC voltage obtained from the solar module. The brushless direct current (BLDC) motor, which drives automotive applications, is fed by VSI, which converts solar DC power to AC voltage. The solar cell, sometimes referred to as a photovoltaic (PV) cell, is simulated and represented in this model. Through a combination of chemical and physical processes known as the PV effect, solar energy is converted into electrical power by the solar cell, an electrical component. When exposed to sun radiation, its properties such as voltage and current will change. Solar panels are another name for the components that make up PV modules. A photovoltaic panel is made up of many solar cells connected in parallel and series. A source, diode, and two resistors may be used to create a single solar cell (Salkuti, 2019; Salkuti, 2021; Sandeep et al., 2020).

The EVs of today averagely consume up to 150 Wh / km of battery capacity (Ntombela et al., 2023). Given that 50 km is the average daily travel distance, then 18,250 km is the total distance to be traveled per year. Based on this calculation, there will be a need for EVs generating 2,737,500 Watt-hours of energy per year. In USA, solar panels of the monocrystalline type generate 263 kilowatt-hours per square kilometers per year. This shows that averagely 10.5 m^2 area of solar plates will be needed to meet the energy demands of solar vehicles. The most feasible location to install solar panels on road vehicles is their rooftop covering an average area of 1 m^2. As earlier mentioned the setup then would be capable to generate 263 kilowatt-hours per year of energy theoretically. However, it is practically difficult to generate 100 % of this theoretical energy due to shades along the travel path or road and also alterations of the shade from the optimal angles for effective orientation to and capture of sunlight. Thus, based on this limitation, an estimated 60 % of the theoretical value mentioned is a reasonable amount. This would then give an estimated value of 150 kilowatt-hours per year, thereby increasing the driving distance by an extra 3 km (Auto, 2019). Nonetheless, the development of technology is being done on how to use solar panels on vehicle rooftops to power the vehicle entirely or part of its components such as cooling and lighting units.

4.2 Batteries

Considering high cost, batteries are not only the most crucial component of electric cars, but they also affect their range and autonomy (OECD Library, 2020). The batteries' weight is a disadvantage, though. They are large and heavy, taking up a lot of space. The typical weight of an EV battery is 200 kg. However, depending on the battery type and quantity utilized, this may change. Adding extra batteries won't extend the driving range of EVs; instead, it will burden the driving motor with additional weight, which will need more energy (Berjoza & Jurgena, 2017). Secondly, adding more batteries will not result in any efficiency gains since the extra energy would be wasted. Consequently, managing the batteries' energy properly is a superior technique to boost the vehicle's efficiency using batteries (Sanguesa et al., 2021). For electric cars and plug-in hybrid electric vehicles, energy management and control are crucial components. Therefore, an essential component of EVs should be a system that can monitor, regulate and manage the energy coming from the battery. Since overcharging batteries may harm them and reduce their dependability, this management system should regulate the charging and discharging of the battery to ensure their security and safety. Although there exist systems to control the pace at which electric cars charge and discharge, the majority of them lack intelligence and do not take into account the optimization of harvested energies under varying conditions of travel.

4.3 Kinetic energy recovery

A kinetic energy recovery system (KERS) is a device that uses braking to recover the kinetic energy of a moving vehicle. It can do this mechanically with a flywheel or electrically with the motor drive acting as a generator. The recovered energy can be stored in super capacitors and batteries for later use, or it can be used directly to extend the vehicle's range (Alamili, 2019). Braking causes a vehicle to experience one of the inevitable energy losses. Applying the brakes during motion causes the brake pads to push on the wheel disc, slowing down or stopping the car. Friction causes the kinetic energy of the vehicle to be lost as heat as it slows down. The quantity of energy that is changed as a result of braking is determined by how hard, how often, and how long it is applied. In urban traffic, braking occurs more often than on highways. Because of the frequent stop-and-go traffic in the city and the low speed restrictions, braking is frequently necessary (Umut & Recep, 2018). Up to 62.5 percent of the vehicle's energy is squandered while braking often in metropolitan traffic (Vodovozov et al., 2021). Thus it is estimated that fuel consumption would drop by up to 40 % in the event that brake energy losses were entirely avoided and losses were also recovered as usable energy.

The schematic representation of regenerative braking systems' general functionality is shown in Fig. 4 (Clegg, 1996; Gupta et al., 2014).

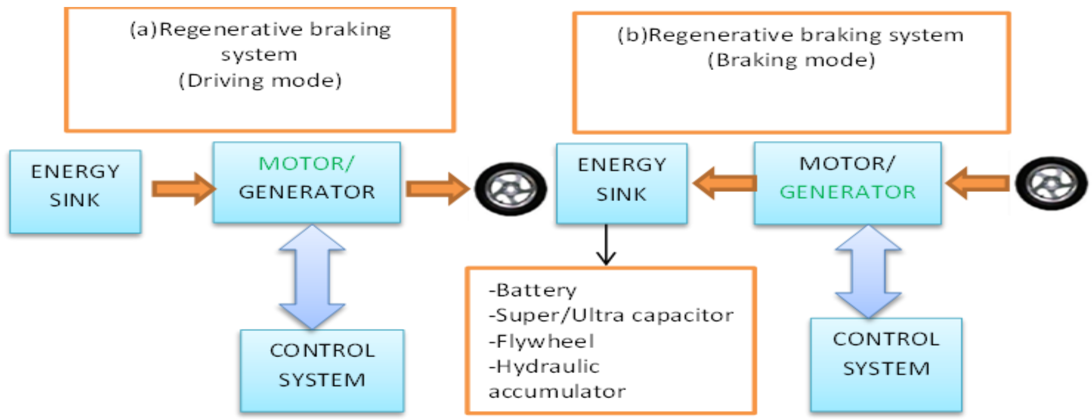

Figure 4: Diagrammatic illustration of how regenerative braking works while the car is moving (a) when brakes are applied and (b) when the brakes are applied (Umut & Recep, 2018)

4.4 Energy from the wind (aerodynamic) energy harvesting

To extend the range of electric vehicles, technology has been developed to gather energy from airflow while the vehicle is in motion. In order to create power that may be utilized in the vehicle, this system collects air from the front side of the car as it is moving and channels it into turbines that house alternators. While the low-pressure air outlet discharges from the system through the back or sides of the automobile, the air flow turns the turbines and produces power that is used to charge the batteries. In electric vehicles (EVs), the kinetic energy of airflow may be turned into electrical energy to some extent, but the drag force of the win opposes the direction of travel. Therefore, a wind drag force of equal but opposing reaction opposes the vehicle. For instance, at a speed of fifteen meters per second, an equal but opposite force proportional to the speed opposes the vehicle. Air resistance and friction must thus be overcome by the moving vehicle (Ferdous et al., 2011).

4.5 Harvesting of energy from vibration

Research into different energy collecting devices has been prompted by the ever-increasing desire for greater driving range and efficiency in electric vehicles (EVs). Vibration energy harvesting (VEH) is one of them that have the most potential as it can catch and use the many wasted vibrations that are present in electric vehicles. This section examines the state of VEH in EVs at the moment, emphasizing important technology, possible uses, and obstacles to general deployment. Dharmik et al. (2019) showed that energy from moving cars' vibrations may be captured and re-injected into the system to improve energy management and use. Zhang et al. (2016) created a simulation model as an application of energy analysis to capture kinetic energy from vibrations of vehicles using shock absorbers. Under some circumstances, vibrational mechanical energy from a moving vehicle can be captured by a harvesting device and transformed into electrical energy. The oscillating motion of a body from its initial position is known as vibration in mechanical systems (Thomson, 2018). It is the outcome of uneven pressures or forces acting on an item. It happens to cars during acceleration, deceleration, and traveling over uneven terrain, wasting engine or power source energy (Dharmik et al., 2019; Hendrowati et al., 2012). Vibration in a car may have a variety of negative effects, such as making a ride more uncomfortable, affecting the body and chassis, decreasing engine efficiency, and increasing fuel consumption (Mou et al., 2015). Vibrations have an effect on some human body components, including the muscles, joints, bones, and neurological system. An essential part of reducing undesired vibrations is the suspension system's shock absorbers or dampers, which immediately improve the vehicle's stability when it accelerates, decelerates, or brakes (Dharmik et al., 2019). For more effective transportation, vibrational energy from vehicles' vertical motions can be collected, transformed into electrical energy, and then returned to the system.

Shock absorbers are used to absorb shock from the vibrations of a moving vehicle. This enhances the comfort of the moving passengers. The hydraulic shock absorber is the most widely utilized kind of shock absorber in use today. It dissipates the vibration energy by turning it into heat (Sultoni et al., 2013). It has been stated that the energy potential of vibration energy harvesters with different parameters ranges from 46 to 7500 W. Theoretically, vibration amplitude values enhance the amount of vibration energy that may be recovered, and the resonance frequency yields the maximum energy value (Zuo et al., 2010). But the range of frequencies in which the conventional car suspension system can safely reduce vehicle vibration is between 0.5 and 10 Hz (Jha, 1976).

Zuo et al. (2010) designed and constructed an electromagnetic shock absorber after optimization. Hadas et al. (2012) harvested 35 mW of power from vibrations. Hendrowati et al. (2012) established a mathematical model of the multilayer piezoelectric vibration energy recovery system (ML PZT VEH) with 1 degree of freedom and conducted a simulation study. The suspension test configuration of a quarter vehicle model with two degrees of freedom yielded optimum output values of 6.23 V voltage and 1.6 mW power, to which the ML PZT VEH mechanism was fitted. Ordoñez et al. (2021) used finite element analysis to model a linear electromagnetic vibration energy harvester and produced 23.8 mW of power output. Phan et al. (2021) optimized the system to produce 28.6 mW of power. The designs did not show any effects that might alter how well car suspension systems function.

Research on vibrations can not only help eliminate the negative effects of vibrations on human body parts, but it can also revolutionize the automotive industry by improving drivetrain efficiency and converting vibrations into electrical energy that can be used in electric vehicles to improve less expensive agricultural transportation while extending drive range.

DISCUSSION AND COMPARISON OF VARIOUS ENERGY HARVESTING TECHNOLOGIES IN ELECTRIC VEHICLES

Conventional internal combustion engine vehicles have a lot of drawbacks which range from negative impacts on the environment to their significant role in reducing farmers' income through excessive spending on fuels and maintenance during the transportation of their farm produce and personnel. Electric vehicles offer a promising replacement for internal combustion engines since they are not just environmentally friendly but have limited maintenance and operations cost. Their lesser moving parts imply less frequent breakdowns or maintenance. They do not consume fuel which reduces a significant portion of farmers' income. Unfortunately, electric vehicles cannot be easily adopted for agricultural transportation due to their limited range compared to internal combustion engine vehicles. The most feasible current approach to solve this problem is harvesting energies in EVs to improve the efficiency of their engines. Solar energy and aerodynamic energy harvesting in EVs are theoretically possible but practically difficult to implement.

Suspension systems in cars are primarily designed to reduce road vibrations and maintain friction between the car and the road, which promotes safety and comfort while driving. Research is being done on energy harvesting devices for the automobile industry to improve fuel economy and lessen emissions in cars.

Depending on operation principle, vibration energy systems are usually classified as electromagnetic, piezoelectric and electrohydraulic. In contrast to electromagnetic and piezoelectric energy harvesting devices, it is asserted that mechanical (hydraulic/pneumatic) methods have some drawbacks such as oil leakage. Since agricultural roads are usually rough, vibration energy harvesting can play a significant role in harvesting energy in electric vehicles for agricultural transportation.

Using regenerative braking systems is a further technique for energy recovery. It shows a great potential for application agricultural electric vehicles. Table 2 compares the different energy harvesting technologies in electric vehicles as highlighted in this study.

Table 2: Comparison of different energy harvesting technologies in electric vehicles

Energy harvesting technology	Energy source	Advantage	Disadvantage	Application in EVs
Solar	Sunlight	It is renewable and abundant	Low energy outputs since solar intensity is limited by shades on the road and car geometry	Car roofs
Wind	Wind	It is renewable	Low energy output and impractical due to efficiency and aerodynamic problems	Not yet practical for EVs
Vibration	Mechanical vibrations	Wasted energy through vibrations can be recovered	Relatively low output compared to regenerative braking	Car suspension system
Regenerative braking	Kinetic energy	It has a significant energy recovery potential and improves braking efficiency	Efficiency can be affected by the battery state of charge and road conditions	Widely used in EVs

CONCLUSION AND FUTURE PERSPECTIVES

The current most important issues that need utmost attention in the world today are energy, agriculture, and the environment. It is critical to employ electric vehicles to reduce the negative effects of agricultural transportation such as fuel prices and maintenance on the income of farmers in Cameroon and around the globe. Currently, electric vehicles adoption is the most environmentally acceptable method of reducing the impact that transportation vehicles with internal combustion engines have on climate change due to greenhouse gas emissions. However, for full adoption, further research is needed, as electric vehicles face the problem of shorter driving range than cars with internal combustion engines. As a result of the extensive and growing usage of fossil fuels as a source of energy, these resources are quickly depleting and atmospheric pollution is rising. Due to this circumstance, people are now more aware of how important it is to support environmental consciousness and fuel efficiency.

Regenerative braking and vibration energy harvesting show a great potential for applications in agricultural electric vehicles. Solar and wind energy harvesting are theoretically possible but need more research in for their practical applicability.

Optimised energy harvesters produce more harvested energy than non optimised devices. Very negligible number of researchers have attempted to use numerical methods and computer algorithms to optimise the energies harvested. Artificial intelligence-based algorithms through modeling and optimization, will play a very significanct role in increasing the energies harvested in EVs. Improved energy outputs will extend the driving range of electric vehicles for use in agriculture, particularly for transporting purposes. Due to the renewable nature of all the energy harvested, this will significantly reduce the negative effects of maintenance and fuel costs on farmers' revenue during transit.

Research on the application of computer based algorithms to optimize and produce the best amount of harvested energy in EVs will play a significant contribution in the adoption of EVs for sustainable agricultural transportation.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest

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