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Review Article

Green Transit: Harnessing Renewable Energy For Sustainable Integration

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ABSTRACT

Present review explores various renewable energy sources and their potential applications in transportation. It provides an overview of different technologies including solar energy, wind energy, hydroelectric energy, biomass energy, geothermal energy, tidal energy, wave energy, hydrogen fuel cells, and various energy harvesting methods. Their importance in sustainable transportation through an analysis of efficiency, market trends, and methods have also been highlighted in the report. Similarly, the study also encounters management of organic waste materials for minimizing greenhouse gas emissions, moreover, the major benefit it persists include waste management, rural development, and employment for a sustainable environment at present time. The analysis also attempted to advance the knowledge of renewable energy integration into a transportation sector by evaluating earlier reports of available literature and market data, thereby promoting a sustainable and environmentally responsible society.

Key words: Solar, wind, hydroelectric, Biomass energy, Sustainable transport

Introduction

The atmospheric pollution is getting triggered day-by-day through the interaction of particulate matter, sulfur dioxide, and nitrogen oxides, which are produced by non-renewable energy sources from transportation and industries. The combustion of fossil fuels and other non-renewable energy sources emits large amounts of greenhouse gases, including carbon dioxide, into the atmosphere(Ou et al., 2015). These contaminants are the factor in respiratory ailments, acid rain, and smog. They also affect negatively on the quality of air, particularly in places with high population density. Similarly fossil fuels like gasoline and diesel are burnt in automobiles and disclose a considerable amount of greenhouse gases into the atmosphere leads to pollution of air and climate change. These substantial change in the environmental circumstances affect human health(Chang et al., 2017; Dominković et al., 2018; Gilmore et al., 2014; Morgan et al., 2014; Obileke et al., 2021; Park & Kwon, 2016). Health issues such as heart disease, respiratory disorders, and some cancers can be brought on by exposure to environmental contaminants and an analysis of the potential risks that newly identified pollutants provide to public and environmental health. Hence, in this drastic situation utilization of renewable energy is essential to accomplishing sustainable transportation. Similarly, the transportation system become more sustainable and the pollutant emissions can be decreased by switching to renewable energy sources.

Moreover, the present article provides a comprehensive and comparative analysis of various renewable energy sources for transportation including solar energy (Adhisuwignjo et al., 2017; Lanjekar et

al., 2023) wind energy (Fagiano et al., 2012; Morgan et al., 2014), hydroelectric energy (Ou et al., 2015) , biomass energy (Demirbas et al., 2009; Kheshgi et al., 2000), geothermal energy (Ramazankhani et al., 2016), tidal energy (Khare & Bhuiyan, 2022), wave energy (Serna Cantero, 2013), (Onsa & Elsadig, 2019) hydrogen fuel cells (Rath et al., 2019), and their benefits for generating a sustainable environment. A comprehensive review of existing literature on various renewable energy sources and their utilization in transportation has been conducted (Table). In order to acquire pertinent information on the effectiveness of renewable energy in market size, and its growth forecasts, through prior research information, industrial report, and market analysis been executed in the study. Each renewable energy technology's market data has assessed to determine present trends and potential future developments. These required looking at the size of market, rates of expansion, as well as significant variables that impacted how effectively renewable energy became prevalent in the transportation sector. A comparative assessment has been performed to assess the individual renewable energy source's viability for implementation of a particular transportation operation. Evaluation of efficiency of energy from renewable source has been performed through multiple variables including its effect on environment, scalability, and efficiency. To get useful insights into advantages and drawbacks associated with deploying the renewable energy in transportation, case studies of actual applications has been performed under consideration. The information regarding renewable energy for environmentally friendly vehicles is shown in tabular form (Table 1 & 2). To reduce the negative effects on the environment, renewable energy has become a necessity component in the present era. These renewable energies have broadened our modern horizons and aid in environmental protection. However, sources like wind, solar, hydrogen, water, biomass are the most common in this field of science which has been elucidated in table.

Assessment of the efficiency of Solar Power Plants

The kind of renewable energy source through solar technology employed, plant's location, the type of weather, system design and solar power plants. An outline of the efficiency factors for several kinds of solar power plants are provided. Photovoltaic Solar Power Facilities: PV solar panels use semiconductor materials like silicon to directly convert sunlight into electricity. PV panels usually have an efficiency of between 15% and 22%, while some more sophisticated models have been shown to achieve efficiencies of above 25% in lab environments(Lanjekar et al., 2023). PV efficiency is influenced by several factors, including solar cell quality, temperature, shade, tilt angle, and sun position. Concentrated Solar Power: The concentrated ratio of sunlight attains the effectiveness of systems for heat transmission and conversion, which utilized Mirrors or lenses to focus sunlight onto a narrow area. CSP plants have an overall efficiency range of 20% to 30% or more; some of the more sophisticated designs have efficiencies that are closer to 40%. Hybrid solar power plant is generated by the combination technology of PV and CSP facilities to increase flexibility and efficiency power. These technology facilities to attain higher efficiency and more dependable electricity output. Hybrid solar power plants also associate for the enhancement of overall system efficiency and grid integration by adjusting changing weather and its demand patterns. Similarly, Floating solar power plants mounted on bodies like lakes, reservoirs, or coastal regions, can provide further advantages including less land usage and improved cooling for solar panels. A few of the variables that affect the effectiveness of floating solar plants are wind speed, water depth, water quality, and anchoring mechanisms. Even though they might have maintenance and environmental effect issues, floating solar plants can nevertheless attain competitive efficiencies on par with those of land-based solar installations(Waseem et al., 2019). However, as materials, technology, and system integration continue to grow, solar power plant efficiency keeps rising. The general efficiency and dependability of solar power generation are further improved by advancements in energy storage, grid integration, and hybridization with other renewable energy sources.

Iran's location near the equator, at 25.2969° N, puts it in the optimum position to receive solar energy. Iran sourced 900 MW of its electricity from solar power in 2020; this included 420 MW of household solar power plants and 480 MW of solar power plant. Iran's top three provinces are Yazd, Fars, and Kerman, which produce roughly 68, 58, and 47 MW of solar energy, respectively. Iran still has plenty of undeveloped territory available for solar power facilities Sirjan, is a city in Kerman province where a 10 MW power can be built with $16.14 million. The payback period of the invested capital is within 4 years (Ramazankhani et al., 2016). The sites are being revealed and investigated to find the most acceptable locations for the construction of more solar power plants and done by using the Angstrom-Prescott model, which is the finest and most suitable method for the computation of global solar radiation sites. The largest quantities of solar radiation are found in southern, equatorial countries, where the development of various solar power plant types has been rapidly increasing over the past decade. Bayareh in 2017 explored the numerical modelling of solar chimney power station in southern Iran, according to findings, the best and worst cases would result in optimal cost increases of 4.63% and 17.60%, respectively. Taner gave a presentation on the economics of a solar power plant in the 20,000 square meter Aksaray city, Turkey which can produce 1.65 million kWh/m2 per year. A parabolic collector power plant was simulated by Trabelsi et al. where they had looked into various weather patterns and evaluated the electrical, thermal, and financial performance of this power plant using both dry and warm cooling method. Eljrushi and Zubi conducted an economic, technical, and

comparative examination of PV power plants that are intended to be erected in the southern part of Libya. Some other researchers also have studied Concentrated Solar Power (CSP) plants to work in some countries such as Iran, Turkey and Iraq. A systematic review and design methodology of CSP plants were presented by Zhang et al in the year; they introduced all solar collector sorts and evaluated the daily and monthly variations of the solar irradiation flux.

Recent trends in wind energy technology

Using wind turbines, the kinetic energy of moving air masses can able to convert into usable wind energy. The main component of these turbines is usually a tower with big blades that collect wind energy and transform it into mechanical energy(Chou et al., 2021). Through a generator located inside the turbine, this mechanical energy is subsequently transformed into electrical energy. The Earth's rotation and solar radiation constantly replenish the wind, making wind energy a renewable resource. Wind can be harnessed for as long as the sun shines and the Earth revolves. There are various kinds of modern wind turbines where the small turbines are for rural or household use to giant utility-scale turbines utilized in wind farms(Morgan et al., 2014). The wind speed, turbine size, and efficiency lead to influence how much electricity a wind turbine can produce. Towering wind turbines often capture more energy since wind speed rises with height. Wind turbines typically operate between three and five meters per second (m/s) when the wind is at its strongest, which is between twelve and twenty-five m/s. Worldwide wind energy capacity has been expanding rapidly, and many nations have included wind power in their plans for renewable energy(Fagiano et al., 2012). Europe, the US, and China are the top three producers of wind energy. Ultimately, wind energy is essential to the shift towards a low-carbon and more sustainable energy system because it produces clean, renewable electricity that helps to meet the world's expanding energy needs(Rehder et al., 2012).

Assessment of Components of Hydrogen Fuel Cells

Utilizing the chemical events occurring between both oxygen and hydrogen, hydrogen fuel cells produce power and clean water. In an electrochemical process between hydrogen and oxygen, a hydrogen fuel cell produces heat and water as byproducts while creating energy. It functions like a battery does not need to be recharged. Instead, hydrogen and oxygen are available, it will continuously generate energy (Rath et al., 2019). Their benefits are many and varied, ranging from being a renewable energy source to having excellent effectiveness and low emissions of pollutants. If there is a consistent supply of hydrogen and oxygen, hydrogen fuel cells can continuously produce energy and require just to be repeatedly recharged. Anode, cathode, and electrolyte membrane are the three main components of a hydrogen fuel cell. Hydrogen molecules electrolyte at the anode, dividing into protons and electrons (Vertès et al.,). While the electrons move through an external circuit to produce electricity, these protons cross the electrolyte membrane to get to the cathode. As we know when electrons flow electricity is generated. There are different types of prominent fuel cell types: Proton exchange membrane fuel cells (PEMFCs): These fuel cells have a high efficiency and quick startup times, but they depend on platinum catalysts, which might affect their cost-effectiveness. They operate at relatively low temperatures and are frequently employed in applications like automobile vehicles. Solid Oxide Fuel Cells (SOFC): These fuel-efficient devices can generate power at high temperatures and can be used with a variety of fuels, but they also degrade materials at greater temperatures(Serna Cantero, 2013). Alkaline fuel cells (AFC): These mostly find usage in space applications, where their alkaline electrolyte is employed. They are dependable and efficient, although they are susceptible to contaminants and need pure hydrogen. Molten Carbonate Fuel Cells (MCFC): These fuel cells function at elevated temperatures and are frequently employed in extensive. Oxygen Input: The fuel cell's cathode, or positive electrode, receives oxygen, most commonly from the atmosphere. Electron Flow and Water Formation: Water (H_2O) is produced at the cathode when oxygen molecules mix with protons that have travelled through the PEM and electrons from the external circuit (Wulf & Kaltschmitt, 2013). The electricity produced by single fuel cell is relatively small however, on the other hand, a fuel cell stack is made up of several fuel cells piled on top of one another. This allows for a higher power output that can be used for a variety of purposes, including as powering cars, supplying backup power to buildings, and acting as portable power sources. Hydrogen fuel cells are more attractive than conventional fossil fuel combustion engines since they generate energy with a high efficiency and only release water vapor as a byproduct, making them environmentally friendly. Additionally, they are adaptable, finding use in portable gadgets, fixed power generation, and transportation. For widespread use, there are still obstacles to overcome in the areas of infrastructure, storage, and hydrogen generation.

Use of Biomass energy as a sustainable renewable resource:

Organic materials, mostly plant-based materials and agricultural waste, are the source of biomass energy, which is fuel that may be used to produce heat, electricity, or other types of energy. Because the organic materials used to produce biomass energy may be renewed by human activity or natural processes, it is seen as a renewable resource(Wulf & Kaltschmitt, 2013). Organic elements can be included in biomass, like: Forestry residues and wood residues from agriculture; such as agricultural wastes and animal manure, similarly Energy crops, such as misc. acanthus and switch-grass. Similarly, oorganic municipal solid waste, such as leftover food, yard debris and Waste from industry such as sawdust and paper pulp can be used for

these process(Kheshgi et al., 2000). Technologies like Combustion, Gasification, and biochemical conversation can be used to turn biomass into useable energy. The organic waste materials can help minimize greenhouse gas emissions, the biomass resources are plentiful and widely accessible, they can be found in different places widely. Moreover, the major benefit it persists include waste management, rural development, and employment generation. Hence biomass related energy production might be suitable and sustainable for the present generation. In general, biomass energy has the potential to be a major factor in the shift to a low-carbon and more sustainable energy system, especially when it is generated from waste and residues and combined with other renewable energy sources(Obileke et al., 2021). However, to guarantee the sustainability and feasibility of biomass energy projects, thorough consideration of environmental, social, and economic considerations is mostly necessary. Similarly Geothermal energy is a renewal energy that harness heat from the earth's interior to generate electricity and provide heating and cooling for various application(Demirbas et al., 2009). As like to that Tidal and wave energy are forms of renewable energy that harness the kinetic energy of ocean tides and waves to generate electricity. The energy of the fluctuating ocean tides carries on by the moon's and sun's gravitational pull and get captured to produce tidal energy. Several methods such as tidal stream generator, tidal barrage, and tidal lagoons can be used to capture the tidal energy. Tidal stream generators harness the energy of flowing tidal currents by using underwater turbines that resemble wind turbines(Kheshgi et al., 2000). Usually, these turbines are placed on the seafloor in regions where tidal currents are very strong. These massive structures are built over bays or coastlines to catch and retain tidal water at greater intensities Similarly during low tide, it releases the tidewater through a turbine and produce energy.

Sustainable transportation in energy generated by solar system:

Photovoltaic cells, which use solar energy, can transform sunshine into electricity that can be used to charge batteries or power electric cars. Depending on the technology and area, this process' efficiency ranges from 15% to 22%. The market for solar vehicles has grown significantly globally in recent years. Estimated to be worth USD 383.4 million in 2022, it is expected to grow to USD 1,658.6 million by 2030, showing a strong 20.2% compound annual growth rate throughout the forecast period. These developments help create a more environmentally friendly and sustainable energy landscape (MacKay, 2013). In order to produce electricity from sunlight that may be used to power electric vehicles, solar highways include solar panels into the surface of the road. The efficiency ranges from 10% to 15%, depending on the design and region. The market for solar highways was estimated to be worth USD 31.33 billion globally in 2022, and over the forecast period, it is anticipated to develop at a CAGR of 12.70% was reported by(Wu et al., 2020). Similarly, Jia et al., 2020 done an experiment on electric trains that run on solar power are produced by installing solar panels on train roofs or along railroad rails. Most people are between 20% and 40% efficient. With a compound annual growth rate (CAGR) of 8.5% from 2023 to 2030, the size of the solar-powered train market is expected to reach $3 billion. In order to produce electricity for propulsion and onboard systems, solar-powered airships embed solar panels onto their surfaces 10% to 20% efficiency had been found by (Xu et al., 2020) and colleagues. The solar-powered vehicle market was valued at USD 431.86 million in 2022 and is expected to rise at a robust compound annual growth rate (CAGR) of 37% from 2023 to 2030, when it is expected to reach USD 5,359 million. Ships that are solar-powered are outfitted with solar panels to provide power for internal systems and propulsion. 10% to 20% is the usual efficiency. Projected to increase at a CAGR of 14.2% from 2022 to 2031, the worldwide solar boat market, estimated at $0.65 billion in 2021, is expected to reach $2.4 billion by (Tercan et al., 2021). Bicycles with solar panels installed can produce electricity for assistive motors and onboard electronics. This is known as a solar-powered bicycle. Usually, efficiency ranges from 5% to 10%. With a predicted CAGR (Compound Annual Growth Rate) of 8.38% between 2024 and 2032, the worldwide e-bike market, currently valued at USD 33.31 billion in 2023, is expected to reach USD 68.47 billion by 2032 by Prof. Apostolu and his collegues in the year 2018 in Netherland. Ferries equipped with solar panels for propulsion and onboard equipment are known as solar-powered ferris whose efficiency ranges from 10% to 20%(Obi et al., 2017). The growing need for effective and environmentally friendly transportation solutions is demonstrated by(Gilmore et al., 2014) in worldwide ferry market would reach a value of $34.6 billion by 2027. Solar-powered trams use integrated solar panels on their roofs to produce electricity for the tram's propulsion and internal systems. Efficiency varies usually between 10% and 20%. As like to that according to the report of Mikołaj Bartłomiejczyk 2018, with a compound annual growth rate (CAGR) of 3.2%, the global market for solar-powered trains is predicted to reach USD 2.76 billion by 2030. Similarly, (Xu et al., 2020) had installed solar panels on scooters to provide power for the vehicles' motor and internal components. A schema for generation of solar energy has been elucidated in Figure 1.

Figure: 1 A schematic representation of solar power panel system for sustainable energy production.

Efficiency varies, usually ranging from 5% to 10%. With a market value of $383.4 million in 2022, the worldwide solar vehicle industry is expected to increase to $1658.6 million by 2030 from $456.6 million in 2023. Lanjekar et al., 2023 had prepared a traditional rickshaw with photovoltaic-powered by adding solar panels to produce electricity for the vehicle's propulsion and internal functions. Their efficiency varies, usually between 5% and 10%. The size of the worldwide e-rickshaw market was estimated at US$ 1.55 billion in 2023 and is projected to increase at a compound annual growth rate (CAGR) of 14.9% from 2023 to 2030, when it is likely to reach US$ 4.11 billion. Bus rapid transit (BRT) vehicles fitted with solar panels to produce electricity for onboard systems and propulsion are known as solar-powered BRT systems. Their efficiency varies, usually between 10% and 20%. In 2022, the bus rapid transit (BRT) market was estimated to be worth USD 1.79 billion globally. The market is expected to expand at a compound annual growth rate (CAGR) of 7.3% from USD 1.90 billion in 2023 to USD 3.12 billion by 2030 reported by (Rath et al., 2019) Kumar *et al.,* and colleagues in 2024. However, research publications on the urban delivery automobiles with installed solar panels provide electricity for their refrigeration and propulsion systems reported by Pengzhan Zohu *et al.* 2021. variable efficiency, usually between 5% and 10%. The size of the solar vehicle market was anticipated to be USD 380.3 million in 2022, and between 2023 and 2032, it is projected to grow at a compound annual growth rate (CAGR) of more than 12%. As like to that the installation of solar panels on taxis lowers operating expenses by producing electricity for the vehicle's motor and interior electronics. Between 5% and 10% sows the usual efficiency. Based on a strong compound annual growth rate (CAGR) of 37% over the forecast period from 2023 to 2030, the solar-powered vehicle market, which was valued at USD 431.86 million in 2022, is expected to soar to USD 5,359 million by 2030 given byPark & Kwon, 2016. Solar-powered autonomous vehicles use solar panels to fuel its propulsion and internal systems, increasing their range and decreasing downtime. Typically, the efficiency ranges from 5% to 10% with a compound annual growth rate (CAGR) of 35.50% from 2024 to 2031, the global market for solar-powered cars is predicted to reach a value of USD 46.11 billion reported by (Waseem et al., 2019).

Wind energy as an environmentally friendly transportation

Using turbines to capture wind energy, produces electricity for grid-connected charging stations or electric cars. Their efficiency ranges from 30% to 50%, which depends upon wind speed and quality and category of turbine used. The market for wind energy worldwide was estimated to be worth US$ 81.31 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 10.10% from 2023 to 2032, or about US$ 211.85 billion by Fagiano et al., 2012. Wind propulsion devices, such sails or rotors, are used in shipping to help conventional ships operate with less fuel. Efficiency varies with fuel savings range from 5% to 15% on average. For the projected period of 2023–2031 the global wind-assisted propulsion market is anticipated to grow at a CAGR of 82.7% reported by (Chou et al., 2021). In order to reduce the amount of electricity use, wind-powered cable cars use wind energy to power them in mountainous or urban locations. varies in efficiency, usually between 5% and 15%. With a noteworthy compound annual growth rate (CAGR)

of 11.2%, the cable car and rope-ways market been projected to reach a value of US$ 2,771.2 billion by 2030 from an estimated US$ 1,193.9 billion by the end of 2022 by (Morgan et al., 2014) and his associates.

Ocean renewable energy: for a sustainable power generation:

Research on wave-based energy uses a variety of techniques to transform ocean wave energy into electrical power. The 20% to 40% efficiency range is covered. In the upcoming years, the wave energy market is expected to increase significantly. The global wave energy market is anticipated to develop at a compound annual growth rate (CAGR) of 27.2% from 2020 to 2027, reaching $141 million been reported by (Lv et al., 2023). As like to that taking advantage of temperature differential between warm surface water and cold deep water, Ocean Thermal Energy Conversion (OTEC) produces energy. Usually, the efficiency is between 1% and 3%. The market for Ocean Thermal Energy Conversion (OTEC) Systems expected to grow from US$ million in 2022 to US$ million in 2029, with a compound annual growth rate (CAGR) of % from 2023 to 2029 by Elizabeth *et., al* 2014. Sea Using floats or turbines, current energy captures the kinetic energy of ocean currents. Usually, efficiency ranges from 20% to 40%. During the projection period, the global ocean power market is expected to develop at a compound annual growth rate (CAGR) of 21.2%, from its estimated USD 670.5 million in 2021 by Y. C. Chang et al., 2016 in Journal of Navigation from Cambrige University. Production of bioenergy from offshore macroalgae biomass through environmental considerations, technological advancements, and obstacles using marine biomass, such as algae or seaweed, as a source of energy, ocean biomass energy produces biofuel has been reported by(Kheshgi et al., 2000) Fernand et al. 2017. And its efficiency typically falls between 20% to 40%. The ocean energy industry, which was estimated to be worth USD 890.12 million in 2023, is expected to expand at a rate of 23.7% between 2024 and 2030, or USD 4.879.85 billion. As like to that using turbines, tidal energy harvests energy from the tides' movement has also reported. The efficiency ranges from 15% to 35% on average. The size of the tidal energy market was estimated at USD 0.63 billion in 2021 and is expected to increase at a compound annual growth rate (CAGR) of 33.5% from USD 0.84 billion in 2022 to USD 8.45 billion by 2030 by Khare & Bhuiyan, 2022.

Geothermal based renewable energy for the generation of power:

The viability of geothermal energy resources including its production and transportation under renewal resource has also taken its advancement since last few decades. As the name suggests, geothermal is the technique for generating electrical power or driving automobile geothermal heat pumps by harnessing heat from the Earth's interior. Efficiency is quite high, usually above 90%. The size of the geothermal power market was estimated at USD 4.10 billion in 2021 and is expected to increase at a compound annual growth rate (CAGR) of 5.26% from USD 4.31 billion in 2022 to USD 6.17 billion by 2030 been observed by (Okolie et al., 2019). Research on geothermal heat pump northern China with regard to energy and environmental concerns been reported by (Y. Chang et al., 2017), where they found heat generated from the earth's crust get harnessed by geothermal heat pumps to provide heating and cooling for electric cars and charging stations. Typically, the efficiency is greater than 300% (COP of 3). The geothermal heat pump market had a 2023 valuation of USD 4.3 billion, and between 2024 and 2032, projected to grow at a 4.4% CAGR by the core research team. Similarly reports on the reduced dependency on fossil fuels has been achieved by using geothermal energy for cargo ship propulsion and heating systems by giving efficiency ranges from 20% to 30% on average(Shnell et al., n.d.). Geothermal energy was estimated to be a $6.6 billion global market in 2021. The sector expected to increase at a compound annual growth rate (CAGR) of 5.9% from 2022 to 2027 to reach $9.4 billion by the core research team from Oak ridge National laboratory United States.

Production of hydrogen fuel for a renewable energy source:

Current developments, unresolved issues, and potential uses of hydrogen fuel cells in the portable and transportation industries also be an eco-friendly alternative. Fuel cell vehicles made from hydrogen, which generate energy by combining hydrogen and oxygen. Efficiency ranges from 40% to 60% on average. The market for hydrogen fuel cell vehicles was valued at USD 0.9 billion in 2022, and it is expected to increase significantly over the next several years, with a predicted CAGR of 45.3% from 2023 to 2029, reaching a peak worth of almost USD 17.88 billion (Rath et al., 2019) in their content. An accurate evaluation of the most recent advancements in hydrogen generation, its storage, and transportation methods has been listed by (Vertès et al., n.d.). Further the researcher also reports on using energy from renewable sources, water molecules get divided to make hydrogen gas through a process known as electrolysis. The efficiency typically falls between 60% and 80% of the limit. In the review the research group also report by 2024, the electrolysis hydrogen generation market, estimated at USD 13.1 billion in 2023, leading to a compound annual growth rate (CAGR) of more than 7.2%. Through gasification or fermentation for biohydrogen production produces hydrogen gas from organic resources like biomass or wastewater(Wulf & Kaltschmitt, 2013). Efficiency ranges from 20% to 40% on average. Between 2023 and 2028, the global biohydrogen market is expected to expand at a compound annual growth rate (CAGR) of about 28.70% (Tercan et al., 2021). Wave-driven hydrogen gas generation through desalination plants propelled by wave energy produce hydrogen as a byproduct despite producing clean water(Serna Cantero, 2013). Efficiency varies; for desalination, it is usually 15% to 30% and for hydrogen production, it is 20% to 40%. Valued at USD 1.03

billion in 2022, the marine energy market increased at a compound annual growth rate (CAGR) of 22.84% between 2023 and 2032. By2032, it's anticipated that the market would grow to USD 8.05 billion (Lv et al., 2023) had cited in the content in the publication. Hydrogen-fueled based high-speed trains were powered by hydrogen fuel cells, which provide zero-emission substitute for traditional trains. usually operates at 40% to 50% efficiency. Over the course of the forecast period, the Hydrogen Trains Market is anticipated to expand at a CAGR of 43.8%, reaching US$ 49 reported by Kai Deng et al. 2022. Similarly report on a high-speed passenger ferry vechile powered by hydrogen and its analysis and cost effectiveness has been found by(Waseem et al., 2019) Fedric *et al.,* 2019.

Mechanical based harvesting an innovative approach for renewable energy:

Using piezoelectric materials embedded in highways or other infrastructure, piezoelectric energy harvesting transforms mechanical energy from moving vehicles into electrical energy efficiency ranges from 5% to 10% depending on traffic volume and road conditions. The market for piezoelectric energy harvesting systems was estimated to be worth USD 597.93 million in 2022. From there, it is expected to develop rapidly, with a compound annual growth rate (CAGR) of 4.75% through 2028. Xuezheng Jiang et al. 2014 has provided information for this content. Magnetostrictive energy retrieval is a technique that can be used to capture energy from vehicle motions. It works by using the magnetostrictive effect to transform mechanical strain into electrical energy. Usually, efficiency ranges from 10% to 20%. Thermoelectric generators are expected to see a 14.2% compound annual growth rate (CAGR) from 2021 to 2026 references from (Annapureddy et al., 2017) included for this research. Amiryar & Pullen, 2017 had utilized a revolving flywheel, energy storage stores kinetic energy for use in electric or hybrid cars sowing its efficiency more than 80% than other. The flywheel energy storage market was valued at USD 0.7 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 6.2% to reach USD 1.3 billion in 2034.

Waste to energy: a pathway for sustainable and renewable energy:

Report on Waste transportation and integrated waste-to-energy conversion in island communities was documented by (Zsigraiová et al., 2009). Waste garbage-to-energy involves burning organic garbage or using other methods to turn it into energy. The 20% to 40% efficiency range is covered. The research group expect the size of the waste-to-energy market estimated at USD 35.82 billion in 2021 and is expected to increase at a compound annual growth rate (CAGR) of 7.5% from USD 38.51 billion in 2022 to USD 68.68 billion by 2030. Research on the recent developments in the use of agricultural waste and wastewater as feedstock for microbial fuel cells for bio-electricity has grooming day by day. Electricity from agricultural waste generated through anaerobic digestion or burning of organic waste materials, such as crop residues or manure, provides electricity. Usually, efficiency ranges from 20% to 40%. In 2022, the bio-energy market was estimated to be worth USD 118.8 billion. Based on projections, the energy Market business is expected to develop at a compound annual growth rate (CAGR) of 7.5% from USD 127.8 billion in 2023 to USD 212 billion by 2030 been reported by S. Pandit et al., 2021. By using microbial fuel cells or anaerobic digestion, bioelectricity from food waste transforms organic waste from food preparation or consumption into electricity. Efficiency varies, usually between 10% and 20%. In 2021, the market for bioenergy was valued at USD 116.5 billion worldwide. By 2030, it is anticipated to have grown at a compound annual growth rate (CAGR) of 7.7% to reach USD 229 billion (2022–2030) which has been cited by (Xin et al., 2018). Similarly, (Muradov & Smith, 2008) had observed the release of methane gases from organic waste decomposition in landfills which was been captured as biogas from these sites and used as a fuel for transportation whose efficiency varies, usually between 40% and 60%. The biogas market is anticipated to grow at a compound annual growth rate (CAGR) of 6.3% from 2023 to 2033, from US$ 75 billion in 2023 to US$ 138 billion by 2033. A comprehensive analysis of the process of energy conversion from waste has been presented in Figure. 2 through diagrammatic representation. However, an economic and technological study of methane hydrate pellet transportation through self-preservation effect has been analyzed by Rehder et al., 2012 at Germany. Further the research group has observed extraction of transportation-grade methane from submerged and used as fuel. In 2022, the market for gas hydrates, namely the methane hydrates segment, was worth USD 0.72 billion. Hence, methane hydrates can be a potentially plentiful and unexplored energy source for sustainable renewable fuel.

Figure 2: Diagrammatic illustration of waste-to-energy conversion process for a sustainable transportation system

Algal fuel: a possible substitute for production of renewable energy

Algae based bio-fuel is a technology that uses algae to generate biofuels such as bioethanol and biodiesel. The efficiency ranges from 20% to 50% on average. The market for algae-based biofuels was projected to be worth USD 8.38 billion in 2022 and is projected to grow to USD 9.14 billion in 2023 by (Bracmort, n.d. and co researchers. Similarly, Kheshgi et al., 2000 reported generation of biofuel by extracting energy from oceanic biomass, such as brown algae, seaweed. Efficiency ranges from 20% to 40% on average. The ocean energy market was estimated to be worth USD 890.12 million in 2023 and is projected to grow at a compound annual growth rate (CAGR) of 23.7% from 2024 to 2030, to reach USD 4.879.85 billion. As like to that, Goria et al. 2024 has reported generation of algal Biohydrogen production by photosynthesis and processing of algae sowing a variation in its efficiency between 5% and 10%. Whereas Rajee, 2018 2018 publish the future of green jet fuel using algal biomass. An environmentally friendly substitute for fossil fuels, algal-based aviation biofuel generates biofuels from algae for use in aircraft as its efficiency varies, usually between 20% and 40%. He also reported the size of the algae biofuel market estimating to be USD 8.4 billion in 2022 and is expected to increase at a compound annual growth rate (CAGR) of 8.7% from 2023 to 2032, reaching a market size of USD 18.9 billion. Algae-based hydrogen production requires cultivating algae in order to use photobiological or photoelectrochemical processes to produce hydrogen gas whose efficiency varies between 5% and 10% has been reported by Catal and Kavakli 2020. The researcher also intimates the algal industries and global valuation they also confirmed that the projected growth rate 8.8% CAGR from 2023 to 2031, with a financial value of US$ 5.7 million. Biomass energy generates bioenergy for transportation by using organic materials like wood or biofuels and its efficiency ranges from 25% to 50%. The market for biomass power generation was estimated to be worth USD 91.3 billion in 2023 and is projected to increase at a compound annual growth rate (CAGR) of 3.0% to reach USD 105.7 billion by 2028. Hence, the possibility of using biomass for generate sustainable energy was been reported by Demirbas et al., and his colleague in 2009.

Discussion

The findings enhance various opportunities presented by renewable energy technologies for DE-carbonizing the transportation sector. While each source offers distinct advantages including high efficiency, availability, and minimal environmental impact, challenges such as intermittency, scalability, and infrastructure requirements persist. Therefore, a holistic approach that integrates multiple renewable sources and emphasizes the innovation in storage and distribution is essential for realizing a sustainable transportation ecosystem obtaining highest for solar system where as the energy production through biomass for sustainable transporting level is also at par the limit under consideration has been presented in Fig. 1.

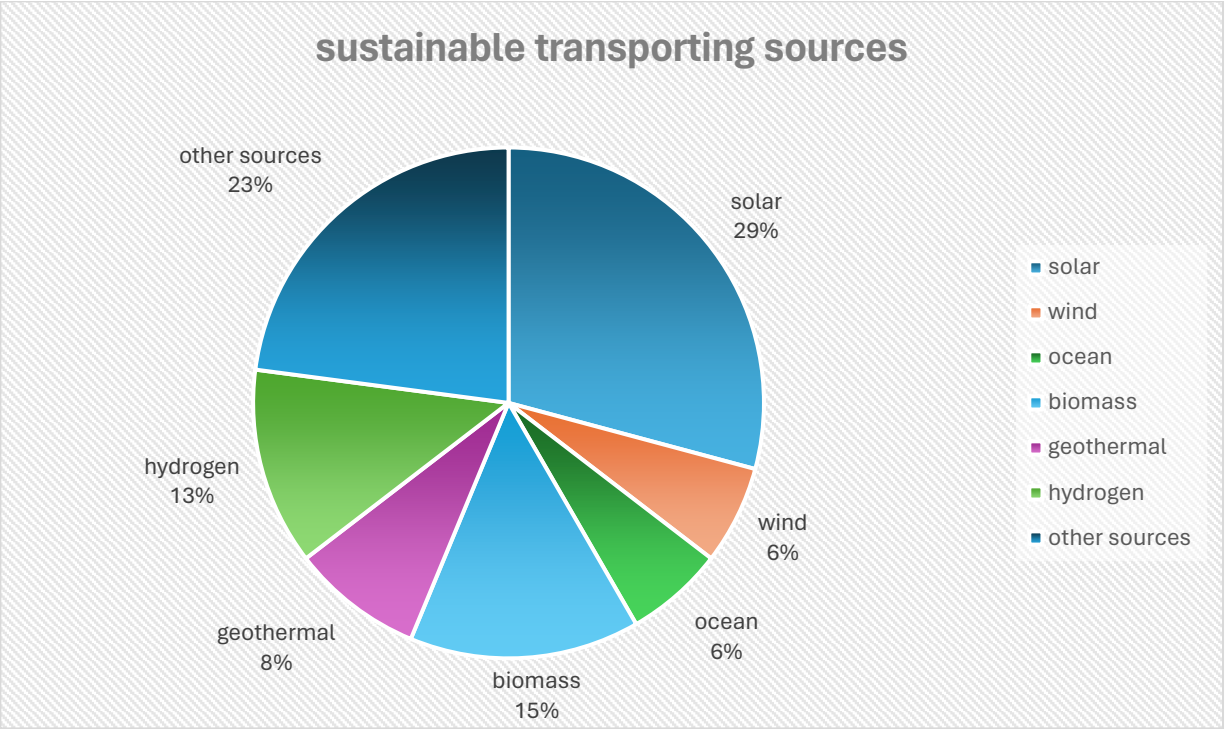

Figure 3: Pi chart showing sustainable transporting sources mentioned by various research group

With the given population increase our planet needs to breathe as there is increase in pollution and so much contamination. The pie chart explains the percentage of existing types of renewable sources in sustainable transporting. The statistical chart also helps to visualize the data that is being used to make us aware of the scientific technologies those are on their ways to save our planet presented in Figure 3. The sustainable ways of transporting are one of those. Here the solar is the most widely used source, there are various ways we can use it as. For example, the solar batteries, and the panels, they have become an integral part of the sustainable transportation and technology. Hydrogen must be the second major, it contributes to fuel production, the imagination of a car working with just everything but non-renewable fuel has actually come true in this era. Biomass is something we are all aware about, they contribute to the formation of many types of gases and fuels through various aerobic and anaerobic processes. Algae also contribute to this. Ultimately, there are so many technologies still undiscovered or ongoing, and each one of them would not just help the human kind but also this plane to breathe.

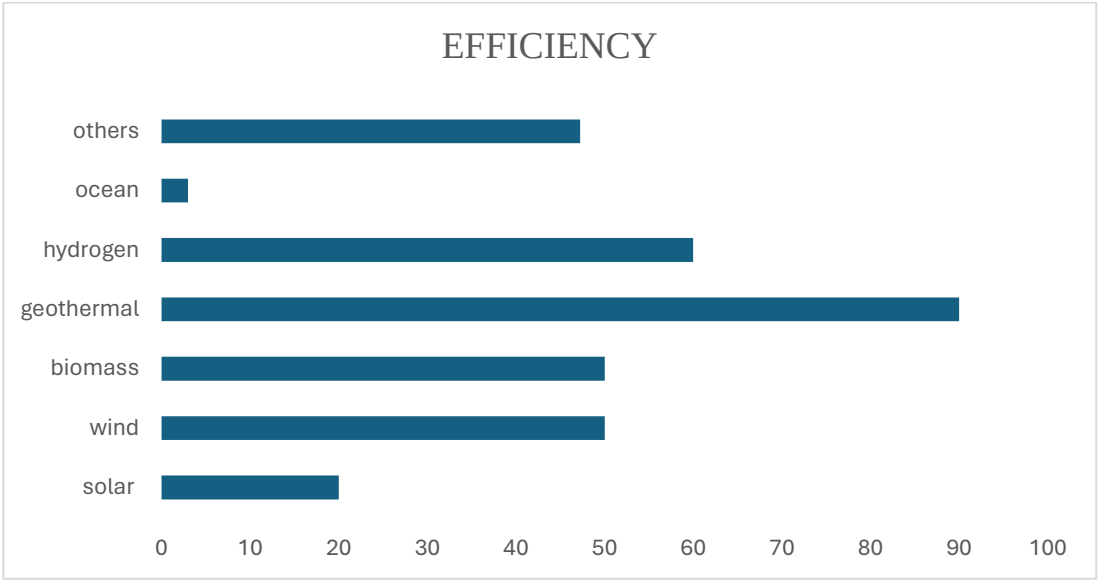

Figure 4: Renewable resources and their efficiency

Efficiency aids in the accurate evaluation of any uprising's response. In the present review efficiency pertains to sustainable methods of transportation. To adequately illustrate its effectiveness, the corresponding examined data was transformed into a graph format. Starting with geothermal energy, it

has demonstrated a great deal of efficiency in terms of sustainable transportation methods which has been depicted in Figure 4. They are a fantastic resource to replace fossil fuels and release very little greenhouse gas. Additionally, biomass is a readily available natural fuel that helps with transportation technology and purification of air because it presents relatively little environmental risk. In comparison, solar power is a little less efficient as its environmental advantages are confined to the periods of daylight. In every circumstance, despite the effectiveness these are, these are the ideal sources for humanity to transition to.

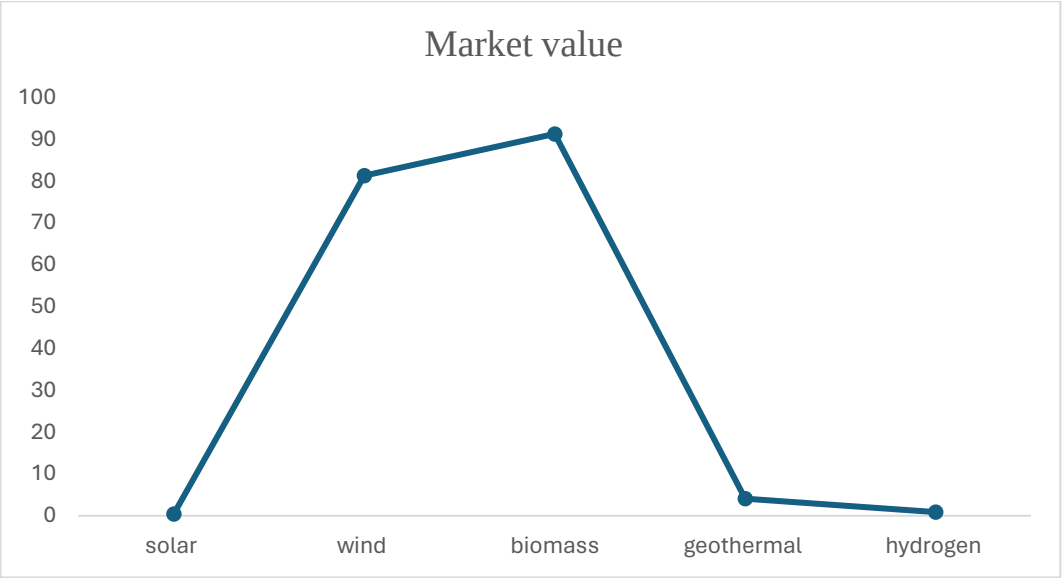

Figure 5: Market value of different renewable resources

Every product's value on the marketplace is often determined by a number of variables, including cost, accessibility, effectiveness, and quality. The market worth of the above-mentioned sources has been clarified in the graph Figure 5. Biomass provides increasingly in demand as it is affordable and efficient. Because of its adaptability, biomass also aids in maintaining the equilibrium of the carbon cycle. Wind being the second in demand is mostly because of its no dependance in fossil fuels as wind alone can handle the charging and handling of vehicles. As solar, geothermal, and hydrogen energy sources are more expensive and scarcer, there is proportionately less demand for them. However, both human health and aquatic ecosystems are seriously threatened by algal blooms but they are the major elements in present time for the generation of sustainable energy. Some Prediction shows algal blooms through environmental characteristics to address major environmental problems as they can tolerate stress. Algae are essential to the biosphere since they are the principal organic stuff and generators of oxygen Chakraborty *et al.,* 2016, Darshana *et al.,* 2021. On the other hand, for long-term sustainability and economic development waste water algal sample can be used for experimental analysis in future prospective. At present time major analysis technique like Artificial Neural Network (ANN), Gradient Boosting Decision Tree (GBDT), and Support Vector Machine (SVM) machine learning techniques (MLT), are widely used for predicting waste water algal blooms for the generation of a sustainable renewable energy resource (Tiwary et al., 2023).

Conclusion

In summary, by minimizing the dependency on fossil fuels and managing climate change require an upgrade to renewable energy sources for transportation. Even while each renewable energy source has advantages and disadvantages of its own, a combination of various sources and cutting-edge technologies is necessary to create a transportation system that is both efficient and sustainable in the long run. In order to overcome current obstacles and realize the full potential of renewable energy for transportation, further research and development work is required.

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Table: 1 Reports available on the utilization of solar energy its efficiency and market value

Sl no.	SOURCES	METHODOLOGY	EFFICIENCY	MARKET VALUE	REFERENCE

1.	Solar Energy	Convert sunlight into electricity and power vehicles	15% to 22%.	Market size at 383.4 USD million in 2022.	David J. C. MacKay
2.	Solar roads	Integration of solar panels on road surfaces generate electricity	10% to 15%.	Market was valued at 31.33 billion USD in 2022.	Lingjie Wu et al.
3.	Solar-powered Trains	Integrates solar panels on train roofs generate electricity.	20% to 40%.	Market size estimated to reach 3 billion USD by 2030	Limin Jia et al.
4.	Airships	Integrates solar panels on airship surfaces to generate electricity for propulsion.	10% to 20%.	Vehicle Market exhibited a valuation of 65 .00 to 431.86 million USD in 2022	Yuanming XU et al. Şafak Hengirmen et al.
5.	Bicycles, scooters, rickshaw	Bicycles, scooters, rickshaw were equipped with solar panels to generate electricity	5% to 10%.	Market is valued at USD 33.31 Billion in 2023.	S Adhisuwignjo et al. Rui Zhu et al. Pranay Rajendra et al.
6.	Ferris and Trams	Ferries and trams equipped with solar panels to generate electricity for movement	10% to 20%.	Market is projected to reach a value of 34.6 billion USD by 2027	Manasseh et al. Cawas Phiroze Nazir
7.	Bus, Delivery Vehicles, taxi, Ambulance	Bus, delivery van, equipped, taxi and ambulance in urban areas equipped with solar panels to generate electricity for mobility.	Variable, typically 5 to 20%.	The global Rapid Transit market size was valued at 1.79 billion USD in 2022.	Rajeev Kumar et al. Pengzhan et al. Eunil Park et al. Mohammad Waseem et al.

Table 2: Earlier reports on utilization of wind, biomass energy, its efficiency and market value

Sl no.	Wind Energy	Wind harness with turbines or rotor for electricity used in ship and car	5% to 50%.	Market was valued at 81.31 billion USD in 2022	Lorenzo et al. Todd Chou et al. Eric Morgan et al.
1.	Biomass Energy	Wood or plant used to produce hydrogen and energy in fermentation.	25% to 50%.	Market size was valued at 91.3 billion USD in 2023	M. Fatih Demirbas et al. Christina Wulf et al.
2.	Bioelectricity from Microbial cell	Electricity generated from organic matter using microbial fuel cells.	Typically 10% to 20%.	NA	Ke Christ Obileke et al.
3.	Bioelectricity from Agricultural Waste & food waste	Electricity produced from food and agro waste materials through anaerobic digestion	Variable, typically 20% to 40%.	Market was valued at 118.8 USD billion in 2022.	Andres F et al. Xiaodong et al.
4.	Ocean biomass Energy	Harnesses energy from oceanic biomass such as algae or seaweed for biofuel production.	Variable, typically 20% to 40%.	Market was valued at USD 890.12 million in 2023	Haroon S et al.
5.	Algal Bio energy Production	Cultivates algae to produce hydrogen gas and other fuel through liquefaction .	Variable, typically 5% to 50%.	The Algae Biofuel Market Size accounted for USD 8.4 Billion in 2022	Kajol Goria et al., Rajee Olaganathan Kelsi Bracmort, Tunc Catal et al. Longwen et al., Haroon S et al.
6.	Biogass from landfills	Captures methane gas emitted from decomposing organic waste in landfills for use as a transportation fuel.	Variable, typically 40% to 60%.	The biogas market is expected to upsurge from US$ 75 Billion in 2023 to US$ 138 Billion by 2033, exhibiting a CAGR of 6.3% from 2023 to 2033.	Nazim Muradov et al.
7.	Geothermal Heat-assisted Greenhouses for Biofuel Crops	Utilizes geothermal heat to maintain optimal temperatures in greenhouses for growing biofuel crops, increasing yield and reducing energy input.	Variable, depending on location and crop type.	The global geothermal energy market size was valued at $6.6 Billion in 2021, and geothermal energy industry is projected to reach $9.4 billion by 2027, growing at a CAGR of 5.9% from 2022 to 2027.	Mohammad-Ebrahim et al.