Energy Reports 15 (2026) 109319

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Review article

Sustainable and efficient use of integrated technology solutions in energy management

Wisam Abu Jadayil [a,*], Mohammad Alkhedher [b], Ghada Shwaheen, Mohamad Ramadan [c]

[a] MEM/MPM, College of Engineering, Abu Dhabi University, Abu Dhabi 59911, United Arab Emirates
[b] Mechanical and Industrial Engineering Department, Abu Dhabi University, Abu Dhabi 59911, United Arab Emirates
[c] Lebanese International University, Beirut 146404, Lebanon

ARTICLE INFO

Keywords:
Green Energy Efficiency
Smart grids
Energy-efficient appliances
Clean transportation
Electric vehicles
Energy management
Sustainability

ABSTRACT

Energy management is important for exploiting the positive aspects of green technologies and achieving sustainable energy use. The increasing global demand for energy and the environmental impacts of fossil fuel use have intensified the need for effective energy management strategies that integrate green technologies and sustainable transportation solutions. This paper examines the importance of green energy demonstration technology and clean transportation development for sustainable energy management. By focusing on the type of integration of smart grid, energy efficient home appliances, advanced building energy control systems, hybrid energy systems and wide temperature variation of material PCM to improve thermal efficiency. Development continues by combining new innovative solutions with effective management strategies and exploring how effective application contributes to reduced energy consumption and environmental impact. In addition, advances in clean transportation—electric vehicles (EVs) and hybrids—have been critically evaluated for their potential to reduce greenhouse gas emissions and fossil fuel dependence. In comparison, this study provides an analysis based on efficiency, price-performance ratio and integration capability; Strengths and challenges are given per approach. In addition, this paper has identified significant challenges and obstacles - including costs, technological challenges, and regulatory obstacles - and offered solutions to overcome these barriers. Findings from this paper imply that Smart Grid Systems can make a difference between 10% and 15%, which challenges the ability to protect users with data protection safety conditions; Energy-Efficient Appliances have been found to save energy by up to 30%, which deters potential use due to financial reasons alone. Ultimately, the goal of this paper is to facilitate energy management strategies and support the implementation and integration of these technologies into comprehensive energy management strategies for a more sustainable and more resilient energy future.

1. Introduction

Cities show significant negative environmental impacts due to the concentration of economic activities, high intensity resource use and extensive use of non-renewable energy. Put differently, the fact that cities are responsible for more than 70% of the world's energy consumption, produce more than 75% of greenhouse gas (GHG) emissions, and are home to more than 50% of the region's population justifies their importance to the environment (Bibri and Krogstie, 2020). Carbon dioxide (CO_2) emissions are the primary cause stress of anthropogenic weather trade, contributing to developing international temperatures and environmental instability. Data from the Global Carbon Project (2022) indicates that worldwide CO_2 emissions reached 36.6 billion lots in 2022, underscoring the pressing want for sustainable electricity solutions. The accumulation of CO_2 inside the surroundings results in accelerated radiative forcing, resulting in intense climate sports, melting ice caps, and developing sea levels (Climate Change, 2021, 2025). This has a test examines strength manage answers that focus on mitigating CO_2 emissions on the equal time as enhancing electricity efficiency, thereby assisting sustainable development goals.

At the "Energy Conservation and Energy Efficiency Working Group" meeting that happened in Beijing on June 5, 2017, strength performance grow to be taken into consideration a first-rate difficulty count for dialogue. Committed to operating together on initiatives using renewable

* Corresponding author.
E-mail address: Wisam.abu-jadayil@adu.ac.ae (W. Abu Jadayil).

https://doi.org/10.1016/j.egyr.2026.109319
Received 19 December 2025; Received in revised form 11 March 2026; Accepted 11 April 2026
Available online 19 April 2026

power a good way to enhance natural resource utilization and strength performance. An critical indicator of fair power improvement and use is strength efficiency (Hansen et al., 2024; Yao et al., 2021). In addition, it helps to determine whether economic growth is dependent on the level of energy use or improvements in energy efficiency. Apart from all this, energy efficiency has become an important policy option to address the interrelated issues of climate change and energy security (Sharma et al., 2014). Global population growth increases the demand for energy and natural resources (Maja and Ayano, 2021; Muzayanah et al., 2022). To meet their needs, industrial companies are expanding with new technologies and processes. Rapid growth in resource use and energy consumption has negative effects on the environment, including pollution, greenhouse gas emissions and waste production (Hashmi and Alam, 2019; Khan et al., 2021). Energy and resources are the two most important factors for economic progress. Economic progress is impossible without adequate resources and energy; Therefore, they should be used wisely and appropriately.

Two increasingly important elements in our pursuit of sustainability are clean transport and green energy efficiency technologies. Optimizing energy use and reducing greenhouse gas emissions worldwide depends to a large extent on the integration of these technologies. That said, assessing the sensible effectiveness of these technologies requires a know-how in their quantitative influences. The development of electricity-efficient commercial structures and device has shown great ability in green electricity efficiency generation. Compared to conventional incandescent lamps, strength-green lights technologies which includes LED bulbs deplete to seventy-five% less energy. According to an (Canton, 2021) Evaluation, Global use of LED lights may want to save extra than 1,four hundred terawatt-hours of strength with the aid of 2030, equivalent to the annual electricity intake of the complete African continent. Furthermore, the (U.S. Department of Energy Top Accomplishments in, 2022, 2024) The report states that when combined with smart power control systems, high-performance HVAC systems in commercial homes have been shown to reduce power consumption by up to 40%.

The developing recognition of electric vehicles (EVs) is vital to decreasing reliance on fossil fuels for clean transportation. Global EV income reached 10.5 million in 2022, up 60% from the 12 months earlier than, according to (Global EV Outlook, 2022, 2024). The development of infrastructure and energy call for are notably impacted by means of this rise. According to the IEA, the worldwide market for electric vehicles is predicted to reduce CO2 emissions via about 1.5 billion metric tons via 2030. However, improvements in battery era and the accessibility of charging infrastructure are conditions for the great use of EVs. As of proper now, predictions for battery expenses have dropped with the aid of 89% due to the fact that 2010, however more drops are required to make batteries widely cheap and scalable (IRENA, 2024).

Although green energy efficiency technologies and clean transportation systems have advanced significantly, there are still many significant research gaps. The absence of integrated analysis that combines different technologies under a single energy management framework is a significant drawback of research currently being published. Most of the previous review studies have tended to focus on specific domains, such as smart grids, energy efficient buildings, electric vehicles or renewable energy systems, without adequately analyzing the interactions, synergies and potential conflicts that arise when these technologies are used in combination in real energy systems.

In addition, many of the studies now available provide descriptive summaries of technology advances, but provide little comparative analysis of their effectiveness, maturity level, scalability, and integration issues. Because of this, the broader implications of integrating these technologies for long-term sustainability, system resilience and large-scale energy management have not received sufficient attention. Widespread use of sustainable transport and energy-efficient technologies is still hindered by problems with grid connectivity, infrastructure development, compatibility with energy storage and economic feasibility.

Highlighting phase change materials (PCM), smart grid technologies, energy efficient appliances, building energy management systems, hybrid renewable energy systems and clean transportation technologies, this review provides an integrated approach to sustainable energy management to overcome these barriers. This study highlights opportunities to increase energy efficiency, reduce greenhouse gas emissions, and aid the transition to low-carbon energy systems by focusing on the interconnection and system-level integration of these technologies, as opposed to previous reviews that look at these technologies separately. In order to improve energy efficiency and promote low-carbon energy systems, this study aims to present a comprehensive and integrated overview of new technologies for sustainable energy management. This study focuses on current advances in sustainable energy management systems using a structured narrative review methodology. Important scientific databases such as Scopus, Web of Science, ScienceDirect and Google Scholar were used to collect relevant material. The search focused on articles from 2015 to 2025, using terms such as energy management systems, smart grids, energy efficient buildings, electric vehicles, hybrid renewable energy systems and phase change materials.

This review is filling a research gap in the existing literature and provides new synthesis for the integrated solutions in energy management. It is needed because of the lack of cross-sector energy management perspectives and trying to connect the green technologies within a unified energy management framework. Whereas the comparative assessment of multiple technologies is relatively limited in the literature, this review is synthesizing recent advancements by highlighting their capabilities and discussing their limitations.

Although this study is a review-based analysis, it provides practical insights for the implementation of integrated energy management systems. The findings can support policymakers, urban planners, and energy engineers in designing sustainable energy strategies by identifying effective combinations of smart grid technologies, energy-efficient appliances, building energy control systems, PCM-based thermal management, hybrid energy systems, and clean transportation solutions.

2. Green technology

Green technology serves a "green" objective, as the term implies. Green inventions are those that benefit the environment and often include recycling, renewable resources, safety and health concerns, energy efficiency, and other areas. Natural resources are limited in the earth and some have already been exhausted or destroyed. Toxins that cannot be eliminated from drinking water or food crops cultivated on polluted soil, for instance, are commonly found in household batteries and devices, which can contaminate groundwater after disposal (Kumar et al., 2021). The effects on people's health are profound. Therefore, it is essential that all investors take the environment into account. They ought to realize how beneficial green innovations and clean technology are to business. These are growing markets with revenues that are rising quickly. Customers need to know that investing in green inventions can lower their energy costs and that these products are often safer and healthier (Hashmi and Alam, 2019). Because of energy use, our environment is facing several serious problems, such as depletion of fossil fuels, air pollution, degradation of the atmospheric greenhouse effect, climate change, global warming, and so forth. Many solutions, such as the creation of the RE100 campaign and the objective of net zero emissions by 2050, have been put into place to address the problems brought about by the usage of nonrenewable fuels. The advancement of green energy technologies is essential to achieving these aims. Technology, products, devices, equipment, and energy services that depend on data and software that is protected by patents and/or trademarks are collectively referred to as green energy technology. Ideas from the circular economy, like recycling, reused materials, extended product lifecycles, and sustainable product design, have been highlighted in recent advances (Global EV Outlook, 2022, 2024).

In this context, green technology shows up itself in the creation of sustainable practices (Danish and Ulucak, 2020), mechanisms that facilitate the mitigation of pollution and environmental impacts across the life cycle, the opening and development of new markets, and the innovation of new goods, services, or procedures (Alam and Murad, 2020). One of the most effective substitute approaches to sustainable development is now green technology (Aswathy and Saravanan, 2024). In particular, to comprehend the impact of environmental technologies and the creation of policies and decision making, green growth requires technological and market innovations (Awan, 2019). Aswathy and Saravanan define green or ecotechnology as the continuously evolving categories of practices, practices, and materials, from non-toxic cleaning products to methods for producing energy (Abbas et al., 2019). It encompasses sustainable or environmental technology. It takes both the immediate and long-term effects on the environment into account (Abbas et al., 2019). Green technology, which includes energy efficiency, health and safety issues, recycling, renewable resources, and many other things, is by definition ecologically friendly (Awan, 2019). To ensure businesses have sustainable growth in a demanding and competitive business climate, companies must implement the optimal resource utilization plan (Abbas et al., 2019). The growing importance of integrated green technologies for improving environmental sustainability and energy system resilience has been highlighted by recent studies. For example, (Abu Jadayil et al., 2025) emphasize the importance of waste-to-energy innovations, carbon capture technology and decentralized energy systems to promote sustainable energy transitions and reduce environmental impacts.

Integrated energy systems have become a popular strategy for enhancing the flexibility of energy systems and facilitating the incorporation of renewable energy. Coordinated control of several energy carriers, such as heat, gas, and electricity, is made possible by these systems, which can greatly improve carbon management techniques and grid stability (De Lorenzi et al., 2025). This review uses an integrated framework that links smart grid systems, storage technologies, renewable energy generation, and sustainable end-use applications inside a single energy management structure in order to increase clarity and methodological transparency.

Five consecutive steps comprise the methodical flow: (1) Renewable energy production and resource integration; (2) Electrochemical, mechanical, and chemical energy storage and conversion systems; (3) Demand-side management and smart grid coordination; (4) End-use applications, such as energy-efficient appliances and electric vehicles; and (5) Technical, economic, and environmental performance evaluation. This framework integrates performance efficiency, cost-effectiveness, scalability, and environmental impact while enabling methodical technology comparison.

3. Significance of green technologies in energy management

Therefore, significant measures must be taken to reduce CO2 emissions from transportation and other energy-related industries. Countries all across the world are setting both short-term and long-term objectives to fight global warming in the wake of the Paris Agreement. Many nations committed to reaching net-zero CO2 emissions by 2050 during the 2019 UN Climate Summit. The energy revolution is quite concerned about reaching these ambitious objectives (Mohideen et al., 2021).

Energy management, which maximizes energy efficiency and minimizes inefficiencies in production and consumption, is essential to maximizing the impact of green technologies. Energy is used more responsibly and efficiently when green technologies are integrated into power grids and industrial processes by effective energy management systems (Mishra and Singh, 2023). Energy management strategies, which monitor and control energy use, are directly related to the deployment of energy-efficient technologies in buildings and industrial sectors. Energy managers can assess usage trends and modify operations to increase energy efficiency by using automated systems and smart meters. In addition to reducing operating costs, it reduces greenhouse gas emissions and energy requirements, thereby reducing the environmental impact (Marinakis, 2020). In the context of clean transport technology, energy management ensures that electric vehicles are connected to the energy grid in a way that avoids system overload. Smart energy management systems can balance grid demand and promote energy saving by planning EL charging for low traffic. Transport networks become even more sustainable and efficient when renewable energy sources such as solar energy are integrated into EV charging stations (Alsharif et al., 2021).

Green technologies in combination with modern energy management technology and the integration of renewable energy sources enable the best possible use of energy resources within the framework of energy management. The use of energy-efficient appliances and smart network technologies, which provide better monitoring and management of energy use, can drastically reduce energy waste and energy expenditure. Similarly, by reducing greenhouse gas emissions and dependence on fossil fuels, clean transport options such as electric vehicles help global sustainability goals.

Digital technologies are used by smart grids to monitor power supply, improve demand response and incorporate renewable energy sources. They promote energy-efficient systems and objects, automate energy management and react in real time. By reducing energy losses and improving power flow, smart networks support sustainable energy use (Muqeet et al., 2023). Energy-green home equipment, which includes low-energy refrigerators, LED lights, and excessive-efficiency HVAC structures reduce strength demand, reduce strain on infrastructure and conserve resources (González-Torres et al., 2022). When these technologies are used, energy management becomes more efficient, waste is reduced and energy use increases, which is beneficial for businesses and consumers. In addition, because they run on electricity, reduce dependence on fossil fuels, and can be charged using renewable energy sources, electric vehicles (EVs) are important for sustainable transportation (He et al., 2020). Reducing energy use and achieving sustainability goals depends on their wide distribution.

With many innovations, green technologies are taking the lead in the fight for sustainable energy management. A number of green technologies are used for sustainable electricity use (see Figs. 1 and 2 below). Increased energy efficiency and sustainability are facilitated by smart grid systems, energy-efficient appliances, energy management of buildings and improved lighting technologies. In addition, the construction industry is changing due to green building technologies such as passive solar architecture, green roofs and walls, energy efficient HVAC systems and sustainable manufacturing techniques (Ghazimirsaeid et al., 2023). Conventional modes of transportation are being transformed by clean transportation technologies, such as electric, fuel cell, and hybrid cars (Anjana and Shaji, 2018; Sharif et al., 2023; Zhang et al., 2020).

To increase sustainability, reduce greenhouse gas emissions, and promote resource efficiency in many industries, this paper examines the integration of clean transportation and green energy efficiency technologies into energy management and efficiency.

3.1. Green energy efficiency technologies

Efficient energy use and production are important components of the world's ambitious goals for sustainable development, as well as measures to deal with environmental impacts and climate change. It is becoming clearer that energy efficiency has major economic, environmental and social benefits (Parise et al., 2017). However, it is clear that much energy efficiency potential is still unknown. Although energy efficiency is improving, it cannot keep up with rising economic activity in all industries. In terms of energy efficiency, we can define energy intensity as the quantity of energy required to create one unit of output. It calculates how much a unit of energy improves the economy. This

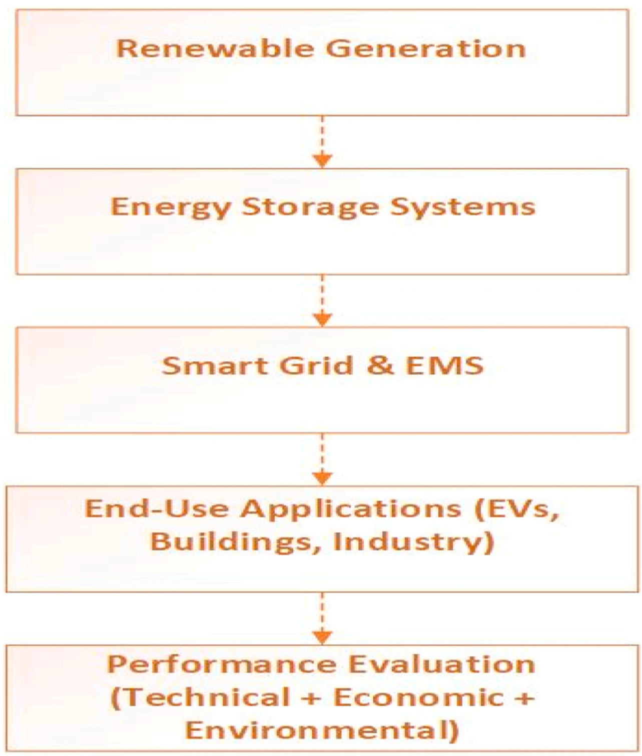

Fig. 1. Integrated Energy Management Framework Linking Technical, Economic, and Environmental Dimensions.

amount is computed by dividing GDP, or the total income of a nation, by total primary energy consumption, which includes all fuels and energy-generating fluxes. This indicator calculates the fuel and flow efficiency of a specific economy. A nation's energy intensity decreases as it grows more efficient and cuts down on wasted energy. Lower energy intensity means less energy-to-GDP conversion costs, based to the International Energy Agency. Energy efficiency is heavily influenced by technological advancements in power generation, storage, distribution, conversion, and consumption (Gao et al., 2012).

Reducing energy consumption is the aim of energy efficiency technologies while preserving or enhancing the intended level of production or service. To maximize these devices' performance and efficacy, energy management techniques are essential (Chua et al., 2013). The following are some instances of energy-efficient technologies and the related facets of energy management. See Fig. 3.

3.1.1. Smart grids

The phrase Smart Grid refers to more than a single technology or even a specific combination of distinct technologies. Is an "umbrella" term that refers to a variety of electric power system technologies, both hardware and software. Some people define Smart Grid as the addition of information and communication technology (ICT) to existing infrastructure. For others, Smart Grid means the construction of new lines for transmission, meters, and renewable energy sources (Stephens et al., 2014). Smart grids have supplanted traditional electricity systems in a number of nations. A smart grid connects current electricity infrastructures with information technology to improve efficiency. The smart grid intends to improve grid performance and reliability while reducing costs across generation, transmission, distribution, and consumption. Consumers now have better access to tariff-related information, allowing them to control their consumption more effectively (Tuballa and Abundo, 2016). Smart grids have revolutionized the way electricity is produced, distributed and used by incorporating advanced sensing, interaction and control technology into the operation of the power grid. Benefits include minimal emissions, safety, reliability and greater efficiency. Using smart demand management, integrating renewable energy sources and practicing power line loss reduction

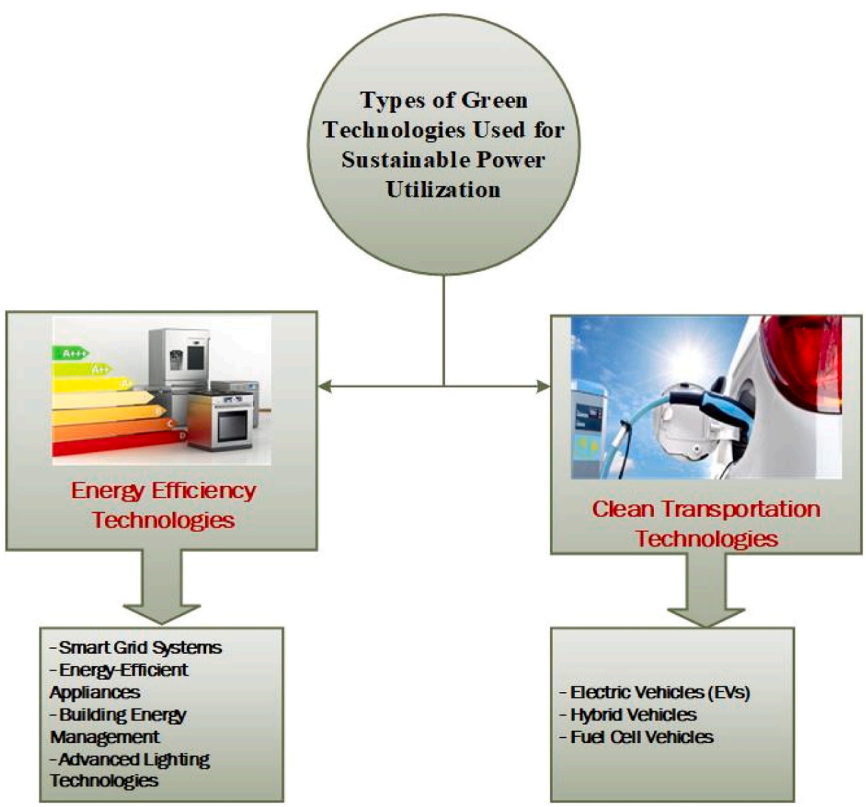

Fig. 2. Types of Green Technologies Used for Sustainable Power Utilization.

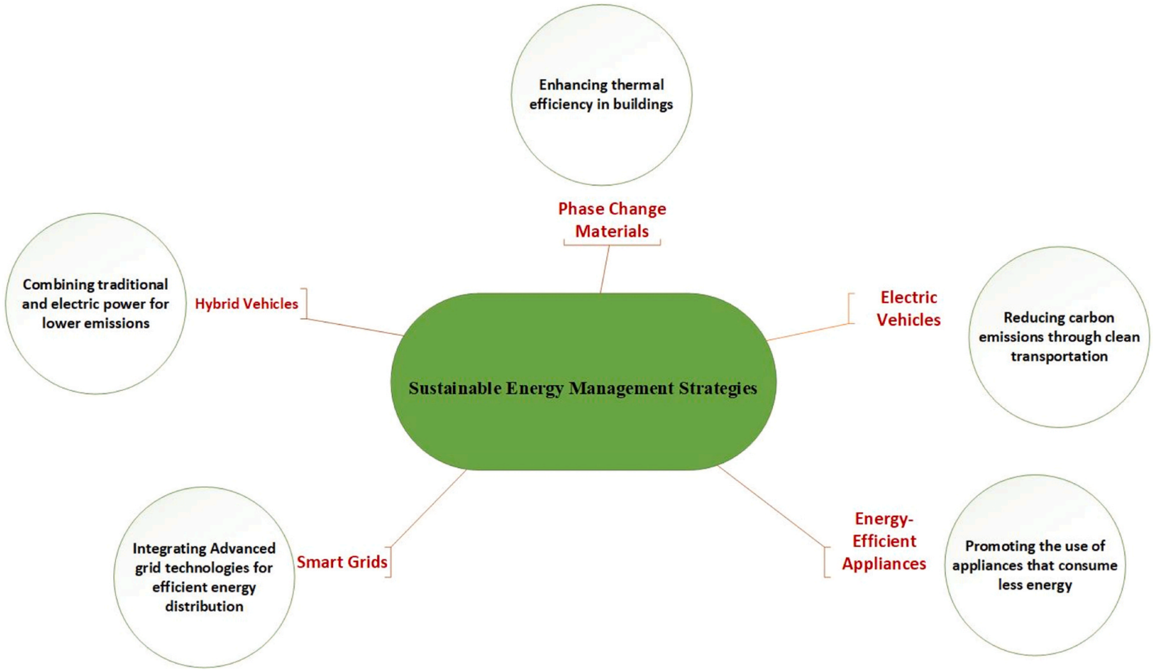

Fig. 3. Sustainable Energy Management Strategies.

techniques increases efficiency (Mei and Zhu, 2013). The primary difference between the smart grid and the traditional power grid is that the smart grid provides reliability without the need for additional resources. In addition to protecting assets such as substations, overhead lines, generators and client equipment, smart grids also aim to increase security through secure communications and software solutions that safeguard infrastructure and customer data (Dileep, 2020).

Smart grids allow two-way transmission of electricity and information. A smart grid system relies heavily on Smart meters, communication networks, and data management systems are examples of advanced metering infrastructure (AMI) technology, which enables two-way communication between utilities and consumers (Gao et al., 2012). The AMI system allows the grid to collect data on customers' energy use, power quality and load profiles. Smart meters can automatically send consumption data to the utility's head office. Customers can also be notified of how much energy they use and the maximum price period (Bilgin et al., 2016). Smart grids provide numerous benefits over conventional energy systems. They increase fault detection and allow self-restoration. Integrated energy assets and renewable generation are easy to contain into them. Smart grids offer state-of-the-art strength storage and top-shaving generation like plug-in electric/hybrid electric vehicles (PHEVs) and thermal-storage air conditioning (Cunjiang et al., 2012). In addition, they provide immediate information and control options, enabling customers and the power, transmission and distribution industry to make timely, well-informed decisions. To quickly identify unauthorized users, traffic jams and power quality problems, smart gadgets collect data. In addition, the network guarantees that connected devices and equipment will function as intended (Dibangoye et al., 2015). Furthermore, hybrid energy structures have become a powerful way to guarantee a stable energy era and improve power efficiency. These structures incorporate multiple power resources, such as wind, solar, and battery storage, to maximize overall performance and reduce reliance on traditional electrical grids. For example, combining solar photovoltaic (PV) systems with battery garages improves grid balancing by increasing the availability of power during high call intervals (Lü et al., 2020). Additionally, in remote locations where centralized grid infrastructure has been damaged, hybrid systems are growing in popularity, encouraging the use of decentralized energy.

Smart grid technologies enable improved real-time energy production, distribution, and consumption monitoring, control, and optimization (Bayram and Ustun, 2017). Energy management technologies maximize energy use, minimize peak demand and enable response programs using advanced metering, data analysis and communication systems (Rathor and Saxena, 2020). Energy management software, time pricing and automated demand response systems are used to proactively control and optimize energy loads. As a result, there is less energy waste and more efficient distribution of energy resources (Bakare et al., 2023). To improve the discussion of these technologies and their role in energy management, quantitative data showing the implementation and impacts of smart grids in different regions is important. Smart grid technology is essential for improving energy distribution, integrating renewable energy sources and increasing overall energy efficiency.

By 2022, nearly 100 million smart meters or around 70% of all households—had been installed all across the country, according to data from the U.S. Department of Energy. In areas with sophisticated smart grid technologies, this can lower peak demand by up to 5% through allowing real-time monitoring of energy consumption (Gao et al., 2022). Between 2021 and 2030, a 20% annual market growth rate is anticipated as a result of the EU's effort for energy efficiency via smart grids. Early users of smart grid technology include Germany and Italy, where penetration rates are almost 80%. By reducing transmission losses by 10%, Germany's smart grid technologies have greatly increased grid efficiency (Sospiro et al., 2021). Smart grid deployment has expanded quickly in China as part of its enormous renewable energy ambitions. More than 500 million smart meters were linked by China's State Grid Corporation by 2023, enabling improved energy load balancing and the integration of solar and wind power into the grid. As a result, energy waste is reduced and dependence on the grid is increased (Thompson, 2023).

Smart grids offer significant improvements over traditional grids in terms of reliability, communication, efficiency and control. It is a power network that uses digital communication technology to monitor, analyze and control energy consumption as well as deliver power to customers. Smart meters allow two-way communication with consumers. On the demand response (DR) side, attractive discounts are offered to ensure consumer participation in adjusting energy use (Jarrah et al., 2015). Integrating non-traditional energy sources improves the reliability and efficiency of smart grids. So does the successful implementation of electric vehicles. Fig. 4 depicts the main suppliers and customers in the smart grid. Arrows indicate the direction of energy movement. Adopting a smart grid in place of a traditional grid, which primarily uses the older grid's current resources, presents a number of issues. Where current traditional grids must be turned into smart grids, evolution techniques must be established to achieve an ideal network capable of carrying out the smart grid's features (Pagani and Aiello, 2016). Principles of graph theory are frequently used to determine the appropriate network and topological models for a smart grid (Babakmehr et al., 2016).

3.1.2. Green energy – efficient appliances

Households consume energy for a variety of purposes, and the amount of energy required varies greatly between household activities. The household sector is critical to energy consumption, and much work has been put toward saving energy in households, which account for one-fifth of worldwide energy demand. When examining energy consumption, it is important to note that individuals do not use electricity directly, but rather use electricity-powered services such as televisions, lighting and refrigerators. In other words, power usage must be analyzed in terms of energy usage (Baldini et al., 2018). The urge to purchase energy-efficient equipment must grow if home energy consumption and carbon emissions are to be reduced. The main source of consumption of energy and carbon emissions in homes is appliances, and their use is growing quickly. Between 2005 and 2015, Chinese households consumed 468 billion kWh of electricity, a 162% increase. Studies show that between 2014 and 2015, household energy carbon emissions rose by 5.8%, making up 11.6% of all household carbon emissions. Nearly 70% of these emissions came from domestic appliances (Wang et al., 2017). Reduced household energy use and emissions are directly impacted favorably by the use of energy-efficient equipment. According to statistics, domestic energy-efficient appliances saved approximately 10 billion kWh of electricity per year in 2017, lowering carbon emissions by 6.5 million tons, which equates to a decrease of 14,000 tons of nitrogen oxide emissions, 14,000 tons of sulfur emissions, and 11,000 tons of particulate matter emissions. There are two ways to reduce the amount of energy used in a home: either cut back or use energy efficient appliances. Research shows that improving energy efficiency is a practical strategy for mitigating climate change and protecting the environment. However, energy users choose to reduce energy consumption over retrofitting or moving to energy-efficient appliances (Häckel et al., 2017).

Domestic consumers' energy usage is a major source of carbon emissions into the environment. For example, in the Chinese market, four million refrigerators and five million televisions get changed every five years (Ma et al., 2013) (Parikh and Parikh, 2016). analysis found that the energy savings of four major home appliances (refrigerator, air conditioner, fan, and TV) are expected to reach 52–145 billion kWh by 2030, accounting for up to 27% of total energy savings. It is also anticipated that using energy-saving equipment will result in a 30% reduction in carbon emissions by 2030. Researchers stated that energy-efficient home appliances are the quickest and most effective way to ensure environmental sustainability (Zhou and Yang, 2016) (Sonnenberg et al., 2011). assert that the selection of energy-efficient equipment has been significantly influenced by environmental issues. According to (Alam et al., 2014), people who are more knowledgeable about energy-efficient products are more likely to use them.

Moreover, Phase change materials (PCMs) have demonstrated giant

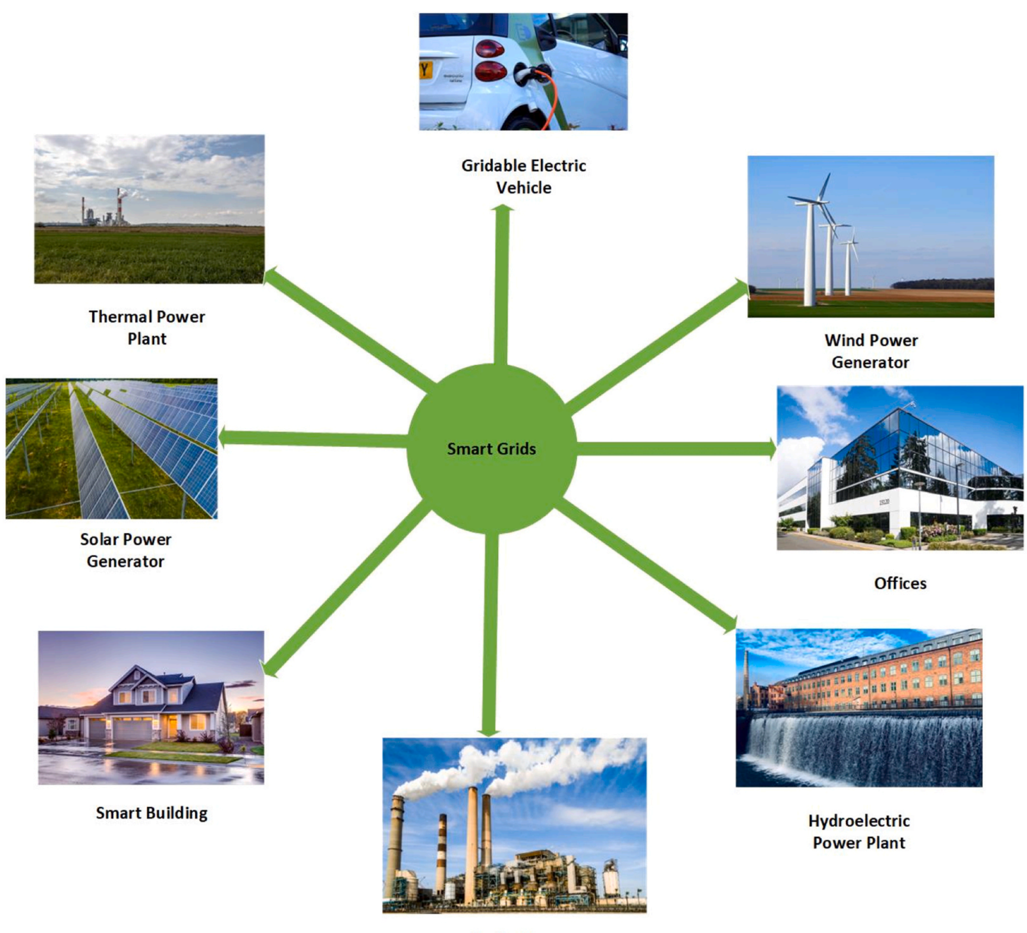

Fig. 4. Smart Grid Customers.

capability in enhancing thermal performance throughout numerous applications, consisting of solar panels and thermal reactors. PCMs absorb and release heat at certain stages of the phase transition, enabling efficient thermal garage. According to recent research, PCM integration with solar cell systems can increase electrical efficiency by up to 15% (Kazemian et al., 2023). Furthermore, concentrated photovoltaic structures have been effectively cooled using metal foam structures embedded with PCM, thereby increasing efficiency and reliability (Zhao et al., 2020). These innovations play an important role in increasing the use of renewable power and reducing energy losses in thermal methods.

Applications of PCMs such as solar panel cooling, PCMs integrated with solar panels reduce overheating, improve power and stiffness, other thermal reactors, PCMs optimize heat retention, and ensure robust thermal conditions for industrial processes. Third, more suitable building insulation materials increase heat retention in homes, thereby reducing power consumption in HVAC structures. Studies such as "Phase Change Material (PCM) based full thermal storage equipment to manage sonochemical reactor heat" (Chibani et al., 2023) Reveal the effectiveness of PCM to stabilize the thermal environment, reduce strength loss and improve overall performance.

3.1.3. Energy management of green buildings

Buildings used for residential, commercial, educational, healthcare, and industrial purposes are consuming an increasing amount of energy. 30–45% of global energy is consumed by buildings (Ashouri et al., 2019), Most of the energy being used by subsystems such as lighting, water, safety, heating, and cooling systems. Within this framework, current efforts are concentrated on making sure that, in order to meet the standards for energy efficiency in buildings, operational needs are met at the lowest practical energy cost while preserving an environmentally pleasant building (Doukas et al., 2007). Energy efficiency is regarded as the most successful approach in many developed and emerging countries to manage and overcome rising energy demand (Al-Rakhami et al., 2019). In any event, improving the energy efficiency of these systems is difficult since they must often meet complicated operating requirements, dynamic energy demands, and comfort criteria (Wang et al., 2019). Depending on how they are used, buildings are currently equipped with Building Energy Management Systems (BEMS). BEMS is a set of strategies and practices aimed at improving efficiency, performance, and energy use (Bonilla et al., 2018). This technology enables energy management duties such as automated demand response, managing expenses, identifying anomalies, and organizing information (Jota et al., 2011). There are various studies and research papers that describe sophisticated BEMS utilization for subsystems such as heating and cooling systems (Seeam et al., 2018; Jiang et al., 2017) or the entire building (Rotger-Griful et al., 2017). Energy conservation in buildings has been the subject of a great deal of research during the last ten years. Commercial structures are typically designed during the building planning stage with established occupancy levels and work schedules in mind. These schedules have been seen to diverge dramatically from actual occupancy behavior, wasting energy (Naylor et al., 2018).

Buildings can function as intelligent systems, encouraging the transition to a more viable energy consumption perspective. They can accelerate the adoption of sustainable technology while lowering carbon emissions, productivity, operational expenses, well-being, use of energy, and comfort (D'Oca et al., 2018). There are many different kinds of buildings nowadays, depending on the goals of design. Figs. 5 and 6 illustrates the different types of buildings, such as green, net-zero, and smart. Green buildings are usually made with the environment in mind at every stage of the building process, from design and construction to operation and maintenance to demolition and reconstruction. In order to achieve net-zero energy use and, consequently, annual carbon emissions, net-zero energy buildings must supply their energy through security measures and sustainable electric power generators within the

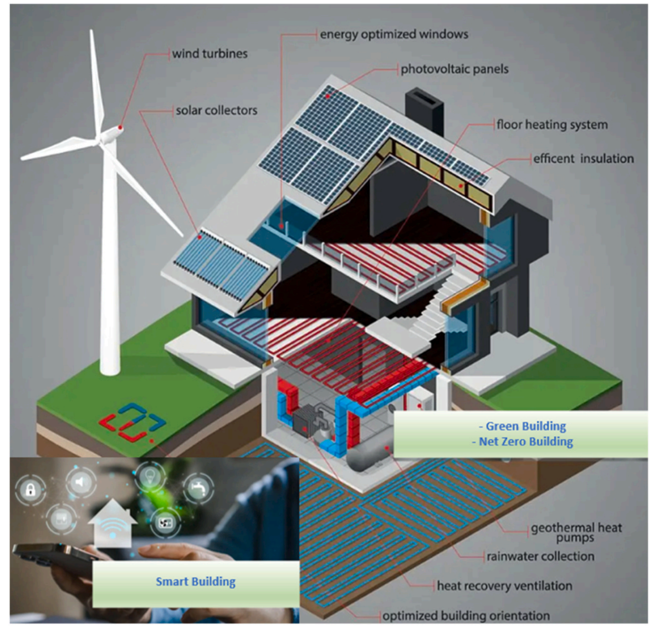

Fig. 5. Various Eco-Friendly Buildings.

structure (Pan et al., 2014). The integration of energy and technology systems into buildings is referred to as "smart building." This places a focus on energy efficiency, automation, occupant comfort, and resource management (Shaikh et al., 2016).

Energy management's core idea is to continuously, systematically, and effectively assess energy usage, with a focus on energy cost optimization in relation to user attributes, finance capacities, energy demands, funding options, and accomplished emission reductions (Doukas et al., 2009). With the use of energy management systems (EMS), customers can satisfy both their own and utilities suppliers' goals by utilizing load demand patterns and estimations of renewable energy (Di Piazza et al., 2017). These systems can use a variety of control logics to monitor and manage the energy use of buildings, machinery, and industries (Lee and Cheng, 2016). Table 1 lists numerous studies on energy efficiency technologies and the methodology utilized in each.

According to recent studies, sophisticated AI technologies can significantly improve smart grid performance by improving energy demand forecasting, grid operation optimization and real-time monitoring. These intelligent systems make it possible to make energy infrastructure more sustainable and adaptable, able to integrate a variety of energy sources (Madani et al., 2025). Overall, the evaluated research show that energy-efficient appliances and smart grid technologies are important for enhancing energy management and lowering energy usage. Real-time monitoring, demand-response systems, and better load balancing are all made possible by smart grids, which can greatly increase the dependability and efficiency of electrical systems. On the other hand, the main way that energy-efficient appliances help is by lowering the amount of energy used in homes and buildings.

Although both strategies increase energy efficiency, their maturity levels and implementation difficulties are different. While energy-efficient appliances are comparatively simpler to install but offer more gradual energy savings, smart grid technologies frequently necessitate significant infrastructure investment, sophisticated communication networks, and regulatory assistance. Because efficient appliances lower overall consumption at the end-user level and smart grid technologies optimizes energy distribution and demand response, their simultaneous adoption can offer complementary benefits. Long-term sustainability objectives can be supported and system efficiency can be greatly increased by integrating various technologies into a single energy management framework.

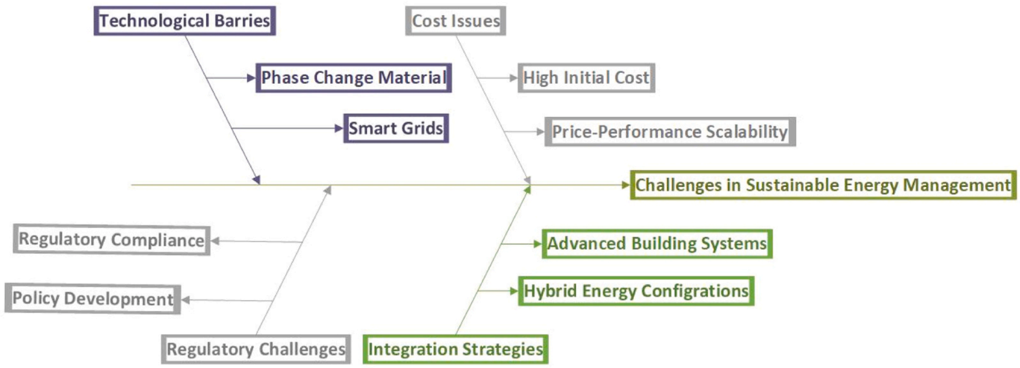

Fig. 6. Overcoming Challenges in Sustainable Energy Management.

3.2. Clean transportation technologies

The transportation sector appears to be one of the most significant hurdles to sustainable development (Mathiesen et al., 2015). For the past ten years, the transportation sector in the European Union that relies on fossil fuels has been responsible for nearly one-fifth of the emission of GHG and one-third of all final energy consumption (Alises and Vassallo, 2015). Transportation still uses more fossil fuels than it did in the past, despite recent developments in certain countries' power and heat sectors demonstrating notable achievement in lowering demand and embracing more RES. The transportation sector's reliance on fossil fuels may be considerably reduced by the development of alternative fuels, more fuel-efficient automobiles, and battery EVs, however integrating the heating, electricity, and transport industries allows for a more extensive utilization of renewable energy sources. But there isn't a single, easy way to use RES to reduce carbon dioxide released in the transportation industry (Mathiesen et al., 2015). As a result, multiple studies have been conducted to explore the various feasible options for the future sustainable transportation sector. While some academics examine the whole transport sector, many studies focus on a specific mode of transportation, technical solution, or planning scheme that applies to one or more areas.

Three types of electric vehicles were covered by the author: plug-in hybrid electric vehicles, fully electric vehicles, and hybrid electric cars. The authors found that while electric vehicles were more fuel-efficient than other car models, CO2 emissions could be higher if the electricity needed for recharging the batteries came from coal- or oil-fired power stations. Likewise, a thorough examination of electric vehicles and associated technologies is provided in (Shareef et al., 2016), highlighted how crucial it is to carry out more research in this field in order to lower costs and improve the technical capacities of batteries for electric cars. A summary of strategies for plug-in hybrid electric vehicles and electric vehicles that maximize charging, conducted by (Rahman et al., 2016), concluded that building a charging infrastructure is essential to the future growth of electric vehicles (Raslavičius et al., 2015) studied the technical and legislative facets of Lithuania's deployment of electric vehicles. By applying a SWOT analysis (Weaknesses, Opportunities, Threats, and Strengths), the writers found that encouraging companies to invest in plants that produce batteries or power trains can have a transformative effect on the local electric vehicle sector. But emphasis was placed on the government's active involvement in order to achieve the latter. Additionally, the cost implications of making the quick changeover to electric vehicles were looked at in (Riesz et al., 2016).

Trailer carrying in distribution centers, transit depots, container ports, and other areas has shown to be a valuable application for electric trucks. Compared to diesel cars, improved electric trucks require less maintenance and are quieter. The effects of EVs on the power market, particularly management mechanisms and vehicle-to-grid (V2G) technology, were studied by Shafie-Khah et al. Additionally, they examined how the transportation sector and sporadic renewable energy sources interact (Shafie-Khah et al., 2016). They argued that EVs will primarily target the spinning reserves and auxiliary services markets. Stochastic approaches should be utilized to address uncertainties such as vehicle numbers, charging prices and times, state of charge, and driving behaviors. In addition, numerous academics focused on the integration of the power and transportation sectors. investigated alternative economic models for implementing battery electric cars in Denmark, with an emphasis on how renewable energy sources and electric cars interact. According to what they found, some countries like Denmark offer great political and economic conditions for the development of these kinds of business models. The authors of (Chang et al., 2017) examined the environmental impact of a number of biofuels as potential solutions for the transportation industry in the future, including bioethanol, biodiesel, and bio-hydrogen. They discovered that biofuels can still contribute to the reduction of fossil fuel consumption, even with the current volume of fossil fuels utilized for biomass farming and biofuel production (Ail and Dasappa, 2016) An analysis of Fischer-Tropsch (FT) synthesis technology for biofuel production was carried out in the study, which revealed that FT synthesis from biomass is a viable method for creating sustainable fuel. The most productive bio-oil was palm oil.

The cultivation of waste land for the production of biomass was studied in (Pfeifer et al., 2016). However, the authors demonstrated that the grown biomass in Croatia is not financially viable. Anderson (Anderson, 2015) examined how using biofuel affected car emissions. He found that even with increased gasoline use, greenhouse gas emissions may decrease, however air quality is projected to decline with higher use of biofuel. Furthermore, biofuels have been identified as a potential solution for mitigating increasing demand for energy in the Australian transportation sector (Azad et al., 2015), whereas in Thailand (Lecksiwilai et al., 2017), biofuels have demonstrated superior environmental performance to their fossil-based counterparts. However, their manufacture requires substantially more water. Datta (Sadeghinezhad et al., 2013), investigated alternate fuels for compression ignition engines and discovered that, while biodiesel use has much higher environmental benefits than standard diesel, it degrades engine performance.

To increase the driving range of EVs and make the switch to EVs more sustainable, clean transportation technology and energy management are essential. There are challenges in integrating EVs into the electrical grid, such as rising energy costs and problems with grid stability (Kene and Olwal, 2023). To overcome these issues, EV charging optimization and control solutions have been developed (Wang et al., 2023). Moreover, the advancement of driving energy management technologies, like multi-power source drive systems and adaptive torque control, may greatly increase the driving range of EVs (Li et al., 2022). Furthermore, coordinating grid-connected EV charging with renewable energy can improve power balance and lower battery aging costs,

Table 1
Studies on Green Energy Efficiency and its Relationship to Energy Management.

No	Article	Insights	Methodology	Contributions
1	(Alsalemi et al., 2023)	The research describes a modular suggestion system for increasing residential household energy savings by utilizing a context appliance-level energy database from seven household appliances.	- Modularity is built into the system architecture through customizable sub-components. - Machine learning is utilized to automatically profile appliances, as well as rank-based evaluation systems.	- The paper introduces an adaptable recommender system to enhance family energy savings. - The recommender system uses modularity and methods from machine learning to provide recommendations.
2	(Jafari, 2023)	The study addresses the manufacture and selling of two types of electricity-powered home appliances: energy-efficient and inefficient models. The government supports energy-efficient products by cutting tax rates on their manufacturers and distributors.	Game-theoretic frameworks are used to make decisions in various competitive contexts and power systems.	- The article examines a supply chain encompassing the government, vendors, manufacturers, organizations, and customers. - The paper employs game-theoretic frameworks to make decisions in various contexts.
3	(Waris and Hameed, 2020)	The study analyzes the factors that influence consumers' willingness to buy energy-efficient household appliances, such as understanding of eco-labels, concerns about the environment, as well as perceived consumer effectiveness.	- Non-probability quota for age and education - Purposive sampling method	- Created a theoretical framework for understanding consumers' intentions to purchase energy-efficient household equipment. - Discovered key indicators of purchasing intention, including as knowledge of eco-labels and concern for the environment.
4	(Kim and Ha, 2021)	The study addresses the barriers to the implementation of Building Energy Management Systems (BEMS) and highlights critical components of the BEMS industry ecosystem.	- A survey of significant players was undertaken using the analytical hierarchy process (AHP). - Identifying main obstacles to the implementation of BEMS	- Identified main barriers to the introduction of BEMS using Fourth Industrial Revolution technology. - Created policies that promote the development of an effective BEMS industrial ecosystem.
5	(Bianco et al., 2020)	The study presents a Building Energy Management System for a smart building that incorporates renewable energy sources and an HVAC system.	- Use of novel insulating material and installation of cogeneration, trigeneration, and solar technologies. - Create a Building Energy Management System to optimize smart building operations.	- A proposal for a Building Energy Management System for smart buildings. - Creation of an optimization and simulation tool to manage HVAC systems.
6	(Anees et al., 2019)	For sensor nodes in smart grids, the study proposes an energy-efficient multi-disjoint route opportunistic node connection routing technique.	- The multi-disjoint path opportunistic node connection routing protocol (EMOR), which uses little amounts of energy. - Makes use of buffering size, working-sleeping cycle, residual energy, and relation factor quality.	A multi-disjoint path opportunistic node connection routing protocol that is energy-efficient was presented. - Increased energy consumption overall, packet delivery rate, network lifetime, and end-to-end delay.
7	(Kuyumani et al., 2018)	The study examines communication technologies that can be used in smart grids.	- Examines communication technologies for use in smart grids. - Simulation results for the Additive White Gaussian Noise (AWGN) channels are shown.	- Looks into communication technologies for use in a smart grid. - Develops a model and network of communications field for the power system.
8	(Nleya et al., 2016)	The study explores improving energy efficiency in cooperative power systems using power scheduling algorithms and resource allocation, without mentioning smart grid energy-efficiency technologies.	- Clustered and hierarchical power scheduling algorithms optimize tariffs, storage, and distribution, while solar intensity prediction improves resource allocation, planning, and network traffic management.	- Smart grid infrastructure is divided into three sub-smart infrastructures. - Power scheduling proposal to improve power trade, distribution, and storage efficiency.

resulting in a low-cost carbon reduction transition (Gan et al., 2023). Although comparisons of EV charging electricity prices offer valuable insights into operational cost advantages, it is important to recognize a number of limitations. Time-of-use pricing structures, system carbon intensity, and geographic location all have a substantial impact on electricity rates. Total ownership costs may also be impacted by the availability of infrastructure, the cost of battery deterioration, and legislative incentives like tax credits or subsidies. These elements should be taken into account when interpreting the study's cost-efficiency results since they may have an impact on their generalizability.

Table 2 lists numerous studies on clean transportation technologies and the methodology utilized in each.

The cost-effectiveness, scalability, and effectiveness of green energy efficiency and clean transportation solutions must all be taken into consideration while evaluating them. Understanding each technology's potential, constraints, and applicability in the larger framework of sustainable energy management will be made easier with the aid of this study. Table 3 provides an updated viewpoint by comparing the scalability, cost-effectiveness, and effectiveness of various technologies,

Table 2
Studies on Clean Transportation and its Relationship to Energy Management.

No	Article	Insights	Methodology	Contributions
1	(Kene and Olwal, 2023)	The energy management of grid-based large-scale charging stations for electric cars is covered in the paper that is being presented.	- bio-inspired methodologies, computational intelligence methods, swarm intelligence-based optimization. - Ant-based swarm algorithm using centralized, hybrid, and distributed controllers.	- Investigates the effects of large-scale EV charging on the grid's electricity distribution system. - Evaluates optimization options for reducing the high cost of grid energy use.
2	(Wang et al., 2023)	The paper provides an overview of driving energy management for electric vehicles, highlighting the efficiency enhancement through torque vectoring control techniques and dual-motor coupling drive systems.	- Evaluation of the energy losses associated with driving electric cars. - A review of the decentralized drive system's torque vectoring control schemes and the dual-motor coupling drive system's settings and power distribution methods.	- A driving energy management approach can increase the driving range of electric vehicles. - Using new multi-power source drive systems can significantly improve the driving range of EVs.
3	(Li et al., 2022)	The study looks at the relationship between energy and mobility as well as grid-connected electric vehicle battery anti-aging energy management.	- Creation of a revolutionary online battery anti-aging energy management technique. - GEV charging coordination is treated as multi-objective learning using the DRL method.	- Creation of an online battery anti-aging energy management strategy for the energy-transportation nexus. - Coordination of GEV charging using multi-objective learning to enhance penetration of renewable energy sources while lowering battery aging costs and power swings.
4	(Gan et al., 2023)	This study examines energy management solutions for hybrid electric vehicles (HEV).	The study discusses the development of an energy management strategy using deep reinforcement learning (DRL) algorithm and its integration with the intelligent transportation system (ITS).	- The work examines the development of energy management techniques for hybrid electric vehicles using deep reinforcement learning algorithms. - The study covers the problems and solutions of applying these tactics.
5	(Zahedmanesh et al., 2021)	The study explores the technological and economic aspects of an integrated solar photovoltaic system, including an electric vehicle parking lot, bus charging station, and electric transit system.	- Cooperative decision-making (CDM) approach for the virtual energy hub (VEH). - A supervisory control system that employs agents for planned CDM and related services.	- Proposed cooperative decision-making technique for a virtual energy center. - Creating a supervisory control system with agents for optimum energy management.
6	(Sabri et al., 2022)	The study covers hybrid electric vehicles (HEVs) as a clean transportation technology and investigates how to increase fuel efficiency using an adaptive energy management system (EMS).	- Model-Based Design - Fuzzy logic-based EMS	- An investigation on the fuel-saving potential of power-split type HEVs using fuzzy logic-based EMS. - A model-based approach with nonlinear data mapping provides more output alternatives.
7	(Teimoori and Yassine, 2022)	The offered paper examines the issues and potential remedies for energy management in Electric Vehicles (EVs), which are classified as clean transportation technology.	- The research employs a literature review methodology to examine current EV energy management issues and solutions. - The study also examines the usage of Federated Learning (FL) and Blockchain technologies to protect information.	- Addressing energy constraints to boost EV popularity. - Developing ways to guarantee user data privacy.
8	(Vellingiri et al., 2022)	The research introduces a deep learning-based state-of-charge prediction technique for renewable energy management in hybrid electric vehicles, enhancing accuracy through a convolution neural network and long short-term memory model.	- HCNN-LSTM model with Barnacles mating optimizer (BMO) for hyperparameter optimization.	The establishment of a novel DLSOC-REM approach for estimating SOC in HEVs. - Create a hybrid convolution neural network and long short-term memory (HCNN-LSTM) model for precise SOC estimate.

depending on recent research.

Due to their potential to lower greenhouse gas emissions and reliance on fossil fuels, clean mobility technologies—especially electric vehicles (EVs)—represent an essential part of sustainable energy systems. However, energy storage capacity, integration with renewable energy sources, and the availability of charging infrastructure all have a significant impact on their efficacy. EVs provide lower operating emissions and more energy efficiency as compared to conventional transportation systems, but their widespread use presents new difficulties for electrical

Table 3
Comparative Analysis of Green Technologies.

Technology	Efficiency Improvement (%)	Effectiveness	Cost-Efficiency	Scalability	References
Smart Grid Systems	20–30% decrease in peak demand	increases the flexibility and reliability of the grid.	High starting expenses but long-term cost-effectiveness.	High scalability, necessitates updating infrastructure.	(Bilgin et al., 2016; Dibangoye et al., 2015)
Energy-Efficient Appliances	10–25% decrease in consumption of energy	Directly lowering operating expenses and energy consumption	short payback times as a result of energy savings.	Both the commercial and residential sectors can readily adopt it.	(Wang et al., 2017; Ismail et al., 2023)
Building Energy Management	15–35% increase in energy efficiency	efficient at lowering building energy consumption.	Moderate expenses and long-term savings.	Scalable but requiring investments in retrofits.	(Naylor et al., 2018; Shaikh et al., 2016)
Electric Vehicles	60–70% more energy-efficient than Internal Combustion Engine vehicles	Increases range and efficiency while lowering emissions.	Decreasing costs, high initial investment.	High scalability with infrastructure development.	(Mathiesen et al., 2015)
Hybrid Energy Systems	30–50% energy savings in hybrid setups	Reduces heating/cooling energy demand.	High (cost-effective, low maintenance for passive heating and cooling)	Moderate (optimal for specific uses)	(Ma et al., 2021)
Phase Change Materials (PCMs)	20–40% improvement in thermal efficiency	(Enables greater renewable integration)	Moderate (requires spending money on several systems)	Moderate (Effective for off-grid or rural locations)	(Farid et al., 2021)

grids, such as higher demand and possible peak load pressures.

By allowing EVs to act as distributed energy storage devices, integration with smart grid technologies and vehicle-to-grid (V2G) systems can help reduce these difficulties. By enabling bidirectional energy flows, this integration increases the overall efficiency of energy systems and supports grid stability. Therefore, in addition to increasing vehicle efficiency, successful implementation of sustainable transportation technologies depends on their coordinated integration with larger energy management infrastructure.

Through enhanced monitoring and demand-response mechanisms, smart grid technology can cut transmission and distribution losses by roughly 10–15% (Bilgin et al., 2016). Optimizing energy consumption and distribution requires the use of energy efficiency technology, especially smart grid systems. The technologies provide notable advantages in terms of lower operating expenses and improved grid stability. Modern lighting technology and energy-efficient appliances both provide significant energy savings and are easy to use widely (Naylor et al., 2018). Clean transport technologies, especially electric vehicles, can effectively reduce emissions and dependence on fossil fuels. Electric vehicles are becoming more affordable and scalable as more charging stations are delivered. Fuel cell cars are more expensive than electric cars, and despite their potential, there are infrastructure issues (Mathiesen et al., 2015). Although green energy efficiency technologies can save money over time by reducing energy bills, they can be expensive up front, especially for complex systems such as building energy management technologies. But as energy savings increase, these solutions become more and more affordable. On the other hand, clean transport technologies are initially more expensive, especially when it comes to the price of buying vehicles and building the necessary infrastructure, such as charging stations. The initial cost of ownership remains a significant barrier to the widespread use of electric vehicles, despite the fact that they are generally cheaper to operate than conventional vehicles.

Efficiency can be increased by up to 50% by using hybrid energy systems that incorporate renewable energy sources like wind and solar. Due to their complex maintenance and control systems, they can prevent scaling as well as increase energy reliability. By developing climate-adapted hybrid models and complex control algorithms, efficiency and cost-effectiveness can be increased (Ma et al., 2021). PCMs are very useful for increasing thermal efficiency in solar panels and buildings, as they have been shown to increase energy efficiency by 25–40%. However, their integration is hindered by material costs and a lack of consumer knowledge. Their adoption can be sped up by encouraging research into affordable PCM solutions and including these materials in green building guidelines (Zhao et al., 2020).

4. Challenges and barriers

Sustainability and environmental impact reduction need the use of green technologies into energy management plans. To fully utilize these technologies, a number of obstacles and challenges must be removed. These difficulties include infrastructure constraints, legislative barriers, and expensive startup expenses in addition to technical intricacies. In order to properly utilize the advantages of green technologies and realize a sustainable energy future, these obstacles must be removed, the Table 4 offers a thorough summary of the current state of green technologies by thoroughly analyzing these issues and suggesting potential solutions.

The main barriers and challenges that prevent the implementation of green technologies are shown in the table. One of the main difficulties to the widespread use of green energy efficiency technologies is high upfront expenses. Organizations may find it challenging to invest in cutting-edge technologies like energy-efficient industrial processes and smart building management due to these costs. Adoption is further hindered by the technical complexity of integrating these systems, which requires a level of experience that many businesses may not have. Regional standards and compliance requirements are examples of regulatory barriers that increase complexity and can cause implementation delays and increased costs (Kuzior et al., 2023). Among these, smart grid technologies stand out for their ability to optimize energy use and distribution. Clean transportation technologies, including fuel cell vehicles, electric vehicles (EVs) and hybrids, face challenges such as infrastructure development, pricing and customer engagement. Recent advances in battery technology and increasing government subsidies are removing some of these barriers, making EVs more competitive (Shafie-Khah et al., 2016). Electric vehicles are particularly noteworthy because they reduce greenhouse gas emissions directly from the transport sector.

Traditional and renewable energy sources are used in hybrid energy systems, which present complicated control system needs and maintenance difficulties. By developing user-friendly control algorithms and user interfaces, operators can increase system performance and reliability. In addition, the development of climate-adaptable hybrid models will improve scalability and performance (Lü et al., 2020). PCM offers much promise for improving solar panel and thermal reactor thermal efficiency. However, low awareness and concerns about material costs have prevented widespread use. Funding research and development to produce more economical and thermally efficient PCM formulations can promote their use. Promoting PCM-integrated construction designs will also facilitate the use of these materials in sustainable construction practices (Chibani et al., 2023).

Table 4
Challenges, Barriers, and Proposed Solutions in Green Technologies.

Green Technology	Challenges and Barriers	Proposed Solutions	References
Smart Grid Systems	High initial cost, cybersecurity, difficult integration, difficult regulations, and worries about data privacy.	Government support and incentives, cutting-edge cybersecurity precautions, scalable and modular integration solutions, encouraging legislative environments, and strong data privacy laws.	(Dileep, 2020)
Energy-Efficient Appliances	The high initial cost of energy-efficient equipment can potentially discourage its adoption, especially in households with lower incomes and Customers may lack knowledge on energy savings opportunities or the benefits of energy-efficient products.	To help with the initial expenditures, implement refunds, subsidies, or low-interest borrowing. Improve consumer knowledge by using clear labeling guidelines and awareness programs.	(Hesselink and Chappin, 2019)
Building Energy Management	High initial costs for technologies and materials used in energy-efficient construction, opposition to departing from traditional building techniques, blending in with the current buildings.	Analysis of long-term cost reductions and funding alternatives, Training and instruction for architects and builders, Government incentives and retrofit solutions.	(Al-Rakhami et al., 2019)
Electric Vehicles (EVs)	High starting costs, the infrastructure needed for charging, the life span and range of batteries, the source of raw materials, and customer acceptability.	Increased charging networks, government incentives, advances in battery technology, the procurement of sustainable raw materials, and consumer education initiatives.	(Shafie-Khah et al., 2016)
Hybrid Energy Systems	Inconsistent renewable energy sources, complicated control systems, maintenance difficulties, a lack of technical know-how, and increased installation prices.	Construct control interfaces that are easy to use and hybrid models that are tailored for different climates.	(Ma et al., 2021)
Phase Change Materials (PCMs)	Lack of knowledge about the advantages of PCM, issues with large-scale integration costs, and the availability of appropriate PCM materials with the required thermal characteristics	Invest in R&D to create better PCM formulations and encourage the use of them in environmentally friendly building techniques.	(Chibani et al., 2023)

5. Future research directions

The development of energy-efficient technologies, especially innovative materials, intelligent sensors and Internet of Things-based systems that optimize energy use in real time, should be the main effort in future energy management and energy efficiency research. Next-generation clean transport options such as vehicle-to-grid systems and improved battery technologies also require more study. Creating a comprehensive framework for energy management that includes storage devices, renewable energy and energy efficient technology is also important. The usefulness of laws and regulations promoting sustainable energy consumption, as well as social and behavioral factors influencing green technologies, should also be examined. Keeping these issues in mind.

6. Conclusion

The findings of this study have direct implications for energy policy and sustainable development planning. Integrated energy management systems support the achievement of Sustainable Development Goal 7 (affordable and clean energy) by increasing efficiency and renewable access. They also contribute to SDG 9 (industry, innovation and infrastructure) through the modernization of smart grids and SDG 13 (climate measures) by reducing greenhouse gas emissions in many sectors. Policymakers can leverage these integrated frameworks to design incentive mechanisms, optimize investments in grid infrastructure, and accelerate the transition to clean transportation while ensuring energy access and economic feasibility.

This paper's thorough analysis highlights how crucial it is to incorporate green energy efficiency technologies and clean transportation choices into a broader framework for sustainable energy management. Energy-efficient appliances, sophisticated energy management systems in buildings, and smart grids have been shown through studies to play a significant role in optimizing energy use, which reduces greenhouse gas emissions and improves resource efficiency. Furthermore, it has been shown that clean transport technologies such as fuel cells, hybrids and electric cars are essential for reducing carbon emissions and reducing dependence on fossil fuels.

Comparative analysis has shown that although clean transport systems and green energy efficiency technologies both have significant advantages, they differ in terms of cost and scalability. Energy-efficient solutions have proven to be more scalable and cost-effective in the long run across various industries, while they initially require capital expenditure. In contrast, clean transport technologies are more expensive to begin with and present structural problems, but due to the benefits to society and the environment, they will be an important part of energy management plans in the future. Complementary technology integration is another important strategy. For example, connecting electric vehicles (EVs) to smart grids has been shown to increase demand-side efficiency and grid stability by 20%. In addition, spending money on PCM for thermal storage can reduce energy waste in heating and cooling operations and increase the energy efficiency of thermal reactors and solar panels by 30–40%. Although these technologies have much in common in terms of efficiency, cost and scalability, the comparative analysis conducted for this research also showed that they have much in common. Three main barriers to general adoption of these technologies have been highlighted: high initial prices, technical limitations and regulatory barriers. However, the paper also provides practical answers to these problems, and highlights the need for continuous innovation, legislative support and interdisciplinary collaboration. The article concludes that a sustainable energy future can only be achieved by combining green energy efficiency technologies with clean transport options. The study's findings provide useful information that can guide future research, policy formulation and the use of energy management technology that puts sustainability, flexibility and efficiency first. Interested parties can work together to create a more efficient and sustainable energy environment that meets the demands of current and future generations by identifying and addressing recognized constraints and problems, as well as putting proposed solutions into practice.

The practical application of this study lies in providing guidance for policymakers, engineers, and urban planners to implement integrated energy management systems by selecting appropriate combinations of smart grid technologies, energy-efficient appliances, thermal management solutions, and clean transportation systems for sustainable energy development.

CRediT authorship contribution statement

Ramadan Mohammad: Investigation, Formal analysis, Conceptualization. **Ghada Shwaheen:** Writing – original draft, Data curation. **Alkhedher Mohamad:** Visualization, Resources, Methodology, Funding acquisition. **Wisam Abu Jadayil:** Writing – review & editing, Validation, Supervision.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work, authors used QuillBot to improve the Language of the manuscript. After using this tool, the authors reviewed and edited the content as needed, and take the full responsibility of the content of the published article.

Declaration of Interest and Submission and Verification Statement

We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

All authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

All authors declare that this research is funded by Abu Dhabi University (Internal Grant 19300947).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

Abbas, J., et al., 2019. The effects of corporate social responsibility practices and environmental factors through a moderating role of social media marketing on sustainable performance of business firms. Sustain 11, 3434. https://doi.org/10.3390/SU11123434.

Abu Jadayil, W., Shwaheen, G., Ramadan, M., Alkhedher, M., 2025. Beyond energy: review of innovations in green technologies for resilience and environmental sustainability. Energy Rep. 13, 5410–5426. https://doi.org/10.1016/j.egyr.2025.04.067.

Ail, S.S., Dasappa, S., 2016. Biomass to liquid transportation fuel via Fischer Tropsch synthesis – technology review and current scenario. Renew. Sustain. Energy Rev. 58, 267–286. https://doi.org/10.1016/J.RSER.2015.12.143.

Alam, M.M., Murad, M.W., 2020. The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. Renew. Energy 145, 382–390. https://doi.org/10.1016/J.RENENE.2019.06.054.

Alam, S.S., Nik Hashim, N.H., Rashid, M., Omar, N.A., Ahsan, N., Ismail, M.D., 2014. Small-scale households renewable energy usage intention: theoretical development and empirical settings. Renew. Energy 68, 255–263. https://doi.org/10.1016/j.renene.2014.02.010.

Alises, A., Vassallo, J.M., 2015. Comparison of road freight transport trends in Europe. Coupling and decoupling factors from an Input–Output structural decomposition analysis. Transp. Res. Part A Policy Pr. 82, 141–157. https://doi.org/10.1016/J.TRA.2015.09.013.

Al-Rakhami, M., Gumaei, A., Alsanad, A., Alamri, A., Hassan, M.M., 2019. An ensemble learning approach for accurate energy load prediction in residential buildings. IEEE Access 7, 48328–48338. https://doi.org/10.1109/ACCESS.2019.2909470.

Alsalemi, A., Amira, A., Malekmohamadi, H., Diao, K., 2023. A modular recommender system for domestic energy efficiency. Environ. Chall. 13, 100741. https://doi.org/10.1016/J.ENVC.2023.100741.

Alsharif, A., Tan, C.W., Ayop, R., Dobi, A., Lau, K.Y., 2021. A comprehensive review of energy management strategy in Vehicle-to-Grid technology integrated with renewable energy sources. Sustain. Energy Technol. Assess. 47, 101439. https://doi.org/10.1016/J.SETA.2021.101439.

Anderson, L.G., 2015. Effects of using renewable fuels on vehicle emissions. Renew. Sustain. Energy Rev. 47, 162–172. https://doi.org/10.1016/J.RSER.2015.03.011.

Anees, J., Zhang, H.C., Baig, S., Lougou, B.G., 2019. Energy-efficient multi-disjoint path opportunistic node connection routing protocol in wireless sensor networks for smart grids. Sensors 19 (17), 3789. https://doi.org/10.3390/S19173789.

Anjana, K.R., Shaji, R.S., 2018. A review on the features and technologies for energy efficiency of smart grid. Int. J. Energy Res. 42 (3), 936–952. https://doi.org/10.1002/er.3852.

Ashouri, M., Haghighat, F., Fung, B.C.M., Yoshino, H., 2019. Development of a ranking procedure for energy performance evaluation of buildings based on occupant behavior. Energy Build. 183, 659–671. https://doi.org/10.1016/J.ENBUILD.2018.11.050.

Aswathy, S., Saravanan, G., 2024. Green technology literature from India as reflected in Web of Science from 2000 to 2015. Libr. Philos. Pr. ⟨https://shs.hal.science/halshs-02108200⟩.

Awan, U., 2019. Effects of buyer-supplier relationship on social performance improvement and innovation performance improvement. Int. J. Appl. Manag. Sci. 11 (1), 21–35. https://doi.org/10.1504/IJAMS.2019.096657.

Azad, A.K., Rasul, M.G., Khan, M.M.K., Sharma, S.C., Hazrat, M.A., 2015. Prospect of biofuels as an alternative transport fuel in Australia. Renew. Sustain. Energy Rev. 43, 331–351. https://doi.org/10.1016/J.RSER.2014.11.047.

Babakmehr, M., Simões, M.G., Wakin, M.B., Harirchi, F., 2016. Compressive Sensing-Based Topology Identification for Smart Grids. IEEE Trans. Ind. Inform. 12 (2), 532–543. https://doi.org/10.1109/TII.2016.2520396.

Bakare, M.S., Abdulkarim, A., Zeeshan, M., Shuaibu, A.N., 2023. A comprehensive overview on demand side energy management towards smart grids: challenges, solutions, and future direction. Energy Inform. 6 (1), 1–59. https://doi.org/10.1186/S42162-023-00262-7.

Baldini, M., Trivella, A., Wente, J.W., 2018. The impact of socioeconomic and behavioural factors for purchasing energy efficient household appliances: a case study for Denmark. Energy Policy 120 (May), 503–513. https://doi.org/10.1016/j.enpol.2018.05.048.

Bayram, I.S., Ustun, T.S., 2017. A survey on behind the meter energy management systems in smart grid. Renew. Sustain. Energy Rev. 72, 1208–1232. https://doi.org/10.1016/J.RSER.2016.10.034.

Bianco, G., Bracco, S., Delfino, F., Gambelli, L., Robba, M., Rossi, M., 2020. A building energy management system based on an equivalent electric circuit model. Energies 13 (7), 1689. https://doi.org/10.3390/EN13071689.

Bibri, S.E., Krogstie, J., 2020. Smart eco-city strategies and solutions for sustainability: the cases of royal seaport, stockholm, and western harbor, malmö, sweden. Urban Sci. 4 (1). https://doi.org/10.3390/urbansci4010011.

Bilgin, B.E., Baktir, S., Gungor, V.C., 2016. A novel data collection mechanism for smart grids using public transportation buses. Comput. Stand. Interfaces 48, 19–29. https://doi.org/10.1016/J.CSI.2016.04.003.

Bonilla, D., Samaniego, M.G., Ramos, R., Campbell, H., 2018. Practical and low-cost monitoring tool for building energy management systems using virtual instrumentation. Sustain. Cities Soc. 39, 155–162. https://doi.org/10.1016/J.SCS.2018.02.009.

Canton, H., 2021. International energy agency—IEA. Eur. Dir. Int. Organ 684–686. https://doi.org/10.4324/9781003179900-103/INTERNATIONAL-ENERGY-AGENCY.

Chang, W.R., Hwang, J.J., Wu, W., 2017. Environmental impact and sustainability study on biofuels for transportation applications. Renew. Sustain. Energy Rev. 67, 277–288. https://doi.org/10.1016/J.RSER.2016.09.020.

Chibani, A., Dehane, A., Merouani, S., Hamdaoui, O., 2023. Phase Change Material (PCM)-based thermal storage system for managing the sonochemical reactor heat: Thermodynamic analysis of the liquid height impact. Ultrason. Sonochem. 98, 106483. https://doi.org/10.1016/J.ULTSONCH.2023.106483.

Chua, K.J., Chou, S.K., Yang, W.M., Yan, J., 2013. Achieving better energy-efficient air conditioning – a review of technologies and strategies. Appl. Energy 104, 87–104. https://doi.org/10.1016/J.APENERGY.2012.10.037.

Climate Change 2021: The Physical Science Basis | Climate Change 2021: The Physical Science Basis. Accessed: Mar. 21, 2025. [Online]. Available: ⟨https://www.ipcc.ch/report/ar6/wg1/⟩.

Cunjiang, Y., Huaxun, Z., Lei, Z., 2012. Architecture design for smart grid. Energy Procedia 17, 1524–1528. https://doi.org/10.1016/J.EGYPRO.2012.02.276.

D'Oca, S., Hong, T., Langevin, J., 2018. The human dimensions of energy use in buildings: a review. Renew. Sustain. Energy Rev. 81, 731–742. https://doi.org/10.1016/J.RSER.2017.08.019.

Danish, Ulucak, R., 2020. How do environmental technologies affect green growth? Evidence from BRICS economies. Sci. Total Environ. 712, 136504. https://doi.org/10.1016/J.SCITOTENV.2020.136504.

De Lorenzi, A., Gambarotta, A., Marzi, E., Morini, M., Saletti, C., 2025. Regulatory-driven optimization of integrated energy systems: a legal and policy-compliant framework for flexibility and carbon management. Energy Rep. 14, 157–172. https://doi.org/10.1016/j.apenergy.2022.118934.

Di Piazza, M.C., La Tona, G., Luna, M., Di Piazza, A., 2017. A two-stage Energy management System for smart buildings reducing the impact of demand uncertainty. Energy Build. 139, 1–9. https://doi.org/10.1016/J.ENBUILD.2017.01.003.

Dibangoye, J., Doniec, A., Fakham, H., Colas, F., Guillaud, X., 2015. Distributed economic dispatch of embedded generation in smart grids. Eng. Appl. Artif. Intell. 44, 64–78. https://doi.org/10.1016/J.ENGAPPAI.2015.05.007.

Dileep, G., 2020. A survey on smart grid technologies and applications. Renew. Energy 146, 2589–2625. https://doi.org/10.1016/j.renene.2019.08.092.

Doukas, H., Nychtis, C., Psarras, J., 2009. Assessing energy-saving measures in buildings through an intelligent decision support model. Build. Environ. 44 (2), 290–298. https://doi.org/10.1016/J.BUILDENV.2008.03.006.

Doukas, H., Patlitzianas, K.D., Iatropoulos, K., Psarras, J., 2007. Intelligent building energy management system using rule sets. Build. Environ. 42 (10), 3562–3569. https://doi.org/10.1016/J.BUILDENV.2006.10.024.

Farid, M., Khudhair, A.M., Razack, S.A.K., Al-Hallaj, S., 2021. A review on phase change energy storage: materials and applications. Therm. Energy Storage Phase Chang. Mater. 4–23. https://doi.org/10.1201/9780367567699-2.

Gan, J., Li, S., Wei, C., Deng, L., Tang, X., 2023. Intelligent learning algorithm and intelligent transportation-based energy management strategies for hybrid electric vehicles: a review. IEEE Trans. Intell. Transp. Syst. 24 (10), 10345–10361. https://doi.org/10.1109/TITS.2023.3283010.

Y. Gao, C. Fang, and J. Zhang, A Spatial Analysis of Smart Meter Adoptions: Empirical Evidence from the U. S. Data, 2022.

Gao, J., Xiao, Y., Liu, J., Liang, W., Chen, C.L.P., 2012. A survey of communication/networking in Smart Grids. Futur. Gener. Comput. Syst. 28 (2), 391–404. https://doi.org/10.1016/J.FUTURE.2011.04.014.

Ghazimirsaeid, S.S., Jonban, M.S., Mudiyanselage, M.W., Marzband, M., Martinez, J.L.R., Abusorrah, A., 2023. Multi-agent-based energy management of multiple grid-connected green buildings. J. Build. Eng. 74, 106866. https://doi.org/10.1016/J.JOBE.2023.106866.

Global Carbon Budget (2022), 2022. Earth Syst. Sci. Data 14, 4811–4900. https://doi.org/10.5194/essd-14-4811-2022.

Global EV Outlook 2022 – Analysis - IEA. Accessed: Sep. 24, 2024. [Online]. Available: 〈https://www.iea.org/reports/global-ev-outlook-2022〉.

González-Torres, M., Pérez-Lombard, L., Coronel, J.F., Maestre, I.R., Yan, D., 2022. A review on buildings energy information: trends, end-uses, fuels and drivers. Energy Rep. 8, 626–637. https://doi.org/10.1016/J.EGYR.2021.11.280.

Häckel, B., Pfosser, S., Tränkler, T., 2017. Explaining the energy efficiency gap - expected utility theory versus cumulative prospect theory. Energy Policy 111, 414–426. https://doi.org/10.1016/j.enpol.2017.09.026.

S. Hansen, P. Langlois, and P. Bertoldi, Appendix B International Partnership for Energy Efficiency Cooperation Declaration2009 ,, Accessed: May 17, 2024. [Online]. Available: 〈https://ieeexplore.ieee.org/abstract/document/9558461/〉.

Hashmi, R., Alam, K., 2019. Dynamic relationship among environmental regulation, innovation, CO2 emissions, population, and economic growth in OECD countries: a panel investigation. J. Clean. Prod. 231, 1100–1109. https://doi.org/10.1016/j.jclepro.2019.05.325.

He, Y., Liu, Z., Song, Z., 2020. Optimal charging scheduling and management for a fast-charging battery electric bus system. Transp. Res. Part E Logist. Transp. Rev. 142, 102056. https://doi.org/10.1016/J.TRE.2020.102056.

Hesselink, L.X.W., Chappin, E.J.L., 2019. Adoption of energy efficient technologies by households – Barriers, policies and agent-based modelling studies. Renew. Sustain. Energy Rev. 99, 29–41. https://doi.org/10.1016/J.RSER.2018.09.031.

IRENA, Renewable Energy Statistics 2022 Statistiques D'Energie Renouvelable 2022 Estadisticas De Energia Renovablle 2022, p. 31, 2022, Accessed: Sep. 26, 2024. [Online]. Available: 〈https://www.irena.org/publications/2022/Jul/Renewable-Energy-Statistics-2022〉.

Ismail, K.A.R., et al., 2023. Enhancement techniques for the reduction of heating and cooling loads in buildings: a review. J. Energy Power Technol. 5 (4), 1–44. https://doi.org/10.21926/JEPT.2304031.

Jafari, H., 2023. Energy storage by improving energy-efficiency of electricity home appliances under governmental supporting policies: a game-theoretic approach. J. Energy Storage 63, 106972. https://doi.org/10.1016/J.EST.2023.106972.

Jarrah, M., Jaradat, M., Jararweh, Y., Al-Ayyoub, M., Bousselham, A., 2015. A hierarchical optimization model for energy data flow in smart grid power systems. Inf. Syst. 53, 190–200. https://doi.org/10.1016/J.IS.2014.12.003.

Jiang, L., Yao, R., Liu, K., McCrindle, R., 2017. An epistemic-deontic-axiologic (eda) agent-based energy management system in office buildings. Appl. Energy 205 (August), 440–452. https://doi.org/10.1016/j.apenergy.2017.07.081.

Jota, P.R.S., Silva, V.R.B., Jota, F.G., 2011. Building load management using cluster and statistical analyses. Int. J. Electr. Power Energy Syst. 33 (8), 1498–1505. https://doi.org/10.1016/J.IJEPES.2011.06.034.

Kazemian, A., Khatibi, M., Entezari, S., Ma, T., Yang, H., 2023. Efficient energy generation and thermal storage in a photovoltaic thermal system partially covered by solar cells and integrated with organic phase change materials. Renew. Sustain. Energy Rev. 188, 113705. https://doi.org/10.1016/J.RSER.2023.113705.

Kene, R.O., Olwal, T.O., 2023. Energy management and optimization of large-scale electric vehicle charging on the grid. World Electr. Veh. J. 14 (4). https://doi.org/10.3390/wevj14040095.

Khan, I., Hou, F., Le, H.P., 2021. The impact of natural resources, energy consumption, and population growth on environmental quality: fresh evidence from the United States of America. Sci. Total Environ. 754, 142222. https://doi.org/10.1016/J.SCITOTENV.2020.142222.

Kim, E., Ha, Y., 2021. Vitalization strategies for the building energy management system (BEMS) industry ecosystem based on AHP analysis. Energies 14 (9), 2559. https://doi.org/10.3390/EN14092559.

Kumar, N., Singh, H., Kumar, A., 2021. Renewable energy and green technology. Renew. Energy Green. Technol. https://doi.org/10.1201/9781003175926.

M. Kuyumani, M.K. Joseph, and S. Hassan, Communication Technologies for Efficient Energy Management in Smart Grid, 2018 Int. Conf. Adv. Big Data, Comput. Data Commun. Syst. icABCD 2018, Sep. 2018, doi: 10.1109/ICABCD.2018.8465454.

Kuzior, A., Samusevych, Y., Lyeonov, S., Krawczyk, D., Grytsyshen, D., 2023. Applying energy taxes to promote a clean, sustainable and secure energy system: finding the preferable approaches. Energies 16 (10), 1–26. https://doi.org/10.3390/en16104203.

Lecksiwilai, N., Gheewala, S.H., Silalertruksa, T., Mungkalasiri, J., 2017. LCA of biofuels in Thailand using Thai Ecological Scarcity method. J. Clean. Prod. 142, 1183–1191. https://doi.org/10.1016/J.JCLEPRO.2016.07.054.

Lee, D., Cheng, C.C., 2016. Energy savings by energy management systems: a review. Renew. Sustain. Energy Rev. 56, 760–777. https://doi.org/10.1016/J.RSER.2015.11.067.

Li, S., Zhao, P., Gu, C., Li, J., Cheng, S., Xu, M., 2022. Online battery protective energy management for energy-transportation nexus. IEEE Trans. Ind. Inform. 18 (11), 8203–8212. https://doi.org/10.1109/TII.2022.3163778.

Lü, X., et al., 2020. Energy management of hybrid electric vehicles: a review of energy optimization of fuel cell hybrid power system based on genetic algorithm. Energy Convers. Manag. 205, 112474. https://doi.org/10.1016/J.ENCONMAN.2020.112474.

Ma, G., Andrews-Speed, P., Zhang, J., 2013. Chinese consumer attitudes towards energy saving: the case of household electrical appliances in Chongqing. Energy Policy 56 (May 2013), 591–602. https://doi.org/10.1016/j.enpol.2013.01.024.

Ma, R., Cai, H., Ji, Q., Zhai, P., 2021. The impact of feed-in tariff degression on R&D investment in renewable energy: the case of the solar PV industry. Energy Policy 151, 112209. https://doi.org/10.1016/J.ENPOL.2021.112209.

Madani, S., Tavasoli, A., Khoshtarash Astaneh, Z., Pineau, P.O., 2025. Large language models integration in smart grids. Energy Rep. 14 (22), 1562–1577. https://doi.org/10.1016/j.egyr.2025.06.051.

Maja, M.M., Ayano, S.F., 2021. The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries. Earth Syst. Environ. 5 (2), 271–283. https://doi.org/10.1007/s41748-021-00209-6.

Marinakis, V., 2020. Big data for energy management and energy-efficient buildings. Energies 13 (7). https://doi.org/10.3390/en13071555.

Mathiesen, B.V., et al., 2015. Smart energy systems for coherent 100% renewable energy and transport solutions. Appl. Energy 145, 139–154. https://doi.org/10.1016/j.apenergy.2015.01.075.

Mei, S.-W., Zhu, J.-Q., 2013. Mathematical and control scientific issues of smart grid and its prospects. Acta Autom. Sin. 39 (2), 119–131. https://doi.org/10.1016/S1874-1029(13)60014-2.

Mishra, P., Singh, G., 2023. Energy management systems in sustainable smart cities based on the internet of energy: a technical review. Energies 16 (19). https://doi.org/10.3390/en16196903.

Mohideen, M.M., Ramakrishna, S., Prabu, S., Liu, Y., 2021. Advancing green energy solution with the impetus of COVID-19 pandemic. J. Energy Chem. 59 (January 2021), 688–705. https://doi.org/10.1016/j.jechem.2020.12.005.

Muqeet, H.A., Liaqat, R., Jamil, M., Khan, A.A., 2023. A state-of-the-art review of smart energy systems and their management in a smart grid environment. Energies 16 (1), 472. https://doi.org/10.3390/EN16010472.

Muzayanah, I.F.U., Lean, H.H., Hartono, D., Indraswari, K.D., Partama, R., 2022. Population density and energy consumption: a study in Indonesian provinces. Heliyon 8 (9), e10634. https://doi.org/10.1016/j.heliyon.2022.e10634.

Naylor, S., Gillott, M., Lau, T., 2018. A review of occupant-centric building control strategies to reduce building energy use. Renew. Sustain. Energy Rev. 96, 1–10. https://doi.org/10.1016/J.RSER.2018.07.019.

Nleya, B., Mutsvangwa, A., Dewa, M., 2016. A smart grid based algorithm for improving energy efficiency of large scale cooperating distributed systems. IEEE PES Power Conf. Power 11–15. https://doi.org/10.1109/POWERAFRICA.2016.7556560.

Pagani, G.A., Aiello, M., 2016. From the grid to the smart grid, topologically. Phys. A Stat. Mech. Appl. 449, 160–175. https://doi.org/10.1016/J.PHYSA.2015.12.080.

Pan, J., Jain, R., Paul, S., 2014. A survey of energy efficiency in buildings and microgrids using networking technologies. IEEE Commun. Surv. Tutor. 16 (3), 1709–1731. https://doi.org/10.1109/SURV.2014.060914.00089.

Parikh, K.S., Parikh, J.K., 2016. Realizing potential savings of energy and emissions from efficient household appliances in India. Energy Policy 97, 102–111. https://doi.org/10.1016/j.enpol.2016.07.005.

Parise, G., Parise, L., Malerba, A., Pepe, F.M., Honorati, A., Chavdarian, P.Ben, 2017. Comprehensive peak-shaving solutions for port cranes. IEEE Trans. Ind. Appl. 53 (3), 1799–1806. https://doi.org/10.1109/TIA.2016.2645514.

Pfeifer, A., Dominković, D.F., Ćosić, B., Duić, N., 2016. Economic feasibility of CHP facilities fueled by biomass from unused agriculture land: case of croatia. Energy Convers. Manag. 125, 222–229. https://doi.org/10.1016/J.ENCONMAN.2016.04.090.

Rahman, I., Vasant, P.M., Singh, B.S.M., Abdullah-Al-Wadud, M., Adnan, N., 2016. Review of recent trends in optimization techniques for plug-in hybrid, and electric vehicle charging infrastructures. Renew. Sustain. Energy Rev. 58, 1039–1047. https://doi.org/10.1016/J.RSER.2015.12.353.

Raslavičius, L., Azzopardi, B., Keršys, A., Starevičius, M., Bazaras, Ž., Makaras, R., 2015. Electric vehicles challenges and opportunities: lithuanian review. Renew. Sustain. Energy Rev. 42, 786–800. https://doi.org/10.1016/J.RSER.2014.10.076.

Rathor, S.K., Saxena, D., 2020. Energy management system for smart grid: an overview and key issues. Int. J. Energy Res. 44 (6), 4067–4109. https://doi.org/10.1002/ER.4883.

Riesz, J., Sotiriadis, C., Ambach, D., Donovan, S., 2016. Quantifying the costs of a rapid transition to electric vehicles. Appl. Energy 180, 287–300. https://doi.org/10.1016/J.APENERGY.2016.07.131.

Rotger-Griful, S., Welling, U., Jacobsen, R.H., 2017. Implementation of a building energy management system for residential demand response. Microprocess. Micro. 55, 100–110. https://doi.org/10.1016/J.MICPRO.2017.10.006.

Sabri, M.F.M., Husin, M.H., Suhaili, S., Masra, S.M.W., 2022. Adaptive energy management strategy for sustainable operation of hybrid electric vehicle. J. Sustain. Sci. Manag. 17 (6), 159–171. https://doi.org/10.46754/jssm.2022.06.012.

Sadeghinezhad, E., Kazi, S.N., Badarudin, A., Oon, C.S., Zubir, M.N.M., Mehrali, M., 2013. A comprehensive review of bio-diesel as alternative fuel for compression ignition engines. Renew. Sustain. Energy Rev. 28, 410–424. https://doi.org/10.1016/J.RSER.2013.08.003.

Seeam, A., Laurenson, D., Usmani, A., 2018. Evaluating the potential of simulation assisted energy management systems: a case for electrical heating optimisation. Energy Build. 174, 579–586. https://doi.org/10.1016/J.ENBUILD.2018.06.063.
Shafie-Khah, M., Neyestani, N., Damavandi, M.Y., Gil, F.A.S., Catalão, J.P.S., 2016. Economic and technical aspects of plug-in electric vehicles in electricity markets. Renew. Sustain. Energy Rev. 53, 1168–1177. https://doi.org/10.1016/J.RSER.2015.09.079.
Shaikh, P.H., Nor, N.B.M., Nallagownden, P., Elamvazuthi, I., Ibrahim, T., 2016. Intelligent multi-objective control and management for smart energy efficient buildings. Int. J. Electr. Power Energy Syst. 74, 403–409. https://doi.org/10.1016/J.IJEPES.2015.08.006.
Shareef, H., Islam, M.M., Mohamed, A., 2016. A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles. Renew. Sustain. Energy Rev. 64, 403–420. https://doi.org/10.1016/J.RSER.2016.06.033.
Sharif, A., Kocak, S., Khan, H.H.A., Uzuner, G., Tiwari, S., 2023. Demystifying the links between green technology innovation, economic growth, and environmental tax in ASEAN-6 countries: the dynamic role of green energy and green investment. Gondwana Res. 115, 98–106. https://doi.org/10.1016/j.gr.2022.11.010.
Sharma, D., Sandhu, S., Misra, S., 2014. Energy efficiency improvements in asia: macroeconomic impacts. SSRN Electron. J. (406). https://doi.org/10.2139/ssrn.2511098.
Sonnenberg, N.C., Erasmus, A.C., Donoghue, S., 2011. Significance of environmental sustainability issues in consumers' choice of major household appliances in South Africa. Int. J. Consum. Stud. 35 (2), 153–163. https://doi.org/10.1111/j.1470-6431.2010.00964.x.
P. Sospiro, L. Amarnath, V. Di Nardo, G. Talluri, and F.H. Gandoman, Smart Grid in China, EU, and the US: State of Implementation, pp. 1–15, 2021.
Stephens, J.C., Wilson, E.J., Peterson, T.R., 2014. Emerging smart grid struggles. Smart Grid Evol. (August), 1–14. https://doi.org/10.1017/cbo9781107239029.003.
Teimoori, Z., Yassine, A., 2022. A review on intelligent energy management systems for future electric vehicle transportation. Sustain 14 (21), 1–23. https://doi.org/10.3390/su142114100.
S. Thompson, Strategic Analysis of the Renewable Electricity Transition: Power to the World without Carbon Emissions?, 2023.
Tuballa, M.L., Abundo, M.L., 2016. A review of the development of Smart Grid technologies. Renew. Sustain. Energy Rev. 59, 710–725. https://doi.org/10.1016/j.rser.2016.01.011.
U.S. Department of Energy Top Accomplishments in 2022 | Department of Energy. Accessed: Sep. 24, 2024. [Online]. Available: ⟨https://www.energy.gov/articles/us-department-energy-top-accomplishments-2022⟩.
Vellingiri, M.T., Mehedi, I.M., Palaniswamy, T., 2022. A novel deep learning-based state-of-charge estimation for renewable energy management system in hybrid electric vehicles. Mathematics 10 (2). https://doi.org/10.3390/math10020260.
Wang, D., et al., 2023. Review of energy-saving technologies for electric vehicles, from the perspective of driving energy management. Sustain 15 (9), 1–17. https://doi.org/10.3390/su15097617.
Wang, W., Hong, T., Li, N., Wang, R.Q., Chen, J., 2019. Linking energy-cyber-physical systems with occupancy prediction and interpretation through WiFi probe-based ensemble classification. Appl. Energy 236, 55–69. https://doi.org/10.1016/J.APENERGY.2018.11.079.
Wang, Z., Wang, X., Guo, D., 2017. Policy implications of the purchasing intentions towards energy-efficient appliances among China's urban residents: Do subsidies work? Energy Policy 102, 430–439. https://doi.org/10.1016/J.ENPOL.2016.12.049.
Waris, I., Hameed, I., 2020. An empirical study of consumers intention to purchase energy efficient appliances. Soc. Responsib. J. 17 (4), 489–507. https://doi.org/10.1108/SRJ-11-2019-0378/FULL/XML.
Yao, X., Yasmeen, R., Hussain, J., Hassan Shah, W.U., 2021. The repercussions of financial development and corruption on energy efficiency and ecological footprint: evidence from BRICS and next 11 countries. Energy 223, 120063. https://doi.org/10.1016/j.energy.2021.120063.
Zahedmanesh, A., Muttaqi, K.M., Sutanto, D., 2021. A cooperative energy management in a virtual energy hub of an electric transportation system powered by PV generation and energy storage. IEEE Trans. Transp. Electrif. 7 (3), 1123–1133. https://doi.org/10.1109/TTE.2021.3055218.
Zhang, J., Wang, Z., Zhao, H., 2020. The impact of consumer subsidy on green technology innovations for vehicles and environmental impact. Int. J. Environ. Res. Public Health 17 (20), 1–23. https://doi.org/10.3390/ijerph17207518.
Zhao, C., Opolot, M., Liu, M., Bruno, F., Mancin, S., Hooman, K., 2020. Numerical study of melting performance enhancement for PCM in an annular enclosure with internal-external fins and metal foams. Int. J. Heat. Mass Transf. 150, 119348. https://doi.org/10.1016/J.IJHEATMASSTRANSFER.2020.119348.
Zhou, K., Yang, S., 2016. Understanding household energy consumption behavior: the contribution of energy big data analytics. Renew. Sustain. Energy Rev. 56, 810–819. https://doi.org/10.1016/j.rser.2015.12.001.