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Advancements in Energy Efficiency Technologies in the U.S.: A Decade of Innovation and Impact

Vishakha Yadav
DNV, Oak Brook, IL
vishakha.yadav@dnv.com

Abstract: *The United States, as the largest global energy consumer, has witnessed significant advancements in energy efficiency technologies over the past century, driven by policy interventions, technological innovation, and evolving environmental priorities. This study explores the evolution of energy efficiency from the foundational policies of the 1970s to recent legislative frameworks such as the Inflation Reduction Act of 2022. It highlights major technological advancements across key sectors, including smart building systems, industrial energy innovations, renewable energy integration, and transportation efficiency. The economic and environmental impacts of these advancements are profound, with significant cost savings, reduced greenhouse gas emissions, and enhanced sustainability. By analyzing the synergy between federal and state policies, private sector contributions, and cutting-edge technologies, this paper underscores the critical role of energy efficiency in mitigating climate change, fostering economic growth, and achieving long-term energy security and resilience. The findings emphasize the need for accelerated adoption, policy support, and innovation to overcome existing barriers and unlock the full potential of energy-efficient solutions*

Keywords: Energy Efficiency, Technological Innovations, Greenhouse Gas Emissions, Renewable Energy Integration, Grid Modernization

I. INTRODUCTION

The US, as the largest global consumer of energy, has seen its energy usage double since 1963, with per capita and GDP-based energy consumption exceeding that of many other developed nations. Despite its economic and technological advancements, the country's underutilization of energy efficiency technologies accounts for nearly 50% of this disparity[1]. However, advancements in energy-efficient practices have already shown their potential to curb this trend. For instance, in states like California and New York, electricity use per capita has remained steady since 1980, even as it increased by 50% in the rest of the country. Studies from the National Academy of Sciences project that broader adoption of energy-efficient technologies could reduce U.S. energy use by 17–22% by 2020 and 25–31% by 2030. These findings highlight the critical role energy efficiency plays in achieving sustainable development while maintaining economic growth[2].

Technological innovations have been at the forefront of this progress, driving significant reductions in greenhouse gas (GHG) emissions across key sectors. In transportation, advancements such as improved fuel economy standards under a CorporateAverageFuelEconomy (CAFE) program and a growing adoption of electric vehicles (EVs) have drastically reduced emissions[3]. Since 1975, vehicle efficiency improvements have cut GHG emissions by approximately 3 billion metric tons, and further widespread EV adoption by 2030 could decrease global CO_2 emissions by over 1.5 gigatons annually. The industrial sector has similarly benefitted from technologies like waste heat recovery, advanced manufacturing systems, and initiatives such as the EPA's Energy Star for Industry program[4], which together eliminate over 50 million metric tons of CO_2 emissions annually[5].

The residential and commercial sectors have also made substantial strides through energy-efficient building designs, modern appliances, and advanced systems, supported by robust building codes like the International Energy Conservation Code (IECC)[6]. These measures have collectively reduced CO_2 emissions by over 200 million metric tons annually, underscoring the transformative impact of energy-efficient technologies. As key sectors like buildings, transportation, and industry continue to unlock their potential, accelerated adoption, policy support, and innovation remain essential for overcoming barriers and driving sustainable progress[7].

This research aims to trace the development, progress, and effects of energy efficiency technologies in the US, with a focus on how these technologies have helped lower energy consumption, lessen emissions of greenhouse gases, and promote long-term economic growth. Buildings, transportation, and industry are some of the important sectors that this research aims to highlight in order to achieve national and global sustainability objectives via the integration of renewable energy, innovative technology, and friendly regulations. Focussing on these innovations' capacity to promote long-term resilience and energy security, the research also intends to assess their environmental and economic advantages.

II. EVOLUTION OF ENERGY EFFICIENCY TECHNOLOGIES IN THE U.S.

During the twentieth century, technical advancements, legal measures and changes in social, economic and environmental factors led to a drastic transformation of the traditional American ideas of energy efficiency. The roots of the energy efficiency can be dated back to the oil crises early 1970s that exposed the American economy to great insecurity and steep fuel prices [8].This has resulted in the formation of outstanding laws including Energy Policy and Conservation Act of 1975 that sought to lay down the trend by having CAFE standards in enhancing the efficiency of transport [9]. The following further extended increased energy efficiency to buildings and appliances where movements including the NAECA of 1987 and the launch of the Energy Star program in 1992 shaped habits and saved energy[10][11].

The NAECA was initiated in 1987 and in the following years the focus on energy conservation extended to buildings and appliances. Major reductions in energy use occurred in the decades after this law went into effect because of the minimal efficiency requirements it imposed on home equipment [12]. In addition, another major advancement towards energy efficient products and services came in 1992 when the US EPA started the Energy Star programme.

The quality of technologies increased from smart technologies to renewable energy integration and advanced policy structure such as Energy Independence and Security Act of 2007 and The American Recovery and Reinvestment Act of 2009[13]. More recent endeavors such as the Inflation Reduction Act of 2022 have gone a step further in creating more incentives to promulgate energy-efficient solution across residential, commercial, and industrial segment[14]. This has brought association ship between federal and state policies, private sectors and technology into focal points of the United States' commitment towards uptake of efficient and sustainable energy use [15].

A. Role of Policies and regulations in Advancing Energy Efficiency

A strong structure of federal and state laws, backed by rules that encourage sustainability, lower energy use, and slow down climate change, has greatly influenced energy efficiency in the US [16]. These measures act as a basis of technological advancement, economic development as well as soil conservation [17].

B. Federal Policies Supporting Energy Efficiency

At the federal level, there are numerous policies, tax incentives, even grants and compliance standards for energy efficiency in the country.

1. Tax Incentives and Credits

- The Energy Efficient Home Improvement Credit was also provided by the Inflation Reduction Act (IRA) of 2022, which allows homeowners to deduct up to 30% of the costs for approved home improvements which include energy efficient windows, doors and insulation but not exceeding $1,200 per year[18].
- Commercial buildings that reduce their energy and power expenditures by 50% are eligible for tax deductions of up to $1.80 per square foot under the Energy Efficient Commercial Buildings Deduction (Section 179D).

2. Grants and Funding Programs

- The SEP offers grants to states for establishment of energy efficiency and renewable energy projects for cost effective energy and energy diversification.

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- Insulation and heating system repairs are two examples of the kinds of energy-saving modifications that low-income families may get money for under the WAP. Over 7 million homes have been weatherized, resulting in annual energy bill savings averaging $283 per household[19].

3. Regulations and Standards

- Appliances and equipment that adhere to energy conservation requirements set by the US DOE have helped save around $2 trillion in energy costs since 1987.
- Higher fuel efficiency criteria for cars and the elimination of inefficient incandescent bulbs in favour of more energy-efficient alternatives like LEDs were both imposed by the EISA of 2007.

C. Recent Legislative Developments

1. Inflation Reduction Act (IRA) of 2022

- The historic $369 billion investment in energy efficiency is made possible by the IRA's commitment to energy and environment initiatives. It supports tax credits for home improvements, energy-efficient manufacturing, and retrofitting buildings for better energy performance.
- The Greenhouse Gas Reduction Fund, established under the IRA, provides $27 billion to help low-income communities access energy-efficient technologies[20].

2. Clean Energy Standards (CES)

- Clean energy source quotas have been mandated by CES regulations in several states. As an example, the CES in New York City is working to lower total energy consumption by promoting renewable energy and incorporating energy efficiency measures [21].

D. State-Level Initiatives

Policies have been made with respect to problems and resources to suit each state, hence engendering a culture of innovation and application of energy efficiency.

- Californians have saved more than $100 billion in energy expenditures since the 1970s because to the state's Title 24 Building Energy Efficiency Standards, which establish strict guidelines for both residential and non-residential energy efficiency.
- Massachusetts' Green Communities Act mandating energy efficiency in its utility operations and has placed the state as the most energy efficient in the U.S, according to ACEEE.

III. MAJOR AREAS OF TECHNOLOGICAL ADVANCEMENTS

This last decade has seen incredible innovations in deployment of efficiencies in energy in different industries. There are more advanced systems of construction, for example smart thermostats to control energy usage, and better heating and air conditioning systems. These factors have not only increasingly shaped efficiency standards with renewables integration, electric vehicles, and IoT devices [22]. These collective technologies help to solve the problem of energy waste, cost reduction and environmental liabilities [23].

A. Building Technologies

In the last ten years building energy efficiency as a field has been through dramatic changes that shape our urban lives and sustainable future. Smart green buildings, which combines energy saving systems with safety systems and telecommunications as well as automation systems, has become an essential feature of contemporary urban environment [24]. These structures integrate with application systems like smart occupancy sensors, automatic lighting, and efficient energy handling air units in order to conserve energy without affecting comfort or security.

Smart HVAC Systems, especially Variable Air Volume (VAV) systems, hybrid configurations, and advanced central plant have been a successfully introduced advancement. These systems reduce energy consumption especially in heating, ventilating, and air conditioning whilst preserving the quality of air indoors [25]. The coupling of chilled water

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and condenser water also makes efficiency a reality through working harmoniously with BAS to deliver optimal energy control and operational reliability[26].

Besides HVAC advancement, other related gains include the noticeable decrease in reflected environmental impact and operational expenses arising from energy-efficient insulating materials and LED lights. Modern methods of insulating walls and roofs effectively isolate home and require lesser energy for heating and cooling [27]. On the other hand lighting, LED advances are more significant as they are normally accompanied by installation of auto control systems and the energy saving and durability in using LED lighting is excellent. Collectively, these innovations are creating a world of high-performance green buildings that also provide safer, more efficient, and comfortable shelter to the growing urban populace[28].

Figure 1 depicts the Comparison of Single IP Network and Proprietary Networks in intelligent buildings.

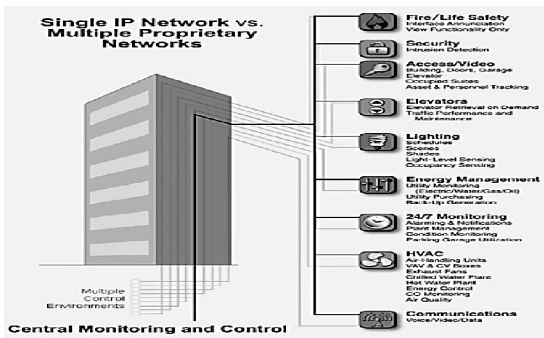

Figure 1: Comparison of Single IP Network and Proprietary Networks in Intelligent Buildings.

1. Innovations Driving Energy Efficiency in Buildings:

- **Intelligent Buildings:** Emergence of smart buildings integrating energy efficiency, life safety systems, telecommunications, and workplace automation into a unified computerized framework.
- **Advanced Building Automation Systems (BAS):** Enhanced automation capabilities managing lighting, HVAC, and security systems through occupancy sensors and time-based controls, improving energy optimization.
- **Efficient Air-Handling Units:** Introduction of Variable Air Volume (VAV) systems for precise temperature control, lower energy consumption, reduced noise, and improved air quality.
- **Chilled Water and Condenser Systems:** Deployment of systems for cooling and efficient heat exchange, reducing energy usage while maintaining optimal building temperatures.
- **Smart Lighting Solutions:** Implementation of automated lighting controls with occupancy sensors and photocells to minimize wastage and improve productivity by matching lighting to activity levels.
- **Central Plant Innovations:** Integrated central plants utilizing combined heat and power systems, enabling peak energy performance while supporting emergency power needs.
- **Occupant-Centric Approach:** Focus on occupant comfort, safety, and productivity as a core design philosophy in energy-efficient technologies.

Reduced Environmental Impact: Significant advancements in systems reducing greenhouse gas emissions and promoting sustainability[29].

B. Industrial Energy Efficiency Innovations

Over the last decade, Industry 4.0 has revolutionized renewable energy integration, enabling cost-effective and environmentally friendly power generation. Virtual power plants and microgrids have been at the forefront, combining energy sources such as hydropower, wind, solar, geothermal, and biomass to enhance production efficiency. The incorporation of IoT technologies has significantly addressed supply shortages by improving real-time demand-supply monitoring and system efficiency.

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Advanced systems like Supervisory Control and Data Acquisition (SCADA) have further optimized renewable energy integration, enhancing transmission system management by reducing power losses and detecting faults in transmission lines[30].

1. Smart Home Technologies

Energy efficiency advancements have extended into residential settings with the adoption of smart home technologies. These innovations offer convenience, cost savings, and reduced carbon emissions.

- **Smart Home Hubs:** Devices that monitor and control energy usage, automating tasks like turning off idle appliances or scheduling operations for energy-intensive devices.
- **Smart Thermostats:** Equipped with machine-learning capabilities, these devices optimize energy consumption by adapting to user patterns, ensuring efficient climate control.

2. Electric Vehicles (EVs)

Electric Vehicles (EVs) represent a transformative step toward sustainable transportation, offering solutions to reduce dependency on fossil fuels and mitigate environmental impacts[31]. The integration of advanced technologies in EVs has improved their efficiency, accessibility, and adoption across the globe.

- Electric vehicles have seen remarkable growth, with over 2.32 million EVs and 5.4 million hybrid EVs now on U.S. roads. EVs offer superior efficiency by converting electricity directly into motion and recovering energy during braking. They significantly reduce emissions, cutting nearly 4.6 metric tons of carbon dioxide per vehicle annually.
- Solid-State Batteries: Innovations in EV battery technology have addressed limitations by offering extended ranges and faster charging times. As costs decrease, these batteries are poised to dominate the EV market.

3. Lighting and Solar Innovations

Lighting and solar technologies have undergone transformative advancements over the past decade, significantly contributing to energy efficiency and sustainability in modern buildings. These innovations have not only reduced energy consumption but also enhanced functionality and adaptability to meet the diverse needs of users.

- **LED Light Bulbs:** Since their commercial introduction in 1972, LEDs have revolutionized lighting by using 75% less energy and lasting much longer than traditional bulbs. They help households save up to $600 annually.
- **Solar Panels:** Building on the photovoltaic effect discovered in 1839, solar technology has become a cornerstone of renewable energy. Solar farms and power plants now provide significant contributions to global energy needs, with nations setting ambitious solar energy adoption goals.

C. Renewable Energy Integration

The term "renewable integration" describes the process of connecting renewable energy sources to the power system. A clean energy future may be possible with the help of renewable sources, which get their power from naturally renewing resources like water, wind, and sunlight. These energy sources vary greatly from fossil fuels, which may make it difficult to integrate renewable energy into the system [32]. Achieving a sustainable energy future and boosting the integration of renewables depend on overcoming these hurdles.

The amount of power generated by renewable sources in the US is above 20% and is still rising. The following figure shows how each kind of renewable energy will contribute to the overall amount of electricity produced in 2022 [33]. The US achieved a milestone in 2022: renewable energy production outpaced coal. Predictions indicate that wind power will grow by 11% by 2025 and solar power by 75% for residential use. In a year, American power consumption is more than tripled by the nation's renewable energy resources, which are abundant in the resource-rich United States. Figure 2 depicts the contribution by each renewable energy sources.

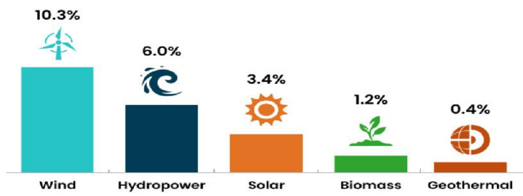

Figure 2: Renewable Energy Contribution by Source.

Many of these problems may be solved by grid energy storage, which stores renewable energy while it is plentiful for use when other renewables are not currently accessible. For further integration of renewable energy sources, grid storage solutions must also be updated.

Grid energy storage has several promising alternatives, such as hydrogen, pumped storage hydropower, and batteries, but there are still significant obstacles to overcome in order to deploy these storage choices on a large enough scale, for long enough durations, and at a fair enough cost[34].

More renewable energy integration is possible thanks to the Grid Storage Launchpad at PNNL, which is working to solve these problems and advance grid energy storage technologies of the future.

D. Transportation Efficiency

Advancements in transportation efficiency have significantly transformed the mobility landscape, focusing on reducing energy consumption, lowering emissions, and enhancing sustainability. These innovations have been driven by the need to mitigate environmental impact and improve economic efficiency across various modes of transportation.

1. Emerging Renewable Energy Sources

The integration of renewable energy sources into transportation has become a transformative force in the sector:

- **Fuel Cells (FCs):**Hydrogen is transformed into power using fuel cells, which also produce water as a by-product. They offer high efficiency, low noise, and environmental friendliness, making them a promising alternative energy source for transportation[35].
- **Photovoltaic (PV) Cells and Wind Energy:** PV cells and wind energy systems generate clean electricity to power transportation systems. While effective, these energy sources are geographically dependent and require supportive infrastructure.

2. Fuel Cell Technologies in Transportation

Fuel cell technology plays a critical role in stationary, distributed, and portable power applications in transportation:

- **Advantages:** High efficiency, low maintenance requirements, and compatibility with Vehicle-to-Grid (V2G) systems for grid integration.
- **Limitations:** Challenges such as hydrogen storage, transportation losses, and safety concerns related to hydrogen's flammability[36].
- **Electric Vehicle Advancements:** EVs are leading the charge as eco-friendly solutions to urban mobility challenges, classified into two major categories:
- **All-Electric Vehicles (AEVs):** Operate entirely on electricity with no emissions.
- **Hybrid Electric Vehicles (HEVs):**Electric powertrains and internal combustion engines work together to maximise fuel economy.

3. Vehicle-to-Grid (V2G) Technology

V2G technology has revolutionized energy management by enabling EVs to function as mobile energy storage units, enhancing grid efficiency and renewable energy integration. Key aspects include:

- **Bidirectional Power Flow:** Facilitated by advanced power converters that allow energy to flow between vehicles and the grid[37].
- **Intelligent Energy Management Systems (EMS):** EMS regulates the battery's State.

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IV. ECONOMIC AND ENVIRONMENTAL IMPACT

The economic and environmental impacts of energy efficiency technologies have been profound. Economically, these advancements have driven cost savings, created green jobs, and boosted innovation-driven markets. Environmentally, they have significantly reduced greenhouse gas emissions, curbed energy waste, and supported sustainable development efforts, making a substantial contribution to combating climate change.

On the environmental front, energy efficiency technologies have played a pivotal role in reducing greenhouse gas emissions by lowering reliance on fossil fuels. The company has also ensured that energy wastage is minimized through enhancement of effective processes coupled with structures hence conserving the resources. Through decreasing the demand for the non-renewable energy[38], these technologies contribute to the overcoming of the current weakness of many developed countries' energy security and increasing the resilience of their energy systems that rely on clean, renewable energy sources.

A. Contribution to cost savings for businesses and consumers

- **Direct Cost Savings:** The content focuses on illustrating how energy efficiency minimizes operation expenses in organizations by utilizing gadgets such as LEDs, HVAC, and EMS. It mentions the significant impact on consumers, citing energy-efficient appliances and residential upgrades that lower utility bills by 25-30%[39][40].
- **Quantitative Evidence:** The U.S. Environmental Protection Agency (EPA) figure of $450 billion in savings through Energy Star-certified products substantiates the financial impact on both businesses and consumers. Estimated savings of $200-$400 annually for households further reinforce the consumer benefit.
- **Reinvestment in the Economy:** The section discusses how cost savings are reinvested into the economy, driving innovation, expanding operations, and creating jobs, which directly ties to economic growth[41].

B. Reduction in greenhouse gas emissions

Global Context and Goals:

The content discusses international efforts to reduce greenhouse gas emissions, including the Paris Agreement's goals to limit global temperature rise to below 2°C and ideally 1.5°C.

- **Focus on Industrial Emissions:** It highlights the industrial sector's significant contribution to GHG emissions in the U.S., emphasizing that this sector plays a crucial role in achieving emission reduction goals[42].
- **Decarbonization Strategies:** The text outlines key strategies for reducing GHG emissions, such as energy efficiency, industrial electrification, low-carbon fuels, and carbon capture technologies. These strategies directly align with the goal of reducing greenhouse gas emissions[43].
- **Quantitative Data:** The inclusion of data on the industrial sector's share of emissions and specific manufacturing industries contributing to CO_2 emissions provides strong evidence for the sub-heading[44].

C. Role in meeting sustainability goals.

Environmental Benefits from Emerging Technologies:

Focuses on technologies reducing emissions and pollutants, aligning with sustainability goals. Highlights long-term strategies for sustainable development and staying ahead of regulations, which directly support sustainability objectives[45].

Energy Efficiency Regulations and Frameworks:

Pre-pandemic regulations to enhance energy efficiency and promote sustainability align with the sustainability goals.post-pandemic legislative shifts focus on stricter building codes, energy-efficient systems, renewable energy integration, and transparency in energy consumption data. These changes emphasize long-term environmental and economic sustainability[46].

- **Benefits of Energy Efficiency:** Directly links energy efficiency to lower greenhouse gas emissions and water use, cost savings, job creation, and stabilization of energy demand. Environmental benefits include reduced emissions and improved air quality, essential for achieving sustainability[47].

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- **Health Benefits and Pollution Reduction:** Highlights energy efficiency measures reducing air pollution and energy demand, benefiting both outdoor and indoor environments. The role of weatherization and air conditioning upgrades aligns with goals to improve resource utilization while enhancing living standards.
- **U.S. EPA's ENERGY STAR Program:** Promotes energy-efficient solutions, reduces greenhouse gas emissions, and improves resource utilization. Tools like the Portfolio Manager help track and manage energy and water use, contributing to sustainability efforts[48].

V. LITERATURE REVIEW

This section reviews previous studies by various authors, focusing on the advancements in energy efficiency technologies in the United States.

The paperPitis and Al-Chalabi, (2016), provides a novel approach to using MMB. The present obstacles are surmounted by the unitless indicator, sometimes known as the BEF. By way of a real-world case study, the article explains the fundamentals of MMB and BEF. Implementing ISO 50001 is a breeze using the MMB idea, which any IS&P owner may utilise. Utilities (in their DSM programs), NRCAN, and the U.S. Department of Energy - Energy-Star Certification for Plants Program may all use the BEF indication to replace their current inefficient benchmarking practices with a dependable rating system model that describes the energy efficiency of any IS&P[49].

In this paperKhobragade et al., (2022),There includes discussion of solar systems, renewable energy systems, and smart grids. For the thermal energy storage system, the smart system for the solar collector is developed. IoT-based photovoltaic system operation is shown and explored. A smart system has the potential to boost thermal storage efficiency and make solar power systems more efficient overall. The article delves into solar collectors, renewable energy systems, thermal energy storage, smart system evaluations, and the potential of these technologies for the future[50].

This paperMasanet et al., (2009),describes in brief the modelling methodology that accounts for the energy consumption and GHG emissions along the supply chain of various products and services bought by Americans. The methodology integrates "bottom-up" fuel end-use models for specific IO sectors with an input-output supply chain modelling strategy. Energy and policy experts may get a deeper understanding of the technology and processes that contribute to the energy and greenhouse gas ldquo footprints rdquo of products and services via this fuel end use modelling detail[51].

This paper Babaghayou, Chaib and Labraoui, (2023),proposes a method for adjusting the transmission power dynamically, which may improve energy efficiency and let mobile devices work longer in fog computing settings. Before offloading a job, mobile devices adjust their transmission power based on their own position and the positions of nearby access points. The method makes use of four different transmission power levels: the default is 3.6 mW for access points that are more than 265 m away, 2.7 mW for 210–265 m, 1.8 mW for 150–210 m, and 0.9 mW for 150 m or less[52].

This paper Singh and Walia, (2024), presents a novel approach using the grasshopper algorithm to improve the energy efficiency of virtual machine (VM) migration in cloud computing. This methodology reframes resource allocation techniques to address the complexity of VM selection from heavily utilized physical machines (PMs). Its effectiveness is evaluated in comparison to traditional VM migration techniques and optimization algorithms such as Firefly and Artificial Bee Colony (ABC). Relatively large measures that work as evaluation criteria for algorithms include energy saving, prevention of SLA-V and most importantly resource exploitation[53].

Conclusion And Future Work

Energy efficiency measures have served a key function in the United States to control energy consumption and emissions and thereby present economic as well as ecological benefits. Through advancements and implementations in structures, transport, and industries bolstered by supportive polices and incorporation of renewable energy the country has been in a position to bring down GHG emissions and energy inefficiency. There are numerous programs like Energy Star thereby licensing legislation acts like the Inflation Reduction Act of 2022 to push for efficiency programs. But, again such factors as high start-up costs and infrastructure constraints are still present. This paper identifies these challenges as vital to advance the use of energy efficiency technologies required to meet the targets outlined under sustainability.

The future studies should target new opportunities for energy saving through AI and big data, new energy storage solutions and improved integration of renewables into the grid. It is thus important to extend effective efficiency solutions to the target end use population in the economically disadvantaged regions. These and other failures mean that policy frameworks need to adapt in order to close regulatory loopholes and promote private capital investment in sustainable technologies. These advancements can be promoted by the U.S. to lead the world in energy efficiency contributing to combating effects of climate change, and providing for long term energy security.

REFERENCES

[1] P. P. Jubin Thomas, "Predictive big data analytics for supply chain demand forecasting," IJCRT, vol. 10, no. 6, pp. h868–h873, 2022, doi: 10.1016/B978-0-443-18464-2.00011-X.
[2] A. Hasanbeigi and L. Price, "A review of energy use and energy efficiency technologies for the textile industry," Renewable and Sustainable Energy Reviews. 2012. doi: 10.1016/j.rser.2012.03.029.
[3] J. Thomas and H. Volikatla, "AI-Enhanced Demand Forecasting Dashboard Device Having Interface for Certificate of Registration for a UK Design," 2024
[4] J. Thomas and J. R. Vummadi, "Machine Learning Driven Device for Enhanced Quality Oversight in Supply Chains," 2024
[5] X. Pan, B. Ai, C. Li, X. Pan, and Y. Yan, "Dynamic relationship among environmental regulation, technological innovation and energy efficiency based on large scale provincial panel data in China," Technol. Forecast. Soc. Change, 2019, doi: 10.1016/j.techfore.2017.12.012.
[6] K. V. V. and S. G. Jubin Thomas , Piyush Patidar, "An analysis of predictive maintenance strategies in supply chain management," Int. J. Sci. Res. Arch., vol. 06, no. 01, pp. 308–317, 2022, doi: DOI: https://doi.org/10.30574/ijsra.2022.6.1.0144.
[7] J. Thomas, K. V. Vedi, and S. Gupta, "An analysis of sustainable e-commerce logistics in supply chain management," Int. J. Sci. Res. Arch., vol. 08, no. 01, pp. 965–972, 2023.
[8] R. Goyal, "The Role Of Business Analysts In Information Management Projects," Int. J. Core Eng. Manag., vol. 6, no. 9, pp. 76–86, 2020.
[9] C. Ionescu, T. Baracu, G. E. Vlad, H. Necula, and A. Badea, "The historical evolution of the energy efficient buildings," Renewable and Sustainable Energy Reviews. 2015. doi: 10.1016/j.rser.2015.04.062.
[10] A. Prieto, B. Prieto, J. J. Escobar, and T. Lampert, "Evolution of computing energy efficiency: Koomey's law revisited," Cluster Comput., vol. 28, no. 1, 2025, doi: 10.1007/s10586-024-04767-y.
[11] R. Goyal, "EXPLORING THE PERFORMANCE OF MACHINE LEARNING MODELS FOR CLASSIFICATION AND IDENTIFICATION OF FRAUDULENT INSURANCE CLAIMS," Int. J. Core Eng. Manag., vol. 7, no. 10, pp. 34–44, 2024.
[12] M. Gopalsamy, "Predictive Cyber Attack Detection in Cloud Environments with Machine Learning from the CICIDS 2018 Dataset," IJSART, vol. 10, no. 10, pp. 36–46, 2024.
[13] M. Gopalsamy, "Artificial Intelligence (AI) Based Internet-ofThings (IoT)-Botnet Attacks Identification Techniques to Enhance Cyber security," IJRAR, vol. 7, no. 4, pp. 414–419, 2020.
[14] E. Worrell et al., "Emerging energy-efficient technologies for industry," Energy Eng. J. Assoc. Energy Eng., 2002, doi: 10.1080/01998590209509345.
[15] M. Gopalsamy, "AI-Driven Solutions for Detecting and Mitigating Cyber Threats on Social Media Networks," Int. J. Adv. Res. Sci. Commun. Technol., vol. 3, no. 2, pp. 692–702, 2023, doi: 10.48175/IJARSCT-13094P.
[16] Y. Majeed et al., "Renewable energy as an alternative source for energy management in agriculture," Energy Reports. 2023. doi: 10.1016/j.egyr.2023.06.032.
[17] R. Bishukarma, "Scalable Zero-Trust Architectures for Enhancing Security in Multi-Cloud SaaS Platforms," Int. J. Adv. Res. Sci. Commun. Technol., vol. 3, no. 3, pp. 1308–1319, 2023, doi: 10.48175/IJARSCT-14000S.
[18] R. Bishukarma, "The Role of AI in Automated Testing and Monitoring in SaaS Environments," Int. J. Res. Anal. Rev., vol. 8, no. 2, pp. 846–851, 2021.
[19] A. Goyal, "Optimising Cloud-Based CI / CD Pipelines : Techniques for Rapid Software Deployment," TIJER, vol. 11, no. 11, pp. 896–904, 2024.

[20] V. S. Thokala, "Enhancing User Experience with Dynamic Forms and Real-time Feedback in Web Applications Using MERN and Rails," IJRAR, vol. 10, no. 3, pp. 87–93, 2023.

[21] M. Mohan Tito Ayyalasomayajula, A. Tiwari, R. Kumar Arora, and S. Khan, "Implementing Convolutional Neural Networks for Automated Disease Diagnosis in Telemedicine," in 2024 Third International Conference on Distributed Computing and Electrical Circuits and Electronics (ICDCECE), 2024, pp. 1–6. doi: 10.1109/ICDCECE60827.2024.10548327.

[22] J. Roy, S. Dasgupta, and D. Chakravarty, "Energy Efficiency: Technology, Behavior, and Development," in The Handbook of Global Energy Policy, 2013. doi: 10.1002/9781118326275.ch17.

[23] R. Arora, A. Kumar, and A. Soni, "Deep Learning Approaches for Enhanced Kidney Segmentation : Evaluating U-Net and Attention U-Net with Cross-Entropy and Focal Loss Functions Deep Learning Approaches for Enhanced Kidney Segmentation : Evaluating U-Net and Attention U-Net," Preprints.org, 2024, doi: 10.20944/preprints202408.1816.v1.

[24] V. H. U. Eze, J. S. Tamball, O. F. Uzoma, N. I. Sarah, O. Robert, and O. O. Wisdom, "Advancements in Energy Efficiency Technologies for Thermal Systems: A Comprehensive Review," INOSR Appl. Sci., 2024, doi: 10.59298/inosras/2024/1.1.1010.

[25] H. Herring and R. Roy, "Technological innovation, energy efficient design and the rebound effect," Technovation, 2007, doi: 10.1016/j.technovation.2006.11.004.

[26] Sandra V. B. Jardim*, "The Electronic Health Record and its Contribution to Healthcare Information Systems Interoperability," Procedia Technol., 2013.

[27] S. Bauskar, "A Review on Database Security Challenges in Cloud Computing Environment," Int. J. Comput. Eng. Technol., vol. 15, no. 5, pp. 842–852, 2024, doi: 10.5281/zenodo.13922361.

[28] S. Bauskar, "ADVANCED ENCRYPTION TECHNIQUES FOR ENHANCING DATA SECURITY IN ADVANCED ENCRYPTION TECHNIQUES FOR ENHANCING DATA SECURITY," Int. Res. J. Mod. Eng. Technol. Sci., vol. 05, no. 10, 2023, doi: 10.56726/IRJMETS45283.

[29] S. Kubba, "Impact of Energy and Atmosphere," in Handbook of Green Building Design and Construction, 2017. doi: 10.1016/b978-0-12-810433-0.00009-5.

[30] T. Zhao, H. Zhou, J. Jiang, and W. Yan, "Impact of Green Finance and Environmental Regulations on the Green Innovation Efficiency in China," Sustain., 2022, doi: 10.3390/su14063206.

[31] T. Hofman and C. H. Dai, "Energy efficiency analysis and comparison of transmission technologies for an electric vehicle," in 2010 IEEE Vehicle Power and Propulsion Conference, VPPC 2010, 2010. doi: 10.1109/VPPC.2010.5729082.

[32] S. A. Solarin, M. O. Bello, and A. K. Tiwari, "The impact of technological innovation on renewable energy production: accounting for the roles of economic and environmental factors using a method of moments quantile regression," Heliyon, 2022, doi: 10.1016/j.heliyon.2022.e09913.

[33] H. Sinha, "A Comprehensive Study on Air Quality Detection Using ML Algorithms," J. Emerg. Technol. Innov. Res. www.jetir.org, vol. 11, no. 9, pp. b116–b122, 2024.

[34] H. Sinha, "Predicting Bitcoin Prices Using Machine Learning Techniques With Historical Data," IJCRT, vol. 12, no. 8, pp. c760–c769, 2024, doi: 10.3390/e25050777.

[35] H. Sinha, "Predicting Employee Performance in Business Environments Using Effective Machine Learning Models," IJNRD - Int. J. Nov. Res. Dev., vol. 9, no. 9, pp. a875–a881, 2024.

[36] P. Khare and S. Srivastava, "AI-Powered Fraud Prevention: A Comprehensive Analysis of Machine Learning Applications in Online Transactions," J. Emerg. Technol. Innov. Res., vol. 10, pp. f518–f525, 2023.

[37] S. shrivastava Khare, Pranav, "Transforming KYC with AI: A Comprehensive Review of Artificial Intelligence-Based Identity Verification," J. Emerg. Technol. Innov. Res., vol. 10, no. 12, pp. 525–531, 2023.

[38] P. Khare and S. Srivastava, "Enhancing Security with Voice: A Comprehensive Review of AI-Based Biometric Authentication Systems." 2023.

[39] V. V. Kumar, S. R. Yadav, F. W. Liou, and S. N. Balakrishnan, "A digital interface for the part designers and the fixture designers for a reconfigurable assembly system," Math. Probl. Eng., 2013, doi: 10.1155/2013/943702.

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[40] V. V. Kumar, M. K. Pandey, M. K. Tiwari, and D. Ben-Arieh, "Simultaneous optimization of parts and operations sequences in SSMS: A chaos embedded Taguchi particle swarm optimization approach," J. Intell. Manuf., 2010, doi: 10.1007/s10845-008-0175-4.

[41] O. O. Nosa, J. Okhuarobo, A. Talabi, and M. Ogieva, "The relevance of energy efficient projects to the US economy," Am. J. Humanit. Soc. Sci. Res., no. 09, pp. 46–59, 2024.

[42] V. V. Kumar and F. T. S. Chan, "A superiority search and optimisation algorithm to solve RFID and an environmental factor embedded closed loop logistics model," Int. J. Prod. Res., vol. 49, no. 16, pp. 4807–4831, Aug. 2011, doi: 10.1080/00207543.2010.503201.

[43] Pranav Khare and Shristi Srivastava, "Data-driven product marketing strategies: An in-depth analysis of machine learning applications," Int. J. Sci. Res. Arch., vol. 10, no. 2, pp. 1185–1197, Dec. 2023, doi: 10.30574/ijsra.2023.10.2.0933.

[44] S. Sundaramoorthy, D. Kamath, S. Nimbalkar, C. Price, T. Wenning, and J. Cresko, "Energy Efficiency as a Foundational Technology Pillar for Industrial Decarbonization," Sustain., 2023, doi: 10.3390/su15129487.

[45] V. V Kumar, "An interactive product development model in remanufacturing environment : a chaos-based artificial bee colony approach," MASTER Sci. Manuf. Eng., 2014.

[46] V. V. Kumar, A. Sahoo, S. K. Balasubramanian, and S. Gholston, "Mitigating healthcare supply chain challenges under disaster conditions: a holistic AI-based analysis of social media data," Int. J. Prod. Res., 2024, doi: 10.1080/00207543.2024.2316884.

[47] V. Kumar, V. V. Kumar, N. Mishra, F. T. S. Chan, and B. Gnanasekar, "Warranty failure analysis in service supply Chain a multi-agent framework," in SCMIS 2010 - Proceedings of 2010 8th International Conference on Supply Chain Management and Information Systems: Logistics Systems and Engineering, 2010.

[48] K. Ullah et al., "Ancillary services from wind and solar energy in modern power grids: A comprehensive review and simulation study," J. Renew. Sustain. Energy, vol. 16, no. 3, 2024, doi: 10.1063/5.0206835.

[49] C. Pitis and Z. Al-Chalabi, "Evaluation of energetic efficiency of the industrial systems by using benchmark energy factor," in Canadian Conference on Electrical and Computer Engineering, 2016. doi: 10.1109/CCECE.2016.7726669.

[50] P. Khobragade, P. Ghutke, V. P. Kalbande, and N. Purohit, "Advancement in Internet of Things (IoT) Based Solar Collector for Thermal Energy Storage System Devices: A Review," in 2022 2nd International Conference on Power Electronics and IoT Applications in Renewable Energy and its Control, PARC 2022, 2022. doi: 10.1109/PARC52418.2022.9726651.

[51] E. Masanet, K. J. Kramer, G. Homan, R. Brown, and E. Worrell, "Assessment of supply chain energy efficiency potentials: A U.S. case study," in 2009 IEEE International Symposium on Sustainable Systems and Technology, ISSST '09 in Cooperation with 2009 IEEE International Symposium on Technology and Society, ISTAS, 2009. doi: 10.1109/ISSST.2009.5156697.

[52] M. Babaghayou, N. Chaib, and N. Labraoui, "Dynamic Transmission Power Adjustment for Enhanced Energy Efficiency and Extended Lifespan of Mobile Devices," in 6th International Conference on Networking and Advanced Systems, ICNAS 2023, 2023. doi: 10.1109/ICNAS59892.2023.10330459.

[53] J. Singh and N. K. Walia, "Optimizing Cloud Computing Energy Efficiency with a Grasshopper-Inspired Technique for Virtual Machine Migration," in 2024 International Conference on Advancements in Power, Communication and Intelligent Systems (APCI), 2024, pp. 1–6. doi: 10.1109/APCI61480.2024.10616664.