A Review of Energy Efficient Technology and Carbon Trading for Reducing Carbon Emissions

Abstract

This review addresses the energy efficient technology and carbon trading for reducing carbon emissions. Energy-efficient technologies (EET) and carbon trading are mechanisms for mitigating climate change. EET offers direct ways to reduce emissions by improving the efficiency of energy use in various sectors. The use of technologies such as Variable Frequency Drives (VFD) in compressors, enhanced thermal performance in buildings, and smart lighting systems demonstrate significant potential in cutting energy consumption and thereby emissions The roles of carbon credits in international emission trading schemes, emphasizing their dual purpose of environmental protection and revenue generation for developing nations. The study explores into various types of carbon credit projects, including the Clean Development Mechanism (CDM) and the Verified Carbon Standard (VCS), highlighting their distribution and impact across different regions. The importance of forests in carbon dioxide absorption and the challenges of ensuring permanence and accounting for carbon sequestration are also discussed. Additionally, the document examines policy recommendations, such as carbon pricing and emission reduction targets set by the Intergovernmental Panel on Climate Change (IPCC).

Key words: Energy, Carbon emissions, Renewable, Climate change

1. Introduction

"In India, around 92 million tons of crop residue is burned every year, causing several negative impacts on the climate as well as on human health" (Chanda et al 2021). High levels of carbon emissions contribute significantly to global warming and climate change. By reducing emissions, we can slow down the rate of climate change and its associated impacts on weather patterns, sea levels, and biodiversity. Lower carbon emissions mean better air quality, which can lead to improved health outcomes. Studies have shown that reducing emissions can prevent premature deaths, respiratory issues, and cardiovascular diseases. Investing in emission reduction technologies can lead to long-term economic benefits. For instance, energy-efficient appliances and renewable energy sources can reduce energy costs over time. Climate change affects crop yields. Reducing emissions can minimize the adverse effects on agriculture, ensuring food security for the growing global population. Reducing reliance on fossil fuels and increasing the use of renewable energy sources can enhance energy security and independence. Emission reduction is key to sustainable development. It allows for economic growth while ensuring that natural resources are available for future generations.

Many countries have made international commitments to reduce carbon emissions, such as the Paris Agreement. It aims to limit global warming to below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C. Meeting these targets is crucial for global cooperation on climate action. Reducing emissions helps preserve ecosystems and biodiversity, which are vital for maintaining the balance of our planet's environment. There is a growing recognition of the need for individuals and corporations to act responsibly and reduce their carbon footprint as part of their social responsibility.

"Due to global lockdowns, there was a temporary reduction in CO2 emissions in 2020. In 2021, global CO^2 emissions rebounded by 4.8%, reaching 34.9 $GtCO^2$, consuming 8.7% of the remaining carbon budget for 1.5 °C warming. The largest rebounds were in the power, industry, and ground transport sectors, with aviation also showing significant increases. Emissions in China, the USA, EU27+UK, India, and Russia rebounded in 2021, with Japan being the exception, not showing a substantial rebound" (Liu et al, 2022)

"Currently, the USA, EU and UK plan to reach net zero by 2050, China and Russia by 2060, and India by 2070, leaving limited time to meet emission targets. If each country's emissions continuously decline by the same amount per year to achieve net zero by the target, the US and the EU27 and UK would need to reduce their emissions from the current 2021 levels by 167 MtCO2 per year and 105 MtCO2 per year, respectively. China would further have to reduce their emissions by 286 MtCO2 per year, and Russia by 41 MtCO2 per year to achieve targets of net zero by 2060. With plans for net zero by 2070, India's reductions would need to be 51 MtCO2 per year".(Liu et al, 2022)

"India has four targets to be achieved decarbonized by the year 2030 including the following: 1. India will reach its non-fossil energy capacity to 500 GW by 2030. 2. India will meet 50% of its energy requirements from renewable energy by 2030. 3. India will reduce the total projected carbon emissions by one billion tonnes from now onwards till 2030. 4. By 2030, India will reduce the carbon intensity of its economy by less than 45%. The fifth target announced at COP26 is India's commitment to net zero by 2070"(Roadmap-to-India-2030-Decarbonization-Target.pdf (teriin.org)).

The carbon market allows entities with emissions above the cap to buy emission allowance certificates, while those below the cap can sell their surplus reduction. This market mechanism is expected to make it more cost-efficient for companies to decarbonize, especially in emerging economies like India where access to finance for the energy transition is a challenge.

Digital technology can significantly reduce carbon emissions by promoting green technology innovation, upgrading industrial structures, and optimizing energy consumption structures. Huang et al (2024) analyzed data from 30 regions in China over a 12-year period, and found that digital technology plays a crucial role in areas with higher economic development, more extensive environmental regulation, and greater energy intensity. To reduce greenhouse gas emissions, we need to shift towards new innovated and improved technologies. Energy-efficient technologies were developed by many countries and researchers to reduce energy consumption and provide the same work output.

2. Energy-Efficient Technology

Energy-efficient technologies span various sectors, including residential, industrial, and transportation, aiming to reduce the amount of energy required to perform the same tasks.

2.1. Renewable Energy Sources

Wind power, solar power, and hydropower are renewable energy technologies that can contribute to decarbonization in the energy sector. However, these technologies differ significantly from conventional power plants. The integration of renewable energy into the power generation system presents several challenges. While the reliability of the power system plays a key role in achieving decarbonization targets, it often faces obstacles and failures that undermine progress. Unfortunately, these challenges and potential technological solutions are seldom addressed in the existing literature. Mahidin et al (2021) study aims to investigate the technological solutions and challenges within the domain of power systems. By reviewing a matrix of solutions and examining the interrelated technological challenges, this research provides valuable insights for future development. Developing a matrix that encompasses various renewable technology solutions can help overcome the challenges associated with renewable energy. Moreover, these technological solutions have the potential to prioritize cost-effective energy production. By grouping the identified technology solutions, specific challenges can be effectively mitigated. The categories established in this study contribute to identifying specific requirements and increasing transparency in the future integration of renewable energy sources.

Alaaeldin M et al (2020) presents “a grid-connected double storage system (DSS) consisting of pumped-storage hydropower (PSH) and battery. The system is supplied by photovoltaics and wind turbines. In the proposed hybrid system, batteries absorb excess renewable energy that cannot be stored in PSH and they cover loads that cannot be supplied from the water turbine. To improve the system performance, a novel energy management strategy for the DSS is proposed. The strategy is based on an optimized factor that governs the charging process of the DSS. The problem of the optimal system design is solved by a non-dominated sorting genetic algorithm (NSGA-II). The multi-objective function considers simultaneously the minimal investment cost and minimal CO2 emissions. A comparative study of photovoltaic/wind/pumped-storage hydropower and photovoltaic/wind/double storage systems is performed to show the effectiveness of the proposed strategy in terms of system economic and environmental performance. The considered location of the PSH station is on Attaqa Mountain at Suez (Egypt). The results indicate the effectiveness of the proposed energy management strategy for the storage system from economic and environmental perspectives. Coupling the battery with the PSH reduces the electricity cost by 22.2% and results in minimal energy exchange with the national grid (5% of the annual demand). A sensitivity analysis shows the largest variation of the electricity cost with changing the capital cost of the solar and wind generators. Also, it is observed that when the load increases, the optimal size of the system components increases, but it isn't proportional to the demand increase as could be expected”.

Ghenai C &Bettayeb M (2020) present “the results of an optimized design of a grid-connected renewable energy system for a university building in this paper. The study utilizes integrated modelling, simulation, optimization, and control strategies to evaluate performance and select the best hybrid renewable power system. The main objective is to design a grid-connected renewable energy system that can meet the building's electric load with high renewable energy penetration, low greenhouse gas emissions, and low energy cost. Hourly simulations, modelling, and optimization techniques are employed to assess the performance and cost of different hybrid power system configurations using load following and cycle charging control strategies. The results demonstrate that the grid-tied solar PV/fuel cell hybrid power system performs well in the tested system architectures. With a solar PV capacity of 500 kW and a fuel cell capacity of 100 kW integrated with the grid, the total energy generated from the grid-tied renewable energy system to meet the desired load amounts to 26% from the grid (purchased), 42% produced from the solar PV, and 32% from the fuel cell. Out of the total annual power produced, 95% is utilized to meet the AC primary load of the building, while 5% is fed back to the grid. The paper also presents the daily performance and electricity generation from the proposed grid-tied solar PV/fuel cell power system. The proposed system, with the ability to sell electricity back to the grid, achieves a high renewable fraction (40.4%), low levelized cost of energy ($71/MWh), and low carbon dioxide emissions (133 kg CO2/MWh)".

Anon (2024) endorsed that "the resulting hydrogen is stored for later use at the site's hydrogen fueling station or converted back to electricity (via a hydrogen internal combustion engine or fuel cell) and fed to the utility grid during peak-demand hours. Located at the National Wind Technology Center near Boulder, Colorado, the Wind2H2 project aims to improve the system efficiency of producing hydrogen from renewable resources in quantities large enough and at costs low enough to compete with traditional energy sources such as coal, oil, and natural gas".

Advanced technology and improved lifestyle is responsible for increasing anthropogenic carbon emission. To control anthropogenic emissions there is a need of increasing awareness amongst stakeholders to adopt such methods which are technologically better but environmentally safe. Emission mitigation policies, regulations and fuel-switching measures result into carbon emission saving up to 25%. Also shifting power generation technology from conventional sources to cogeneration or hybrid technology results into a substantial reduction in carbon emissions.Improvement in thermal performance of building envelope leads to reduction in carbon emission. Retrofitting, reconstruction and selection of appropriate U-factors for building materials lead to a saving of carbon emission up to 31–36%. Reuse, recycling and regeneration energy through combustion together can save up to 10% of total energy and subsequently emissions.

The construction process should be made more environmentally friendly by replacing part of energy-intensive building material by waste or recycled material. Use of prefabricated building elements, replacing energy-intensive clinker in Portland cements (Fly ash, furnace slag), minimizing production energy in cement (dry process of clinker formation), minimizing production energy in masonry blocks (CMU, CSRE wall), using timber-based material and recycled steel can achieve substantial reduction in energy and emission. Sixty-five to 95% clinker to cement ratio results in around 32% reduction in CO2 emission. Use of recycled steel saves about 80% of energy in the production process.

"Crop stubble burning or agricultural biomass burning is one of the highest contributors to this emission. In India, around 92 million tons of crop residue is burned every year, causing several negative impacts on the climate as well as on human health. Under the Kyoto Protocol, Carbon trading and Clean Development Mechanism (CDM) are the two robust processes to mitigate GHG emissions for any country. In this study, overview of world's carbon market and analysed how much carbon credit India may have traded in the world carbon market, if emissions from the crop residue burning were stopped in the Indian agricultural sector. Further we have fitted an econometric model to determine the effect of carbon trading on other stock market variable".(Chanda et al, 2021)

2.2. Building Efficiency

2.2.1 Energy Efficient Windows

Glass frontages have an important role in buildings in terms of energy demand, thermal comfort, and daylighting: the main total energy losses (up to 60%) can depend on the windows, especially in highly glazed buildings. To speed up refurbishment of existing buildings towards Nearly Zero Energy Buildings. Windows with granular silica aerogel and low-emissivity coatings significantly reduce thermal transmittance and energy loss, improving both heating and cooling efficiency in buildings.

The properties of facade materials strongly affect building energy performance. This study investigates the effects of four fundamental facade properties on the energy efficiency of office buildings in Tokyo, Japan. The aim is to reduce heating and cooling energy demands. The study also considers fundamental design factors such as volume and shape. Takeshi I (2015) found that "reducing the solar heat gain coefficient and window U-value, and increasing the solar reflectance of the opaque parts, are promising measures for reducing energy demand. However, reducing the U-value of the opaque parts may decrease heating energy demand while increasing cooling energy demand in some cases, as cooling tends to be the predominant energy demand. Therefore, these promising measures for reducing building energy demand are recommended, but careful considerations are needed when applying an appropriate U-value to the opaque parts. Overall, this study provides fundamental ideas for adjusting the facade properties of buildings".

Buratti C et al (2017) "The paper deals with the potential of high energy-efficient windows with granular silica aerogel for energy saving in building refurbishment. Different glazing systems were investigated considering two kinds of granular silica aerogel and different glass layers. Thermal transmittance and optical properties of the samples were measured and used in building simulations. The aerogel impact on heat transfer is remarkable, allowing a thermal transmittance of 1.0–1.1 W/(m^2·K) with granular aerogel in interspace only 15 mm in thickness. A 63% reduction in U-value was achieved when compared to the corresponding conventional windows, together with a significant reduction (30%) in light transmittance. When assembled with low-e glass, the U-value reduction was lower (31%), but a moderate reduction in light transmittance (about 10%) was observed for larger granules. Energy simulations for a case study in different climate conditions (hot, moderate, and cold) showed a reduction in energy demand both for heating and cooling for silica aerogel glazing systems when compared to the conventional ones. The new glazings are a suitable solution for building refurbishment, thanks to low U-values and total solar transmittance, also in warm climate conditions".

Cheong CH et al (2014) "Cooling load in a highly glazed residential building can be excessively large due to uncontrolled solar energy entering the indoor space. This study focuses on the cooling load reduction and changes in the daylighting properties via applying a double window system (DWS) with shading with various surface reflectivity in highly glazed residential buildings. Evaluation of thermal and daylighting performances is carried out using simulation tools. The reductions in cooling load and energy cost using DWS are evaluated through a comparative simulation considering conventional windows: a single window and a double window. Three variables of window types, natural ventilation, and shading reflectivity are reflected in the study. According to our results, the implementation of DWS reduced cooling load by 43%–61%. Electricity cost during the cooling period was reduced by a maximum of 24%. However, a shading device setting that prioritizes effective cooling load reduction can greatly decrease the daylighting factor and luminance level of indoor space. A DWS implementing shading device with highly reflective at all surfaces is an appropriate option for a more comfortable thermal and visual environment, while a shading device with low reflectivity at rear of the surface can contribute an additional 4% cooling load reduction".

Rashidzadeh Z et al (2023) use"a facade thatcontrols interaction between the building and the environment. Advancements in control technologies and material science give the opportunity to use smart windows in a high-performance facade to improve the building's energy performance and users' comfort. This study aims to propose practical recommendations for smart windows' implementation over various climate zones across the world. To follow this aim, 54 studies published from 2013 to 2022 collected from architecture, engineering, and material science databases and have been reviewed, and seven types of smart windows including electrochromic, photovoltachromic, gasochromic, thermochromic, photochromic, hydrochromic, and Low-E have been identified. Moreover, the thermal properties and visual features of smart coatings used in the windows and their impacts on energy efficiency and users' comfort were recognized. Then, a comparative study was conducted to identify and propose the most efficient coating utilized in the structure of smart windows across different climate zones".

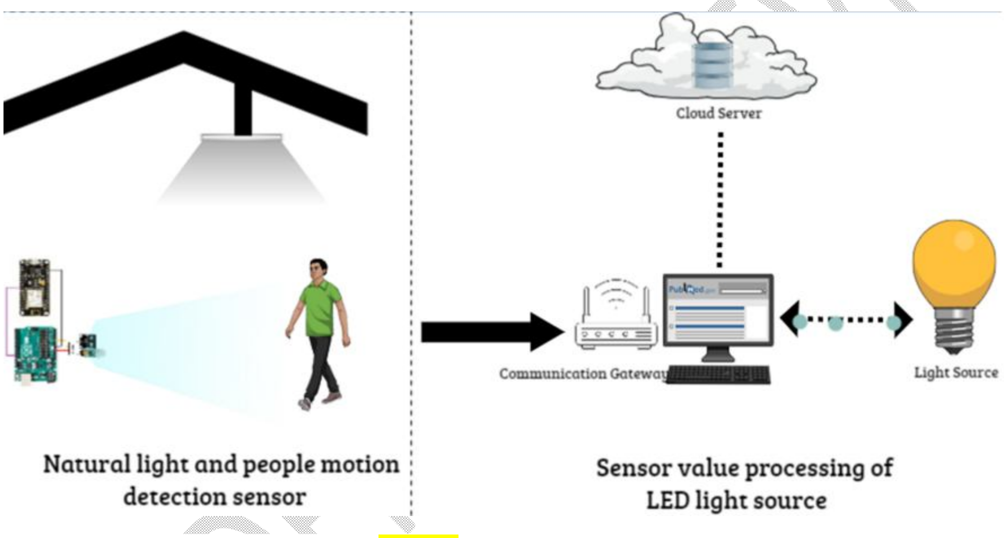
Hong SK et al (2023) "reduce energy consumption in the summer by controlling a smart window system. The study focuses on the dimming control algorithm and its impact on lighting and cooling energy. The smart window system includes suspended particle display glass and light-guiding glass, which actively respond to changes in the environment and control light transmittance and solar reflectance. Simulations were conducted to develop optimal control algorithms and controllers based on solar radiation. The complex smart window system was then installed in a test room, along with the control algorithm and controller. To ensure accuracy, separate test and reference rooms were constructed. The experimental results showed a reduction of approximately 36.9% in cooling energy consumption and a 54.5% reduction in lighting energy consumption in the test room compared to the reference room. Additional simulations and experiments confirmed that complex smart window systems can significantly reduce energy consumption in office buildings".

2.2.2 Lighting Technologies

Saving energy has become one of the most important issues these days. The most waste of energy is caused by the inefficient use of the consumer electronics. Particularly, a light accounts for a great part of the total energy consumption. Various light control systems are introduced in current markets, because the installed lighting systems are outdated and energy-inefficient. However, due to architectural limitations, the existing light control systems cannot be successfully applied to home and office buildings. Intelligent household LED lighting systems significantly reduce energy consumption by using multi-sensors and wireless communication technology. Motion sensors, occupancy sensors, photosensors, and timers that automatically adjust lighting based on activity and daylight availability Therefore, Byun et al. (2013) this paper propose"an intelligent household LED lighting system considering energy efficiency and user satisfaction. The proposed system utilizes multi-sensors and wireless communication technology in order to control an LED light according to the user's state and the surroundings. The proposed LED lighting system can autonomously adjust the minimum light intensity value to enhance both energy efficiency and user satisfaction. We designed and implemented the proposed system in the test bed and measured total power consumption to verify the performance. The proposed LED lighting system reduces the total power consumption of the test bed up to 21.9%"

Widartha V P et al (2024) aimed "to enhance the energy efficiency of smart lighting systems by using light source data. A multifaceted approach was employed, involving the following three scenarios: sensing device, daylight data, and a combination of both. A low-cost sensor and third-party API were used for data collection, and a prototype application was developed for real-time monitoring. The results showed that combining sensor and daylight data effectively reduced energy consumption, and the rule-based algorithm further optimized energy usage. The prototype application provided real-time monitoring and actionable insights, thus contributing to overall energy optimization".

Fig 1 : Sensor detecting procedure



Cheng Y et al (2020) "reduce energy consumption by implementing a smart lighting system that integrates sensor technologies, a distributed wireless sensor network (WSN) using ZigBee protocol, and illumination control rules. A sensing module consists of occupancy sensors, including passive infrared (PIR) sensors and microwave Doppler sensors, an ambient light sensor, and lighting control rules. The dimming level of each luminaire is controlled by rules taking into consideration occupancy and daylight harvesting. The performance of the proposed system is evaluated in two scenarios, a metro station and an office room, and the average energy savings are about 45% and 36%, respectively. The effects of different factors on energy savings areanalyzed, including people flow density, weather, desired illuminance, and the number of people in a room. Experimental results demonstrate the robustness of the proposed system and its ability to save energy consumption. The study can benefit the development of intelligent and sustainable building".

2.2.3 Smart Thermostats

Smart thermostats are Wi-Fi thermostats that can be used with home automation and are responsible for controlling a home's heating, ventilation, and air conditioning. They perform similar functions as a Programmable thermostat as they allow the user to control the temperature of their home throughout the day using a schedule, but also contain additional features, such as sensors and Wi-Fi connectivity that improve upon the issues with programming.

Lou R et al (2020) "The present research leverages prior works to automatically estimate wall and ceiling R-values using a combination of a smart WiFi thermostat, building geometry, and historical energy consumption data to improve the calculation of the mean radiant temperature (MRT), which is integral to the determination of thermal comfort in buildings. To assess the potential of this approach for realizing energy savings in any residence, machine learning predictive models of indoor temperature and humidity, based upon a nonlinear autoregressive exogenous model (NARX), were developed. The developed models were used to calculate the temperature and humidity set-points needed to achieve minimum thermal comfort at all times. The initial results showed cooling energy savings in excess of 83% and 95%, respectively, for high- and low-efficiency residences. The significance of this research is that thermal comfort control can be employed to realize significant heating, ventilation, and air conditioning (HVAC) savings using readily available data and systems".

Kwak Y et al (2016) develop"an efficient predictive control method for building energy simulation in real-time. Accurate prediction is crucial in predictive control, and errors can occur when using model predictive control (MPC) based on simulations due to uncertain data input. To reduce error, the simulation should incorporate current circumstances, such as improved weather forecast data. Therefore, this study focuses on developing a simulation method that utilizes daily updated weather forecast data. The proposed method generates a real-time weather data file for Energy Plus-specific building energy simulation. The data file includes calculations from web-based forecast data, equations, built-in functions of Energy Plus, and other default weather elements from the building controls virtual test bed (BCVTB). Specifically, the method generates a 24-hour weather data file every day. The proposed method achieves a mean bias error (MBE) of 1.3% and a coefficient of variation of root mean squared error (Cv(RMSE)) of 20.1% in weather prediction".

2.3. Industrial Processes

2.3.1 High-Efficiency Motors and Drives:

Rathikrindi K S et al (2018)"Variable Frequency Drives (VFD's) are used in many applications, from small appliances to large coal plant drives. By selecting and sizing the VFDs along with suitable motors, significant energy savings can be achieved. While there are other energy savings schemes available, VFDs have the potential to save energy ranging from 20% to 65%, depending on the application and its range of operation. Currently, air conditioners commonly use electric motors, which are essential components. These motors, responsible for driving pumps, fans, compressors, and other machines, account for 45% of global electricity use. However, users often fail to explore energy savings opportunities due to a lack of awareness. This paper aims to demonstrate how energy can be saved through VFD controlled motor driven systems for compressors used in air conditioner applications.

The paper will present the potential energy savings opportunities between Fixed Speed Motor Compressors and VFD controlled Motor compressors".

Gómez, J.R et al (2020) "improve energy efficiency in industry, one of the possible methods is to replace IE1 energy class motors with IE3 motors. Authors propose a methodology that is based on calculating the possibility of energy savings by performing a prior estimation of the savings and identifying some economic opportunities for the replacement of motors with higher-efficiency ones. The method does not evaluate all the motors in the studied facilities but uses the potential energy savings to select the motors for evaluation. As a result, a full economic evaluation of the final solution is provided based on the discounted cash flow methods"

Agrawal S.K (2019) "In another developing country, India, it has been found that the electric motors used in industry are mainly of the IE1 energy class or lower-efficiency motors, and the need for their replacement is again reported in order to reduce electricity consumption".

Davydov, V et al (2019) "Hardware and software results are obtained and analysed and are then presented for the multi-starter control of a single system. With the help of an adaptive neural network controller, connected in a circuit with direct control of the torque of an induction motor, the energy efficiency, quality and reliability of the electric drive control in an industrial plant are improved".

Heat Recovery Systems:

Jouhara et al (2018) "Waste heat recovery methods include capturing and transferring the waste heat from a process with a gas or liquid back to the system as an extra energy source. The energy source can be used to create additional heat or to generate electrical and mechanical power. Waste heat can be rejected at any temperature; conventionally, the higher the temperature, the higher the quality of the waste heat and the easier optimisation of the waste heat recovery process. It is therefore important to discover the maximum amount of recoverable heat of the highest potential from a process and to ensure the achievement of the maximum efficiency from a waste heat recovery system. Economisers or finned tube heat exchangers that recover low – medium waste heat are mainly used for heating liquids. The system consists of tubes that is covered by metallic fins to maximise the surface area of heat absorption and the heat transfer rate".

2.3.2 Transportation

Electric Vehicles (EVs): Hybrid electric vehicles (HEVs) are more fuel efficient than conventional vehicles because they use the energy stored in batteries, and the extra power from the electric motor can allow for a smaller engine. These features improve fuel economy without sacrificing performance. HEVs use the following technologies to improve fuel efficiency:

a. Regenerative braking: The electric motor resists the drivetrain, and the energy from the wheels turns the motor like a generator.
b. Electric motor drive/assist: The electric motor helps the internal combustion engine (ICE) during acceleration.

c. Stop-start: The engine turns off when the vehicle isn't moving to avoid idling and wasting fuel.
d. Battery power: The battery powers auxiliary loads and reduces engine idling.

Fuerst P F et al (2019) "The growing demand for energy efficiency gains in vehicles has led to several advances in more technological and efficient driving units, projects using lighter and more resistant materials and, in particular, a deeper study of aerodynamic studies in order to understand the fluid flow around the object of study. This work presents an aerodynamic study for a vehicle of high-energy efficiency, through computational fluid dynamics simulation in Ansys Fluent software. The main objective is to obtain the traction and drag force vectors acting on the vehicle at different speeds and to better understand the airflow before, during and after contact with the vehicle. With the possession of results, it was facilitated the implementation of improvements that enabled the vehicle to operate even more efficiently".

2.3.3 Battery energy storage technologies are gaining popularity globally for grid level applications due to rapidly reducing costs of installations along with technological advancements. It has features like quick response time, distributed energy/power- balancing capabilities, and phased installation, which make them eminently suitable for handling the reliability and intermittency of RE generation (TERI, 2021). India has initiated efforts for the deployment of grid scale battery storage on scale through the recent SECI tenders. BESS may emerge as one of the preferred options for flexibility and ensuring grid stability. According to estimates by the International Energy Agency (IEA), the global share of India in battery deployment would be 35% by 2040. The most commonly used battery chemistries for grid-level applications in the current scenario are based on lead, sodium, nickel, transition metals (vanadium, chromium, and iron), and lithium electrochemistry. There are many technologies which are at demonstration level. Figure 1 provides an overview of various grid-scale technologies. Some of these technologies like molten rocks, flywheel, super capacitors, green hydrogen are in the nascent stages of development or are still not able to find deployment at the scales, which make them cost effective. IRENA estimates that by 2030 the total installed cost of flow batteries, still very much in development, could drop by two-thirds; high-temperature batteries by 56–60%; flywheels by 35%; and compressed air energy storage by 17% (IRENA, 2019). Such cost declines along with expected performance improvements would make these new battery storage systems cost-competitive for more applications, particularly ones involving longer discharge periods. The CEA has estimated that capital cost of batteries would decline from 7 crore/MW (USD 0.89 million/MW) in 2021– 2022 to 4.3 crore/MW (USD 0.54 million/MW) in 2029–2030 for a 4-hour discharge duration, equivalent to 18,750 ($250/kWh) in 2021–2022 and 11,550 ($154/kWh) in 2029–2030.

2.3.4 Variable Frequency Drives (VFDs)

Rathikrindi K S et al (2018) "Variable Frequency Drives (VFD's) are used in many applications ranging from small appliances to the largest of coal plant drives wherein it's possible to achieve significant amount of energy savings through proper selection and sizing of the VFDs along with suitable motors". Though we have various other conventional energy savings schemes available, VFD has significant amount of energy saving potential ranging from 20% to 65 % opportunities depending on the application and its range of operation. "As on today, air conditioners are quite commonly used and therefore electric motors are essential to be part of air conditioners. Electric motors driving pumps, fans, compressors and other machines are responsible for 45% of global electricity use in worldwide wherein huge energy savings opportunities are available" [4]. But at the same time, energy savings opportunities are not explored by user due to lack of awareness on the energy savings opportunities. The purpose of this paper is to show how to save energy through VFD controlled motor driven systems for compressor used in air conditioner applications. In this paper, the possible energy savings opportunities between Fixed Speed Motor Compressors Vs. VFD controlled Motor compressors is presented.

Gómez, J.R et al (2020) suggest improving energy efficiency in industry by replacing IE1 energy class motors with IE3 motors. They propose a methodology that estimates energy savings and identifies economic opportunities for replacing less efficient motors. The method selects motors for evaluation based on their potential energy savings, rather than evaluating all motors in the studied facilities. Ultimately, a comprehensive economic evaluation of the final solution is provided using discounted cash flow methods.In another developing country, India, it has been found that the electric motors used in industry are mainly of the IE1 energy class or lower-efficiency motors, and the need for their replacement is again reported to reduce electricity consumption.

Davydov et al (2023) presented "the multi-starter control of a single system. With the help of an adaptive neural network controller, connected in a circuit with direct control of the torque of an induction motor, the energy efficiency, quality and reliability of the electric drive control in an industrial plant are improved".

Carbon Trading

Carbon credits are crucial for addressing climate change. They incentivize emissions reduction and promote a transition to a low-carbon economy. These credits can be used to offset emissions from power plants, factories, and transportation. They are issued by governments or international organizations and can be bought and sold on carbon markets. One carbon credit is equal to 1000 kg of carbon dioxide. It represents the difference between allowed carbon emissions and the actual amount emitted.

According to the Intergovernmental Panel on Climate Change (2001), atmospheric concentrations of CO_2, CH_4, and N_2O have increased by approximately 31%, 151%, and 17% respectively between 1750 and 2000. This global concern about climate change led to the Kyoto Protocol in 1997, which sets legally binding emission targets for industrialized countries to achieve from 2008 to 2012. As of August 2011, 191 countries have signed/ratified the Kyoto Protocol.

The Kyoto Protocol includes several flexibility mechanisms to mitigate climate change. These mechanisms include International Emission Trading (IET), Joint Implementation (JI), and Clean Development Mechanism (CDM). International emission trading, also known as cap and trade, is a market-based approach that provides economic incentives for reducing greenhouse gas (GHG) emissions. Annex I countries can trade their emissions Assigned Amount Units (AAUs) through this mechanism. Joint Implementation allows any Annex I country to invest in emission reduction projects in other Annex I countries with lower cost of reducing emissions, serving as an alternative to domestic reductions.

Clean Development Mechanism (CDM) enables developed industrialized countries (Annex I) to meet their emission reduction targets by initiating projects to reduce emissions in developing countries (Non-Annex I) that have signed the Kyoto Protocol. These projects can be implemented globally wherever they are most cost-effective. CDM helps developing countries adopt new technologies, reduce GHG emissions, and save energy. The reductions achieved through CDM projects are measured and subtracted from a baseline of predicted emissions that would occur without the project. The CDM is overseen by the CDM Executive Board (CDM EB) and operates under the guidance of the Conference of the Parties (COP/MOP) of the United Nations Framework Convention on Climate Change (UNFCCC). All major GHGs are traded within the carbon market, not just CO_2. The other gases are converted to their carbon dioxide equivalent (CO_2e) using their global warming potential (GWP). CO_2e represents the amount of carbon dioxide that would have the same global warming effect. The GWP of major GHGsis provided in Table 1.

Table 1: Global warming potential (GWP) of the major GHGs

CO_2	1
Methane	26
Nitrous Oxide	296
HFC-125	3,400
HFC-134a	1,300
HFC-143a	4,300
HFC-152a	120
HFC-227a	3,500
HFC-236F	9,400
Perfluoromethane(CF_4)	5,700
Perfluoroethane (C_2F_6)	11,900
Sulfur hexafluoride (SF_6)	22,200

Carbon credits and trading: Carbon credits are certificates awarded to countries successful in reducing GHG emissions. They support nature conservation and generate revenue for developing and underdeveloped countries. Carbon credits encourage GHG reduction by capping annual emissions and allowing the market to assign a monetary value to any shortfall through carbon trading. One carbon credit is equivalent to one tonne of CO_2 emitted. These credits can be exchanged between businesses or bought and sold internationally at market prices. Companies can reduce emissions by adopting new technology or improving existing technology, or by collaborating with developed nations to set up new projects (Nair et al., 2014).

3.2. Types of projects that generate carbon credits

Carbon credit projects are designed to mitigate greenhouse gas emissions, resulting in the generation of carbon credits. These credits can be traded on carbon markets or immobilized to offset emissions. In this context, two essential carbon credit mechanisms, namely the Clean Development Mechanism (CDM) and Verified Carbon Standard (VCS), are examined and contrasted to evaluate the success of projects (Von et al, 2018). The distribution of CDM projects, in general, and renewable energy-based CDM power projects, in particular, has been skewed across India. The ten states of Andhra Pradesh, Chhattisgarh, Gujarat, Himachal Pradesh, Karnataka, Maharashtra, Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh have accounted for more than 90% of the RE-based CDM power projects and 99% of the total number of CERs issued from these projects in India (Sawhney et al, 2014).

Forestry and Land Use: Forests are crucial for environmental conservation becausethey have various functions including the preservation of ecosystems and biodiversity(Ankita et al, 2021), as well as the absorption of carbon dioxide to combat global warming (Seto, 2012). Carbon dioxide absorption is particularly important for preventing the destruction of ecosystems due to global warming. Currently, there are two ways to reduce atmospheric carbon dioxide: reducing emissions or increasing absorption. Tropical rainforests, known for their ecological rarity, have received significant attention (Baccini et al, 2012). However, Lindenmayer et al (2012) highlighted that only 11% of the world's forests are protected, and 4% are used for wood production. The remaining 85% deserve more attention. The retention approach has been proposed as a forest management method to improve ecosystem quality in these "general" production forests. Carbon leakage, which can occur when tree planting or forest protection activity is (partly) counteracted by another activity that results in extra emissions elsewhere. Permanence: a forest protected or planted during a certain period of time may be subject to clearing during future periods; or replanting of trees after a rotation period has ended is not always guaranteed. Moreover, permanence of sequestered carbon in forests is challenged by the risks of natural forest disturbances (e.g. Fires and insects). The complexity of accounting, in terms of, for example, the capacity of different tree species to store carbon, determining where carbon is sequestered (e.g. soil and trunks), how to account for carbon sequestered in wood after a harvest, as well as handling the differences in terms of carbon accounting between harvesting and avoiding deforestation. At the same time, especially because of activities in the voluntary markets, big steps have been made in improving the methodologies for carbon accounting in forestry projects, especially concerning addressing uncertainties and mitigation risks. (Van Der Gaast et al, 2018).

Renewable energy projects:Both renewable energy and CDM are considered solutions for environmental problems and climate change, making them a good match for contributing to sustainable development. They both lead to sustainable development and have positive impacts on nations. As of August 2012, the CDM had received a total of 4460 CDM projects in the pipeline. Of these projects, 69% are related to renewable energy. The majority of CDM projects are focused on wind, hydro, and biomass energy, with 2,523 projects (28%), 2,280 projects (26%), and 906 projects (10%) respectively. Only one CDM project is related to tidal energy, which is expected to generate 1,104,000 Certified Emission Reductions (CERs) in 2012 (Das et al, 2023). In other words, tidal energy is estimated to produce 315k CERs per year.

Blue carbon ecosystems, such as mangrove forests, tidal marshes, and seagrass meadows, are gaining international recognition as natural climate solutions to address climate change. It is estimated that these ecosystems cover approximately 36-185 million hectares and have the potential to store around 8,970-32,650 Tg C (teragrams of carbon). In addition to their climate benefits, they also provide important co-benefits. Protecting existing blue carbon ecosystems could prevent the emission of approximately 304 (141-466) Tg (95% CI bounds) of carbon dioxide equivalent (CO_2e) per year. Furthermore, large-scale restoration efforts could remove an additional 841 (621- ,064) Tg CO_2e per year by 2030. This is equivalent to approximately 3% (0.5-0.8% from protection and 2.3-2.5% from restoration) of annual global greenhouse gas emissions. The potential of blue carbon as a nature-based solution depends on the actions taken by society. Therefore, it is crucial to prioritize the restoration of blue carbon ecosystems during the UN Decade on Ecosystem Restoration (2021-2030). Additionally, emerging blue carbon markets should consider incorporating the value of co-benefits into financial frameworks to support the necessary investments for restoration and conservation.(Macreadie et al, 2021)

Waste management: The waste sector contributes to greenhouse gas (GHG) emissions primarily through carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and a few other gases with smaller quantities. These emissions are released during various processes and components of the waste management cycle, including collection, material recovery, biological and thermal processes, and landfilling. In 2010, these emissions accounted for approximately 3% (1446 × 106 $MTCO_2E$) of global GHG emissions (Blanco et al., 2014). Maalouf et al. (2014) tested a model in both developed and developing economies to assess the impact of waste composition, management processes, energy consumption, and other input parameters on variations in emissions. Their scenario analysis showed that implementing best practices such as recycling, biological treatment, food waste diversion, and/or energy recovery can lead to significant emission reductions, ranging from 24% to 95%, depending on the specific system tested. On the other hand, improper waste management practices such as open dumping or burning, instead of controlled landfilling or incineration with energy recovery, can increase total equivalent emissions by approximately 30% and 295%, respectively. In conclusion, we argue that applying this model provide valuable guidelines for policy planning and decision-making regarding the viability of processes and investments in carbon credit.

Transportation: In respect to energy and carbon emissions in the transportation sector, the most important factors are energy density and driving range. Electrification and hydrogenation are promising strategies for the future of transportation (Zhou et al 2022). Electricity is currently the preferred choice for transportation due to its efficiency and cost-effectiveness, but high-energy-density alternatives like hydrogen or synthetic fuel are needed in certain areas (Connolly et al 2014). The transition to electrification and hydrogenation also allows for synergies between land and air transportation (Zhou et al, 2022). When comparing the environmental sustainability, energy efficiency loss, and capital costs of hydrogen and methanol, it is evident that green methanol is preferable for short-term zero-carbon transportation, while green hydrogen is more suitable for long-term zero-carbon transportation (li et al, 2022). Furthermore, achieving decarbonized transportation necessitates the use of a combination of sustainable fuels (such as biofuels and electrofuels) and new powertrains (such as electric vehicles and hydrogen vehicles). Given the considerable carbon emissions from the transportation sector (approximately 23% in China), e-transportation has gained popularity, particularly when coupled with renewable energy sources and flexible power interactions like vehicle-to-building and vehicle-to-grid technologies(Zhou et al, 2023).

4. Policy Recommendations

Incentives for Innovation: The World Bank has several global schemes to reduce greenhouse gas (GHG) emissions. Here are some key points from these documents:

1. Carbon Pricing: Carbon pricing is a key method for incorporating the costs of climate change into economic decision-making. It creates an incentive to reduce carbon emissions and can help raise revenues in a more efficient and less distortive way than alternative sources. Carbon pricing instruments include carbon taxes, emissions trading systems, and carbon crediting mechanisms. The choice of instrument depends on policy objectives and national circumstances.

2. Mitigation Action Assessment Protocol (MAAP): The World Bank has developed the MAAP to enhance carbon pricing and international carbon market readiness. This involves identifying capacity-building needs for carbon pricing and international carbon market development.

3. Global Gas Flaring Reduction Partnership (GGFR): The GGFR is a partnership between the World Bank, governments, and oil & gas companies. It considers the Clean Development Mechanism (CDM) of the Kyoto Protocol as an effective financial incentive for projects that reduce flaring and venting of associated gas.

4. GHG Emissions Inventories: These inventories are needed to prioritize initiatives and track progress in reducing emissions. Under the Paris Agreement, national governments have agreed to rein in these emissions to almost zero within 30 years.

5. Emission Reduction Targets: The Intergovernmental Panel on Climate Change (IPCC) estimates that a 20% absolute reduction in CO_2 emissions is needed by 2030 to maintain a pathway limiting global warming to 2°C, and a 40% absolute reduction in emissions is needed to maintain a pathway to 1.5°C. These schemes and initiatives are part of a comprehensive policy package required to reduce emissions and combat climate change. They aim to create a global carbon market that incentivizes emission reductions and promotes sustainable development. (World Bank Report)

5. Conclusion

Energy-efficient technologies and carbon trading systems offer promising pathways for reducing carbon emissions. The findings highlight that energy-efficient technologies and carbon trading systems are critical in the global effort to mitigate climate change. These two strategies, though distinct, complement each other and can collectively drive substantial reductions in greenhouse gas (GHG) emissions.

Energy-efficient technologies (EET) offer direct ways to reduce emissions by improving the efficiency of energy use in various sectors. The use of technologies such as Variable Frequency Drives (VFD) in compressors, enhanced thermal performance in buildings, and smart lighting systems demonstrate significant potential in cutting energy consumption and thereby emissions. For instance, retrofitting buildings and using energy-efficient windows can reduce energy losses significantly, leading to lower carbon footprints.

Carbon trading, on the other hand, provides an economic incentive for emission reductions. By assigning a monetary value to the reduction of emissions, carbon trading encourages entities to either reduce their emissions or purchase credits from those who have achieved lower emissions. Mechanisms like the Clean Development Mechanism (CDM) and the Verified Carbon Standard (VCS) facilitate this process by validating and distributing carbon credits. The document emphasizes that carbon trading can also support projects in developing nations, promoting sustainable development while addressing global emission targets.

Moreover, the document discusses the critical role of forests in sequestering carbon dioxide. It points out the challenges in ensuring the permanence of carbon stored in forests and the complexities of carbon accounting. Despite these challenges, forestry projects remain a vital part of the carbon credit market.

Policy recommendations from the document stress the importance of carbon pricing and international cooperation. The IPCC's emission reduction targets serve as a benchmark, urging nations to implement comprehensive policy packages that include carbon markets and technological advancements.

In conclusion, combining EET and carbon trading can yield more significant results in the fight against climate change. This synergy requires ongoing innovation, robust policy frameworks, and strong international collaboration. By leveraging these tools effectively, the global community can move closer to achieving substantial emission reductions and mitigating the adverse effects of climate change.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etchave been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

References

1. Abdelshafy, A. M., Jurasz, J., Hassan, H.,& Mohamed, A. M. (2020). Optimized energy management strategy for grid connected double storage (pumped storage-battery) system powered by renewable energy resources. Energy, 192, 116615.

2. Anon. Roadmap-to-India-2030-Decarbonization-Target.pdf (teriin.org).

3. Baccini, A., Goetz, S.J., Walker, W.S., Laporte, N.T., Sun, M., Sulla-Menashe, D., Hackler, J., Beck, P.S.A., Dubayah, R., Friedl, M.A., et al. (2012). Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps.Nature Climate Change, 2, 182-185. [CrossRef]

4. Blanco, G., Gerlagh, R., Suh, S., Barrett, J., Coninck, H.D., Zhou, P.P., &Et, A. (2014). Drivers, Trends and Mitigation.

5. Buratti, C., Moretti, E., &Zinzi, M. (2017). High energy-efficient windows with silica aerogel for building refurbishment: Experimental characterization and preliminary simulations in different climate conditions.Buildings, 7(1), 8.

6. Byun, J., Hong, I., Lee, B., & Park, S. (2013). Intelligent household LED lighting system considering energy efficiency and user satisfaction. IEEE Transactions on Consumer Electronics, 59(1), 70-76.

7. Chanda, S., Malakar, A., &Gorain, S. (2021). An analysis of carbon market and carbon credits in India. Asian Journal of Agricultural Extension, Economics & Sociology, 39(2), 40-49.

8. Cheng, Y., Fang, C., Yuan, J., & Zhu, L. (2020). Design and application of a smart lighting system based on distributed wireless sensor networks. Applied Sciences, 10(23), 8545.

9. Cheong, C. H., Kim, T., & Leigh, S. B. (2014). Thermal and daylighting performance of energy-efficient windows in highly glazed residential buildings: Case study in Korea. Sustainability, 6(10), 7311-7333.

10. Das, A., Saini, V., Parikh, K., Parikh, J., Ghosh, P., & Tot, M. (2023). Pathways to net zero emissions for the Indian power sector. Energy Strategy Reviews, 45, 101042.

11. Dawson, K. A., Hopkins, D. M., & Newman, K. E. (1990). Starch conversion by Saccharomyces cerevisiae. Journal of the Science of Food and Agriculture, 53, 587-594.

12.Dinolova, P., Ruseva, V., &Dinolov, O. (2023). Energy Efficiency of Induction Motor Drives: State of the Art, Analysis and Recommendations. Energies, 16(20), 7136.

13. Erdiwansyah, Mahidin, Husin, H., Nasaruddin, Zaki, M., &Muhibbuddin. (2021). A critical review of the integration of renewable energy sources with various technologies. Protection and Control of Modern Power Systems, 6, 1-18.

14. Fuerst Pacheco, V., & de Miranda, D. A. (2019, May). Aerodynamic Analysis of High Energy Efficiency Vehicles by Computational Fluid Dynamics Simulation. Advanced Engineering Forum, 32, 41-51. Trans Tech Publications Ltd.

15. Ghenai, C., &Bettayeb, M. (2020). Design and optimization of grid-tied and off-grid solar PV systems for super-efficient electrical appliances. Energy Efficiency, 13(2), 291-305.

16. Gómez, J. R., Sousa, V., Eras, J. J. C., Gutiérrez, A. S., Viego, P. R., Quispe, E. C., & de León, G. (2022). Assessment criteria of the feasibility of replacement standard efficiency electric motors with high-efficiency motors. Energy, 239, 121877.

17. Hong, S. K., Choi, S. H., &Jeong, S. G. (2023). Building Energy Savings by Developing Complex Smart Windows and Their Controllers.Applied Sciences, 13(17), 9647.

18. Hopkins, D. M., Dawson, K. A., & Newman, K. E. (1990). Starch conversion by Saccharomyces cerevisiae. Journal of the Science of Food and Agriculture, 53, 587-594.

19. Huang, J., Chen, X., & Zhao, X. (2024). How Digital Technology Reduces Carbon Emissions: From the Perspective of Green Innovation, Industry Upgrading, and Energy Transition. Journal of the Knowledge Economy, 1-33.

20. Ihara, T., Gustavsen, A., &Jelle, B. P. (2015). Effect of facade components on energy efficiency in office buildings. Applied Energy, 158, 422-432.

21. Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., &Tassou, S. A. (2018). Waste heat recovery technologies and applications. Thermal Science and Engineering Progress, 6, 268-289.

22. Kwak, Y., & Huh, J. H. (2016). Development of a method of real-time building energy simulation for efficient predictive control. Energy Conversion and Management, 113, 220-229.

23. Li, J., Zhu, X., Djilali, N., Yang, Y., Ye, D., Chen, R., & Liao, Q. (2022). Comparative well-to-pump assessment of fueling pathways for zero-carbon transportation in China: hydrogen economy or methanol economy? Renewable and Sustainable Energy Reviews, 169, 112935.

24. Lindenmayer, D.B., Franklin, J.F., Lõhmus, A., Baker, S.C., Bauhus, J., Beese, W., Brodie, A., Kiehl, B., Kouki, J., Pastur, G.M., et al. (2012). A major shift to the retention approach for forestry can help resolve some global forest sustainability issues. Conservation Letters, 5, 421-431. [CrossRef]

25. Liu, Z., Deng, Z., Davis, S.J., et al. (2022). Monitoring global carbon emissions in 2021. Nature Reviews Earth & Environment, 3, 217-219. https://doi.org/10.1038/s43017-022-00285-w

26. Liu, Z., et al. (2022). Challenges and opportunities for carbon neutrality in China. Nature Reviews Earth & Environment, 3, 141-155.

27. Lou, R., Hallinan, K. P., Huang, K., &Reissman, T. (2020). Smart wifi thermostat-enabled thermal comfort control in residences. Sustainability, 12(5), 1919.

28. Macreadie, P.I., Costa, M.D.P., Atwood, T.B., et al. (2021). Blue carbon as a natural climate solution. Nature Reviews Earth & Environment, 2, 826-839. https://doi.org/10.1038/s43017-021-00224-1

29. Maalouf, A., & El-Fadel, M. (2018). Carbon footprint of integrated waste management systems with implications of food waste diversion into the wastewater stream. Resources, Conservation and Recycling, 133, 263-277.

30. Manish Verma. (2023). Navigating the World of Carbon Credits: Strategies for Emissions Reduction and Market Participation. International Journal of Trend in Scientific Research and Development (IJTSRD), 7(5), 259-264. URL: www.ijtsrd.com/papers/ijtsrd59887.pdf

31. Nair, R.R., Mehta, C.R., & Gupta, M. (2014). Prospects of carbon trading in India agriculture.

32. Rathikrindi, K. S., Paramasivam, S., & Sandeep, L. (2018). Energy saving opportunities through variable frequency drive for commercial air conditioners. In 2018 4th International Conference on Electrical Energy Systems (ICEES) (pp. 338-340). IEEE.

33. Rathikrindi, K. S., Paramasivam, S., & Sandeep, L. (2018). Energy Saving Opportunities through Variable Frequency Drive. 2018 4th International Conference on Electrical Energy Systems (ICEES), 338-340. doi: 10.1109/ICEES.2018.8443219.

34. Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T.A., Salas, W., Zutta, B.R., Buermann, W., Lewis, S.L., Hagen, S., et al. (2011). Benchmarkmap of forest carbon stocks in tropical regions across three continents. Proceedings of the National Academy of Sciences, 108, 9899-9904. [CrossRef] [PubMed]

35. Sawhney, A., & Rahul, M. (2014). Examining the regional pattern of renewable energy CDM power projects in India. Energy Economics, 42, 240-247.

36. Seto, K.C., Güneralp, B., &Hutyra, L.R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences, 109, 16083-16088. [CrossRef] [PubMed]

37. Takeshi, I., Gustavsen, A., &Jelle, B. P. (2015). Effect of facade components on energy efficiency. Applied Energy, 158, 422-432.

38. Von Avenarius, A., Devaraja, T. S., &Kiesel, R. (2018). An empirical comparison of carbon credit projects under the Clean Development Mechanism and Verified Carbon Standard. Climate, 6(2), 49.

39. Widartha, V. P., Ra, I., Lee, S. Y., & Kim, C. S. (2024). Advancing Smart Lighting: A Developmental Approach to Energy Efficiency through Brightness Adjustment Strategies. Journal of Low Power Electronics and Applications, 14(1), 6.

40. Zhou, Y. (2023). Worldwide carbon neutrality transition? Energy efficiency, renewable, carbon trading and advanced energy policies. Energy Reviews, 100026.

41. Zhou, Y. (2022). Low-carbon transition in smart city with sustainable airport energy ecosystems and hydrogen-based renewable-grid-storage-flexibility. Energy Reviews, 1(1), 100001.

42. Zhou, Y. (2022). Transition towards carbon-neutral districts based on storage techniques and spatiotemporal energy sharing with electrification and hydrogenation. Renewable and Sustainable Energy Reviews, 162, 112444.