

Review Article

Harnessing Smart Energy Networks to Combat Climate Change

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A B S T R A C T

One of the most urgent issues of the twenty-first century is climate change, which is mostly caused by greenhouse gas emissions from the energy industry. A promising strategy to reduce these emissions while facilitating more effective energy distribution and consumption is provided by smart energy networks, which integrate digital technology with energy infrastructure. With an emphasis on their ability to incorporate renewable energy sources like solar and wind, lower emissions, and support the Sustainable Development Goals (SDGs), this article investigates how smart energy networks can be used to combat climate change. By exploring the ideas, elements, difficulties, and possible advantages of smart energy systems, we hope to draw attention to their part in forming a sustainable energy future. In addition, we go over the economic and environmental effects of these technologies, as well as their potential contribution to the fight against climate change.

Keywords: Smart Energy Networks, Climate Change, Sustainable Alternatives, Renewable Integration, Environmental Impact, Global Temperatures, Interoperability, Solar Power, Wind Power, Indian Market, Policy Support

Introduction

A major worldwide concern is climate change, which is mostly caused by greenhouse gas emissions from the generation of energy. To lessen the effects of climate change, the energy industry must switch to cleaner, sustainable methods. By combining cutting-edge technology to optimize energy supply, delivery, and consumption, smart energy networks, also known as smart grids, present a possible answer. These networks lower waste, increase grid resilience, and facilitate the effective use of renewable energy sources like solar and wind. Smart grids can facilitate demand-side management, energy storage, and electric vehicles by utilizing automation and real-time data. In order to combat climate change and meet sustainability goals, this research investigates how smart energy networks

might hasten the switch to low-carbon energy systems.¹ With an emphasis on their ability to integrate renewables and increase efficiency, it looks at their technical, economic, and policy implications. Additionally covered are how smart networks might improve energy security and lower carbon emissions. The paper's ultimate goal is to identify tactics for quickening the uptake of smart energy solutions.

Energy Sector Emitts And Climate Changes

One of the largest causes of the increase in greenhouse gas (GHG) emissions, the primary driver of climate change, is the energy sector. This section discusses the causes and consequences of climate change linked to emissions from the energy sector, as well as the critical role the energy sector plays in both contributing to and mitigating climate change.

Climate Change Causes Because of Emissions from the Energy Sector

The following factors are the main reasons why the energy industry contributes significantly to global greenhouse gas emissions, as illustrated in Figure 1.

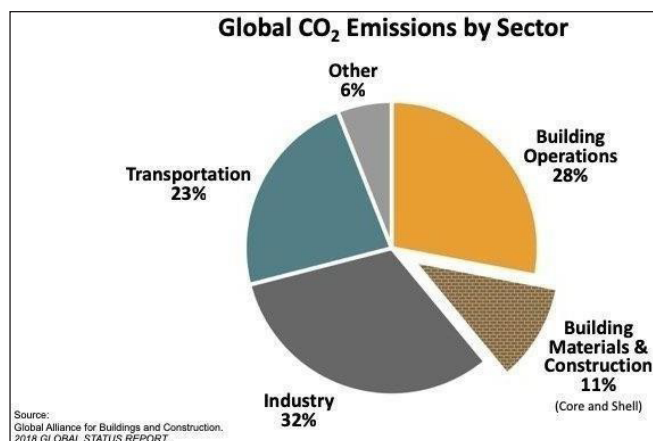


Figure 1. Global CO₂ Emissions by Sector

- **Fossil Fuel Combustion:** Burning fossil fuels including coal, oil, and natural gas for transportation, heating, industrial activities, and electricity generation is the main source of energy-related emissions.
- When these fuels burn, they release carbon dioxide (CO₂) and other dangerous greenhouse gases like nitrous oxide (N₂O) and methane (CH₄).

Consequences of Climate Change Driven by Energy Sector Emissions

- High emissions from the energy sector are causing climate change, which has far-reaching effects on the environment and society.
- Rising Global Temperatures: The main effect of higher GHG emissions is global warming, which causes weather patterns to change, heatwaves to occur more frequently, and extreme weather events like storms, droughts, and floods to occur more frequently.
- Melting of Polar Ice and Rising Sea Levels: As a result of global warming, glaciers and polar ice caps melt, raising sea levels. Millions of people worldwide are being displaced as a result of this threat to coastal towns, ecosystems, and habitats.
- Ocean acidification is the result of the world's oceans absorbing too much CO₂. It damages sectors like fisheries that rely on marine resources, disturbs marine ecosystems, and impacts biodiversity.
- **Ecosystem Disruption:** Biodiversity and ecosystems are also impacted by climate change. Both plant and

animal species are at risk of extinction as a result of altered temperature and precipitation patterns, habitat loss from deforestation, and changes in land use.

- **Impact on Human Health:** Human health is directly impacted by the rise in extreme weather events and the spread of disease brought on by changing climates. For instance, while shifting rainfall patterns may contribute to the spread of diseases like malaria, heat stress can directly cause health problems.
- **Economic Costs:** Emissions from the energy sector cause climate change, which results in large financial losses. In addition to reducing agricultural production and damaging infrastructure, extreme weather also raises the costs of disaster recovery and adaptation. The industries that suffer the most are insurance, tourism, and agriculture.

The Energy Sector's Contribution to Climate Change

In relation to climate change, the energy industry is both a significant cause of the issue and a vital component of its solution.

- **Major Contributor to Emissions:** As previously said, the burning of fossil fuels is primarily responsible for a significant amount of the world's greenhouse gas emissions. The International Energy Agency (IEA) estimates that almost 70% of all emissions worldwide are caused by the energy sector. Since a large portion of energy is still obtained from non-renewable, carbon-intensive sources, the demand for energy, especially in the transportation and industrial sectors, directly affects the number of emissions.
- **Energy Production and Consumption:** A major factor in emissions results is the process used to produce and consume energy. Historically, the main energy sources have been coal, oil, and natural gas, particularly for the production of power and transportation. Significant volumes of CO₂ and other pollutants are released into the atmosphere during their extraction, processing, and burning.
- The energy sector holds great promise for mitigating the effects of climate change. Emissions can be significantly decreased by switching from fossil fuels to renewable energy sources like wind, solar, and hydropower. Carbon footprints can also be decreased by increasing energy efficiency in both energy generation and consumption (energy-efficient buildings, appliances). as illustrated in Figure 2.

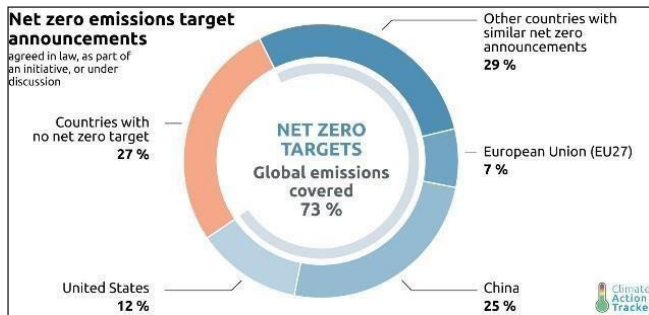


Figure 2. Net Zero Emissions Target Announcements
Smart Energy Networks: Concepts And Components

An important development in the production, distribution, and consumption of electricity is represented by smart energy networks, often known as smart grids. In order to maximize energy flow, boost efficiency, increase dependability, and

integrate renewable energy sources, these systems make use of cutting-edge technologies and digital infrastructure.² The fundamental ideas and essential elements that characterize smart energy networks are listed below.

Smart Energy Network Concepts

The purpose of smart energy networks is to improve the functionality and efficiency of the conventional electrical grid through automation and digital connectivity. Important ideas include:

- **Two-Way Communication:** Smart grids allow for two-way communication between the utility and the end-user, in contrast to traditional grids that only work in one direction (from the power plant to the consumer). This enables instantaneous response to shifting grid conditions and real-time monitoring and management of energy consumption.
- **Real-Time Monitoring:** Constant data gathering and analysis are the foundation of a smart energy network. Advanced meters and sensors collect data on power supply, demand, and system performance. This data is then processed in real-time to control loads, make adjustments, and spot possible problems before they become serious ones.
- **Control and Automation:** Smart grids use automated technologies that can balance loads, reroute power, identify issues, and carry out diagnostics without the need for human intervention.
- **Integration of Renewables:** One of the main advantages of smart grids is their capacity to effectively incorporate intermittent and variable renewable energy sources, like wind and solar. Smart grids are able to match the supply of renewable energy with demand by using sophisticated forecasting and energy storage technologies.

Essential Elements of Intelligent Energy Systems

Smart energy networks are made up of a number of interrelated parts, each of which is essential to improving the system's sustainability, dependability, and efficiency.

The system of smart meters and communication networks known as Advanced Metering Infrastructure (AMI) enables utilities and customers to gather and exchange comprehensive, real-time data on energy usage. Smart meters give utilities accurate information about usage trends, which helps them optimize grid operations. They also give consumers information about how much energy they use, which encourages cost savings and energy efficiency.^{3,4}

- **Systems of Communication:** Data transmission between the different grid components depends on these networks. They make two-way communication possible, facilitating control and sharing of information in real time. To guarantee that any component in the grid can interact easily and securely, communication networks make use of technologies including fiber optics, wireless systems, and power line communication.
- **Systems for Energy Storage:** Batteries and pumped hydro storage are two examples of energy storage technologies that are essential for grid stabilization. When demand peaks or when renewable energy production is low, they release the excess energy that was produced during times of low demand or high renewable energy output. Storage systems improve grid resilience, lessen the curtailment of renewable energy, and balance supply and demand.

Features of Intelligent Energy Systems

Several significant advantages result from the integration of these elements:

- **Enhanced Energy Efficiency:** Smart grids help to significantly lower overall energy consumption by maximizing energy distribution, cutting waste, and motivating users to use energy more efficiently.
- **Grid Resilience and Reliability:** By promptly detecting failures and reducing downtime, automation, real-time monitoring, and rapid reaction capabilities improve the grid's reliability. Additionally, this lessens the effects of disruptions and severe weather.
- **Improved Integration of Renewables:** By controlling their unpredictability, storing excess energy, and guaranteeing that renewable energy contributes effectively to the grid, smart grids enable improved integration of renewable energy sources.

Power Integration: Solar And Wind

Reducing emissions and moving toward sustainable energy systems depend on the incorporation of renewable energy sources, including wind and solar, into smart energy net-

works. The integration of various variable energy sources is improved by smart grids by:

- **Enhancing Grid Stability:** By anticipating generating patterns and streamlining energy dispatch, real-time data analytics and advanced forecasting assist in managing the unpredictability of solar and wind power.
- **Increasing Flexibility:** Energy storage systems ensure a steady supply of electricity by storing excess renewable energy during periods of low demand and releasing it during periods of high demand.
- **Decentralized Energy generating:** By lowering transmission losses and empowering communities to become more energy independent, distributed solar and wind power generating can further boost sustainability initiatives.
- These advancements not only reduce reliance on fossil fuels but also increase the reliability and resilience of the energy grid.

Economic And Environmental Impact

- Smart energy networks have significant effects on the economy and environment. By facilitating the effective use of renewable energy sources and minimizing energy waste, smart grids help the environment by lowering carbon emissions. They also lessen the environmental impact of power plants and the need for new infrastructure by encouraging energy conservation and lowering peak demand.^{5,6}
- Economically speaking, smart energy networks save money by consuming less, energy and increasing efficiency. They allow utilities to defer the need for new infrastructure expenditures, minimize transmission, and distribution losses, and optimize operations. Smart grids and the broad use of renewable energy technologies can also encourage the creation of green jobs, which will boost the economy.
- Environmental concerns impact firms of all sizes in every industry. When insecure consumers and non-governmental organizations are involved, it becomes even more challenging to explore novel and creative ideas, especially in highly established businesses like electricity grids, as illustrated in Table 1. One method to change the situation is to implement smart grids. In terms of the economics and, ecology it is advantageous to both the giver and the recipient, particularly when the recipient, has the opportunity to also become a giver. The transition from non- renewable to renewable energy sources has been debated for a long time, and many of the problems produced by non- renewable energy can now be addressed with the implementation of smart grids.⁵

Table 1.A compilation of the environmental benefits of smart grids, based on the EPRI/DOE framework (EPRI 1020342)

| Benefit Sub- Category | Benefit |
|-----------------------|--------------------------------------|
| Environmental | Electrification |
| | PEVs |
| | Enhanced Energy Efficiency* |
| | Storage |
| | Facilitate Renewables |
| | Reduced CO2 Emissions |
| | Reduced SOX, NOX and PM-10 Emissions |

Challenges And Barriers

The widespread implementation of smart energy networks is hampered by a number of issues, despite the potential advantages:

The incorporation of storage systems, smart technologies, and renewable energy into the current infrastructure necessitates substantial technological advancements and improvements.

- **Cybersecurity:** Because smart grids depend on data connectivity and digital technology, they are susceptible to cyberattacks that could jeopardize grid dependability and security.
- **Challenges in Regulation and Policy:** Regionally disparate laws and policies may impede, the integration of renewable energy sources and the rollout of smart grid technologies.
- **Cost and Investment:** Some places, especially poor nations, may find the upfront costs of deploying smart energy networks—which include infrastructure modifications and technology deployment—to be unaffordable.
- The corporate sector, utilities, and governments must work together to address these issues.

Contribution To Sustainable Development Goals

A number of Sustainable Development Goals (SDGs) of the UN are greatly aided by smart energy networks, especially:

- **Affordable and Clean Energy:** Smart grids help to guarantee that everyone has access to contemporary, affordable, and dependable energy by encouraging the integration of renewable energy sources and enhancing energy efficiency.

- **Industry, Innovation, and Infrastructure:** As smart grids are developed, energy technology innovation is stimulated, allowing for robust infrastructure and sustainable industrial practices.
- **Climate Action:** By boosting energy efficiency, incorporating renewable energy, and lowering the energy sector's carbon footprint, smart energy systems help to reduce greenhouse gas emissions, as supported by trends shown in Figure 3.

These contributions show how the fight against climate change and global environmental initiatives are in line with smart energy networks.

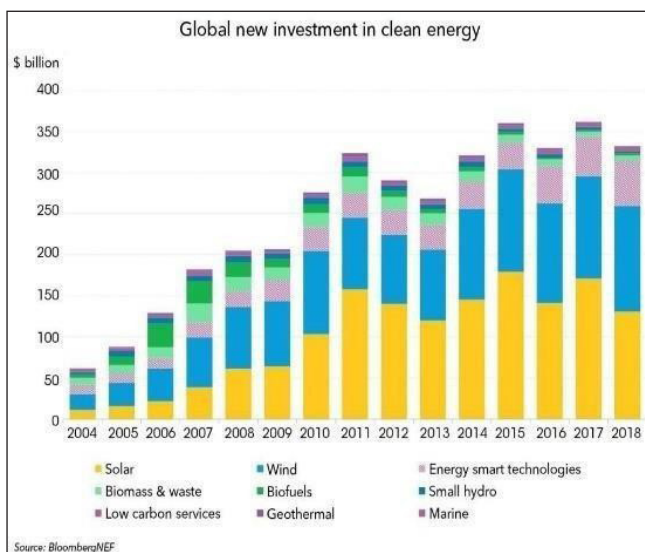


Figure 3. Global new investment in clean energy

Future Potential And Outlook

With developments in artificial intelligence (AI), machine learning, and energy storage primed to significantly improve the efficiency and integration of renewable energy sources, the future of smart energy networks looks bright. The use of smart grid solutions is anticipated to increase as prices for renewable energy technologies continue to decline and these systems become more accessible.

The need for smarter grids will also be fueled by the growth of decentralized energy systems and electric vehicle (EV) usage. It is anticipated that innovations like vehicle-to-grid (V2G) technologies, which enable electric cars to function as energy storage devices, would be crucial for energy distribution and grid stabilization.

Conclusion

By combining renewable energy sources increasing energy efficiency and lowering greenhouse gas emissions smart energy networks provide a revolutionary way to fight climate change and the potential advantages in terms of environmental economic and social outcomes make

smart grids an essential part of the global energy transition even while obstacles including technological constraints regulatory restrictions and investment requirements still exist Realizing a sustainable low-carbon future will require ongoing innovation cooperation and investment in smart energy infrastructure,³ so we can lessen our dependency on fossil fuels slowdown climate change and make a substantial contribution to the UN Sustainable Development Goals by improving the capacities of smart energy systems

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