Industrial Energy Efficiency and Climate Change Mitigation in Smart Cities: A Comprehensive Review

[1]Manju Bargavi, [2]Ms. Bhawna Saraswat, [3]Preeti Naval, and [4]Kuldeep Singh Kulhar

[1] *Professor, Department of Computer Science and Information Technology, Jain (Deemed to be University), Bangalore, India.*
[2] *Scholar, Department of Computer Science Engineering, Sanskriti University, Mathura, Uttar Pradesh, India.*
[3]*Assistant Professor, Maharishi School of Engineering & Technology, Maharishi University of Information Technology, Uttar Pradesh, India.*
[4]*Professor, Civil Engineering, Vivekananda Global University, Jaipur, India.*

Abstract: In the context of escalating urbanisation and climate change, smart cities emerge as a beacon of sustainable urban development, leveraging cutting-edge technology and data analytics to enhance municipal services and the well-being of residents. This review article, focusing on industrial energy efficiency within smart cities, underscores the pivotal role of these urban environments in mitigating climate change impacts. It highlights the industrial sector's substantial contribution to global greenhouse gas emissions, driven by energy-intensive processes predominantly fuelled by fossil fuels. The study presents a comparative analysis of emissions across continents, revealing the industrial activities' significant environmental footprint. It advocates for energy efficiency as a strategic imperative to reduce energy consumption, curb emissions, and foster sustainability. The paper concludes by recommending policy interventions that incentivise eco-friendly industrial practices, endorse the circular use of materials, and promote sustainable economic models. These recommendations are contextualised within Iceland's CAP 2020 initiative, which aims for a significant reduction in emissions by 2030, underscoring the need for sustainable material management, particularly in metallic ores and fossil fuels, to align with environmental sustainability goals. The article calls for a global collaborative effort, beyond individual national policies, to address the urgent challenges posed by climate change, advocating for international cooperation, investment in renewable energy, and a transition towards a more sustainable future.

Corresponding Authour:[1] *b.manju@jainuniversity.ac.in*
[2] bhawnasharmaphd@sanskriti.edu.in
[3] *er.preetinaval09@gmail.com*
[4] k.singh@vgu.ac.in

I. Introduction

A. Definition and Significance of Smart Cities

In recent decades, there has been an unprecedented surge in urbanization, with over half of the global population now residing in urban areas. This dramatic shift towards cities has given rise to the concept of "smart cities," which holds immense significance in the pursuit of sustainable urban development. Smart cities, at their core, represent urban environments that harness advanced technology and data-driven solutions to enrich the well-being of their inhabitants while enhancing the overall efficiency of municipal services [1]. These cities place a premium on integrating state-of-the-art technologies, data analytics, and digital infrastructure to address the urgent challenges of the 21st century. Smart cities adopt a wide array of technologies and innovations, such as Internet of Things (IoT) sensors, smart grids, intelligent transportation systems, and sophisticated data analytics, to monitor and manage various aspects of urban life [2]. These aspects encompass elements like traffic flow, energy consumption, waste management, and public safety. Through the real-time collection and analysis of data, smart cities can make informed decisions, reduce operational costs, and minimize their environmental footprint, ultimately fostering more sustainable, resilient, and liveable urban environments [3].

The significance of smart cities becomes apparent in their potential to tackle a multitude of urban challenges, including congestion, pollution, energy usage, and the effects of climate change. During burgeoning urban populations and the imminent spectre of climate change, smart cities present a promising pathway forward by leveraging technology to optimize energy utilization, curtail greenhouse gas emissions, and enhance the overall quality of life for their residents. Among the various components of a smart city, one of the most pivotal and far-reaching areas of emphasis is industrial energy consumption [4].

B. The Role of Industrial Energy Consumption in Climate Change

Industrial energy consumption plays a pivotal role in the global climate change narrative. The industrial sector, encompassing manufacturing, production, and heavy infrastructure, represents a significant share of global energy consumption and greenhouse gas emissions. The production of goods and the operation of industrial facilities are energy-intensive processes that often rely on fossil fuels, contributing to the release of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. These emissions are a primary driver of climate change, resulting in a myriad of adverse environmental and societal consequences. The connection between industrial energy consumption and climate change is evident through several key factors:

1. Greenhouse Gas Emissions: The industrial sector is a major contributor to greenhouse gas emissions, accounting for a substantial portion of total emissions worldwide. These emissions arise from energy-intensive processes, including the combustion of fossil fuels for electricity generation, heating, and manufacturing operations. Figures 1-8 show the emissions from various major geographical regions.

 https://doi.org/10.1051/e3sconf/202454008001

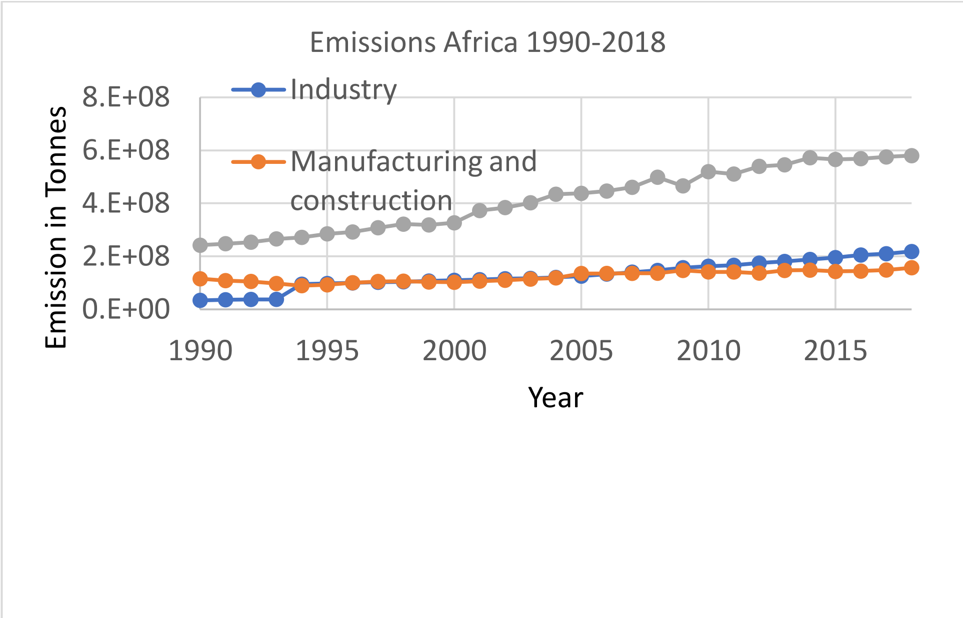

Fig.1. Emissions – Africa Between Year 1990-2018 for the three major sectors – Industry, Manufacturing & construction; and Electricity & heating.

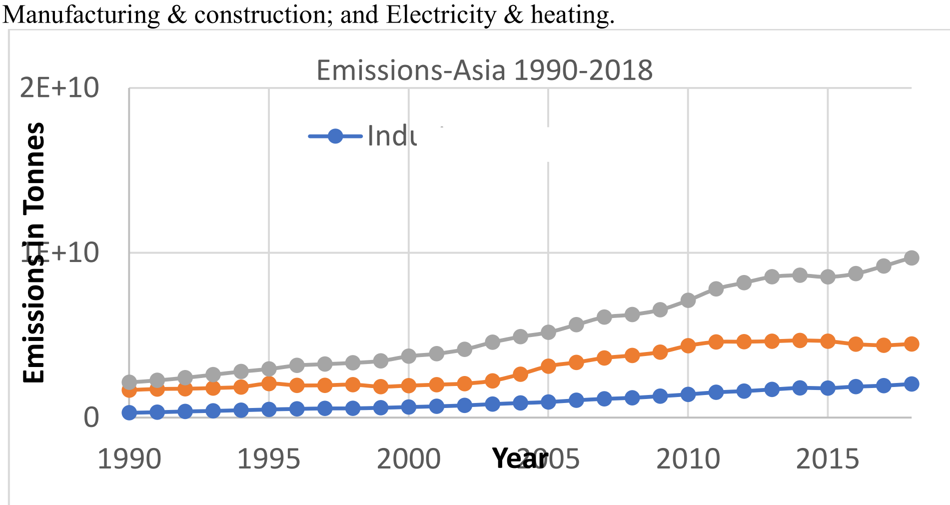

Fig.2. Emissions – Asia Between Year 1990-2018 for the three major sectors – Industry, Manufacturing & construction; and Electricity & heating.

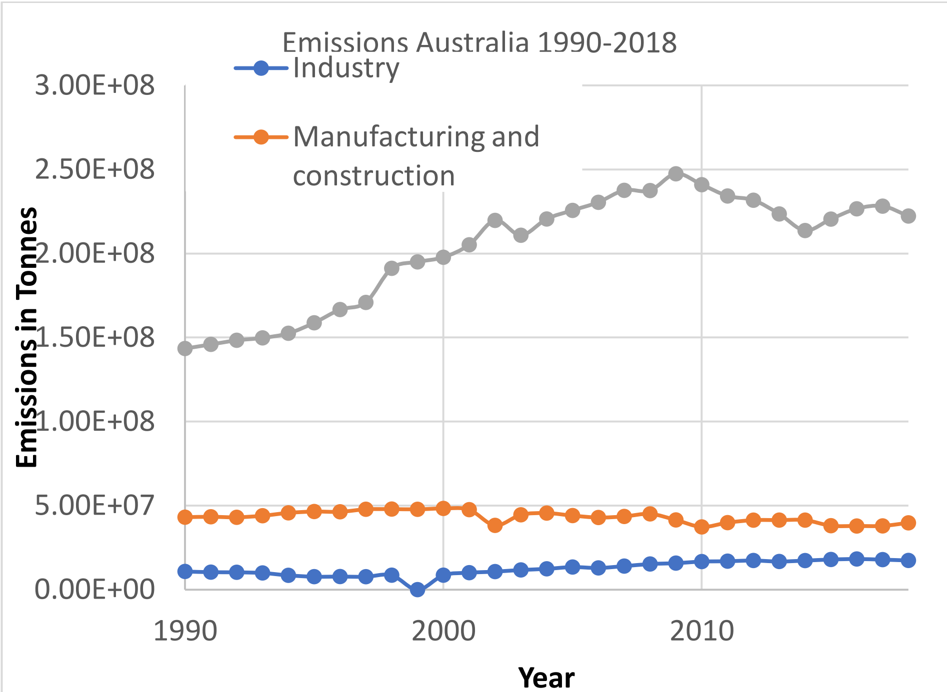

Fig.3. Emissions – Australia Between Year 1990-2018 for the three major sectors – Industry, Manufacturing & construction; and Electricity & heating.

It is observed that China saw an increase in emissions after the 1990s when various corporations started moving their manufacturing bases to China. In the years following 2014, India started seeing a rise in emissions; however, these emissions were addressed through constant government policies for renewables [5].

2. Resource Depletion: High energy consumption in industries often results in resource depletion, such as the overuse of fossil fuels, minerals, and water resources. This not only contributes to environmental degradation but also poses long-term challenges to sustainable development.

- Over the period from 2004 to 2019, this research delves into the intricate relationship between energy sources and energy poverty across a selection of 28 European nations. Among the significant findings, a counteractive association emerges between GDP per capita and energy poverty metrics, implying that economic expansion ameliorates energy poverty conditions. Notably, per capita fossil fuel consumption demonstrates an opposing correlation with two of the three energy poverty indicators, signifying that heightened usage of fossil fuels improves energy poverty circumstances, particularly concerning the adequate heating of households. Conversely, the utilization of renewables and biofuels displays a connection to an increased incidence of arrears on utility bills, underscoring the necessity of cost mitigation for consumers adopting renewable energy sources. Furthermore, the study conducts a comparative analysis of energy transition strategies and energy poverty within Sweden, Germany, and Greece, accentuating the imperative for custom-tailored policies that align with the distinctive conditions of each nation. To gain deeper insights, it is advisable to conduct further research exploring nation-specific relationships and scrutinizing the repercussions of the COVID-19 pandemic on energy markets [6].
- A Significant study has unveiled that Iceland's CAP 2020 initiative is geared towards a substantial reduction in greenhouse gas (GHG) emissions across multiple sectors

by 2030. The investigation in question delves into the dynamics between domestic material consumption (DMC) and GHG emissions in Iceland during the time frame spanning 1990 to 2019. The research outcomes indicate that an upswing in metallic ores consumption is linked to increased GHG emissions, whereas the consumption of biomass and fossil fuels contributes to a long-term reduction in GHG emissions. Notably, biomass consumption plays a role in mitigating GHG emissions in the realms of agriculture and waste management. In contrast, fossil fuel consumption leads to a decline in GHG emissions within the industrial sector. These findings underscore the critical need for sustainable material management, with a particular focus on metallic ores and fossil fuels, to align with the goals set forth by Iceland's CAP 2020 while ensuring the sustainability of the environment. The study underscores the effectiveness of renewable energy sources, such as biomass, in curtailing ecological harm and lends support to the movement away from fossil fuels in Iceland. Furthermore, it underscores Iceland's advantageous position, with its limited reliance on fossil fuels and abundant renewable energy resources, in terms of fulfilling sustainability objectives. To uphold these aspirations, the study offers recommendations for implementing policies that incentivize eco-friendly industrial practices, endorse the circular use of materials, and advocate for sustainable economic approaches. Despite its insightful contributions, it's important to acknowledge that the study's scope is confined to Iceland, and future research endeavors could expand to encompass other countries, consider a broader array of variables, scrutinize sector-specific activities in greater detail, and incorporate more recent data and advanced analytical methodologies [7].

- A study conducted by Umar et al. in 2022 delved into the complex relationship between international capital flows, fossil fuel energy consumption, economic growth, and carbon emissions in the South Asian region over the span of 45 years, from 1975 to 2020. Using a sophisticated econometric approach, they sought to determine the extent to which these factors influence carbon emissions and whether there were any asymmetric effects at play.

The research revealed intriguing findings. Fossil fuel energy consumption and economic growth were identified as major contributors to increased carbon emissions in the long run, with a 1% increase in fossil fuel energy consumption leading to a significant 1.81% rise in carbon emissions. Conversely, remittances and foreign direct investment (FDI) were found to have a mitigating effect, reducing carbon emissions. In the long term, a 1% increase in remittances and FDI led to a decrease in carbon emissions by -0.18% and -0.04%, respectively.

These results have important policy implications. Policymakers should consider remittances and FDI as tools to develop sustainable, environmentally friendly strategies. They should prioritize transitioning to renewable energy sources and investing in green infrastructure to promote sustainable development, particularly in a region that heavily relies on fossil fuels for energy. To further improve the understanding of this complex issue, it would be valuable to expand the study to other regions and use more recent data to explore the dynamics of foreign financial flows, such as foreign aid. This could provide a basis for comparative analysis and offer insights into regional variations in the relationship between capital flows and environmental sustainability. [8].

3. Global Economic Impact: Climate change has far-reaching economic consequences, affecting industries, supply chains, and market stability. Extreme weather events and climate-related disruptions can lead to substantial financial losses, which are often shouldered by businesses and governments. A recent research endeavor expanded a high-dimensional computable general equilibrium (CGE) trade model to scrutinize the potential economic repercussions of global warming on Gross Domestic Product (GDP) and gauge the advantages of upholding the Paris Climate Accord. The research encompassed 139

nations and scrutinized shifts in GDP under diverse climate scenarios. For instance, in the event of global warming surging to 4°C, the potential yearly GDP decline approximates $23,149 billion. This decline is particularly pronounced in regions such as Sub-Saharan Africa, India, and Southeast Asia. Conversely, adhering to the Paris Accord's 2°C objective could yield gains of around $17,489 billion on an annual basis by the year 2100. It is vital to acknowledge various limitations, which include the model's inability to accommodate unforeseen shocks or the repercussions of natural disasters, underscoring the necessity for additional exploration in these domains. Additionally, the research's findings presuppose complete adherence to climate agreements and are contingent on several variables, including U.S. involvement. Nevertheless, these findings underscore the importance of mitigating climate change and its economic impacts, especially in the world's most economically vulnerable regions [9].

4. Risk to Infrastructure: Industrial facilities, especially in coastal areas, are vulnerable to the effects of climate change, such as sea-level rise and extreme weather events. Protecting critical infrastructure is essential for maintaining a reliable industrial base. Study has shown the potential repercussions of climate change on infrastructure systems remain both substantial and fraught with uncertainty. Given this, a logical approach for adapting to climate change in infrastructure is through risk analysis. However, climate change introduces emerging risks due to limited prior knowledge and societal disputes, rendering traditional risk assessment and management approaches unsuitable. Recent advancements in research have introduced tools like probabilistic climate projections, climate services, and resilient decision frameworks to tackle these challenges. Nonetheless, further research is needed to refine the applicability of these methods for infrastructure planning. This perspective discusses the hurdles in addressing climate change risks in infrastructure and summarizes recent innovations while underscoring the importance of future research, which could greatly benefit from the insights of the risk analysis community. [10].

A study has shown that atmospheric CO_2 significantly contributes to reinforcement corrosion in infrastructure, including bridges, buildings, and wharves in various countries, such as Australia, the United States, and the United Kingdom. Rising CO_2 levels due to global warming will increase the risk of carbonation-induced corrosion. Additionally, higher temperatures will accelerate corrosion rates. The impact of climate change on existing and new infrastructure is substantial, with corrosion damage being disruptive and costly to repair. The research introduces a probabilistic approach to predict the likelihood of corrosion initiation and severe cracking in concrete infrastructure exposed to elevated CO_2 levels and temperatures. It's evident that carbonation-induced damage risks may increase by over 400% in certain Australian regions by 2100, while chloride-induced corrosion risks increase by up to 15%. The results highlight the sensitivity of corrosion risks to atmospheric CO_2 levels. Structures in inland arid or temperate climates are particularly vulnerable to climate change and may require adaptation measures. Economic assessments of adaptation strategies, like increasing concrete cover or using more durable materials, are essential for managing infrastructure in the coming century [11].

 https://doi.org/10.1051/e3sconf/202454008001

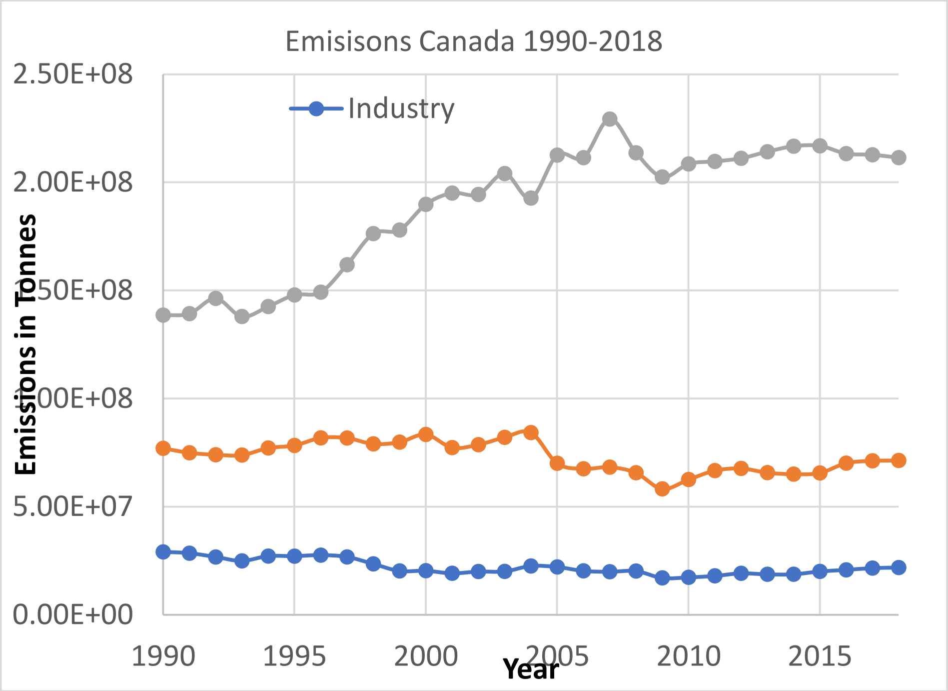

Fig.4. Emissions Canada Between Year 1990-2018 for the three major sectors – Industry, Manufacturing & construction; and Electricity & heating.

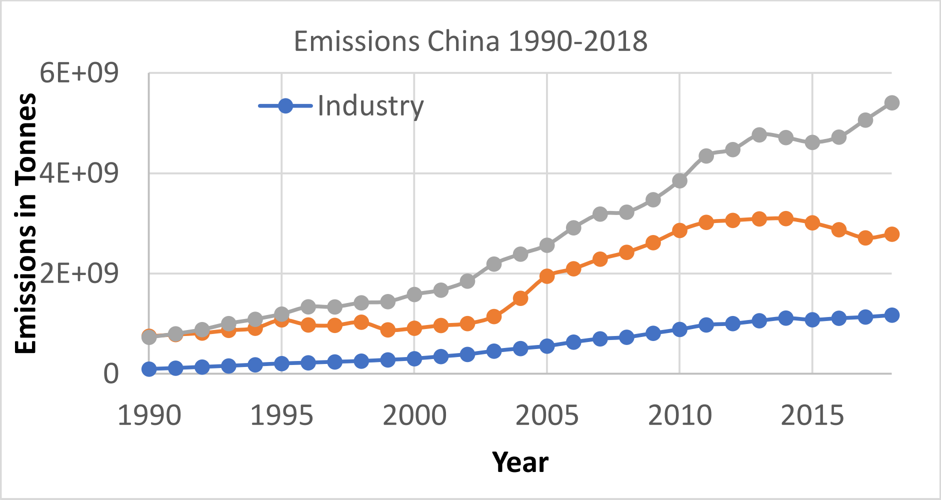

Fig.5. Emissions China Between Year 1990-2018 for the three major sectors – Industry, Manufacturing & construction; and Electricity & heating.

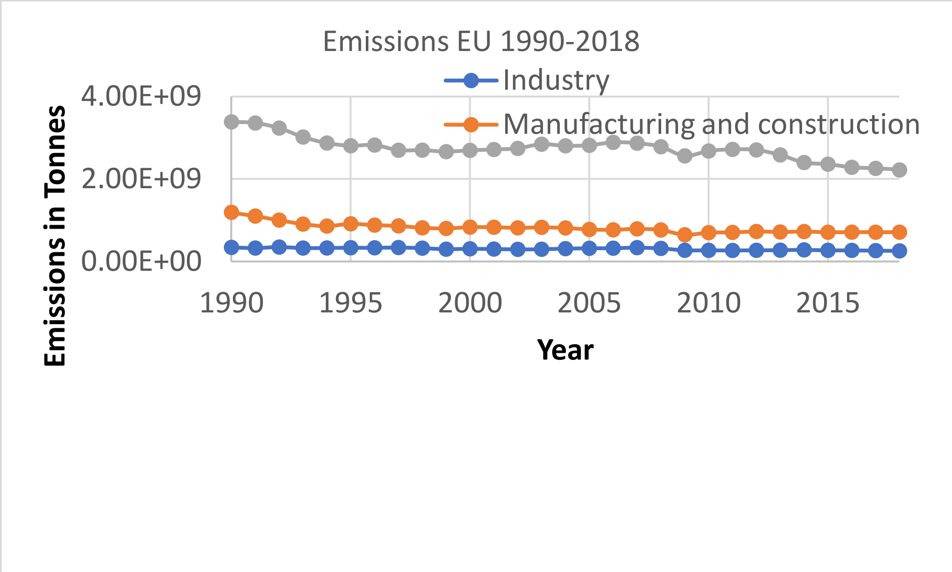

Fig.6. Emissions EU Between Year 1990-2018 for the three major sectors – Industry, Manufacturing & construction; and Electricity & heating.

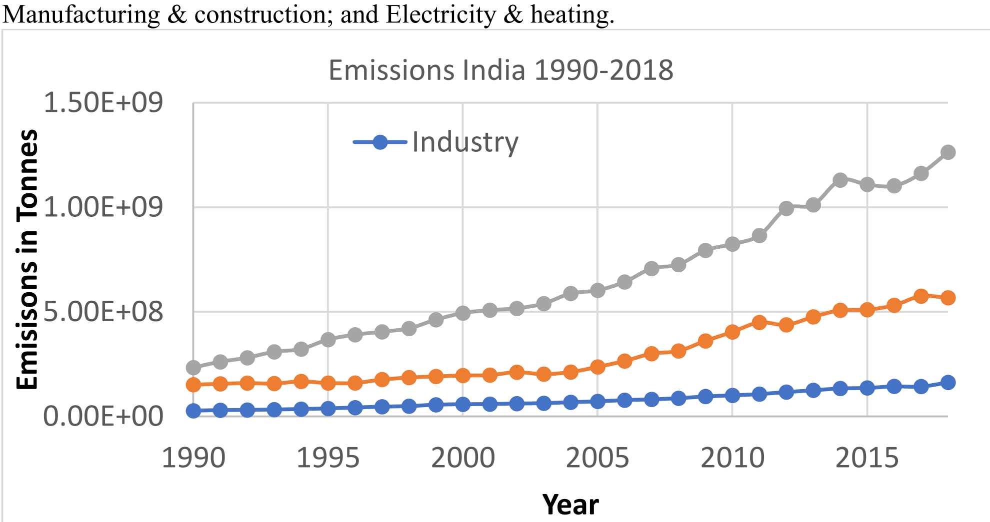

Fig.6. Emissions INDIA Between Year 1990-2018 for the three major sectors – Industry, Manufacturing & construction; and Electricity & heating.

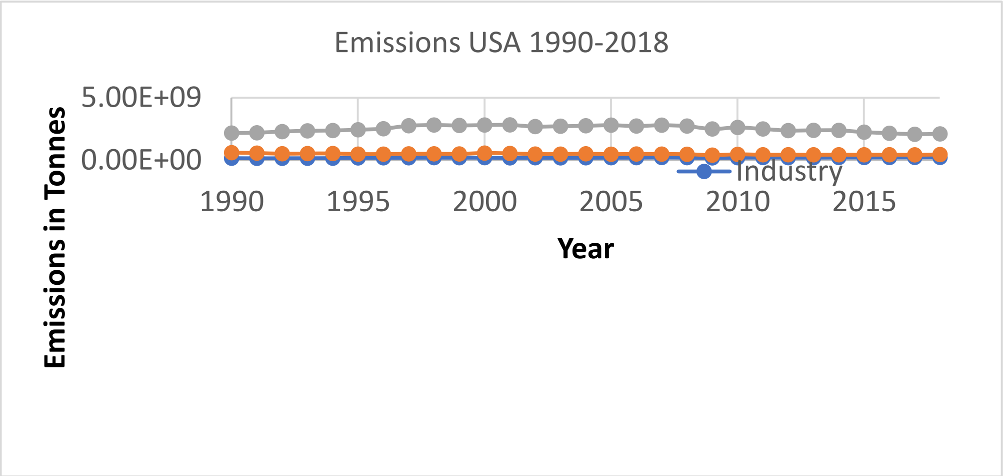

Fig.7. Emissions USA Between Year 1990-2018 for the three major sectors – Industry, Manufacturing & construction; and Electricity & heating.

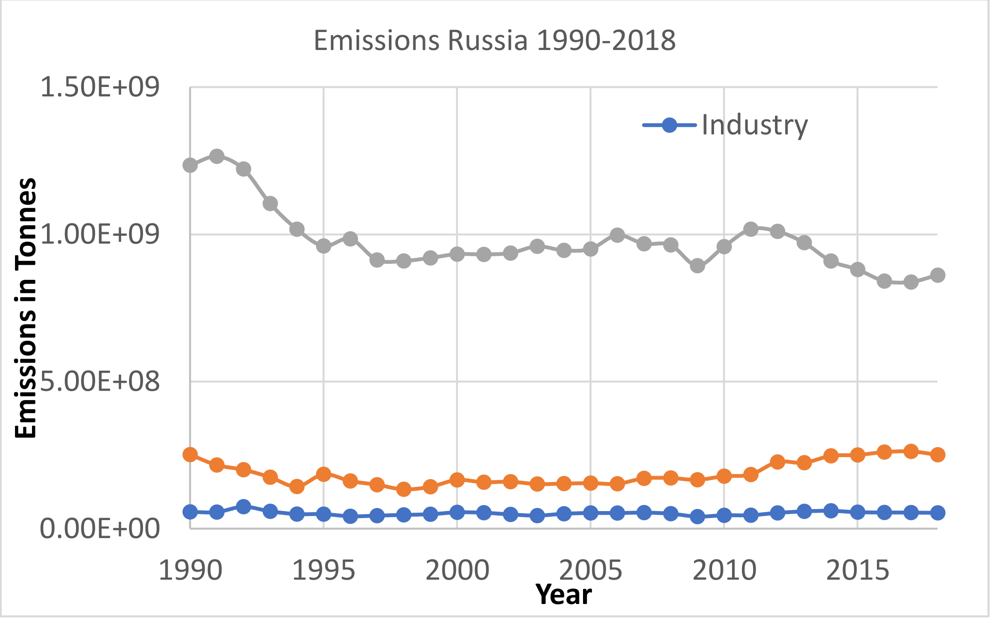

Fig.8. Emissions Russia Between Year 1990-2018 for the three major sectors – Industry, Manufacturing & construction; and Electricity & heating.

Importance of Energy Efficiency in Industrial Sectors

Addressing the challenge of industrial energy consumption and its impact on climate change requires a multifaceted approach, with energy efficiency at the forefront. Energy efficiency refers to the ability to produce more output or services using less energy input. It is a vital strategy for reducing energy consumption, lowering greenhouse gas emissions, and enhancing the sustainability of industrial sectors within smart cities. Here's why energy efficiency in the industrial context is so crucial:

1. Mitigation of Emissions: Improving energy efficiency in industrial processes leads to reduced energy consumption, resulting in lower greenhouse gas emissions. By optimizing manufacturing processes, reducing waste, and adopting efficient equipment and technologies, industries can make significant strides in mitigating their carbon footprint.
2. Operational Cost Reduction: Enhanced energy efficiency directly translates into lower operational costs for industries. By consuming less energy, businesses can cut their utility bills, increasing profitability and economic competitiveness.
3. Resource Conservation: Energy efficiency measures often coincide with resource conservation. Industrial sectors that prioritize energy efficiency tend to reduce their demand for fossil fuels, minerals, and water, contributing to resource sustainability.
4. Technological Innovation: Pursuing energy efficiency encourages technological innovation and the development of cleaner, more sustainable technologies. This, in turn, supports economic growth and enhances a city's reputation as a hub for innovation.
5. Job Creation: The transition to more energy-efficient industrial processes can create job opportunities in research, development, installation, and maintenance of energy-efficient technologies.

As smart cities grapple with the growing challenges posed by urbanization, climate change, and resource constraints, the importance of energy efficiency in industrial sectors becomes increasingly clear. By championing energy-efficient practices and technologies, these cities can lead the charge in mitigating climate change while simultaneously improving the quality of life for their residents. This review article will delve deeper into the strategies, technologies, and policies that underpin industrial energy efficiency in smart cities and explore the innovative solutions that are shaping the future of urban sustainability [11-14].

Challenges and Future Directions

Addressing climate change presents a complex and multifaceted challenge that demands a multifaceted approach. There are numerous challenges to tackle, each with their own unique characteristics and consequences, as well as potential future directions and policy recommendations to consider. One of the most significant challenges in addressing climate change is the need for rapid and widespread mitigation of greenhouse gas emissions. Achieving substantial reductions in emissions requires a global effort that goes beyond the policies of individual nations. Future directions should focus on enhancing international cooperation through agreements like the Paris Climate Accord and expanding the use of renewable energy sources and clean technologies. Governments worldwide should implement policies that incentivize the adoption of clean energy, such as tax incentives, subsidies, and emissions trading systems. Another challenge is the need to adapt to the existing impacts of climate change.

Climate-related disasters like extreme weather events, sea-level rise, and shifts in agricultural patterns pose a threat to communities and ecosystems. Future directions should emphasize investment in climate-resilient infrastructure, disaster preparedness, and sustainable land management practices. These initiatives can help reduce vulnerability and enhance adaptive capacity. Furthermore, addressing climate change involves addressing social and economic disparities. Vulnerable communities, particularly those in developing countries, often bear the brunt of climate change impacts, despite contributing the least to global emissions. Future directions should prioritize equity and justice, providing resources and support for those most affected by climate change. This may involve policies like climate finance mechanisms, capacity-building programs, and technology transfer initiatives to ensure that disadvantaged communities are not left behind.

Effective communication and public engagement represent an additional challenge. Climate change can be a complex, abstract concept that is often difficult for the public to grasp fully. Future directions should involve comprehensive climate education programs that promote climate literacy and encourage public action. Governments, NGOs, and educational institutions should work together to raise awareness about the urgency of climate action and provide accessible information about the impacts of individual choices on the environment. One critical aspect that needs to be addressed is the transition away from fossil fuels. The global economy remains heavily dependent on fossil fuels, which are a major source of greenhouse gas emissions. A shift toward renewable energy sources is essential for mitigating climate change. Future directions should prioritize the development of innovative technologies, energy efficiency measures, and green finance mechanisms to accelerate the transition. Government policies can support this transition by imposing carbon pricing, eliminating fossil fuel subsidies, and setting ambitious renewable energy targets.

In terms of land use and conservation, deforestation and land degradation are critical challenges. Forests play a vital role in sequestering carbon and maintaining biodiversity, yet they continue to be threatened by logging and conversion for agriculture. Future directions should focus on policies that promote reforestation, afforestation, and sustainable land management practices. Protecting natural ecosystems and creating incentives for carbon sequestration can help combat climate change while preserving biodiversity. Finally, a significant challenge lies in the need to shift consumer behavior and the business practices of corporations. Individual choices, consumption patterns, and the activities of the private sector greatly impact emissions. Future directions should emphasize regulations, labeling, and consumer campaigns that encourage sustainable choices and environmental responsibility. Governments can also work to develop sustainable business practices through corporate responsibility standards and carbon disclosure requirements.

In summary, addressing climate change involves a multitude of challenges that require coordinated global action. The future directions to address these challenges include international cooperation to reduce emissions, investment in climate resilience, promoting equity and justice, enhancing climate education and public engagement, transitioning away from fossil fuels, conserving natural ecosystems, and changing consumer behavior and corporate practices. Policymakers, governments, civil society, and the private sector all have a role to play in this urgent and complex endeavor to mitigate the impacts of climate change and secure a sustainable future for all.

References

1. Chapman, S., Watson, J.E.M., Salazar, A. et al. The impact of urbanization and climate change on urban temperatures: a systematic review. Landscape Ecol 32, 1921–1935 (2017). https://doi.org/10.1007/s10980-017-0561-4
2. Song, T., Cai, J., Chahine, T. et al. Towards Smart Cities by Internet of Things (IoT)—a Silent Revolution in China. J Knowl Econ 12, 1–17 (2021). https://doi.org/10.1007/s13132-017-0493-x
3. Sayah, Z., Kazar, O., Lejdel, B., Laouid, A. and Ghenabzia, A. (2021), "An intelligent system for energy management in smart cities based on big data and ontology", Smart and Sustainable Built Environment, Vol. 10 No. 2, pp. 169-192. https://doi.org/10.1108/SASBE-07-2019-0087
4. Kamyab, H., Klemeš, J. J., Van Fan, Y., & Lee, C. T. (2020). Transition to sustainable energy system for smart cities and industries. Energy, 207, 118104. https://doi.org/10.1016/j.energy.2020.118104
5. Lamb, W. F., Wiedmann, T., Pongratz, J., Andrew, R., Crippa, M., Olivier, J. G., ... & Minx, J. (2021). A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. Environmental research letters, 16(7), 073005. 10.1088/1748-9326/abee4e
6. Halkos, G., & Gkampoura, E. C. (2023). Assessing Fossil Fuels and Renewables' Impact on Energy Poverty Conditions in Europe. *Energies*, *16*(1), 560. https://doi.org/10.3390/en16010560
7. Alola, A. A., & Adebayo, T. S. (2023). Analysing the waste management, industrial and agriculture greenhouse gas emissions of biomass, fossil fuel, and metallic ores utilization in Iceland. Science of The Total Environment, 887, 164115. https://doi.org/10.1016/j.scitotenv.2023.164115
8. Umair, M., Yousuf, M.U. Evaluating the symmetric and asymmetric effects of fossil fuel energy consumption and international capital flows on environmental sustainability: a case of South Asia. Environ Sci Pollut Res 30, 33992–34008 (2023). https://doi.org/10.1007/s11356-022-24607-z
9. Kompas, T., Pham, V. H., & Che, T. N. (2018). The effects of climate change on GDP by country and the global economic gains from complying with the Paris climate accord. Earth's Future, 6(8), 1153-1173. https://doi.org/10.1029/2018EF000922
10. Shortridge, J., & Camp, J. S. (2019). Addressing climate change as an emerging risk to infrastructure systems. Risk Analysis, 39(5), 959-967. https://doi.org/10.1111/risa.13234
11. Stewart, M. G., Wang, X., & Nguyen, M. N. (2011). Climate change impact and risks of concrete infrastructure deterioration. Engineering Structures, 33(4), 1326-1337. https://doi.org/10.1016/j.engstruct.2011.01.010
12. Tanaka, K. (2011). Review of policies and measures for energy efficiency in industry sector. Energy policy, 39(10), 6532-6550. https://doi.org/10.1016/j.enpol.2011.07.058

13. Román-Collado, R., & Economidou, M. (2021). The role of energy efficiency in assessing the progress towards the EU energy efficiency targets of 2020: Evidence from the European productive sectors. *Energy Policy*, *156*, 112441. https://doi.org/10.1016/j.enpol.2021.112441
14. Backlund, S., Thollander, P., Palm, J., & Ottosson, M. (2012). Extending the energy efficiency gap. *Energy Policy*, *51*, 392-396. https://doi.org/10.1016/j.enpol.2012.08.042