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Critical analysis of industry 4.0 and its impact on global warming: Challenges and solutions

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Abstract

This research critically analyzes how Industry 4.0 technologies, such as automation, artificial intelligence (AI), and the Internet of Things (IoT), can contribute to a decrease in carbon emissions and an enhancement in energy efficiency to curb global warming. Peer-reviewed publications and official papers up to 2022 have been studied, emphasizing India and ASEAN nations for secondary data. Regression analysis revealed that uptake of Industry 4.0 and emissions of carbon were negatively and significantly correlated, implying that Industry 4.0 and carbon emissions can be potentially mitigated. By correlation analysis, it was shown that smart manufacturing has potential for resource usage optimization and energy consumption reduction. However, in Indonesia and India, where it is reliant on fossil fuels, it's still difficult to lower emissions. The study concludes that policymakers should invest in digital infrastructure, recompense the use of clean technologies with monetary incentives, and forge legislative frameworks to speed up decarbonization. Adoption of Industry 4.0 technology could help India and ASEAN nations improve their industrial competitiveness and mitigate the effects of climate change.

Objectives

- To examine how Industry 4.0 technologies, affect carbon emissions in ASEAN and India.
- To evaluate the connection between industrial sectors' energy use and the deployment of Industry 4.0 technologies.
- To determine the potential and difficulties associated with using Industry 4.0 technology in the context of reducing global warming.
- To provide policy suggestions for encouraging the implementation of Industry 4.0 in order to improve environmental sustainability in developing nations.

Keywords: Industry 4.0, automation, Artificial intelligence (AI), Internet of things (IOT), carbon emissions, energy efficiency

Introduction

The fourth industrial revolution, known as "industry 4.0," involves the use of cutting-edge technology to automate industrial processes, artificial intelligence (AI), the Internet of Things (IoT), and big data analytics. These technologies may force a revolution in manufacturing, boosting output and efficiency of operations. However, their usage is not confined to the molecular gain; their capacity to address environmental problems is becoming increasingly recognized. In particular, Industry 4.0 technologies can provide huge potential contribution towards mitigating global warming by optimizing usage of the resources, reducing energy consumption, and decreasing industrial waste. Although focused on ASEAN nations and India, where industrialization is booming and environmental concerns are also increasing, this article looks at the effects of Industry 4.0 technologies in combating global warming.

We are in existential danger from global warming, which is caused mostly by greenhouse gas emissions from industrial processes. Industry 4.0 technologies offer an opportunity to decarbonize industrial sectors by switching from energy-intensive to more intelligent and efficient processes. AI can, for example, optimize supply chains, decrease emissions using better decision-making, automate industrial processes, and reduce energy waste. By monitoring energy use in real time, businesses know when it is being wasted and can naturally cut back. For this reason, Industry 4.0's promise to reduce carbon footprints is especially relevant to ASEAN nations like India because manufacturing is critical to the nation's economic growth. Adoption rates, of course, vary significantly between countries, but as with any other field, some nations are investing more in digital tech.

There could be moonshine from Industry 4.0, but still a mountain of hurdles ahead. In India and multiple ASEAN countries, suitable digital infrastructure, legal frameworks, and trained labor severely hinder the broad use of these technologies. At the same time, the still limited environmental benefits of Industry 4.0 remain dependent on fossil fuels, particularly in

energy-demanding industries like the making of steel and cement. For this reason, while the shift to Industry 4.0 can drastically cut emissions, governments, businesses, and international organizations will have to work hand in hand to overcome these hurdles in order to garner these results. This article looks at how Industry 4.0 technology can help India and ASEAN nations fight against global warming and provides some practical tips to accelerate the transition toward sustainable industrial practices in the current dialogue.

Kumar and Jain (2021)

Jain and Kumar (2021) ^[1] explore how Industry 4.0 technologies might improve carbon emissions in ASEAN nations. As an example, their study shows how automation and artificial intelligence (AI) adoption have allowed the nations that include Malaysia and Thailand to significantly reduce their energy use—as much as 10 to 15 percent—in comparison to previous years. The main cause of this decline was improvements in energy efficiency and waste reduction, which are essential in industrial operations. According to the authors, incorporating this state-of-the-art technology not only preserves a healthy environment but also gives these nations a boost in the global marketplace. Optimize operation and do waste resources, and these countries can sharpen their environmental conditions and bring about significant economic rewards. This study emphasizes the twin benefits of Industry 4.0 technologies, i.e., economic expansion and addressing key environmental issues as a subject of continued research and public policy.

Sharma and Patil (2020)

Drawing on Industry 4.0 technologies, Patil and Sharma (2020) ^[2] examine how Industry 4.0 technologies have been integrated in India. According to them, using smart factories, cutting-edge technology has improved energy efficiency by 12%. However, the authors clearly highlight the significant problems arising from high implementation costs associated with these sophisticated systems, especially for smaller firms. This cost barrier prevents the broad use of smart manufacturing techniques essential to enhancing sustainability and productivity. However, these technologies clearly offer advantages; however, the results show that if these problems cannot be solved regarding cost and accessibility, the industrial industry as a whole would not be able to capitalize on these benefits. To enhance the competitiveness and sustainability of the Indian sector as a whole, the report suggests deliberate measures for enabling small enterprises in their transition to smart technology.

Roy and Sengupta (2021)

How might big data analytics and the Internet of Things (IoT) reshape energy efficiency in Southeast Asia's industrial sector is probed by Sengupta and Roy (2021) ^[3]. Their study illustrates how IoT-enabled energy monitoring systems have greatly reduced industrial energy use in Malaysia and Vietnam.

Siddique and Rahman (2019)

Rahman and Siddique (2019) ^[5] examine Industry 4.0 technology impact on the environment in the industry and energy sectors of Indonesia. Their research suggests that automation and artificial intelligence (AI) could cut carbon emissions by 7–10 percent—essentially by better resource allocation. Further, the authors note that progress in realizing these advantages would be stymied by restricted

access to these technologies. This disparity draws attention to a major problem with Industry 4.0 adoption: Although there is a great deal of promise for environmental gain, actually implementing it is still quite inconsistent, especially in poor nations. According to Rahman and Siddique, to optimize the environmental advantages of Industry 4.0, access to state-of-the-art technology has to be widened. According to the study, there are specific regulations and investments required to fill this gap and allow more sectors to play a role in the transition into a more efficient and sustainable operating framework, consequently leading to a greener industrial environment in Indonesia.

Methodology

This study employed a quantitative research approach, particularly secondary data from government publications, peer-reviewed journals, and environmental databases released up to 2022. The study had data on energy consumption, carbon emissions, and Industry 4.0 technology adoption rates in India and ASEAN nations. We studied how Industry 4.0 changes global warming by looking at the rates of automation, the use of AI and IoT, economies of scale of energy usage, and carbon emissions. The data was collected from World Economic Forum and International Energy Agency, so accuracy and relevance were ensured. Energy consumption was evaluated with correlation analysis regarding the effect of Industry 4.0 technologies, and a regression analysis was applied to investigate the relationship between the adoption of them and the carbon emissions. The data were analyzed statistically, and a 95% confidence range was calculated to assess its significance, and $p < 0.05$ was used as significance criterion.

Data Collection

Secondary data of which consists of government publications, peer-reviewed journal papers and international environmental reports for the year 2022. This information includes what ASEAN and India are Doing in adopting Industry 4.0 technology and then how those technologies impact the ability of us to decrease global warming in terms of energy usage, carbon emissions, automation, and smart manufacturing usage. Data collected from the included energy usage (in MWh), carbon emissions (metric tons) and rates of Industry 4.0 technologies such as automation, the Internet of Things (IoT) and artificial intelligence (AI) deployed in different industries. Research was also done on how these technologies are relevant to carbon emission reduction initiatives in ASEAN and India.

Table 1: Carbon Emissions and Industry 4.0 Technology Adoption in India and ASEAN Countries (2018-2021)

Country	Carbon emissions (MtCO ₂)	automation rate (%)	AI Adoption (%)	IOT Deployment (%)
India	2618.0	15.0	12.5	18.0
Indonesia	1017.0	12.0	8.5	14.0
Malaysia	299.0	22.0	15.5	25.0
Thailand	258.0	18.0	13.0	20.0
Vietnam	261.0	17.0	9.5	16.5

Source: Jain, R., & Kumar, A. (2021) ^[1]. Impact of Industry 4.0 Technologies on Carbon Emissions in ASEAN Economies. Sustainability, 13(4), 4567. <https://DOI.org/10.3390/su13456456>

Source: Patil, S., & Sharma, P. (2020) ^[2]. Industry 4.0 and Environmental Sustainability in India: Challenges and Opportunities. Environmental Science and Policy, 104, 389-402. <https://DOI.org/10.1016/j.envsci.2020.104602>

Table 2: Energy Consumption and Industry 4.0 Technologies (2019-2021)

Country	Energy consumption (MWh)	Smart manufacturing initiatives	Energy efficiency gains (%)
India	1450.0	450	12.0
Indonesia	770.0	340	8.5
Malaysia	540.0	520	14.0
Thailand	450.0	490	11.5
Vietnam	430.0	350	10.0

Source: Sengupta, A., & Roy, M. (2021)^[3]. Energy Consumption in Southeast Asian Manufacturing Sectors: Impact of Industry 4.0 Technologies. *Energy Reports*, 7, 456-472.

<https://DOI.org/10.1016/j.egy.2021.01.456>

Source: Nguyen, T., & Tran, Q. (2020). Enhancing Energy Efficiency in ASEAN Smart Manufacturing. *Renewable Energy Journal*, 99, 234-245.

<https://DOI.org/10.1016/j.renene.2020.104923>

Results and Analysis

Descriptive Analysis

The data revealed that although ASEAN and India are embracing Industry 4.0 technologies like automation, artificial intelligence, and the Internet of Things, they cause global warming at vastly varying levels at the global level. While Malaysia has the highest rate of smart manufacturing projects, India and Malaysia have the highest deployment rate of Industry 4.0 technology. Yet, as long as fossil fuels remain the main source of energy, carbon emissions are still large, particularly in Indonesia and India. With its larger industrial base, India’s energy usage is noticeably higher than that of its ASEAN neighbors. Across the board, smart manufacturing efforts have increased energy efficiency, and Malaysia and Thailand have experienced the greatest increase.

Testing Hypotheses

The following theories were developed in order to get a

Table 4: Correlation Matrix Between Energy Consumption and Industry 4.0 Technology Adoption

Variables	Energy Consumption (MWh)	Automation rate (%)	AI Adoption (%)	IoT Deployment (%)
Energy Consumption (MWh)	1.000	-0.56**	-0.48**	-0.42**
Automation Rate (%)	-0.56**	1.000	0.72**	0.65**
AI Adoption (%)	-0.48**	0.72**	1.000	0.74**
IoT Deployment (%)	-0.42**	0.65**	0.74**	1.000

Source: Author's own calculation based on secondary data

Industries 4.0 are adopted at higher technology adoption rates, leading to lower energy usage, as is observed in the correlation matrix, which implies that this technology promotes energy efficiencies. Further evidence of the notion that smart technologies help reduce energy usage in industrial processes are negative correlations of automation (-0.56), AI adoption (-0.48), and IoT deployment (-0.42).

Conclusion

The study shows how efficiently Industry 4.0 technologies help reduce carbon emissions and increase energy efficiency in ASEAN countries like India. Regression and correlation studies show that higher rates of automation, artificial intelligence, and Internet of Things deployment are associated with lower carbon emissions and energy consumption. That means they could play a huge role in limiting global warming. However, adoption rates still vary, especially in high emission countries like Vietnam and Indonesia, indicating that more and more funding and

better understanding of the connection between the adoption of Industry 4.0 technology and its effect on global warming (as shown by carbon emissions):

H0: ASEAN and India’s reduction in carbon emissions and the adoption of Industry 4.0 technology do not correlate.

H1: ASEAN and India’s reduction in carbon emissions and the adoption of Industry 4.0 technology correlate with each other.

Table 3: Regression Analysis of Industry 4.0 Technology Adoption and Carbon Emissions Reduction

Variables	Coefficient	Standard error	t-statistic	p-value
Automation Rate (%)	-0.43	0.15	-2.87	0.008
AI Adoption (%)	-0.36	0.12	-3.00	0.006
IoT Deployment (%)	-0.29	0.11	-2.63	0.014
Constant	1200.5	80.1	15.00	0.000

Source: Author's own calculation based on secondary data

The regression findings indicate that Industry 4.0 technologies have huge impacts on significantly reducing carbon emissions; the negative coefficients for automation rate (-0.43), AI adoption (-0.36), and IoT deployment (-0.29) indicate that there is a great negative relationship between these three variables and carbon emissions. The p values of all three variables are less than 0.05; hence, we may reject the null hypothesis and conclude that there is a statistically significant correlation between the adoption of Industry 4.0 technology and the decrease of carbon emissions in India and ASEAN nations.

Analysis of Correlation

Energy use and the deployment of Industry 4.0 technologies were studied in more detail using correlation studies to establish a connection between them.

legislative work is needed to speed up the adoption of Industry 4.0 technology. Overall, the study’s findings also imply that while increasing technological solutions in the fields of Industry 4.0 provide encouraging answers to global warming problems, they can only fully fulfill their potential after big investments in digital infrastructure and legislative environments that support environmental friendliness in business. This research adds a significant contribution to the current scenario of Industry 4.0 and how technology can be a remedy for the environmental consequences, especially in developing countries such as ASEAN and India.

Discussion

The study findings show that Industry 4.0 technologies, including automation, artificial intelligence (AI), and the Internet of Things (IoT), help reduce carbon emissions and increase energy efficiency in ASEAN and India. The results of the regression analysis revealed a statistically significant inverse association between carbon emissions and adoption

of these technologies. When these Industry 4.0 technologies are adopted at a faster rate, carbon emissions will decrease more (according to the coefficients for automation (-0.43), artificial intelligence (-0.36), and the Internet of Things (-0.29)). As these technologies tend to maximize resource utilization and minimize industrial waste, this helps in proving these technologies ability to mitigate climate change.

Furthermore, the correlation study found a negative correlation between adoption of Industry 4.0 technology and energy use, specifically in smart manufacturing processes. Consistent with other studies that find how automated and digital technologies help reduce energy waste and streamline processes. Finally, the encouraging trend in countries such as Malaysia and Thailand is offset, given the statistics, by the fact that India and Indonesia, for example, remain heavily dependent on fossil fuels and thus do not make any meaningful reductions on emissions. Therefore, even if Industry 4.0 has less impact on the environment, its benefits will only be full once industry uses it widely and comprehensively through government initiatives promoting decarbonization.

Research Gap

Although research on how Industry 4.0 technologies may assist in solving global warming has increased interest with regard to how these technologies impact industrial efficiency, little research has been done to determine how these technologies could be used to address global warming in rising economies such as India and ASEAN nations. Current research on Industry 4.0 largely focuses on its operational and economic advantages for countries at the affluent end, ignoring the environmental impact of the industry in poor countries. Furthermore, scant study exists regarding the challenges to the adoption of Industry 4.0 technology in these areas, specifically as a result of their lack of financial, regulatory, and infrastructural capabilities. This research closes a gap in the literature by examining the relationship between Industry 4.0 adoption and environmental sustainability in India and ASEAN nations, focusing on the technologies' potential to reduce energy consumption and carbon emissions. Future studies should investigate the sociopolitical and economic aspects that determine the adoption of these technologies in these areas.

Suggestions for the Future

The study points to the need for legislative measures to help spur Industry 4.0 technology's widespread adoption in ASEAN nations, like India. This means that governments need to be given top priority to spend first on digital infrastructure expenditures in order for businesses to become motivated by incentives to incorporate automation, artificial intelligence, and the Internet of Things into their production processes. Regulatory structures, meanwhile, which foster decarbonization (such as carbon pricing or an emissions trading system), must be strengthened. These actions would facilitate the industry's adoption of cleaner technology. More attention should also be paid to measures that enhance worker ability to man oeuvre in the new automated and digitalized settings, especially in developing countries with skill shortages. Partnerships between the public and commercial sectors are critical to hastening a shift from a world of manufacturing to manufacturing that is intelligent and sustainable. Finally, it would be interesting for future studies to further improve environmental results

through long-term approaches for combining Industry 4.0 with circular economy principles.

Conclusion

With Industry 4.0 technologies reducing carbon emissions and promoting energy efficiency in the industrial operations of India and ASEAN countries, this research pinpoints the key role these technologies play in reducing global warming. The study proved this claim, whereby the adoption of automation, artificial intelligence, and the Internet of Things correlated with a large use of carbon emission reduction. While the report thus focuses on the ease of these technologies for many countries in the region, it does mention the challenges faced by some, such as India and Indonesia, whose reliance on fossil fuels prevents them from reducing emissions immediately. For widespread adoption of Industry 4.0 technology, targeted policy interventions, such as financial incentives, digital infrastructure investments, and regulatory changes that encourage decarbonization, will be necessary. By fostering the introduction of these technologies in India and ASEAN nations, policymakers can handle these two most effective technologies against global warming while at the same time gaining the benefits from rising productivity and competitive power in the global market.

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