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AI-DRIVEN DECARBONIZATION: A PATHWAY TO CARBON NEUTRALITY

ДЕКАРБОНІЗАЦІЯ ЗА ДОПОМОГОЮ ШІ: ШЛЯХ ДО ВУГЛЕЦЕВОЇ НЕЙТРАЛЬНОСТІ

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Climate change poses an existential threat, underscoring that preserving nature is essential for humanity's survival. Achieving carbon neutrality – a balance between emitted and absorbed CO_2 – is crucial to protect ecosystems and human society. This requires rapid decarbonization: transitioning from fossil fuels to sustainable practices in energy, industry, and transport. In this context, artificial intelligence (AI) has emerged as a powerful enabler for climate action. AI systems can analyze complex datasets on emissions and climate impacts, helping stakeholders make informed, data-driven decisions [1, p. 15]. From optimizing renewable energy integration to forecasting emissions and informing policy, AI offers innovative approaches to reduce greenhouse gases. According to recent studies, AI-driven technologies could help cut global greenhouse gas emissions by up to 5–10%, equivalent to 2.6–5.3 gigatons of CO_2 if scaled worldwide [2, p. 21]. By leveraging AI as a catalyst for decarbonization, we can accelerate the transition to a carbon-neutral economy – a vital step toward preserving nature and humanity's future.

Global CO_2 emissions continue to reach record highs (over 37 billion tons in 2023), driven by economic growth and fossil fuel use [3, p. 33]. Reversing this trend calls for comprehensive decarbonization strategies worldwide, including scaling renewable energy, enhancing energy efficiency, electrifying transport, and protecting carbon sinks. AI can significantly optimize these global strategies. In particular, AI excels at processing big data on emissions, energy use, and climate variables, uncovering patterns and optimal solutions that humans might miss. For example, AI algorithms can continuously monitor energy systems and industrial processes via sensors and IoT devices, providing a real-time stream of data to identify inefficiencies and emission hotspots [4, p. 19]. This enables a shift from periodic reviews to continuous optimization – companies and governments can swiftly adjust strategies in response to AI insights, cutting emissions more responsively [5, p. 25].

One key contribution of AI is improving the accuracy of carbon footprint measurements and tracking. Machine learning models can integrate diverse data (e.g., satellite observations, production logs, traffic data) to quantify emissions more precisely across regions and sectors [6, p. 14]. Better measurement builds accountability and helps target the biggest emitters. AI systems also excel at optimizing complex systems. In energy grids, AI can forecast electricity demand and renewable supply, then optimally balance power distribution in real time [7, p. 28]. This ensures renewable energy is utilized efficiently while minimizing reliance on carbon-intensive backup power. Indeed, AI-driven grid management reduces wasted energy and improves overall efficiency [8, p. 30], supporting a cleaner energy mix.

Furthermore, AI can enhance emerging solutions like carbon capture and storage (CCS) – from identifying ideal geological sites for CO_2 storage to dynamically controlling capture processes. An International Energy Agency study found AI could potentially reduce CCS costs by up to 30%, making this decarbonization approach more viable [9, p. 34]. Across these examples, AI acts as a force-multiplier: it accelerates innovation and optimizes the deployment of low-carbon technologies.

Accurate forecasting of CO_2 emissions is vital for crafting effective mitigation plans [10, p. 41]. Machine learning (ML) techniques are being deployed across industries to predict emission trends and identify opportunities to reduce carbon output. By learning from historical data and real-time inputs, ML models can project future emission levels under various conditions. This foresight enables companies and governments to take proactive measures – implementing changes before emissions grow too high

[11, p. 45]. Reliable CO_2 forecasts provide significant guidance for choosing optimal ways to reduce emissions [12, p. 47].

AI and ML are already driving carbon mitigation in multiple sectors:

– Electric Power: Electric utilities use ML to forecast electricity demand and renewable generation (solar, wind) with high precision. For instance, Google's DeepMind applied neural networks to predict wind farm output 36 hours in advance, allowing operators to make optimal energy delivery commitments a day ahead [13, p. 50]. This increased the economic value of wind power by roughly 20% by making wind energy more predictable and easier to integrate [14, p. 52].

– Manufacturing and Industry: AI analyzes production data to pinpoint where energy is wasted or processes can be improved. AI-based solutions can boost manufacturing productivity by up to 20% and reduce material waste by about 4% [15, p. 55].

– Transportation and Logistics: AI and ML help forecast travel demand and optimize logistics, directly cutting fuel consumption. Smart logistics and traffic AI can cut fuel use by 15–20% in some contexts [16, p. 60].

– Buildings and Cities: AI-based control systems adjust HVAC (heating, ventilation, and air conditioning) in real-time based on occupancy and weather, reducing energy consumption [17, p. 62].

Sound policy is the backbone of climate solutions. From setting emissions targets and designing carbon pricing to planning sustainable infrastructure and conservation programs, policymakers face complex decisions with far-reaching consequences. AI-powered decision support systems (DSS) leverage AI's analytical power to synthesize vast information – scientific data, economic indicators, emissions models – into actionable intelligence for policy planning [18, p. 70].

Beyond monitoring, AI plays a growing role in policy scenario analysis and optimization. Policymakers can use AI-driven simulators to explore different pathways. For example, AI might predict a heatwave and advise the grid to pre-cool buildings at off-peak hours, avoiding peak electricity from gas peaker plants [19, p. 75]. These capabilities enhance decision-making across urban planning, environmental monitoring, and public transport systems.

Conclusions. Artificial intelligence is proving to be a transformative tool in the quest for carbon neutrality. By optimizing decarbonization strategies, forecasting and mitigating emissions in every sector, and empowering policymakers with data-driven insights, AI contributes to a more sustainable and resilient future. Embracing AI-driven decarbonization can significantly hasten the transition to a carbon-neutral economy. The synergy of human innovation and machine intelligence might well be the key to securing a sustainable future.

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