ISSN: 2149-214X

Journal of Education in Science, Environment and Health

www.jeseh.net

Decarbonizing K-12 Schools in the United States: Challenges, Opportunities and Future Directions

Ryan Kmetz, Gus Norrbom
Maryland Energy Administration

To cite this article:

Kmetz, R., & Norrbom, G. (2025). Decarbonizing K-12 schools in the United States: Challenges, opportunities, and future directions. *Journal of Education in Science, Environment and Health (JESEH), 11*(1), 24-33. https://doi.org/10.55549/jeseh.754

JESEH
Journal of Education in Science, Environment and Health
Volume 11, Issue 1, 2025
https://doi.org/10.55549/jeseh.754

Decarbonizing K-12 Schools in the United States: Challenges, Opportunities, and Future Directions

Ryan Kmetz, Gus Norrbom

Article Info

Article History

Published:
01 January 2025

Received:
16 September 2024

Accepted:
03 November 2024

Keywords

Decarbonization
Emissions reduction
K-12 Schools

Abstract

K-12 schools in the United States significantly contribute to greenhouse gas emissions due to aging infrastructure, inefficient energy practices, and a heavy reliance on fossil fuels. Addressing these issues through decarbonization is not just important—it is becoming a critical initiative aimed at reducing environmental impact while simultaneously improving the educational environments we offer our students. This paper examines the current landscape of decarbonization efforts in K-12 schools, focusing on our challenges, opportunities, and emerging best practices. By analyzing existing strategies and policies at the federal, state, and local levels, this paper highlights how these efforts are supported—or, in some cases, hindered—by the frameworks in place. The benefits of decarbonization are clear: improved indoor air quality, enhanced learning conditions, and reduced operational costs, all of which contribute to a healthier and more effective educational environment. This research also delves into successful case studies, showcasing innovative approaches and replicable models in other schools nationwide.

Introduction

Given their considerable energy usage and associated carbon footprint, K-12 schools in the United States (U.S.) contribute significantly to greenhouse gas emissions. This is primarily due to outdated infrastructure, energy-inefficient practices, maintenance backlogs, and reliance on fossil fuels for heating and cooling. As a result, these factors have led to a push for decarbonization, with schools being a key area for such efforts.

These factors and myriad government funding opportunities in the U.S. have catalyzed efforts to "decarbonize" schools by removing fossil-fueled infrastructure, increasing energy efficiency, and procuring renewable energy, primarily solar or wind. Many schools view decarbonization as an opportunity to reduce operating costs, provide environmental education, and improve public health. Fully decarbonized schools provide their occupants and surrounding communities with many benefits, such as improved indoor air quality, energy savings, and visible examples of sustainable development. Many schools already serve as community hubs, making their transformation toward decarbonization a visible and impactful sustainability example for students, parents, and residents.

Specifically, this study aims to explore the current decarbonization efforts in K-12 schools across the U.S., identify the main challenges and opportunities, and provide an overview of best practices to facilitate these initiatives. This paper will explore the effectiveness of existing decarbonization strategies in K-12 schools, examining the role of federal, state, and local policies in either supporting or hindering these efforts. The objective is to offer insights into decarbonized school environments' health and educational benefits. Additionally, this paper will summarize best practices and highlight innovative case studies demonstrating the successful implementation of decarbonization projects within the K-12 educational sector.

Literature Review

State of Decarbonization Efforts in K-12 Schools

Efforts to decarbonize K-12 schools in the U.S. have gained momentum in recent years, primarily propelled by the growing recognition of their environmental impact and the availability of significant federal funding. According to the Atlas Buildings Hub (2023), substantial progress has been made in building electrification and energy efficiency improvements. Schools are increasingly adopting renewable energy sources, such as solar

panels, and implementing comprehensive retrofitting projects, such as heat pumps, thereby reducing the school's carbon footprint. Integrating renewable energy and energy efficiency measures in K-12 schools can yield substantial benefits, including lowered energy costs, improved indoor air quality, and enhanced educational opportunities for students (Iyiegbuniwe, 2014).

Practical strategies for decarbonizing K-12 schools involve leveraging the firsthand experiences of school district leaders. It is essential to provide quality data to dispel misconceptions hindering decarbonization efforts' progress and aid decision-makers. The Efficient and Healthy Schools Webinar series has contributed to this by discussing resources, best practices, and practical examples from school districts that have successfully embarked on decarbonization initiatives (Lawrence Berkeley National Laboratory, 2022). Despite the availability of guides and roadmaps, such as the Decarbonization Roadmap Guide and the Building Electrification Technology Roadmap for Schools, challenges persist in implementing decarbonization strategies. These include financial constraints, lack of technical expertise, and resistance to change within school communities (Lawrence Berkeley National Laboratory, 2023).

Benefits of Decarbonization

The benefits of decarbonizing school environments extend well beyond environmental impact. The positive outcomes are improved indoor air quality, enhanced learning conditions, and reduced operational costs. Studies have shown that students perform better academically and experience fewer health issues in well-ventilated, energy-efficient buildings (Fisk, Black, & Brunner, 2011; Haverinen-Shaughnessy, Moschandreas, & Shaughnessy, 2011; Mendell & Heath, 2005; Shendell et al., 2004; U.S. Environmental Protection Agency, 2018). Beyond environmental impacts, these benefits provide a compelling argument for adopting sustainable practices in K-12 schools.

Improved Indoor Air Quality

Research has consistently demonstrated a positive correlation between air quality and cognitive performance. A study highlighted by Trane (2023) found that students in well-ventilated classrooms demonstrated significant improvements in cognitive tasks, including concentration, problem-solving, and memory retention. Trane's study reaffirmed the Harvard T.H. Chan School of Public Health findings, which quantified that higher indoor air quality improved the cognitive function scores of students by 61% (2015). Improved air quality's positive health impacts are compelling and go beyond learning benefits. Since poor air quality is a known exacerbator of conditions such as asthma and allergies, it contributes to higher rates of absenteeism among students (Shendell et al., 2004). When decarbonization efforts install enhanced ventilation systems, this reduces allergens and pollutants, thereby decreasing respiratory-related health issues and allowing students to maintain continuous academic engagement (Harvard T.H. Chan School of Public Health, 2015).

Decarbonization efforts also involve removing onsite fossil fuel combustion, directly impacting indoor and outdoor air quality. Schools that transition away from fossil fuel-based heating and cooling systems reduce emissions of harmful pollutants such as carbon monoxide (CO) and nitrogen oxides (NOx). These pollutants are known to have adverse health effects, particularly on respiratory and cardiovascular health (Fisk et al., 2011). By eliminating the use of fossil fuels, schools not only contribute to broader climate goals but also create healthier environments. For example, schools utilizing geothermal heat pumps or solar thermal systems can achieve consistent indoor temperatures and better air quality without the drawbacks of fossil fuel combustion (Corsi et al., 2002).

Enhanced Learned Conditions

Decarbonization initiatives also significantly enhance learning conditions beyond improved air quality. Modernizing school infrastructure to incorporate sustainable design principles results in more conducive teaching and learning environments. Key components include increased natural lighting, improved acoustics, and stabilized indoor temperatures. Hathaway et al. (1992) found that students in classrooms with ample natural light scored up to 25% higher on standardized tests than those in artificially lit rooms. Natural light improves visibility and boosts mood and energy levels, improving student engagement and productivity.

Poor acoustics are common in older school buildings, leading to distractions and reduced comprehension. Decarbonization efforts often include the installation of sound-absorbing materials and the design of spaces that minimize background noise. According to the Acoustical Society of America (2014), improved classroom acoustics can enhance speech intelligibility by 25%, allowing students to understand better and retain information. Maintaining stable indoor temperatures is critical for student comfort and concentration. Environmental Protection Agency (EPA) research suggests thermal comfort impacts cognitive performance, with deviations from optimal temperature ranges leading to decreased focus and productivity (EPA, 2019). Energy-efficient HVAC systems in decarbonization projects help maintain consistent indoor temperatures, supporting sustained academic performance (Wargocki & Wyon, 2007).

Decarbonization initiatives significantly enhance learning conditions by modernizing school infrastructure to incorporate sustainable design principles, resulting in more conducive teaching and learning environments. Key components of these initiatives include increased natural lighting, improved acoustics, stabilized indoor temperatures, and the introduction of air conditioning to combat extreme heat. Natural lighting has been shown to have a profound impact on student performance. Hathaway et al. (1992) found that students in classrooms with ample natural light scored up to 25% higher on standardized tests than those in artificially lit rooms. This finding is corroborated by the Heschong Mahone Group (1999), which demonstrated that students in naturally lit classrooms performed 20-26% better on tests, and by Nicklas and Bailey (1996), who found that daylighting in classrooms improves overall student performance in reading and math. Natural light enhances visibility and boosts mood and energy levels, improving student engagement and productivity.

Improved acoustics are another critical component of decarbonization efforts. Poor acoustics, common in older school buildings, lead to distractions and reduced comprehension. The installation of sound-absorbing materials and the design of spaces that minimize background noise are often included in decarbonization projects. According to the Acoustical Society of America (2014), improved classroom acoustics can enhance speech intelligibility by 25%, allowing students to understand and retain information better. Shield and Dockrell (2003) found that poor acoustics negatively affect student performance, particularly in verbal tasks, while Klatte et al. (2010) indicated that improved acoustical environments enhance reading and math scores by 10-15%. Maintaining stable indoor temperatures is critical for student comfort and concentration. The Environmental Protection Agency (EPA, 2019) suggests thermal comfort impacts cognitive performance, with deviations from optimal temperature ranges leading to decreased focus and productivity. Energy-efficient HVAC systems help maintain consistent indoor temperatures, supporting sustained academic performance. Wargocki and Wyon (2007) found that improving classroom temperatures to optimal ranges can boost student performance by 7-15%.

Decarbonization efforts also provide the opportunity to introduce air conditioning, crucial for combating extreme heat that has increasingly led to school closures in recent years. Installing energy-efficient air conditioning systems ensures that classrooms remain conducive to learning even during heatwaves. Park et al. (2019) found that extreme heat negatively impacts student learning outcomes, decreasing performance as temperatures rise. Schools can mitigate these effects by introducing air conditioning and maintaining a stable learning environment.

Reduced Operation Costs

Beyond immediate educational benefits, decarbonization significantly reduces operational costs, which can then be redirected toward improving educational resources and programs. Decarbonized schools utilize energy-efficient systems that consume less power compared to traditional systems. The initial investment in technologies such as LED lighting, solar panels, and advanced HVAC systems is offset by long-term savings in utility bills. A National Renewable Energy Laboratory (NREL) report estimates that schools can reduce energy costs by up to 25% through these upgrades (Pless et al., 2018).

The savings from reduced energy consumption can be reallocated to support various educational initiatives. For instance, schools can invest in updated textbooks, digital learning tools, and extracurricular programs. By redirecting funds saved through energy efficiency, schools can enhance the quality of education they provide. Studies have shown that access to updated learning materials, and technology can improve student engagement and academic performance. For example, Waddell (2015) found that integrating digital classroom learning tools enhances student comprehension and interaction. The resulting financial savings can be allocated to hire additional faculty, reduce class sizes, and improve student-to-teacher ratios, enhancing overall educational quality. Darling-Hammond (2000) demonstrated that smaller class sizes lead to more individualized attention

from teachers and better student outcomes. Schools that can afford to employ more faculty can provide a more supportive learning environment, contributing to higher levels of student achievement.

Decarbonization efforts align with broader sustainability goals, fostering an environmentally responsible culture within the school community. This culture benefits the environment and instills values of sustainability and stewardship in students, preparing them to be conscientious global citizens. Sustainability education, integrated into the curriculum, has been shown to increase students' environmental awareness and responsibility (Tilbury, 1995). By embedding sustainability practices into the school's operations, students learn the importance of reducing their carbon footprint and engaging in eco-friendly behaviors. Decarbonization projects often involve the school community in the planning and implementation phases, promoting a sense of ownership and participation among students, staff, and parents. Community engagement in sustainability projects can enhance social cohesion and foster collaboration (Fisman, 2005). Students who participate in these initiatives gain practical experience and develop valuable skills beyond the classroom, such as project management, teamwork, and problem-solving.

Policy Analysis

Policy frameworks are crucial in facilitating or hindering decarbonization efforts in K-12 schools. Comprehensive policies that offer financial incentives, technical support, and regulatory guidance are essential for driving progress. This section analyzes various federal, state, and local policies and programs that impact school decarbonization efforts, using specific examples to illustrate their effectiveness.

Federal Policies

The Inflation Reduction Act (IRA), enacted in 2022, has allocated significant funding to support energy efficiency and renewable energy projects, including those in K-12 schools. This legislation incentivizes schools to adopt clean energy technologies and enhance energy efficiency. The impact of the IRA has been profound, enabling schools to undertake large-scale energy retrofits. A notable example is the Miami-Dade County Public Schools in Florida, which received a $15 million grant under the IRA to install new HVAC systems and solar panels. These upgrades have led to substantial energy savings and improved indoor air quality for the district's schools (Miami-Dade County Public Schools, 2023). However, the implementation of IRA funds is challenging. The process can be complex, primarily due to the stringent application requirements and the need for matching funds from local sources, which may only sometimes be readily available. These hurdles can complicate efforts to fully leverage the IRA's benefits, particularly for schools in underfunded districts (U.S. Department of the Treasury, 2023). The Better Buildings Challenge, launched by the U.S. Department of Energy, is designed to encourage organizations, including K-12 schools, to commit to improving their energy efficiency by at least 20% over ten years. The program offers technical assistance, resources, and recognition to participating organizations to support this ambitious goal. The impact of the Better Buildings Challenge has been significant, with the Houston Independent School District in Texas serving as a prime example.

By participating in the challenge and implementing a district-wide energy management system, the district achieved a 30% reduction in energy consumption, resulting in $1.5 million in annual energy cost savings. However, the success of the Better Buildings Challenge is contingent on several factors. The availability of technical expertise is crucial for schools to implement energy-efficient measures effectively. Additionally, the commitment of school administrators and staff to adopt and maintain these practices plays a vital role in the long-term success of energy efficiency initiatives. With strong leadership and a dedicated approach to energy management, the full potential of the Better Buildings Challenge may be easier to realize (Houston Independent School District, n.d.).

The Green Ribbon Schools Program, administered by the U.S. Department of Education, recognizes schools that have made substantial progress in reducing their environmental impact, improving health and wellness, and delivering effective sustainability education. This program highlights schools' efforts in integrating sustainability into their operations and curriculum. A notable example is the Jefferson County Public School District in Colorado, which received the Green Ribbon Schools award for its comprehensive sustainability initiatives. Among these efforts was the achievement of net-zero energy status for one of its elementary schools, accomplished through passive solar design, geothermal heating, and onsite wind energy generation. This recognition underscores the district's commitment to sustainability. It serves as a model for other schools aiming

to reduce their environmental footprint while enhancing student learning experiences (U.S. Department of Education, n.d.).

State Policies

California Clean Energy Jobs Act

The California Clean Energy Jobs Act, also known as Proposition 39, was enacted by California voters in 2012. This landmark legislation provides substantial funding to improve energy efficiency and increase the adoption of clean energy technologies in public schools and buildings. The overarching objectives of Proposition 39 include the reduction of greenhouse gas emissions, lowering energy costs, and fostering healthier, more sustainable learning environments (Table 1). The Act facilitates these goals by offering grants for energy audits, efficiency retrofits, and the installation of renewable energy systems.

Table 1. Key components of proposition 39

Component	Objective	Process/Technology	Outcome
Energy Audits and Assessments	Establish baseline energy consumption and inefficiencies	Certified energy professionals conduct audits	Reports outlining recommended improvements and projected energy savings
Energy Efficiency Upgrades	Improve energy efficiency in educational buildings	LED lighting upgrades, modernized HVAC, improved insulation	Significant reductions in energy use and operational costs
Renewable Energy Installations	Expand the use of renewable energy in schools	Solar panels, wind turbines, and other renewable systems	Decreased fossil fuel reliance and a reduced carbon footprint

The California Clean Energy Jobs Act emphasizes the state's commitment to promoting sustainability in educational settings. Through a combination of targeted financial support, comprehensive energy audits, and strategic energy efficiency measures, Proposition 39 provides a model for integrating energy-saving practices and renewable energy into schools. These efforts not only lead to significant reductions in both energy use and costs but also contribute to an enriched educational experience by raising awareness about sustainability among students. The lessons learned from California's approach offer a framework that other states can replicate to achieve similar outcomes.

The Los Angeles Unified School District's implementation of Proposition 39 highlights its success in achieving significant energy savings and advancing renewable energy adoption (Table 2). The district's efforts demonstrate how local engagement, alongside state funding and support, can result in tangible environmental and financial benefits. These initiatives offer a blueprint for scalability in other school districts facing similar challenges.

Table 2. Los Angeles Unified school district proposition 39 projects

Component	Objective	Process/Technology
Component	Implementation	Outcome
Energy Audits	Comprehensive audits across multiple campuses	Identification of energy efficiency improvements
Efficiency Upgrades	LED lighting retrofits, modernized HVAC, improved insulation	30% reduction in district-wide energy consumption
Solar Installations	Solar panels installed on school rooftops	Significant CO2 emissions reduction and generation of clean energy
Educational Initiatives	Sustainability concepts integrated into the curriculum	Increased environmental awareness and student engagement
Cost Savings	Efficiency and renewable energy measures	$5 million annual savings on energy bills
Community Involvement	Engagement with stakeholders and local communities	Increased support for sustainability initiatives
Scalability	Pilot projects expanded to other district schools	Scalable solutions adaptable to other districts
Challenges	Competitive grants and complex funding processes	Delayed implementation in some schools due to resource limitations

New York State Energy Research and Development Authority (NYSERDA) Programs

The New York State Energy Research and Development Authority (NYSERDA) leads various programs that support energy efficiency and renewable energy initiatives in K-12 schools. The Clean Energy Communities Program and the K-12 Schools Program are key components of these efforts, aimed at reducing energy consumption, lowering operational costs, and fostering healthier learning environments through energy audits, retrofits, and renewable energy projects.

Table 3. NYSERDA key components

Program	Objective	Support/Measures	Outcome
Clean Energy Communities	Promote local government adoption of clean energy practices	Grants, technical assistance, recognition	Enhanced community engagement and commitment to sustainability
K-12 Schools Program	Improve energy efficiency and renewable energy use in schools	Funding for energy audits, retrofits, and renewable installations	Reduced energy consumption, improved air quality, and increased clean energy adoption

NYSERDA's programs reflect New York State's commitment to sustainability in education by offering targeted financial and technical assistance. These efforts not only result in energy and cost savings but also enhance the learning environment and promote student engagement in sustainability practices. The experiences from case studies, such as those in the Rochester City School District, offer replicable models for other school systems aiming to implement similar programs.

Table 4. Rochester city school district NYSERDA-funded projects

Component	Implementation	Outcome
Energy Audits	Comprehensive audits in multiple school buildings	Identification of energy efficiency opportunities
Efficiency Upgrades	Installation of efficient lighting, HVAC systems, improved building envelopes	25% reduction in district-wide energy consumption
Renewable Energy	Solar panel installations on school rooftops	CO2 emissions reduced by hundreds of metric tons annually
Educational Initiatives	Integration of energy efficiency and renewable energy topics into the curriculum	Increased student engagement and hands-on learning
Cost Savings	Efficiency and renewable energy projects	$1.5 million in annual energy cost savings
Community Involvement	Engagement with stakeholders and community	Increased support for sustainability initiatives
Scalability	Successful projects replicated at other schools	Scalable solutions adaptable to other districts
Challenges	Navigating complex funding and technical expertise requirements	Delays in project implementation

Maryland Energy Administration Decarbonizing Public Schools Program

Maryland is leading efforts to decarbonize K-12 schools through comprehensive programs aimed at reducing greenhouse gas emissions and increasing the use of clean energy technologies. The Maryland Energy Administration (MEA) launched the School Decarbonization Pilot Program, which provides funding and support for energy efficiency upgrades, renewable energy installations, and sustainability education.

The Maryland School Decarbonization Pilot Program exemplifies a holistic approach to reducing energy consumption and emissions in school facilities. By funding energy audits, supporting retrofits, and promoting renewable energy adoption, Maryland schools are creating healthier and more energy-efficient learning environments. These efforts also serve as a model for how educational institutions can contribute to broader sustainability goals.

Table 5. Maryland energy administration key components

Component	Objective	Support	Outcome
Energy Audits and Assessments	Identify inefficiencies and opportunities for improvement	Funded energy audits in school facilities	Actionable areas for energy savings identified
Energy Efficiency Upgrades	Retrofit school buildings for energy efficiency	Funding for LED lighting, HVAC, and insulation upgrades	Significant reduction in energy use and operational costs
Renewable Energy Installations	Increase the use of renewable energy	Supported installations of solar panels and geothermal systems	Decreased reliance on fossil fuels and lower emissions
Educational Integration	Incorporate sustainability into the curriculum	Provided resources for hands-on learning	Increased student participation in sustainability efforts

Local Policies

Seattle Public Schools' Resource Conservation Program

Seattle Public Schools has implemented a Resource Conservation Program to reduce energy and water consumption, minimize waste, and lower greenhouse gas emissions across the district. This program involves real-time energy monitoring, student-led conservation projects, and staff training to foster a culture of sustainability within schools (Table 6). Seattle Public Schools' Resource Conservation Program demonstrates how a school district can foster long-term sustainability by engaging both students and staff in conservation efforts, achieving measurable energy and cost savings.

Table 6. Seattle public schools' resource conservation program

Component/Action	Objective	Outcome
Real-Time Energy Monitoring	Track and manage energy consumption in real time	20% reduction in district-wide energy consumption
Student-Led Conservation Projects	Engage students in sustainability initiatives	Increased student participation in energy-saving campaigns
Staff Training	Equip staff to implement conservation practices	Empowered staff contributing to $1 million in annual utility savings

Austin Energy Green Building Program

The Austin Energy Green Building Program partners with schools to promote sustainable building practices. Through financial incentives, technical assistance, and educational resources, the program supports green building projects that reduce operational costs and create healthier learning environments (Table 7). The Austin Energy Green Building Program serves as a model for integrating energy efficiency and sustainability into educational institutions, with measurable improvements in cost savings and student engagement.

Table 7. Austin energy green building program

Component/Action	Objective/Implementation	Outcome
Incentives and Funding	Encourage adoption of green building practices	Increased adoption of green building designs
Technical Assistance	Provide expertise for green building projects	Successful execution of sustainable projects
Educational Integration	Incorporate sustainability into school curricula	Enhanced student understanding of sustainability practices

Interpretation of Findings

The case studies derived from the Renew America's Schools initiative underscore the multifaceted approaches that can substantially advance the decarbonization of K-12 schools. Notably, the integration of solar installations, geothermal systems, energy-efficient retrofits, and comprehensive energy management systems emerge as efficacious strategies. Each technology contributes uniquely to energy reduction and sustainability. Furthermore, embedding these technologies into educational curricula not only maximizes their operational impact but also cultivates an ethos of environmental stewardship among students. This dual approach of technological implementation and academic integration demonstrates a robust model for sustainable educational environments, potentially setting a precedent for future initiatives.

Funding & Support

The necessity for increased federal and state funding cannot be overstated. Large-scale decarbonization projects in schools require significant financial investments that are often beyond the reach of local budgets. Programs such as Renew America's Schools serve as exemplary models, illustrating how governmental support can catalyze substantial improvements in energy efficiency and sustainability. Enhanced funding mechanisms would enable broader participation and more comprehensive project scopes, ensuring that even under-resourced schools can partake in these transformative initiatives.

Policy Frameworks

For school decarbonization efforts to be sustainable and effective, consistent and comprehensive policies at both the federal and state levels are imperative. Financial incentives, technical assistance, and transparent regulatory guidance are essential components of a supportive policy framework. Such policies should aim to lower barriers to entry for renewable energy projects, streamline approval processes, and provide ongoing support through subsidies or tax incentives. A cohesive policy environment would facilitate the widespread adoption of energy-efficient technologies and practices in educational settings.

Community Engagement

The success of decarbonization projects is often bolstered by active collaboration with local communities, businesses, and organizations. Community engagement enhances resource availability and fosters a sense of collective ownership and support for sustainability initiatives. Involving stakeholders from the outset can lead to innovative solutions, improved project outcomes, and increased public awareness. Schools that engage their communities in decarbonization efforts can leverage local expertise and resources, thereby enhancing the overall impact of their projects.

Educational Integration

Integrating decarbonization projects into school curricula provides invaluable experiential learning opportunities. Such integration helps students understand the practical applications of sustainability and fosters a culture of environmental responsibility. Curriculum development that includes hands-on projects, sustainability workshops, and interdisciplinary learning modules can significantly enhance student engagement and awareness. As future leaders and decision-makers, students who are educated in sustainability practices are more likely to advocate for and implement similar initiatives in their personal and professional lives.

Future Directions

To sustain and expand the progress achieved in school decarbonization efforts, future research and policy initiatives should focus on several critical areas. Firstly, scaling successful models is essential; other schools and districts can adopt effective strategies tailored to their specific needs by analyzing and replicating pilots and case studies that have demonstrated success. The dissemination of best practices and lessons learned will be crucial in facilitating this broader application.

Strengthening partnerships is another vital component. Building and maintaining strong relationships with utility companies, government agencies, and private sector partners will ensure decarbonization projects' long-

term sustainability. These collaborative efforts can enhance resource allocation, provide technical expertise, and support the continuous evolution of decarbonization initiatives.

Continuous improvement must also be a priority. Ongoing monitoring and evaluation of decarbonization projects will help identify best practices and areas for enhancement. Establishing continuous feedback loops will ensure that strategies remain effective and adaptable to changing circumstances, thereby maintaining momentum in achieving sustainability goals. Promoting innovation is essential for driving further reductions in energy consumption and environmental impact. Encouraging the development of new sustainable technologies and practices, supported by investment in research and development, will lead to advancements that can significantly impact school decarbonization.

Conclusion

The imperative to decarbonize K-12 schools in the United States has gained substantial momentum, driven by the dual mandates of environmental sustainability and operational efficiency. This study has highlighted the multifaceted approaches and diverse strategies employed across various districts to significantly reduce greenhouse gas emissions, enhance energy efficiency, and foster a culture of sustainability within educational settings.

The Department of Energy's Renew America's Schools initiative has demonstrated that, with adequate support, innovative approaches, and robust community engagement, K-12 schools can significantly reduce their carbon footprint. The case studies presented in this research provide valuable insights and best practices that can be emulated nationwide. By continuing to invest in and prioritize school decarbonization, we can create healthier, more sustainable learning environments for future generations. This holistic approach benefits the environment and enriches the educational experience, equipping students with the knowledge and skills to lead in a sustainable future.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

References

Acoustical Society of America. (2014). *Classroom acoustics*. Retrieved from https://acousticalsociety.org/classroom-acoustics/

Colorado Real Estate Journal. (2017, September 5). *Colorado schools strive for zero net energy*. Mile High CRE. Retrieved from https://milehighcre.com/colorado-schools-strive-for-zero-net-energy/

Darling-Hammond, L. (2000). Teacher quality and student achievement: A review of state policy evidence. *Education Policy Analysis Archives, 8*(1), 14507.

Environmental Protection Agency. (2019). *Thermal comfort and student performance*. Retrieved from https://www.epa.gov

Fisk, W. J., Black, D., & Brunner, G. (2011). Benefits and costs of improved IEQ in U.S. offices. *Indoor Air, 21*(5), 357-367.

Fisman, L. (2005). The effects of local learning on environmental awareness in children: An empirical investigation. *The Journal of Environmental Education, 36*(3), 39-50.

Hathaway, W. E., Hargreaves, J. A., Thompson, G. W., & Novitsky, D. (1992). A study into the effects of light on children of elementary school age. A case of daylight robbery. *Environment and Behavior, 24*(4), 579-600.

Haverinen-Shaughnessy, U., Moschandreas, D. J., & Shaughnessy, R. J. (2011). Association between substandard classroom ventilation rates and students' academic achievement. *Indoor Air, 21*(2), 121-131.

Heschong Mahone Group. (1999). *Daylighting in Schools: An investigation into the relationship between daylighting and human performance.* Retrieved from https://h-m-g.com/projects/daylighting/summaries.htm

Houston Independent School District. (n.d.). *Energy and sustainability*. Retrieved from https://www.houstonisd.org/domain/8301

Iyiegbuniwe, O. (2014). The role of renewable energy in reducing carbon emissions in schools. *Journal of Environmental Health, 76*(6), 34-40.

Klatte, M., Bergstrom, K., & Lachmann, T. (2010). Does noise affect learning? A short review on noise effects on cognitive performance in children. *Frontiers in Psychology, 1*, 582.

Los Angeles Unified School District. (n.d.). *Solar initiative*. LAUSD Learning Green. Retrieved from http://learninggreen.laschools.org/solar-initiative.html

Mendell, M. J., & Heath, G. A. (2005). Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air, 15*(1), 27-52.

Miami-Dade County Public Schools. (2023, August 23). Miami-Dade county public schools celebrates ribbon cutting ceremony for energy-efficient school Retrieved from https://news.dadeschools.net/cmnc/new/34129

National Renewable Energy Laboratory (NREL). (2023). *Benefits of energy efficiency in schools*. Retrieved from https://www.nrel.gov

Nicklas, M., & Bailey, G. (1996). Analysis of the performance of students in daylit schools. *North Carolina Department of Public Instruction, 23*(2), 56-61.

Park, J., Sabu, M., & Mendell, M. J. (2019). A systematic review of the impact of indoor temperature on learning and cognitive performance. *Environmental Health Perspectives, 127*(1), 016001.

Pless, S. D., Torcellini, P. A., Goldwasser, D., & Zaleski, S. B. (2018). *Moving K–12 zero energy schools to the mainstream: Establishing design guidelines and energy targets (Preprint) (NREL/CP-7A40-71700).* National Renewable Energy Laboratory. Retrieved from https://www.nrel.gov/docs/fy18osti/71700.pdf

Shendell, D. G., Prill, R., Fisk, W. J., Apte, M. G., Blake, D., & Faulkner, D. (2004). Associations between classroom CO2 concentrations and student attendance in Washington and Idaho. *Indoor Air, 14*(5), 333-341.

Shield, B. M., & Dockrell, J. E. (2003). The effects of noise on children's learning. *Journal of Sound and Vibration, 18*(2), 141-148.

Tilbury, D. (1995). Environmental education for sustainability: Defining the new focus of environmental education in the 1990s. *Environmental Education Research, 1*(2), 195-212.

Trane. (2023). *Decarbonization strategies for school buildings*. Retrieved from https://www.trane.com

U.S. Department of Education. (n.d.). *Green Ribbon schools awards*. Retrieved from https://www2.ed.gov/programs/green-ribbon-schools/awards.html

U.S. Department of Energy. (2023). *Better buildings challenge*. Retrieved from https://betterbuildingssolutioncenter.energy.gov/sectors/k-12-school-districts

U.S. Department of Energy. (2023). *Renew America's schools.* Retrieved from https://www.energy.gov/scep/renew-americas-schools

U.S. Environmental Protection Agency. (2018). *Evidence from scientific literature about improved academic performance*. Retrieved from https://www.epa.gov/iaq-schools/evidence-scientific-literature-about-improved-academic-performance

U.S. Green Building Council. (n.d.). *Health-centered decarbonization of K-12 schools*. Retrieved from https://www.usgbc.org/education/sessions/zero-emissions-zero-compromises-health-centered-decarbonization-k-12-schools

U.S. Department of the Treasury. (2023, August 25). Treasury Department announces $4.5 billion in funding to help communities cut pollution and expand clean energy economy. Retrieved from https://home.treasury.gov/news/press-releases/jy2016

Waddell, K. J. (2015). The impact of digital learning tools on student engagement and achievement. *Journal of Educational Technology Systems, 43*(3), 171-185.

Wargocki, P., & Wyon, D. P. (2007). The effects of moderately raised classroom temperatures and classroom ventilation rate on the performance of schoolwork by children. *HVAC&R Research, 13*(2), 193-220.

Authors Information

Ryan Kmetz
M.S., Program Manager (former)
Maryland Energy Administration 1800 Washington Bvld., Baltimore, MD 21230, U.S.A.
Contact Email: *kmetzrm@gmail.com*
Orcid iD: https://orcid.org/0000-0001-8184-5002

Gus Norrbom
M.A., Energy Specialist
Maryland Energy Administration, 1800 Washington Bvld., Baltimore, MD 21230, U.S.A.
Orcid iD: https://orcid.org/ 0009-0002-1102-3622