

# Green Warehouses: The Benefits, Challenges and Strategies of Industrial Building Decarbonization

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**Abstract:-** As urban areas expand and e-commerce continues its upward trajectory, the environmental impact of industrial spaces, especially warehouses, has garnered focused attention. This study explores the imperative to tackle significant carbon emissions from these key components of global logistics and distribution chains. The process of making industrial warehouses more eco-friendly is identified as a vital step towards reducing the effects of climate change, improving energy utilization, and advancing eco-friendly industrial methods. The paper thoroughly investigates the advantages of adopting green initiatives for warehouses, such as diminished ecological footprints, energy conservation, and adherence to dynamic regulatory demands. It also addresses the obstacles in this journey, including the economic implications of adopting sustainable technologies, challenges posed by existing infrastructure and laws, and the necessity for cooperation among all parties involved. The document concludes by proposing actionable strategies and practices for decarbonizing industrial warehouse facilities, underscoring the importance of cutting-edge technologies, supportive policies, and eco-conscious design approaches in leading the industrial sector towards environmental stewardship. This exploration seeks to enrich discussions on sustainable city development and the essential role that reducing industrial carbon footprints plays in the broader climate action agenda.

**Keywords:-** Green Warehouses, Industrial Decarbonization, Sustainable Industrial Practices, Energy Efficiency in Warehousing, Embodied Carbon Reduction, Operational Carbon Emissions, Renewable Energy Integration, Building Automation Systems (BAS), Electrification Strategies, Carbon Capture and Storage (CCS), Circular Economy in Construction, Lifecycle Emissions of Buildings, Sustainable Building Materials, GRESB Reporting Framework, Environmental Sustainability Benchmarking, Supply Chain Carbon Footprint

## I. INTRODUCTION

Today, the role of industrial structures, especially warehouses, in contributing to the carbon emissions landscape in the United States has become increasingly significant. This is highlighted by data from the Environmental Protection Agency (EPA), which indicates that as of 2020, the industrial sector accounted for about 24% of all energy-related CO<sub>2</sub> emissions in the nation. This period

also sees the warehousing and distribution sectors experiencing a remarkable increase in demand, driven by rapid urbanization and the booming e-commerce sector. The environmental ramifications of these developments, coupled with the escalating need for warehouse space, underscore the pressing need for decarbonization initiatives.

The intersection of soaring demands for warehouse capacity and the push for environmental sustainability underscores the critical need to reevaluate the carbon footprint of these key industrial assets. With the e-commerce market in the U.S. projected to grow by 26% by 2025, the economic importance of this sector is undeniable. However, this growth brings with it the risk of substantial environmental impacts if the status quo remains unchanged. Thus, moving towards the decarbonization of warehouse facilities represents a vital move beyond mere adherence to regulations; it is an essential strategy for climate change mitigation and the promotion of a sustainable future.

This study sets out to explore the advantages, obstacles, and methodologies crucial for the decarbonization of industrial warehouse buildings. It delves into the realm of cutting-edge practices and technological innovations aimed at curbing carbon emissions, offering practical guidance for property owners, managers, and policy makers. By tackling both the direct and indirect carbon emissions linked to these buildings and spotlighting the effectiveness of energy-saving technologies, electrification efforts, and green construction practices, the paper charts a path to more sustainable warehouse operations. Our aim is to not only satisfy the increasing demand for warehousing in an environmentally friendly way but also to contribute to the wider goals of fostering sustainable urban growth and combating climate change.

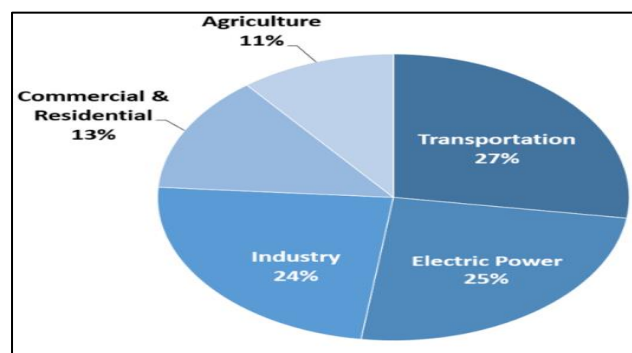


Fig 1: Total U.S. Greenhouse Gas Emissions by Economic Sector in 2020. Total Emissions in 2020 = 5,981 Million Metric Tons of CO<sub>2</sub>e, [www.epa.gov](http://www.epa.gov)

## II. THE CURRENT STATE OF INDUSTRIAL WAREHOUSES

Industrial warehouses stand as critical pillars within the global supply chain, serving the essential function of storing and distributing an extensive range of products and materials. These structures, known for their vast spaces, tall ceilings,

and equipped loading docks, are integral to fulfilling the logistics demands of diverse sectors such as manufacturing, distribution, logistics, and the rapidly expanding e-commerce sector. As key facilitators of trade and commerce, the architectural and functional design of these warehouses significantly influences the ecological footprint associated with industrial processes.

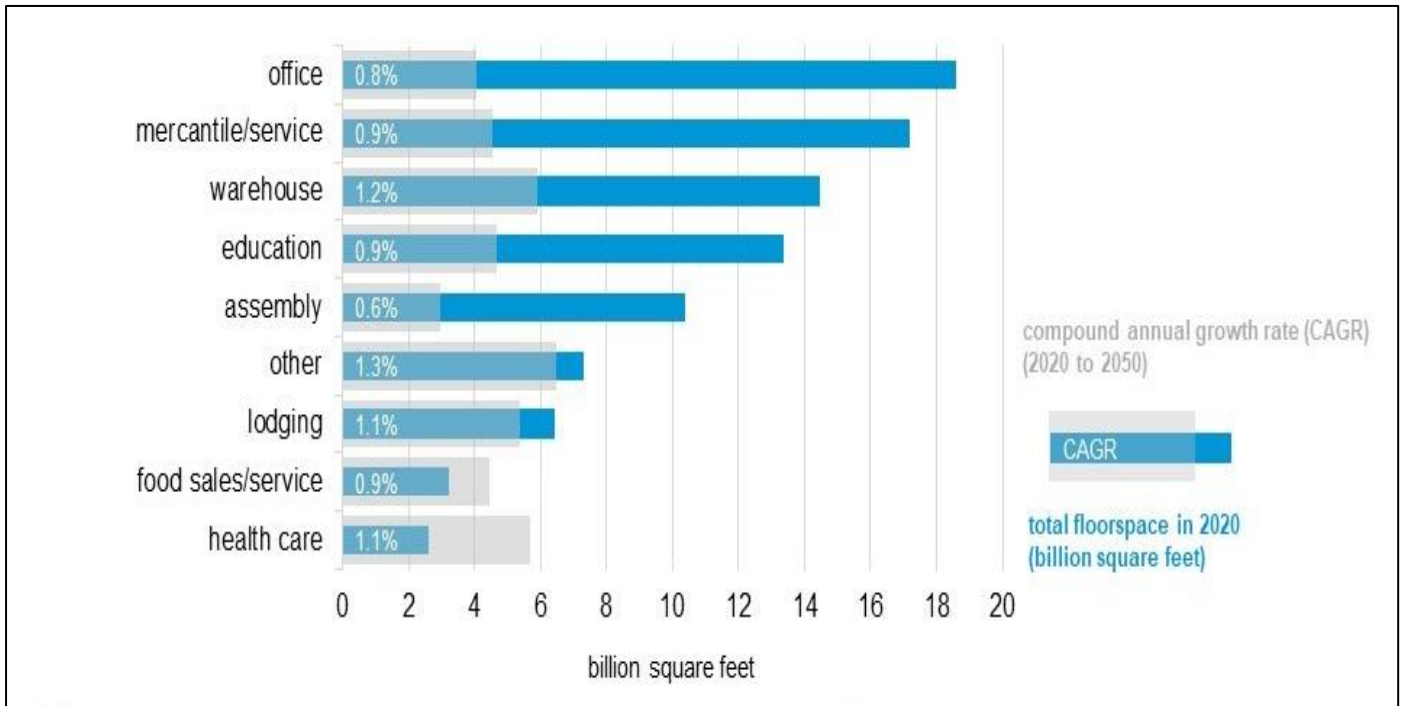


Fig 2: Commercial Floor Space in 2020 and Growth in Floorspace from 2020 to 2050. U.S. Energy Information Administration, Annual Energy Outlook 2021 (AEO2021)

The environmental implications of operating such expansive warehouse facilities are noteworthy, primarily due to their substantial energy consumption and resultant emissions. These emissions are classified into three categories: Scope 1, 2, and 3 emissions, based on their direct or indirect nature.

- **Scope 1** emissions directly stem from sources that are owned or controlled by the facility, including fuel combustion on-site for heating or vehicles operating within the premises.
- **Scope 2** emissions are indirect, arising from the generation of purchased electricity, heat, or steam that the warehouse consumes.
- **Scope 3** emissions represent a broader category of indirect emissions, capturing all other emissions within the company’s value chain, such as those related to the

manufacture and transportation of stored goods, and waste management, posing significant challenges in quantification and reduction efforts.

Given this backdrop, the operational state of industrial warehouses today paints a detailed picture of their economic importance and environmental impacts. With the e-commerce sector's growth and an increasing focus on sustainability worldwide, the eco-efficiency of these warehouses has become a focal point of attention. Mitigating the environmental footprint of these warehouse buildings demands an in-depth understanding of their operational intricacies, energy use patterns, and overall emissions landscape. Such insights are crucial for formulating effective strategies aimed at minimizing their environmental impacts while steering operations toward more sustainable and eco-friendly practices.

SCOPE 1 EMISSION SOURCES	PERCENTAGE OF EMISSIONS
Combustion of natural gas in boilers for space and water heating	15-20%
Combustion of diesel in backup generators	3-5%
On-site transportation (e.g. forklifts) powered by diesel or propane	2-3%
SCOPE 2 EMISSION SOURCES	
Purchased electricity from the grid	30-35%
Purchased steam or hot water from a district heating system	3-5%
Purchased cooling from a district cooling system	2-3%
SCOPE 3 EMISSION SOURCES	
Upstream emissions from energy and fuel production for purchased electricity and district heating/cooling	20-25%
Emissions from transportation of goods to and from the warehouse, including raw materials and finished products	10-15%
Emissions from employee commuting to and from the warehouse	3-5%
Emissions from waste disposal, including landfilling and incineration	2-4%

Fig 3: General Overview of Common Sources of Emissions for Industrial Warehouse Buildings & May Vary Depending on the Specific Operations and Activities of the Warehouse

### III. THE CONCEPT OF EMBODIED AND OPERATIONAL CARBON

In the realm of industrial sustainability, the discussion increasingly gravitates towards the critical roles of embodied and operational carbon in evaluating the environmental footprint of warehouse facilities. **Embodied carbon** encompasses the total greenhouse gas emissions generated by the materials and construction processes over a building's lifecycle, from the initial extraction and production of materials through to the eventual demolition and disposal of the structure. **Operational carbon**, conversely, relates to the emissions resulting from energy consumption during the

active use phase of the building, notably in heating, cooling, lighting, and equipment operation.

For the sector of industrial warehouses, which are marked by their large footprints and high energy demands, a thorough understanding of both embodied and operational carbon emissions is essential for crafting effective decarbonization strategies. These warehouses are particularly prominent sources of operational carbon due to the extensive use of heating and cooling systems, lighting, and operational machinery. Additionally, the process of erecting these warehouses, which often involves significant amounts of steel and concrete, accounts for considerable embodied carbon emissions.

EMBODIED CARBON EMISSION SOURCES	PERCENTAGE OF TOTAL EMISSIONS
• Building materials, including concrete, steel, aluminum, glass, insulation, and roofing materials	60-80%
• Equipment and machinery, including HVAC systems, lighting, and electrical systems	5-10%
• Furniture and fixtures, including desks, chairs, and shelving	2-5%
OPERATIONAL CARBON EMISSION SOURCES	
• On-site fuel combustion for heating	2-5%
• On-site fuel combustion for backup generators	1-3%
• On-site fuel combustion for forklifts and other equipment	5-10%
• Purchased electricity	80-90%
• Employee commuting	1-3%
• Business travel	1-3%
• Upstream transportation and distribution of products and materials	1-5%
• Waste disposal	1-2%

Fig 4: General overview of EC, OC Emissions of Industrial Warehouse Building

The imperative to address these carbon emissions is driven by the global urgency to combat climate change. In the case of industrial warehouses, reducing the carbon footprint involves enhancing the efficiency of energy use to minimize operational emissions and carefully selecting construction materials and practices to lower embodied carbon. Stakeholders across the industrial warehouse sector are thus encouraged to adopt a holistic approach to sustainability, considering the full lifecycle of their facilities to implement practices that significantly lessen their environmental impact.

Therefore, the comprehensive reduction of carbon emissions in industrial warehouses involves a broad spectrum of strategies, from the adoption of energy-efficient operations and the integration of renewable energy sources to thoughtful material selection and design innovations. Such efforts are vital for diminishing the carbon footprint of these essential components of the global supply chain, steering the industry towards a more ecologically responsible and sustainable future.

#### IV. STRATEGIES FOR REDUCING CARBON EMISSIONS

Tackling the carbon emissions from industrial warehouse facilities requires a comprehensive strategy that addresses both the embodied carbon from construction materials and processes, as well as the operational carbon emissions from day-to-day activities. Below are outlined key strategies to guide the decarbonization efforts in this sector:

##### A. Strategies to Minimize Embodied Carbon

###### ➤ *Enhancing Material Efficiency:*

Innovative design solutions that minimize material usage can lead to a significant reduction in embodied carbon. This can be achieved through modular building techniques and designing with an emphasis on waste reduction.

###### ➤ *Selection of Low-Carbon Materials:*

Choosing building materials that have a lower carbon footprint throughout their lifecycle, such as timber from sustainable forests, recycled metals, or innovative low-carbon cement, can drastically lower a warehouse's initial environmental impact.

###### ➤ *Implementation of CCS Technologies:*

The adoption of Carbon Capture and Storage (CCS) technologies in the production of key construction materials like cement and steel allows for the sequestration of CO<sub>2</sub> emissions before they reach the atmosphere, curbing embodied carbon.

###### ➤ *Renewable Energy for Construction Processes:*

Powering construction activities and material production with renewable energy sources diminishes the reliance on fossil fuels, further reducing the embodied carbon associated with building warehouses.

###### ➤ *Promoting Circular Economy Principles:*

Fostering a circular approach to construction by prioritizing the reuse and recycling of building materials and designing structures for ease of deconstruction can conserve resources and reduce the need for new materials, thereby lowering embodied carbon emissions.

##### B. Strategies to Lower Operational Carbon:

###### ➤ *Conducting Energy Efficiency Audits:*

Regular energy audits can identify potential areas for reducing energy consumption across lighting, HVAC systems, and building insulation, pinpointing opportunities to enhance efficiency.

###### ➤ *Harnessing On-site Renewable Energy:*

The installation of solar panels, wind turbines, or other renewable energy systems directly at the warehouse site can significantly reduce operational carbon by offsetting traditional electricity demand.

###### ➤ *Electrification of Systems:*

Moving towards electric heating, cooling, and operational machinery, especially when coupled with renewable energy, helps to eliminate the use of fossil fuels and reduce operational carbon footprints.

###### ➤ *Waste Reduction Initiatives:*

Adopting comprehensive waste reduction and sustainable material management strategies can lessen the indirect carbon emissions linked to waste services and the production of new materials.

###### ➤ *Promoting Sustainable Transportation:*

Encouraging the adoption of electric vehicles for logistics and on-site operations, and providing infrastructure for electric charging, supports a reduction in transportation-related operational carbon emissions.

BUILDING MATERIAL	EMISSIONS PER UNIT	UNITS REQUIRED FOR 300,000 SQFT	TOTAL EMBODIED CARBON EMISSIONS
Concrete	400 kg CO <sub>2</sub> e/m <sup>3</sup>	5,000 m <sup>3</sup>	2,000,000 kg CO <sub>2</sub> e
Steel	1,500 kg CO <sub>2</sub> e/tonne	4,000 tonnes	6,000,000 kg CO <sub>2</sub> e
Aluminum	15,000 kg CO <sub>2</sub> e/tonne	500 tonnes	7,500,000 kg CO <sub>2</sub> e
Glass	800 kg CO <sub>2</sub> e/m <sup>3</sup>	1,000 m <sup>3</sup>	800,000 kg CO <sub>2</sub> e
Insulation	500 kg CO <sub>2</sub> e/m <sup>3</sup>	200 m <sup>3</sup>	100,000 kg CO <sub>2</sub> e
Roofing materials	400 kg CO <sub>2</sub> e/m <sup>2</sup>	100,000 m <sup>2</sup>	40,000,000 kg CO <sub>2</sub> e

Fig 5: Embodied Carbon Emissions

ENERGY USE	EMISSIONS FACTOR (KG CO <sub>2</sub> E/KWH)	ANNUAL ENERGY CONSUMPTION (KWH)	ANNUAL CO <sub>2</sub> E EMISSIONS (METRIC TONS)
Heating	0.204	3,000,000	612
Cooling	0.482	7,500,000	3,615
Ventilation	0.344	1,500,000	516
Lighting	0.057	1,200,000	68
Plug Loads	0.210	4,800,000	1,008
Process Equipment	0.500	5,000,000	2,500
Elevators	0.298	1,000,000	298
<b>TOTAL ANNUAL EMISSIONS</b>			<b>8,617</b>

Fig 6: Operational Carbon Emissions

The tables above provide a general breakdown of embodied & operational carbon emissions of a 300,000 square foot industrial warehouse in the U.S.

Adhering to these outlined strategies not only aids in significantly curbing carbon emissions from industrial warehouses but also aligns with global sustainability goals, offering long-term environmental and financial benefits. Success in these endeavors requires concerted effort, thoughtful investment, and collaboration across all stakeholders involved in warehouse design, construction, and operation.

### V. ROLE OF ENERGY-EFFICIENT TECHNOLOGIES

The significance of energy-efficient technologies in advancing the sustainability of industrial facilities is paramount. As the industry leans into greener practices, leveraging technology to enhance energy efficiency stands as a critical means to diminish energy use and consequently, lower carbon emissions. This method not only aligns with ecological goals but also bolsters operational effectiveness and curtails ongoing energy expenses.

#### A. Sophisticated Building Management Systems (BMS):

At the cutting edge of driving energy efficiency through technology, Sophisticated Building Management Systems play a crucial role. These systems amalgamate software and hardware to exert detailed control over a facility's heating, ventilation, air conditioning (HVAC), lighting, among other operational aspects. By dynamically monitoring and adjusting environmental controls in response to live data, occupancy, and external climate conditions, these systems substantially reduce energy wastage, enhancing the facility's environmental performance.

#### B. Targeted Building Automation Systems (BAS):

Operating in tandem with BMS, Targeted Building Automation Systems specialize in the nuanced management of specific operational facets within a building. These systems automate critical functions such as modulating lighting intensity, adjusting natural light utilization through window shading, and tailoring HVAC output to real-time occupancy and operational demands. This precision ensures energy is deployed efficiently throughout the facility, propelling industrial properties toward their sustainability targets.

### *C. Innovative Energy Storage Technologies:*

The role of modern energy storage solutions, including battery systems and thermal storage, is increasingly crucial in augmenting a building's energy efficiency profile. These technologies store surplus energy generated during low-demand phases, such as daylight hours for solar power, and deploy it during peak demand, minimizing grid dependency and fossil fuel consumption. Moreover, they enable a smoother integration of renewable energy into the facility's energy portfolio, significantly contributing to emission reduction efforts.

By embedding these advanced energy-saving technologies within industrial warehouse operations, we mark a substantial leap towards achieving decarbonization. Sophisticated BMS and targeted BAS streamline energy consumption across numerous building processes, while innovative energy storage mechanisms optimize the use of green energy sources. Collectively, these technological solutions offer a robust framework for slashing energy use and emissions, underscoring the essential role of tech innovation in fostering environmentally sustainable industrial protocols.

## **VI. THE IMPORTANCE OF ELECTRIFICATION**

Electrification emerges as a crucial element in the green transformation of industrial facilities, such as warehouses, marking a shift towards minimizing fossil fuel dependence and embracing renewable energy. This transition to electric power plays a vital role in slashing greenhouse gas emissions, thereby contributing significantly to the global fight against climate change.

### *A. Transitioning HVAC Systems to Electric:*

Within the industrial sector, Heating, Ventilation, and Air Conditioning (HVAC) units rank as top energy consumers, underscoring the importance of their electrification in environmental efforts. Conventionally, these systems operate on fossil fuels, a practice that substantially elevates a facility's carbon output. The move towards electrically powered HVAC solutions, especially through the adoption of high-efficiency heat pumps, represents a greener alternative. These pumps efficiently manage heating and cooling by exchanging heat with the external environment or the ground. Utilizing electricity derived from renewable sources like solar or wind energy can drastically cut the climate control carbon footprint of such buildings.

### *B. Electrifying Warehouse Transportation:*

Beyond the confines of the warehouse itself, electrification also encompasses the transportation systems linked to warehouse operations. Transitioning to electric vehicles (EVs) for logistics, distribution, and intra-warehouse movements significantly curtails emissions compared to traditional diesel or gasoline-powered fleets. Furthermore, setting up EV charging infrastructure at warehouse sites promotes electric vehicle usage among staff and visitors alike, further diminishing the transportation-related carbon footprint.

The role of electrification in decarbonizing industrial buildings is profound and multifaceted. Aligning perfectly with international environmental targets, it also offers warehouses an opportunity to enhance energy efficiency and economic viability over the long term. Through the electrification of both HVAC systems and transportation logistics, warehouses can markedly reduce their operational emissions, steering the industrial sector towards a more eco-friendly and sustainable future.

## **VII. CHALLENGES IN DECARBONIZING INDUSTRIAL WAREHOUSE BUILDINGS**

Navigating the path to making industrial warehouse buildings more sustainable and less carbon-intensive is an essential yet complex journey, marred by a variety of hurdles. These challenges span economic, structural, regulatory, and systemic issues, making the shift towards environmentally friendly operations a daunting task.

### *A. Financial Investment Hurdles:*

A primary obstacle in the quest for decarbonization is the substantial initial investment required to adopt and implement sustainable technologies and practices. The costs associated with upgrading to energy-saving systems, integrating renewable energy solutions, and retrofitting facilities to enhance efficiency and reduce emissions can be prohibitively high. This financial barrier is especially challenging for small to medium-sized enterprises, which might lack the resources or be hesitant about the potential returns on such investments.

### *B. Constraints of Existing Infrastructure:*

Many industrial warehouses are constrained by older infrastructures that weren't designed with modern, energy-saving technologies in mind. Retrofitting these buildings to accommodate new, greener solutions often entails significant technical and financial challenges, including major modifications to the building's electrical layout, structure, and other foundational elements.

### *C. Regulatory Hurdles:*

The decarbonization effort is further complicated by regulatory challenges. Diverse and sometimes conflicting regulations across different areas can lead to confusion and compliance issues for warehouse operators. Additionally, the pace at which regulations evolve can lag behind the rapid advancements in green technology, creating gaps that slow down the adoption of decarbonization measures.

### *D. Conflicting Tenant Requirements:*

Warehouse tenants may have specific needs that clash with the objectives of decarbonization, particularly if their operations are energy-intensive and difficult to sustain using greener technologies. Finding a middle ground that satisfies both the tenants' operational requirements and sustainability targets requires thoughtful negotiation and creative problem-solving.

*E. Supply Chain Limitations:*

The effort to reduce carbon footprints in warehouse operations is closely tied to the broader supply chain, which can present its own set of limitations. The availability of sustainable materials, renewable energy options, and eco-friendly transportation methods directly impacts a warehouse's ability to lower its environmental impact, making the decarbonization of warehouses a collective supply chain issue.

*F. Insufficient Incentives:*

The slow pace of decarbonization is also attributed to a lack of adequate incentives from government and industry associations. Financial incentives such as tax reliefs, grants, or subsidies are critical for making sustainability upgrades more appealing and financially feasible for warehouse operators. Without such incentives, the shift towards greener operations can seem less attractive from a business perspective.

Addressing these decarbonization challenges demands a concerted effort from all stakeholders involved, including warehouse operators, tenants, policymakers, and the supply chain. It calls for innovative financial solutions, supportive regulatory frameworks, and a shared commitment to sustainable practices to successfully transition industrial warehouse buildings towards a greener, low-carbon future.

## VIII. THE ROLE OF GRESB IN ADDRESSING CARBON EMISSIONS

The Global Real Estate Sustainability Benchmark (GRESB) stands as a critical entity within the domain of real estate sustainability, providing a comprehensive methodology for evaluating the ecological performance of properties, including those in the industrial warehouse segment. As the push for eco-friendly real estate practices gains momentum, the influence of GRESB in shaping and assessing the sustainability initiatives of warehouse operations becomes ever more pivotal.

### ➤ *An Overview of GRESB*

Operated by the industry for the industry, GRESB presents standardized, verified Environmental, Social, and Governance (ESG) metrics to investors and other stakeholders in the capital markets. Its mission is to elevate the sustainability profiles of real asset investments globally, making it an invaluable tool for entities within the industrial warehouse sector seeking to minimize their environmental impacts, especially regarding carbon emissions. Engagement with GRESB assessments empowers warehouse operators with the ability to gauge their sustainability endeavors, compare their achievements against industry benchmarks, and pinpoint areas ripe for enhancement.

### ➤ *GRESB's Contributions to Carbon Emission Reductions*

The suite of assessment instruments and benchmarks offered by GRESB is instrumental in tackling carbon emissions from the warehouse sector through several mechanisms:

#### ➤ *Facilitating Standardized Reporting*

GRESB renders a uniform platform for disclosing sustainability performances, inclusive of carbon emission metrics. This uniformity ensures that efforts to diminish carbon footprints are transparent and measurable across the board.

#### ➤ *Establishing Performance Benchmarks*

By allowing warehouse operators to benchmark their environmental achievements against those of their peers, GRESB instills a competitive and motivational spirit to foster carbon reduction strategies, spotlighting sustainability leaders and proliferating industry best practices.

#### ➤ *Highlighting Areas for Emission Reductions*

Through its detailed sustainability assessments, GRESB aids warehouse managers in identifying precise opportunities for curtailing carbon emissions and bolstering overall environmental stewardship.

#### ➤ *Attracting Sustainable Investment*

As investors increasingly prioritize green assets, demonstrating robust sustainability credentials via GRESB can lure investments from those committed to environmental responsibility, thereby fueling further initiatives aimed at carbon mitigation.

#### ➤ *Promoting Responsibility and Proactive Measures*

Engaging with GRESB propels warehouse operators toward adopting and executing detailed carbon reduction strategies, fostering a culture of accountability and ongoing environmental improvement.



Fig 7: <https://www.gresb.com/nl-en/>

In essence, GRESB's role is foundational in advancing the decarbonization agenda within the industrial warehouse sector, highlighting the significance of systematic ESG reporting and benchmarking in steering the real estate industry towards greater sustainability. Leveraging GRESB's methodologies enables warehouse entities to make informed strides in lowering their carbon emissions, contributing significantly to the overarching objectives of climate change mitigation and sustainable industrial progress.

### IX. CONCLUSION

The endeavor to make industrial warehouse buildings carbon-neutral is far more than complying with regulations or meeting environmental standards; it's a crucial pledge towards ensuring a sustainable future for our planet. The close link between the operations of these facilities and the broader issue of climate change highlights the pressing necessity to cut down carbon emissions in this vital sector. It's essential to achieve meaningful decreases in both the direct carbon associated with construction and materials and the ongoing emissions from building use to lessen the impact of climate change and move toward a more sustainable and resilient economic landscape.

Moving forward, the commitment of all parties involved—owners, operators, and workers in these facilities, alongside local communities, policy makers, and national governments—is crucial. By fostering a spirit of cooperation, we can tackle the diverse obstacles decarbonization presents, from the economic and structural challenges to legislative complexities and the nuances of the supply chain. This

collaborative effort aims not just to green warehouse practices but also to nurture more livable communities and ensure prosperity for future generations.

To drive this significant shift towards lower carbon emissions, it's imperative to adopt a comprehensive set of strategies that encompass enhancing energy efficiency, moving towards electrification, using sustainable materials, and embracing renewable energy sources. The importance of systems like GRESB in setting benchmarks and motivating improvements in this area is immense, offering a transparent and structured way for warehouses to gauge and refine their environmental footprint.

In sum, transitioning industrial warehouses towards zero carbon is a path marked by continuous effort, creativity, and collective action. By drawing together diverse stakeholders and harnessing the latest in technology and sustainable practices, we have the opportunity to remodel the industrial landscape into a model of eco-friendly excellence.

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