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Cloud-powered technologies for sustainability

AI, machine learning, the Internet of Things, and other technologies can play a critical role in decarbonization, and the cloud can significantly speed up and catalyze this process.

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Fifteen years into the cloud revolution, it's clear that embracing technologies such as AI and machine learning (ML) has unlocked substantial value.[1] These technologies, which can generally be run faster and more effectively through the cloud, have not only led to cost efficiencies and operational savings but also optimized resource use.[2]

Until recently, however, the tremendous potential of cloud-powered technologies to aid companies in achieving their decarbonization goals has received much less attention. The cloud offers organizations and individuals virtually limitless computing, storage, networking capabilities, and advanced software applications, with generative AI (gen AI) solutions becoming increasingly prevalent. Running these tools on the cloud enables companies to acquire new decarbonization-related capabilities that might previously have been too expensive or time-consuming to build on premise.

Our research suggests that using cloud-powered technologies can accelerate the implementation of 101—or 47 percent—of the 217 representative decarbonization initiatives that are required to achieve the global 1.5° pathway by 2050 (see sidebar "About the research").[3] Given previous estimates that achieving net-zero emissions by 2050 would require spending $9.2 trillion on decarbonization per year,[4] the cloud's potential contribution through these technologies could be worth hundreds of billions of dollars annually.

According to our estimates, the climate benefits could also be significant. In addition to accelerating decarbonization initiatives, cloud-powered

1 "The cloud transformation engine," McKinsey, August 9, 2021.
2 "Projecting the global value of cloud: $3 trillion is up for grabs for companies that go beyond adoption," McKinsey, November 28, 2022.
3 For more on the 1.5° pathway, see "The 1.5-degree challenge," McKinsey, September 16, 2020.
4 "The economic transformation: What would change in the net-zero transition," McKinsey, January 25, 2022.

About the research

The research presented in this article is based on data and insights from the McKinsey Decarbonization Lever Library, a living data repository on emissions impact and costs of decarbonization initiatives. The library includes approximately 1,200 initiatives, with more added monthly. Each initiative represents an action—for example, a change in a process, technology, or fuel—that has the potential to directly decrease carbon emissions. Initiatives include electrification and the use of alternative energy sources such as renewable energy.

The impact of each initiative on emissions is calculated following the principles of life cycle assessment and scrutinized by sustainability and sector experts. Costs (capital expenditures, operating expenditures, and the levelized cost of production) are modeled using the central inputs of commodity price and other variables.

To conduct our research, we identified 217 initiatives—a subset of the current library—that together offer substantial decarbonization opportunities across industries and thus form a meaningful pathway to limiting global warming to 1.5°. To translate these initiatives into on-the-ground impact, we created 455 industry-specific use cases. Each use case lays out a mechanism through which the cloud can accelerate decarbonization within an individual industry. Use cases include dynamic pricing and trading for negative carbon emissions (carbon capture, utilization, and storage), optimization for new electric-equipment integration (electrification), and a smart grid for renewable electricity (alternative energy source).

Numerous permutations of decarbonization initiatives are possible depending on the existing technology or energy source that the corresponding levers intend to address. This is because multiple different technologies can sometimes be used for any individual decarbonization use case, though their cost and impact may vary. In addition, multiple technologies can often combine to accelerate and increase abatement impact. Companies can adopt and apply decarbonization levers based on the cost, decarbonization impact, and technological suitability of the use cases.

technologies can play a role in abating up to 32 metric gigatons of CO_2 equivalent ($GtCO_2e$)—nearly half of the total 65 $GtCO_2e$ that we estimate is required to reach net-zero emissions by 2050. For the subset of initiatives in which the cloud can play a significant role, we calculate that each use of the cloud to power key technologies can reduce the cost of implementing a decarbonization initiative by 2 to 10 percent. On aggregate, we estimate that the total benefit of using the cloud to accelerate decarbonization could be up to 1.5 $GtCO_2e$ per year by 2050. The manufacturing and transportation sectors stand to benefit the most from making full use of these key technologies.

In this article, we'll discuss the considerable potential the cloud has to enhance the sustainability transition by expediting the adoption of decarbonization strategies. We'll explore the impact of three predominantly cloud-powered technologies—AI, ML, and the Internet of Things (IoT)—in accelerating decarbonization initiatives. Additionally, we'll share why manufacturing and transportation stand to benefit most from these technologies, looking more closely at automotive manufacturing. We'll also examine the ways cloud-powered technologies can assist with regulatory and compliance rules and lay out some initial steps for companies to get started using these technologies to achieve their sustainability goals.

Accelerating the most critical decarbonization initiatives using cloud-powered technologies

Many companies already understand the cloud's potential to decrease carbon emissions in IT. Migrating applications to the cloud and shutting down data centers can significantly reduce IT carbon emissions because cloud service providers tend to run ultraefficient data centers on renewable energy.[5] Ensuring ultraefficient data centers are used in the infrastructure mix can represent a significant reduction in IT emissions.

However, the cloud's role in enabling the full set of actions required to get to net zero is less understood. We selected 217 initiatives from the 1,200 levers currently available in the McKinsey Decarbonization Lever Library and found that using the cloud to enable key technologies can play a significant role in accelerating 101 initiatives by reducing lever-implementation costs by 2 to 10 percent (Exhibit 1). Using the cloud to enable key technologies can also provide a lesser benefit (reducing cost by less than 2 percent) on an additional 82 initiatives.

In addition, with increasingly stringent climate-related regulations coming into effect each year, cloud-powered technologies can also play an important role in facilitating, accelerating, and decreasing the cost of target setting, reporting, and compliance. At the root of this benefit is the potential to enhance data observability—an organization's understanding of the location and quality of data within and outside their systems—and enable data exchanges between competitors and across industries, which will become increasingly necessary to address Scope 3 emissions.

The potential of AI, the IoT, and ML in decarbonization

Across initiatives, the following three cloud-powered technologies could, when combined, play an important role in decarbonization:

AI and data exchange for Scope 3 transparency. Compiling and consuming large data sets is faster and cheaper with cloud-based data lake technology, including third-party APIs, queries, documents, and databases. For example, decentralized data exchanges throughout the supply chain can enhance a company's understanding and transparency of its Scope 3 emissions data. This allows the company to uncover new and more cost-effective pathways for decarbonization. Notably, in the logistics sector—in which, according to our analysis, Scope 3 emissions contribute up to 80 percent of total emissions—we estimate that cloud-enabled data observability and exchanges across intricate supply chains could reduce the time to enable an actionable decarbonization strategy from six to eight weeks to as little as one week. Additionally, these data exchanges can help

[5] "The green IT revolution: A blueprint for CIOs to combat climate change," McKinsey September 15, 2022.

Exhibit 1

Cloud-powered technologies will play a central role in the sustainability transition.

Decarbonization initiatives

Levers identified as having the potential to directly decrease carbon emissions

Cloud use cases

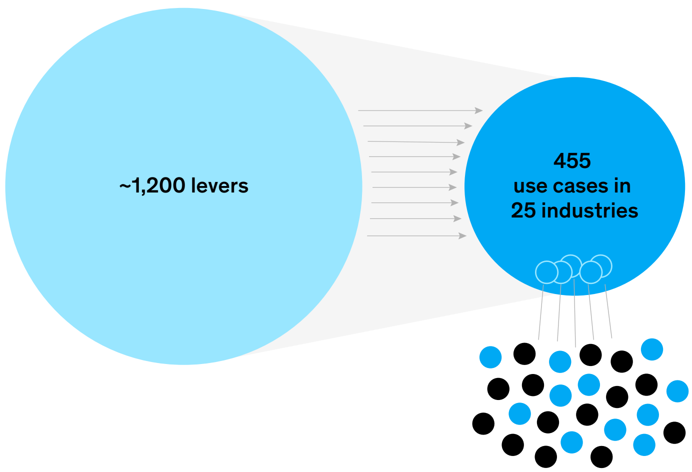
Industry-specific use cases of cloud-powered technologies developed with experts

Benefits of cloud solutions

47% of use cases are significantly accelerated by 2–10% on average[1]

Cloud-powered technologies can play a role in the abatement of up to **32.0 metric gigatons** of CO_2 equivalent ($GtCO_2e$); they can have a direct benefit and impact of 1.5 $GtCO_2e$ vs on premise

Potential annual benefits could total **> $100 billion**



[1]The 47% figure refers to 101 levers out of 217 that were selected as representative of the entire 1,200 levers available. Due to their multi-industry and multitechnology nature, many of these levers are very similar; therefore, the selection of 217 represents a full sample of the 1,200.

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identify emission-reduction opportunities worth as much as 40 percent of a company's emissions through detailed Scope 3 visibility. According to our analysis, this refined data exchange procedure has the potential to save companies approximately 80 percent of the time typically needed for data collection, cleansing, and estimation.

Physical-asset transition based on IoT. Digital-twin technology can make transitioning a business's physical assets (such as machinery, equipment, and facilities) significantly more efficient by allowing companies to upgrade and optimize—or, in some cases, transition to—a digital or automated environment. By employing IoT sensors to capture data from physical objects (goods and raw materials) and convert it into digital information (bits and bytes) as well as share data between assets, a digital twin can serve as a powerful tool for transforming assets with lower emissions. With $4.5 trillion of spending expected by 2050 for adopting or retrofitting to low-emission physical assets,[6] the cost and time required for the asset transition will be critical metrics of success. Historically, our research has found that with digital twin–based diagnoses, companies can typically expect a reduction of more than 10 percent in transition lead time for low-emission assets. In addition, a digital twin can bring a more comprehensive, real-time understanding of how companies' physical assets are used and how they perform, such as their energy and material consumption. With digital-twin technology, companies can reduce their energy consumption by about 10 percent on average.

Leveraging high-performance computing for ML resource optimization, including material, energy, and labor. ML models with virtually unlimited on-demand access to high-performance computing of the cloud can support the creation and execution

[6] "The net-zero transition: What it would cost, what it could bring," McKinsey Global Institute, January 2022.

of complex simulation models. These models play a crucial role in finding a balance between cost and carbon emissions. Critical initiatives with this dual focus include redesigning products, optimizing delivery and charging routes for electric vehicle (EV)–based logistics (where to go and when to charge), and planning for the energy transition (including, for example, suggesting where infrastructure such as EV chargers should be built). McKinsey has found that redesigning products, for example, can reduce costs by 5 to 15 percent and Scope 3 emissions for purchased goods and services by more than 25 percent.[7]

Manufacturing and transportation benefit most from cloud-powered technologies

The impact of cloud-powered technologies on decarbonization efforts will vary by industry, depending on the size of the industry's carbon footprint and the potential for reducing it. Our research suggests that manufacturing and transportation are currently the industries that can benefit most from cloud-powered technologies for decarbonization. This is in part because of their size: the transportation industry, for example, emits nearly a quarter of total global greenhouse-gas (GHG) emissions, according to McKinsey analysis, which means that the rate of decarbonization in this sector has a significant impact on overall decarbonization efforts.[8]

Manufacturing. More than 210 of the 455 cloud use cases we have identified are relevant to manufacturing (see sidebar "Zooming in on automotive manufacturing"). Notable examples include using digital-twin technologies on the manufacturing line, employing real-time analytics for predictive maintenance, and creating a simulator that considers both the financial costs and the carbon emissions associated with product design

7 Stephan Fuchs, Ruth Heuss, Stephan Mohr, and Jan Rys, "Design cost-effective, carbon-abated products with resource cleansheets," McKinsey, September 28, 2020.

8 "Decarbonizing the world's industries: A net-zero guide for nine key sectors," McKinsey, accessed November 8, 2023.

Zooming in on automotive manufacturing

The use of cloud-powered technology can accelerate the automotive-manufacturing sector's end-to-end transition journey (exhibit). From our analysis, we have found that value can come from four concrete areas:

Measurement, tracking, and reporting. The data ingestion and extraction capability of cloud-powered technologies reduces the time for emission baselining from six to eight weeks to one week. By connecting internal enterprise resource planning and management information systems to the cloud, auto manufacturers could identify activity consumptions (the amount of activity that is the source of emissions, such as liters of diesel consumed, kilowatt-hours of electricity used, and so on) and generate estimations for baseline projection. A dashboard that is linked to the data ingestion module and measures the amount of activity and associated emissions can also automatically update to track the emission trajectory.

Road map development. AI and ML modules can develop a decarbonization pathway based on internal targets and peer benchmarks, reducing the development time of these pathways from five to ten weeks to about one week.

Decarbonization initiative implementation. To increase the energy efficiency of any type of manufacturing line for physical products that uses electricity or heat, auto manufacturers can deploy a digital twin to optimize the process and preemptively identify the risks. By using a digital twin, automotive manufacturers could potentially abate 20 percent of total emissions and see a 3 to 12 percent increase in throughput and a 6 to 10 percent increase in energy savings.

Energy transition support. To accelerate the energy transition for decarbonizing Scopes 1 and 2 emissions, organizations could use cloud-powered technologies to more accurately monitor 24/7 the source of electricity used. With the cloud, automotive players will be able to more granularly map the consumption and production of

Zooming in on automotive manufacturing (continued)

electricity and understand the accurate amount and source of green electricity. They can also trade renewable-energy certificates facilitated with a blockchain provenance solution, ensuring security and transparency.

Green-business value unlocks. Along with decarbonization transformation, automotive manufacturers can use cloud-powered technologies to tap into adjacent business areas with the potential for growth. Examples include R&D and the commercialization of alternative-fuel simulations, and redesigning computing-intensive products to lower costs and carbon emissions through AI via high-performance computing.

Exhibit

In automotive manufacturing, cloud solutions can play a significant role in accelerating abatement in some of the most challenging activities.

	Levers	Cloud use cases and solutions	Estimated impact
Implementation	Closed-loop recycling in aluminum production Mechanical recycling in rubber production Mechanical recycling with green electricity in rubber production Mechanical recycling in polypropylene production	High-performance computing with computational chemistry and LCA-based[3] 3-D modeling to simulate material properties based on recycled inputs	1–3% price premium for green metals (expected to rise to ~10% by 2030)
		Decentralized data exchange solutions to implement digital material passports, optimizing the recyclability process	2–5% increase in volume 10–15% logistics cost reduction 20–30% inventory reduction
Energy transition	Switching to renewables (with REC[1]) Scrap steel in an electric arc furnace (EAF) to produce hot-rolled coil steel	Digital twin–based optimization for new equipment (EAF) integration	30% or greater CO_2 reduction Substantial electricity cost savings
	Green hydrogen and green electricity for steel production Green hydrogen to produce hot-rolled coil steel	Sensors, real-time analytics, visualization, and dashboarding for hydrogen distribution network diagnosis and a safety management system for hydrogen transition	Substantial improvement in onsite hydrogen availability and onsite fault reduction
	Switching to renewables (with PPA[2])	24/7 green-electricity PPA[2] supply-monitoring platform	

[1] Renewable energy certificates.
[2] Power purchase agreements.
[3] LCA = life cycle assessment.

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(Exhibit 2). Companies could also achieve cost savings from increased productivity and reduced energy consumption, which will help accelerate the industry's sustainability transition. For example, according to our analysis, using cloud-powered technologies to adjust biomass-related processes based on the composition of raw material can improve yields by up to 5 percent.

Transportation. There are more than 50 decarbonization initiatives relevant to the transportation sector from among the 455 use

Exhibit 2

Manufacturing companies can benefit from applying cloud solutions to their decarbonization journey along a long-term road map.

	1 month	3 months	6 months	12+ months
Company journey	Getting started	Establishing processes and scoring quick wins	Realizing emissions and cost impact with cloud-powered levers	Scaling impact
Example actions	**Develop decarbonization plan** Cloud-powered solutions for a deeper, more actionable, and updatable plan	**Use a cloud CSRD[1] solution** 80% cheaper and 3x faster CSRD[1] reporting and compliance	**Continuously update decarbonization plan** Establish reporting and processes necessary for continuous improvement	**Transform manufacturing process end to end for net zero** • **Supply chain transparency solutions to address Scope 3 emissions** • **Transportation optimization solutions** • **Recycling and circular materials solutions** • **> 200 use cases identified as playing a role in abating > 7 metric gigatons of global CO_2e**
	Develop net-zero road map Prioritization of levers in time based on net present value and CO_2 equivalent (CO_2e) reduction ambition	**Implement quick-win levers** • **Digital twin–based optimization** 3–12% increase in throughput, 6–10% reduction in energy consumption, and up to ~20% emission reduction acceleration • **Energy transition optimization** Mapping energy sourcing and usage to optimize for lower emissions at same cost (up to 30% lower) • **Material recycling opportunities** Using high-performance computing to break down components at different stages of production and identifying opportunities for expanding recycling and sourcing	**Realize impact** • **Real-time performance monitoring and predictive maintenance** 8% reduction in direct maintenance cost and 20% increase in productivity • **Centrally connected sensors for output tracking and quality control** 0.5–1.5% reduction in standard deviation	
	Develop investment and implementation plan Maximizing emissions-abatement ROI and abatement commitments			

[1]Corporate Sustainability Reporting Directive.

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cases identified, and they could play a role in abating up to 2.8 $GtCO_2e$ by 2050. Top initiatives include optimizing loads and routes, charging networks, and real-time warehouses. The acceleration will mostly come from lowering costs, reducing inventory, and reacting more quickly to changing demands in inventory management. Scope 3 visibility, one of the most crucial problems in transportation and logistics decarbonization, can also be significantly enhanced with cloud-powered technologies. For example, the Smart Freight Centre Exchange Network demonstrates how these technologies can enable decentralized, trust-based data exchanges in commercially sensitive situations, enabling all participants to get granular visibility into their Scope 3 emissions.[9]

Facilitating compliance and promoting accountability with cloud-powered technologies

In addition to playing a direct role in accelerating the implementation of decarbonization initiatives, cloud-powered technologies can help companies navigate the evolving environment of sustainability targets and regulations.

Using cloud-powered technologies can enable the use of multiple services for retrieving internal data (such as customer-relationship-management and enterprise-resource-planning tools) and external sources (such as press releases) that can facilitate compliance and reporting. Where primary data sources are not currently available, AI and ML technologies can suggest secondary sources and generate estimations. Gen AI could do even more, with modules that can generate responses to regulators' questions by crawling through data points and creating a narrative from them. Companies can also use the modules to do advanced scenario planning and test decarbonization strategies.

In addition to assisting with reporting and compliance, cloud-powered technologies can establish realistic sustainability targets that are grounded in important internal and external data, as we have already seen in the automotive manufacturing sidebar. Reliable target setting will help companies avoid overshooting and greenwashing claims.

For these reasons, cloud-powered technologies will be an important accelerator of reporting and compliance in relation to regulatory developments such as the European Union's Corporate Sustainability Reporting Directive (CSRD). CSRD requirements are complex and cut across multiple business units (see sidebar "What the European Union's CSRD means for ESG reporting"). Our preliminary internal analysis indicates that once a CSRD tool is in place, the end-to-end process for data connection and output review can be reduced to one to four weeks from several months, potentially saving up to 70 percent in costs and time.

Starting the decarbonization planning and implementation process

Companies should begin by identifying critical decarbonization initiatives, which will depend on factors such as industry and geography. For example, country-by-country differences in the price and availability of renewable energy will be an important determinant of the impact of switching energy sources. With decarbonization initiatives identified, companies can take the following high-level steps:

1. *Develop a technology-enabled decarbonization plan.* The plan, embedded within companies' systems and based on operational data rather than estimates, can provide the basis for a model that can be frequently updated as new solutions become available.

2. *Understand the potential of cloud-powered technologies for each initiative.* Companies will need to identify, within their decarbonization plans, the initiatives where cloud-powered technology can have the biggest carbon and cost impact to accelerate their transition.

9 For more, see "SFC Exchange Network," Smart Freight Centre, accessed September 14, 2023.

What the European Union's CSRD means for ESG reporting

The European Union's Corporate Sustainability Reporting Directive (CSRD), which comes into effect in 2025, will expand the data disclosure requirements for sustainability reporting to approximately 1,200 different data points across 12 standards.[1] Companies will need to disclose information related to multiple environmental, social, and governance (ESG) topics, including reporting on past performance and laying out future targets.

The data collected and reported in response to the CSRD will give companies and regulators a clearer understanding of ESG progress and where further improvements are needed. Companies will also have a much greater ability to benchmark their progress against peers. This understanding should fuel and enable the development of ambitious, actionable sustainability strategies.

This regulation will affect companies' costs, related to retrieving the required qualitative and quantitative data. According to the first estimation from the European Financial Reporting Advisory Group in response to the CSRD, each company will need to staff two full-time-equivalents in addition to current employees.[2] In addition, new administrative and quality assurance costs may increase total compliance costs by more than €1 million for listed companies.[3] The European Union estimates that fines for enterprises that do not disclose information may be as much as €10 million.[4]

1 "Questions and answers on the adoption of European Sustainability Reporting Standards," European Commission, July 31, 2023; *Draft European Sustainability Reporting Standards*, European Financial Reporting Advisory Group (EFRAG), November 2022; Camille Branquart, "Insights from CSRD expert: Key challenges, common mistakes, and tips to get started," Greenomy, June 16, 2023.
2 *Draft European Sustainability Reporting Standards*, European Financial Reporting Advisory Group (EFRAG), November 2022.
3 *Cost-benefit analysis of the first set of draft European Sustainability Reporting Standards*, EFRAG, November 22, 2022.
4 "Guidelines 04/2022 on the calculation of administrative fines under the GDPR: Version 2.1," European Data Protection Board, May 24, 2023.

3. *Develop an investment and implementation plan.* By developing a carefully sequenced plan, companies can maximize decarbonization through judicious investment in critical technologies. Crucially, businesses can consider synergies between the use of cloud-powered technologies for decarbonization and their broader business-backed technology strategy.

Companies aiming to take a leading role in decarbonization cannot afford to overlook the adoption of cloud-powered technologies. In everything from assessment and reporting to major transformations and business enablement, these technologies serve as a crucial tool for achieving decarbonization goals swiftly and efficiently. As companies gear up to comply with increasingly complex sustainability regulations, strategic use of cloud-powered technologies can be a crucial differentiator.

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