STUDENTENERGY

Research Report

Farmers, Artificial Intelligence, and the Water Nexus in the U.S. and Germany

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Abstract

This report investigates how the rapid expansion of artificial intelligence and data centers is reshaping water and energy dynamics for farmers in the United States and Germany. As AI workloads accelerate, data centers emerge as significant users of both direct cooling water and indirect water embedded in electricity generation, often in regions already facing climate-driven water stress and agricultural vulnerability. Using a mixed-methods approach that combines literature review, comparative policy analysis, case studies, and semi-structured interviews, the report evaluates when data center growth intensifies conflict with agriculture and when it can support rural economies and water resilience. The findings show that governance design, transparency of water use, and technology choices such as cooling systems and workload scheduling strongly influence whether AI infrastructure competes with or complements agricultural water needs. The report concludes with recommendations for strategic siting, mandatory water disclosure, hybrid cooling operations, and farmer-inclusive decision-making processes to align digital expansion with long-term food and water security in both countries.

Introduction

Artificial intelligence (AI) continues to be one of the most prominent features of the 21st century economy, with the potential to redefine industries across many sectors, including the agricultural sector. The literature explores the many ways in which AI might be harnessed to increase the yield and efficiency of farming and the many ways AI might cost society in different ways. For example, AI for development (AI4D) is an emergent narrative that purports AI can be extremely beneficial for relatively lower income countries–particularly given their large farming sectors (Toupin & Siad, 2025). At the same time, large infrastructures for AI, such as data centers, can consume 5 million gallons of water per day and increase water stress on local communities (Wroth, 2025).

The manner in which AI creates benefits or imposes costs differs under different development contexts, in part because the development of AI is being led by higher income countries and they have a different context in which they might be deployed. For example, The United States (U.S.) has a high concentration of farmland owned by people who do operate the land themselves, with 31% of farmland in the U.S. is rented or leased out to the farmer ((Malloy, 2023). Not only does AI and its infrastructure have differing impacts across international development contexts, but also in different communities and geographical contexts. For example, there is a bias for data centers to disproportionately impact rural areas, as they are often built in less dense areas (Pan Fang & Greenstein, 2025), and data centers often expand into land that was previously used for farming (Cohn, 2025).

The geographical bias of data centers and their impact on water resources highlights the need to investigate how farmers are impacted by this emerging technology–a topic with scant empirical research. Data centers are rapidly expanding across the globe, raising social and environmental challenges. By analyzing their intersection with farming communities, this research highlights trade-offs and opportunities within the nexus of emerging technologies, water security, and agriculture. The results will inform policymakers, industry leaders, and agricultural stakeholders about strategies for balancing technological progress with equitable resource governance.

The rapid expansion of artificial intelligence (AI) is reshaping the global digital landscape, driving a fast growth in data center construction. While we applaud the swiftness of such digital advancement, there is one key stakeholder expected to be affected by this growth that we often overlook: The agriculture community. Despite having tight scrutiny on carbon emissions produced by data centers, one critical blind spot remains: The water footprint of the physical infrastructure powering AI data centers. Data centers, which are heavily discussed primarily in terms of carbon emissions and electricity consumption, emerges as a major competitor for water. This situation is further exacerbated where data centers are located in regions where farmers already face climate-driven water scarcity.

In Germany, stringent EU-aligned regulations like the Energy Efficiency Act (EnEfG) mandate data centers to report water usage and prioritize sustainable cooling, yet AI-driven expansion in hubs like Frankfurt strains groundwater resources critical for agriculture amid rising droughts. Farmers face indirect competition through power generation's water footprint and direct conflicts in regions like Brandenburg, where industrial draws threaten irrigation for crops. This study examines these dynamics to identify pathways for cooperation, such as dynamic cooling during peak farming seasons, balancing AI growth with food security.

Methodology

This report presents a comparative analysis between the United States and Germany, drawing on insights from literature reviews, stakeholder interviews, and case studies. Each component includes both independent findings specific to each country and comparative results that highlight transnational similarities and differences.

The literature review incorporated a range of sources, including peer-reviewed academic publications, media articles, and gray literature, reflecting the growing salience of data centers and artificial intelligence (AI) applications in recent years (Liang et al., 2025; Mallapaty, 2025). Targeted keyword searches focused on understanding the effects and impacts of AI adoption on farmers, agricultural practices, and water management systems.

Primary data collection involved ten stakeholders selected from authors and relevant actors identified through the literature review. Snowball sampling was also employed to include additional experts and practitioners with pertinent experience. Outreach to participants was conducted primarily via email, and data were collected through online semi-structured interviews and digital surveys. Each interview was subsequently summarized and analyzed thematically to identify key patterns both within and between national contexts.

Case studies were purposively selected from a larger pool of documented examples in both the United States and Germany to illustrate critical dimensions of the AI–farmer–water nexus. Comparative analysis of these case studies emphasized sociopolitical and institutional contextual differences identified in the literature, enabling a deeper examination of how governance structures, technological adoption rates, and policy environments shape outcomes across the two settings.

Literature Review

The following section provides an overview of how AI innovation is occurring in both the U.S. and Germany to contextualize the comparative analysis of our case studies and interviews.

U.S. Context

The literature indicates that the U.S. landscape of data centers and agriculture can be characterized by a plurality of policies that both bolster and regulate AI differently at the federal, state, and local level. Overall, policies in the U.S. are in favor of less regulation and for expedited innovation of AI.

Federal

At the federal level, there has been decreasing regulation of AI since the Biden Administration ended, with President Trump rescinding many of Biden's Executive Orders (EO), including those related to safeguarding from AI (Biden, 2023; Trump, 2025). President Trump's EO focuses on reducing regulatory friction for AI innovation to ensure the U.S. maintains its position as a global leader in AI. The EO states, "It is the policy of the United States to sustain and enhance America's global AI dominance in order to promote human flourishing, economic competitiveness, and national security" (Trump, 2025). Additionally at the federal level, U.S. Representatives Jim Costa and Blake Moore introduced the Unleashing Low-Cost Rural AI Act (H.R. 5227) in September of 2025, which directs agencies to study how data center expansion will impact rural energy and agriculture (Bracken, 2025).

Costa and Moore's newly introduced bill focuses on how AI impacts the energy supply and costs in rural areas, but does not capture the full picture of social impacts. President Trump's directives and the expansion of AI will have consequential impacts on rural areas beyond energy–for example, land use change from transmission expansion and water source depletion are equally valid concerns.

State

When President Trump first proposed the Big Beautiful Bill in 2025, many governors and attorneys general rallied against its inclusion of a ban on AI regulation (Godoy, 2025; Morgan & Shepardson, 2025). This is indicative of some of the state's influence on the landscape of AI and data center expansion.

However, it is notable that states differ in their responses to AI. For example, Michigan has regulation that prevents utilities from having consumers subsidize any rate increases that occur from data centers (*MPSC Approves Terms of Service*, 2025). New York regulates algorithmic pricing, requiring businesses to disclose its pricing, along with regulation on AI companions to ensure they report suicidal ideation or self-harm (*NY Regulates AI Pricing*, 2025). California is also seeming like a leader in AI regulation, with many laws including those that require transparency reports, protections for whistleblowers, and bias or risk mitigation (Gidez, 2025; Valetk et al., 2025).

Local

The landscape of AI at the local level can be characterized as a power struggle between constituents and tech companies because most of the benefits from data centers, by nature, are not reaped by the local community. Benefits to the community might come in the form of economic development through jobs and tax revenues that can be used to invest in the community. However, as seen in one of our interviews, local communities sometimes do not want a large influx of jobs due to the changes that might occur to the community following that influx.

Data centers can also look for local governments that are willing to give them tax breaks and willing to sign non-disclosure agreements to ensure that the environmental impact of this infrastructure remains hidden ("FOIA Friday," 2024; Tortorelli et al., 2025). At the same time, data centers coming in can increase tax revenues for the localities.

The rapid expansion of AI is accelerating data center (DC) infrastructure across the U.S., with profound implications for water and carbon at regional scales. While public scrutiny largely focuses on AI's electricity use and carbon footprint, a growing body of research reveals that water, which is used for cooling and power generation, is often the hidden constraint. The following section covers the key findings of four research articles that shows:

A) Water footprint of DCs are already comparable to other major industries in the U.S.
B) Most of the water footprint is indirect, coming from electricity generation, not on-site cooling
C) Cooling methods creates a difficult tradeoff between water and carbon
D) Geography and grid mix are the most important determinants of total water stress
E) AI exacerbates existing water-stress issues

U.S. Water & Nexus Analysis

1. Scale of DC Water Footprint

Several studies indicate that DCs are now major water users in the U.S. DCs have an operational water footprint of 513 million m^3 per year, making them among the top ten water consumers in industrial and commercial sectors nationally (Siddik et al., 2021). About 90% of U.S. watersheds (most under significant stress) supply water, both direct and indirect, to existing DCs (Siddik et al., 2021).

U.S. DCs consumed about 626 billion litres of water in 2014, and this figure is expected to rise substantially as AI-driven workload expands (Lei et al., 2023). A case study in Dallas, Texas showed that one of Google's DC consumed tripled their on-site water use between 2012 and 2021, reaching 1.34 billion litres per year. This is equivalent to 1/4th of the city's municipal water usage (Lei et al., 2023).

One major tech company's DC evaporated over 23 billion litres of fresh water in 2023. This volume of water is comparable to the water usage of large beverage corporations, and the report projects that U.S. DC water use will double or even quadruple by 2028, reaching figures as high as 280 billion liters per year (Li et al., 2025).

To provide some global context, AI alone could account for 4.2-6.6 billion m^3 of water withdrawal by 2027, and this figure exceeds the total annual water withdrawal of 4-6 countries the size of Denmark (Li et al., 2025).

On average, 1 MWh of DC electricity corresponds to 7.1m^3 of water consumption at a power plant (Siddik et al., 2021). This tells us that a DCs true water footprint cannot be measured from its local cooling system alone.

2. <u>Direct vs. Indirect Water Use</u>

<u>Scope 1: On-Site Water Use for Cooling</u>

On-site water is mainly used for cooling towers in DCs. Li et al (2025) estimate that cooling towers consume 80% of the water they withdraw. Consumption rates range from 1 to 9 liters per kWh, where DCs on the higher end are located in hot, arid regions like Arizona Li et al (2025).

There are three modes of cooling (Gnibga et al., 2024):

A) Wet (more commonly known as 'Evaporative') cooling: highly water-intensive but energy efficient, which means less carbon emissions.
B) Dry cooling: does not use water but consumes large amounts of energy, meaning high carbon emissions.
C) Hybrid cooling: a combination of both modes. Water first cools through the dry section (no water loss). If more cooling is required, then the mode switches to wet cooling, where some fraction of water is evaporated.

<u>Scope 2: Indirect Water Use</u>

Lei et al. (2023) and Siddik et al. (2021) outline that the water intensity of an electricity grid (denoted by the Water Consumption Factor, WCF) is a dominant composition of the total water footprint. In subregions like CAMX, RMPA, and NWPP, most of the DC's water footprint comes from the hydropower reservoir evaporation and thermoelectric plant cooling, not necessarily from onsite cooling Lei et al. (2023). This research outlines that on average, 75% of the total water footprint is from power generation rather than on-site cooling, which shifts our focus on scope 2 water footprint more than scope 1 Siddik et al. (2021). For example, a DC that has a water-efficient cooling system would still have a high water footprint if it is operated in a water-intensive grid, and vice versa.

3. Cooling Technologies and Water-Energy-Carbon Tradeoff

Energy and Carbon Penalties

Dry cooling, dispute saving large volumes of water, is energy intensive and incurs high carbon costs. This is further compounded depending on the location, where in hot climates like Texas, the energy overhead of dry cooling can be 219% higher than in a cooler climate like France (Gnibga et al., 2024). In France where the grid is mainly nuclear and low in carbon, switching to dry cooling increases carbon emissions by 5.1%, but the financial cost makes it unattractive since total cost of ownership (how much it costs to save water) is 3.9x more expensive than in California due to European electricity tariffs (Gnibga et al., 2024).

This research tells us that there is no one-size fits-all solution and solutions are very location dependent. Below are three examples (Gnibga et al., 2024):

A) Texas: Experiencing water stress and hot climate, and has a carbon-intensive grid. Dry cooling would save water but can substantially worsen carbon emissions, indirectly harming agriculture through climate impacts.
B) California: Experiencing water stress but cleaner energy grid. Dry cooling would save water, and the total cost of ownership here is valuable, making dry cooling attractive.
C) France: Though less water-stressed and nuclear-grid, high financial cost makes dry cooling unattractive.

Dynamic/Hybrid Operations

Gnibga et al. (2024) suggests a dynamic cooling strategy where DCs switch between wet and dry cooling modes based on various factors like temperature, precipitation, electricity price, water scarcity, and more. The dynamic mode would save 32-60% water with only 0.7-1.4% increase in cost, carbon, and energy (Gnibga et al., 2024).

This suggests an area for collaboration between DCs and local farmers. DCs can contractually agree to switch to dry cooling mode during peak agricultural season or droughts, where they would absorb slightly higher operational costs in exchange for local permits or social licenses.

4. Geography, Grids, and Water Scarcity Footprints

Hotspot Regions and Grid Water Intensity

Lei et al. (2023) and Siddik et al. (2021) both proved that geographic siting and grid composition is much more important than cooling technology due to scope 2 water footprints.

In the U.S., geographic hotspots with high water footprints include Arizona, New Mexico, California, Rocky Mountains, and Northwest. These areas have a high water footprint primarily due to hydropower and thermoelectric generation. Conversely, regions like NEWE, NYUP, NYLI, and NYCW have a much lower water footprint since their electricity grid comes from thermoelectric plants operated by once-through cooling which withdraws far less water than evaporative systems (Lei et al., 2023).

Water Footprint vs. Water Scarcity Footprint

Siddik et al. (2021) notes the following metrics when considering water footprint:

A) Water Footprint (WF) - Volumetric amount of water used
B) Water Scarcity Footprint (WSF) - Degree to which this use occurs in stressed watersheds

The West and Southwest regions of the U.S. hosts about 20% of DCs, however, accounts for about 70% of the entire industry's WSF (Siddik et al.,2021). Despite these regions providing only 20-30% of available water, it carries a much more disproportionate share of impact because they are located in arid and heavy agricultural zones (Siddik et al.,2021). This gives us insights on placing more emphasis on WSF rather than WF when strategically deciding DC sites.

Strategic Siting Potential

Siddik et al. (2021) highlighted that if new DCs are strategically located in optimal locations, WSF of future infrastructure could reduce by up to 90% and carbon footprint by 55%. Part of this comes from connecting DCs to grids dominated by solar and wind, which have minimal WF.

5. AI as an Accelerator

Training Models

Li et al. (2023) estimated that training GPT-3 consumed 5.4 million liters of water, where 700,000 liters were direct use. The rest was indirect for electricity generation. This figure is expected to rise with new, larger models, like GT-4, which will require more AI workloads. AI workloads are growing at 20% per year (Li et al., 2025).

Water and Carbon Goals are often Misaligned

Li et al. (2025) demonstrated that water and carbon efficiency are weakly correlated (denoted with a correlation of 0.06). Based on this, they proposed two strategies:

A) When: Schedule DC workloads during cooler times of the day or seasons, which will improve cooling efficiency and reduce scope-1 water footprint.
B) Where: Shift AI workloads to DCs in cooler regions and less water-intensive grids.

6. Implications for Energy-Water Nexus and Farmers

From the four articles, we have collected the following insights that are directly relevant to agricultural water security:

A) Blue vs. Green Water Competition
- Blue vs. Green Water Consumption: Agriculture primarily uses green water (soil moisture) and blue water (freshwater) for irrigation. DCs also consume blue water from the same sources that farmers rely on, creating a direct competition for a resource that is already scarce in many regions (Li et al., 2025).

B) Regional Vulnerability
- The West and Southwest U.S., which are some of the key agricultural zones, host about 20% DCs but are responsible for about 70% of the WSF (Siddik et al., 2021). Even though hydropower and nuclear are renewable sources of energy, they are highly water-intensive and exacerbate water scarcity.

C) Local vs. Distant Impacts
- A DC withdraws water from two sources. First is their local watershed (Scope 1), and second is distant watersheds which is used for electricity generation (Scope 2). In other words, a local farmer can feel the impact of water withdrawals from a powerplant built hundreds of miles away, not necessarily the DC nearby them.

D) Policy Levers and Cooperative Models
- Policy frameworks largely need to focus on strategic DC siting (which also includes analyzing electricity grids). Other measures that can address local water footprint includes dynamic cooling operations and spatiotemporal workload scheduling. It is more important to mandate water footprint disclosure (Scope 1 and 2) as a prerequisite for informed local governance to better understand negotiating impacts.

German Context

Germany's multi-level governance structure—spanning federal, state (Länder), and local (municipal) authorities—shapes a sustainability-focused approach to AI data centers, contrasting sharply with the U.S. market-driven model, while navigating water constraints in agriculture-intensive regions.

Federal

At the federal level, the Energy Efficiency Act (EnEfG) imposes stringent requirements on data centers with non-redundant loads over 300 kW, mandating annual energy efficiency reporting by March 31, progressive renewable energy sourcing (50% by 2024, 100% by 2027), Power Usage Effectiveness (PUE) targets (1.3 or lower by 2030 for existing facilities), and waste heat utilization (at least 20% by 2028). These align with EU Taxonomy criteria for green investments and Corporate Sustainability Reporting Directive (CSRD) obligations, requiring water usage disclosure and climate adaptation strategies for larger operators.

State

State-level policies vary by Land, with Hesse (home to Frankfurt) leading through a dedicated data center strategy that promotes renewable integration and heat recovery, as seen in facilities like Digital Realty's FRA20 and Green Mountain's Rhine-cooled sites. Brandenburg, in arid eastern Germany, faces acute groundwater recharge declines due to climate change and over-extraction, prompting state teams to prioritize brownfield redevelopment and infrastructure alignment for data centers amid agricultural competition. States like Bavaria and North Rhine-Westphalia encourage Rhine River cooling and district heating reuse, yet high-density AI workloads challenge liquid cooling efficiency, with Water Usage Effectiveness (WUE) averaging 0.36 liters/kWh.

Local

Local (municipal) regulations dominate siting via Building Code (BauGB) zoning, classifying data centers as commercial/industrial uses permissible in Gewerbe- or Industriegebiete, but requiring case-by-case Bebauungspläne (development plans) without automatic authorization. Frankfurt data centers consume substantial electricity (up to significant city shares) and groundwater/freshwater for cooling, fueling concerns as half of Germany's 401 districts report groundwater stress, particularly where irrigation for energy crops overlaps with hyperscale expansions like Google's €5.5 billion investments. Municipalities often secure städtebauliche Verträge for infrastructure costs, waste heat agreements, and environmental impact assessments (UVPG), strategically siting near renewables to minimize indirect water footprints from power generation.

This bifurcated framework fosters waste heat reuse (e.g., Frankfurt district networks) and advanced cooling, but persistent issues like eastern aridity and AI-driven power densities heighten farmer-water tensions, underscoring needs for integrated federal-state coordination.

Germany’s agricultural sector is undergoing structural, environmental, and technological transformation driven by recurring droughts, groundwater depletion, and the rise of artificial intelligence (AI) in farm management. As climate variability intensifies, the long-term stability of groundwater resources — the backbone of irrigated agriculture — is increasingly uncertain. Simultaneously, digitalization promises to improve production efficiency, yet it requires digital infrastructure and institutional coordination to avoid unequal benefits and unintended water-energy burdens. To understand the potential of AI to support water-resilient agriculture in Germany, this review synthesizes hydrological, agronomic, structural, and governance evidence from five key German-focused references.

Germany Water & Nexus Analysis

1. Groundwater Scarcity and Agricultural Water Risk in Germany

Hydrological patterns and sensitivity to drought

Recent multi-year droughts beginning in 2018 have caused substantial groundwater declines nationwide. Using more than 3,600 groundwater observation wells, Ebeling et al. (2025) quantified spatial differences in groundwater-head responses to meteorological drought. They report time lags of 1–6 months between precipitation-evapotranspiration anomalies and groundwater decline, varying by aquifer permeability and depth (Ebeling et al., 2025). Regions with shallow, unconsolidated aquifers — including Brandenburg, Saxony-Anhalt, and parts of Lower Saxony — exhibit rapid depletion and persistent low Standardized Groundwater Index (SGI) values following drought events (Ebeling et al., 2025). These areas also show long-term decreasing trends signaling structural reductions in recharge rates.

Regional hydrogeological vulnerability

Brandenburg's sandy soils and shallow aquifers create low buffering capacity, making it one of Germany's most drought-sensitive agricultural landscapes (Ebeling et al., 2025). Saxony-Anhalt also demonstrated significant groundwater-head anomalies with prolonged recovery delays. In southern Germany — particularly Bavaria — deeper aquifers and higher precipitation create greater hydrological resilience, but agricultural intensification may reduce this buffer in future drought episodes (Ebeling et al., 2025). These regional discrepancies imply that water scarcity is not a uniform national challenge but concentrated in strategic food-production zones where irrigation is most necessary.

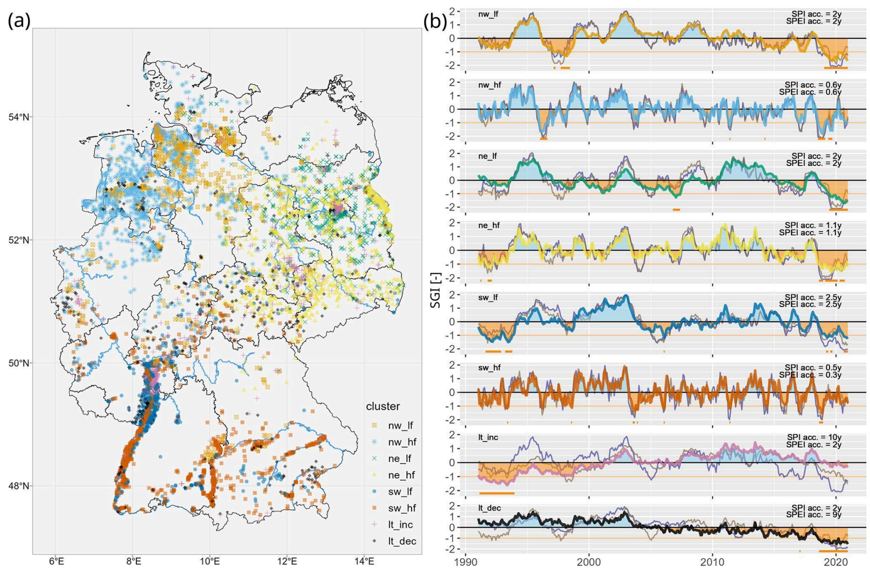

Figure 1. Panel (a) maps groundwater-level anomaly clusters across Germany together with major river systems, while panel (b) shows the corresponding time series of groundwater conditions (SGI) alongside precipitation-based drought indicators (SPIacc, SPEIacc). Negative SGI periods indicating drought are highlighted in orange and positive conditions in blue, with cluster labels reflecting both their geographical location and characteristic groundwater-response patterns (Ebeling et al., 2025).

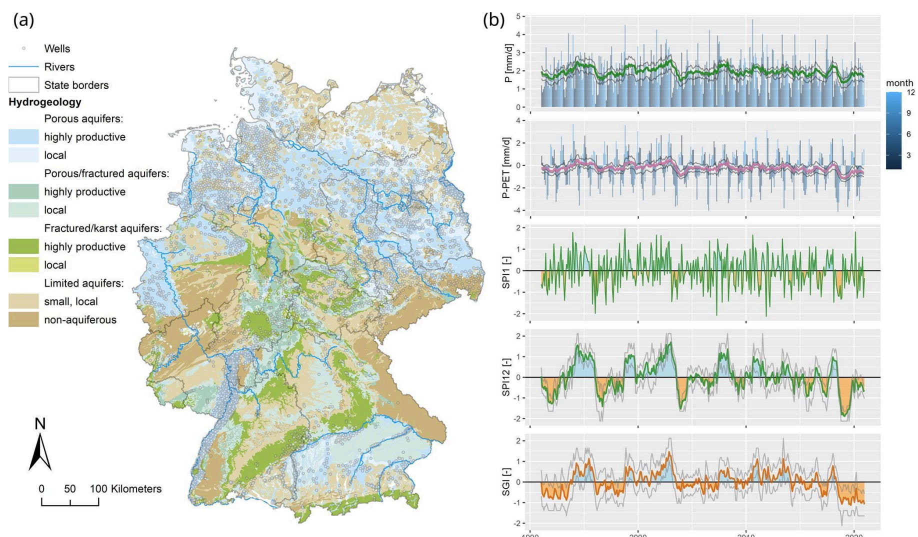

Figure 2. This figure presents groundwater vulnerability categories that reflect how quickly different aquifer systems respond to precipitation–evapotranspiration anomalies, classified into short-, medium-, and long-response times. The color scheme (purple, green, yellow) corresponds to these response groups, derived from the 33rd and 67th percentile thresholds of resptSPEI values within the six identified regional clusters (Ebeling et al., 2025).

2. Agronomic Foundations for Water Resilience

Crop diversification for drought mitigation

Despite hydrological constraints, agronomy provides foundational strategies for stabilizing yields under water stress. Germany's arable area comprises roughly 11.6 million hectares, dominated by wheat, maize, barley, oilseed rape, and rye in relatively narrow rotations (Macholdt, 2025). Simplified systems increase water-sensitivity and yield volatility.

Long-term experimental evidence from German field stations shows that:

- Including grain legumes and cover crops improves soil moisture retention and nutrient cycling.
- Winter wheat yields become more stable under reduced mineral nitrogen inputs.
- Straw retention and green manure practices reduce yield risk in winter barley by up to ~42%, compared with risk levels as high as 78% in simplified rotations (Macholdt, 2025).

These results confirm that diversified crop rotations provide biological drought insurance by improving soil structure, evapotranspiration buffering, and microbial activity.

Limitations without real-time decision intelligence

However, diversified systems still require information-driven management to align planting schedules, nutrient cycling, and water availability. Without predictive monitoring, farmers risk under- or over-irrigating during critical crop phases, undermining resilience gains. Thus, climate-adapted agriculture increasingly depends on AI-enabled decision support to translate agronomic potential into operational performance.

3. Farm Structure and Differential Adoption of AI

Structural duality of German agriculture

The transition to digital agriculture is shaped by Germany's distinct dual farm structure. As Balmann (2025) documents, East Germany retained very large farm enterprises after reunification, many exceeding 1,000 hectares and operated as cooperatives (e.G.) or companies (GmbH). These agricultural corporations benefit from economies of scale, mechanized fleets, and specialized labor — all favorable for deploying AI, precision irrigation, and data-driven resource management.

In West Germany, by contrast, family-run farms typically operate between 30–80 hectares with mixed production systems and limited capital reserves (Balmann, 2025). The smaller scale increases the relative cost of AI and constrains digital experimentation.

Digital divide and regional consequences

This structural asymmetry produces geographical differences in digital water-management capacity:

- Brandenburg and Saxony-Anhalt: large farm sizes facilitate rapid adoption of AI irrigation, yet also face highest groundwater vulnerability (Ebeling et al., 2025; Balmann, 2025).
- Lower Saxony: mixed farm sizes result in heterogeneous digital uptake.
- Baden-Württemberg and Bavaria: smaller average holdings and lower water stress reduce incentives for AI irrigation investment (Balmann, 2025).

AI could therefore increase adaptation resilience in already advantaged farms, while smaller farms in drought-sensitive zones risk falling behind — widening structural inequality.

4. Governance at the Water–Energy–Food Nexus

Institutional fragmentation and value conflict

Nexus-sensitive agricultural innovation depends on governance capable of reconciling environmental, economic, and food-security priorities. Märker (2022) highlights that Germany's current systems operate in sectoral silos: agriculture policy prioritizes production, water policy prioritizes ecological compliance, and energy policy prioritizes climate mitigation. Conflicting normative value orientations among these sectors slow policy integration (Märker, 2022).

Her extended Institutional Analysis and Development (IAD) model shows that fragmented governance leads to:

- Reactive rather than preventive drought planning
- Poor coordination between groundwater allocation and technology incentives
- Challenge in balancing farm profitability with ecosystem protection

AI-assisted irrigation is therefore not only a technical deployment, but a regulatory negotiation requiring cross-sector alignment.

5. AI and the Digital Water Footprint

Infrastructure demands for AI-enabled agriculture

AI relies on substantial computation, cloud connectivity, and data storage, which introduces new environmental externalities. According to BMWK (2025), Germany hosts:

- >2,000 data centers
- 2,730 MW installed IT capacity (2024)
- 20 TWh/year electricity consumption (~4% of total)

By 2030, data-center demand is projected to rise to 31 TWh, and could reach 80 TWh by 2045 if current growth continues (BMWK, 2025). Because modern data centers increasingly use water-dependent cooling systems and operate near growing AI workloads, water use indirectly rises with agricultural digitalization.

<u>Geographic collision of water scarcity and digitalization</u>
Data-center expansion clusters in:

- Frankfurt–Rhine-Main (largest hub)
- Berlin–Brandenburg (fastest hyperscale growth)
- Rhineland (Cologne/Düsseldorf build-out accelerations

Critically, Brandenburg — already facing some of the highest groundwater-drought responses in the country (Ebeling et al., 2025) — is also a major target of AI-computing infrastructure (BMWK, 2025). Thus, AI adoption must be assessed through a full-chain nexus perspective rather than a farm-level efficiency lens alone.

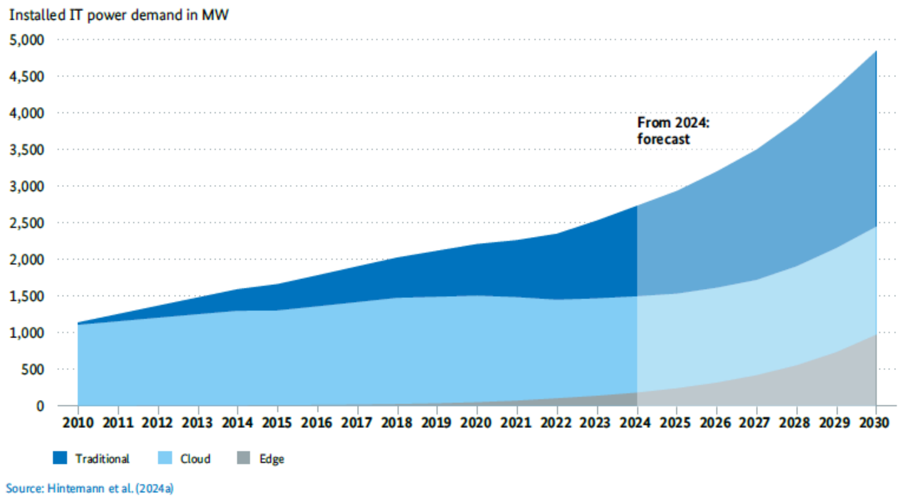

Figure 3. Development of the capacities of data center and smaller IT installations in Germany from 2010 to 2024 and forecast until 2030 (BMWK, 2025)

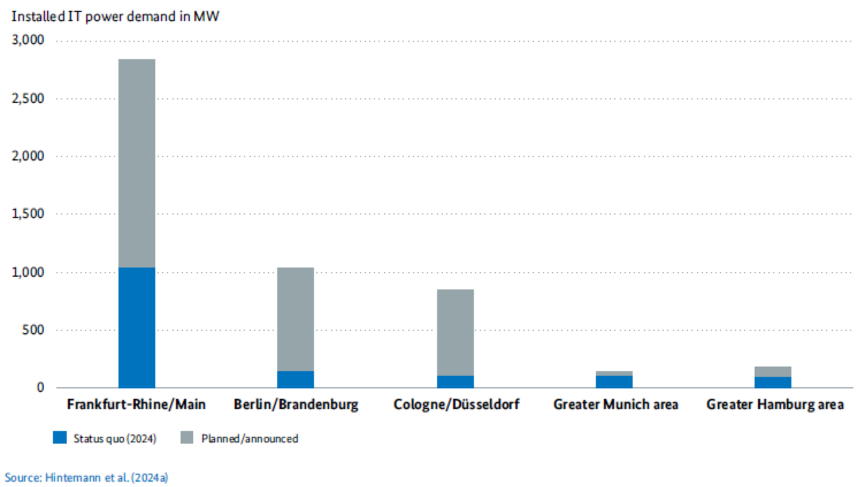

Figure 4. Data centre installed IT power demand that currently exist of are specifically planned in various German regions (BMWK, 2025)

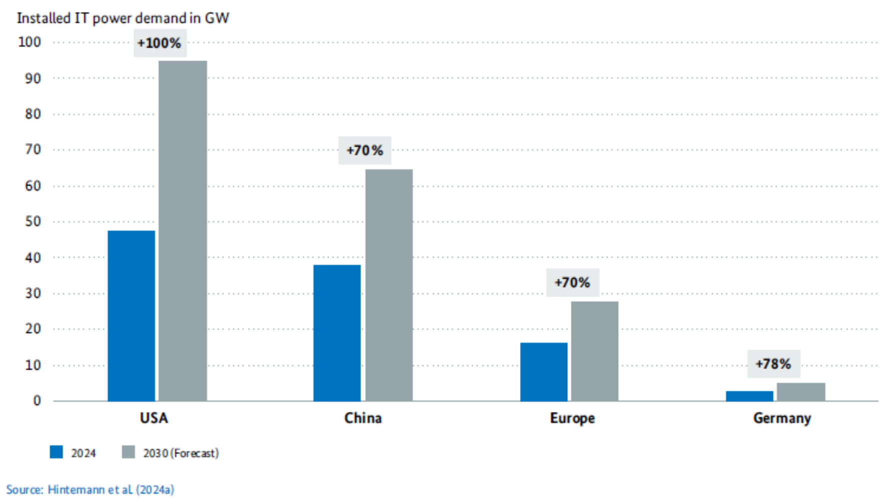

Figure 5. Estimated development of data center capacities in the USA, China, Europe, and Germany in 2024 and 2030. (BMWK, 2025)

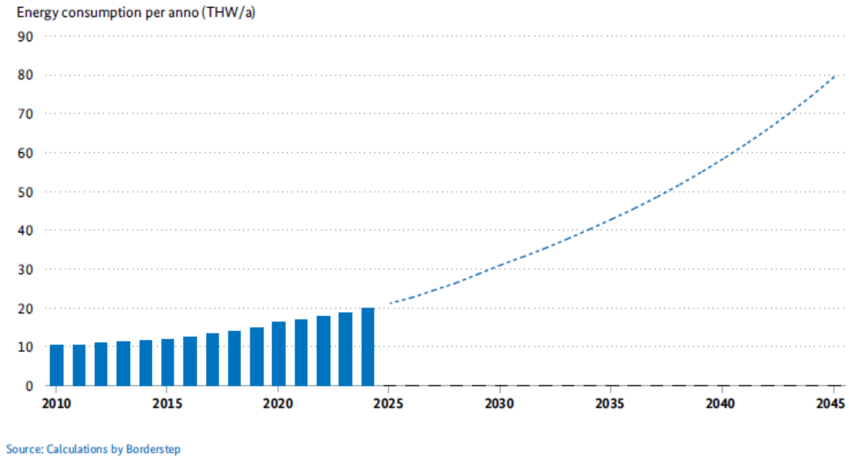

Figure 6. Development of the electricity needs of data centers and smaller IT installations in Germany in the years 2010 through 2024, and long-term prediction through 2045 (BMWK, 2025)

6. Integrated Analysis: AI as a Water-Resilience Lever

Combining insights from the five references reveals an interdependent set of drivers:

1. Hydrological decline elevates irrigation dependency in Brandenburg and Saxony-Anhalt (Ebeling et al., 2025).
2. Diversified agronomy increases drought tolerance but requires precision deployment (Macholdt, 2025).
3. Large farm enterprises are positioned to lead AI adoption (Balmann, 2025).
4. Governance misalignment delays technology-enabled resource coordination (Märker, 2022).
5. Digital expansion introduces new water-energy pressures (BMWK, 2025).

The interaction of these factors determines whether AI will solve or worsen Germany's water-agriculture crisis. In a high-adoption scenario, large farms in eastern Germany could leverage AI-enhanced irrigation scheduling and crop-water monitoring to reduce unnecessary groundwater abstraction during drought recovery phases. In low-adoption contexts, particularly among family farms, lack of digital access may accelerate vulnerability and economic loss.

In summary of this section, groundwater scarcity in drought-sensitive states such as Brandenburg, Saxony-Anhalt, and Lower Saxony poses an urgent threat to agricultural productivity (Ebeling et al., 2025). Agronomic diversification already provides measurable risk reduction (Macholdt, 2025), but fully realizing water-resilient farming requires AI-enabled prediction and precision. Structural differences in farm size and resources mean that AI adoption — and thus water-adaptation benefit — will not be uniform across Germany (Balmann, 2025). Digital infrastructure expansion required for AI places new demands on national water and energy systems, particularly in regions where freshwater stress is already high (BMWK, 2025). Governance frameworks must therefore integrate water, agriculture, and digitalization objectives to ensure that AI supports — rather than undermines — sustainability goals (Märker, 2022).

Ultimately, Germany's agricultural water future will depend on how well AI deployment is aligned with hydrological constraints, farm-structural realities, and nexus-aware governance. When combined strategically with diversified cropping systems and region-specific policy support, AI offers a critical lever for maintaining food security while protecting groundwater resources in an era of increasing climatic instability.

Case Studies

The following section outlines case study examples of the impacts of AI on communities in different contexts.

United States

Saline, Michigan

Saline is a township in Michigan, which is a state within the Great Lakes region of the U.S. In Saline, farming communities and residents are protesting a data center development that is lauded by some as the largest investment the state of Michigan has ever made (Davidson, 2025; Kast & Falconer, 2025). This development is sparking concerns regarding the data center's impact on water, the environment, and residents' utility bills. Despite the potential magnitude of impact, DTE Energy is seeking expedited approval from the Michigan Public Service Commission, which circumvents the contested hearing litigation process to provide energy for this infrastructure project (Kast & Falconer, 2025). Additionally, Related Digital, a development company, filed a lawsuit after the Saline Township Board voted not to allow rezoning for the data center (Allnutt, 2025).

This lawsuit was settled , with the township allowing rezoning and Related Digital earmarking $2 million for community investment, $4 million for agricultural land preservation, and $8 million for area fire services (Allnutt, 2025).

While the Great Lakes ostensibly has abundant water that can support water-intensive projects such as this data center, much of water use actually comes from groundwater sources (Otwell, 2023). 39% of groundwater usage is for irrigation in Michigan (Otwell, 2023), and conflicts over groundwater use with data centers are already underway in the Great Lakes region (Volz, 2025).

Saline is a case study that exemplifies the lack of public participation in AI regulation in developments that may be extremely consequential for farmers. While the township's settlement with Related Digital includes benefits for the community, it is difficult to determine whether the community will net benefit in the long run, especially due to the lack of transparency in the process of determining the data center's impacts.

Oregon

The impact of AWS' DC operations in Eastern Oregon demonstrates how a community investment model that focuses on economical, educational, and environmental sustainability can empower local townships.

Economically, AWS has invested over $15.6 billion in Morrow and Umatilla counties from 2012 to 2021 (About Amazon, 2023). This supported thousands of local jobs and contributed more than $1.1 billion to the local GDP (About Amazon, 2023). These investments have also funded public infrastructure and community assets, such as a water tower and a city hall in Hermiston without taxpayer burden on local residents.

Education wise, AWS directly funds STEM education through partnerships with local colleges and workforce training programs like the Blue Mountain Community College. This involved a $2 million donation to local educational organizations in 2022 alone, and these social initiatives expand STEM learning opportunities to approximately 8000 students (About Amazon, 2023).

Environmentally, AWS has implemented innovative solutions for resource management, most of which involves close cooperation with local agriculture communities.

One of them is to reuse 96% of DC cooling water, which is later provided to farmers at not charge for irrigation (Oregon Counties, 2023). This creates a new, free water source for farmers. Furthermore, AWS signed an agreement with Umatilla Electric Cooperative with a goal of using 100% renewable energy by 2025, where Oregon DCs are already powered by 95% renewable energy (Oregon Counties, 2023).

Such initiatives are complemented by projects like Hermiston's Aquifer Storage and Recovery system, which stores river water for community and AWS use (LeCompte, 2025). This aims to benefit farmers, fish populations, and future generations without costing a dime to local taxpayers (LeCompte, 2025).

Various counties in Eastern Oregon strongly demonstrate how DCs, under the right governance and transparency, can coexist with local agricultural communities and even enrich them.

Germany

These cases illustrate tensions in water-stressed areas, where data centers' blue water demands clash with green water for crops, prompting calls for dynamic cooling and siting reforms.

<u>Frankfurt Data Centers</u>

High electricity (30% city total) and groundwater use for AI cooling competes with agricultural irrigation; farmers note indirect stress from grid water intensity.

Mandated water reporting under EnEfG; shift to hybrid cooling and heat reuse, but electricity access limits expansion.

Brandenburg Irrigation Conflicts

Data centers and industry draw from stressed groundwater, threatening vegetable/potato farmers amid droughts; reuse potential explored but risks overuse.

Regional management concepts developed for conflict resolution between public supply, agriculture, and industry.

Tesla Gigafactory Protests

Massive water extraction (claimed 71,000x average household use) pollutes sensitive lakes, sparking farmer protests over reserves for irrigation and firefighting.

Interviews

United States

We have conducted 4 interviews in the U.S. Two of them were policy personnel from Oregon, and the other 2 were authors of the research papers we used for our literature review. We will not mention their identities as they wished to remain anonymous.

Policy - Oregon

The first two interviews in Oregon demonstrated a positive example of how local farmers and DCs can coexist for mutual benefit.

The interviews revealed that when DCs are integrated in remote communities thoughtfully, it can become strong economic anchors while avoiding major conflicts with agriculture. Even relatively small permanent workforces, typically 100-150 employees per campus, can generate meaningful benefits for the local economy. For instance, those new workers are potential customers for the local grocery store, the local dentist, restaurants, etc. In several Oregon counties, tax revenues generated by DCs fund essential public services and participate in donations and social investments. For example, in Morrow County, Amazon paid up to $54 million in property taxes, which were used to fund public services like schools and libraries. These benefits support residents who value both economic opportunities while preserving their small-town character.

Another positive outlook is that much of the water in local DCs are recycled and discharged back into irrigation channels where it becomes available for farmers. Since Oregon is located near the Columbia River, they were able to install an Aquifer Storage and Recovery (ASR) system, where excess water during the winter is pumped from rivers into underground storage and withdrawn later for DC operations during peak agriculture seasons. This prevents DCs from directly competing with farmers for water during peak growing seasons.

Finally, the interviews demonstrated water and infrastructure policy and foster cooperation between the two groups rather than conflict. Since farmers are price takers, rural governments encouraged DCs to use water efficiently while generating revenue to maintain water delivery systems. For example, DCs often pay the freight of moving and treating water, which lowers the cost for farmers who later receive the discharged water.

From a resource standpoint, DCs in these regions actually use significantly less water per acre than local crops. For example, major crops grown in Oregon, like potatoes, corn, and onions consume around 800,000 gallons per acre per season. On the other hand, a hyperscale DC footprint uses 400,000 gallons of water per acre annually. Moreover, half of this water is returned to agriculture streams for farmers to use.

We concluded that small townships in Oregon demonstrate a strong example of how with the right governance structures, DCs can coexist and even support local agriculture livelihoods. However, these two interviews focused more on scope 1 water footprint. Scope 2 water footprint remains unaddressed, which is a much bigger issue than scope 1 water footprint.

Research Authors

These two interviews highlighted the interaction between AI DCs and agriculture communities are fundamentally location-dependent, and shaped by other factors such as surrounding energy mix and operational design of DCs. Scope 1 on-site withdrawals are the most immediate threat to farming communities since this involves the direct consumption of groundwater and surface water available to irrigation. While Scope 2 water footprint is much larger in volume, its diffuse and geographically spread nature makes it difficult for a local community to identify.

Their research also emphasizes that hybrid cooling technologies can address local water competition. Hybrid cooling offers a promising balance, dynamically switching between dry and wet cooling depending on several factors like weather, grid carbon intensity, local drought conditions, and irrigation seasons.

Our interviews also expressed the critical importance of transparency, public reporting, and much tighter water governance. Both experts highlighted the secrecy around water consumptions and how this prevents farming communities from establishing a strong case when negotiating fair resource-sharing agreements. This lack of transparency can be solved with basin-level public dashboards, mandatory disclosure of scope 1 and scope 2 water use, and 3rd party audits tied to permitting.

As for technological mandates, requiring hybrid cooling is often impractical given the existing infrastructure. However, operational rules are feasible. For example, DCs could be required to reduce wet cooling during peak drought seasons, or temporarily interrupt non-urgent AI training workloads during heatwaves. Their research also showed that AI workloads can be dynamically scheduled, such as running at night or shifting computation to regions with lower water footprint.

Lastly, both interviews identified some meaningful areas for cooperation between farmers and DCs. Although water recycling and hybrid cooling technology can reduce on-site withdrawals, some of the highest impact comes from funding farmer-side conservation. This includes irrigation modernization, investing in soil-moisture technology, and canal rehabilitation. For policymakers in water-stressed regions, such as those in Arizona or Texas, the experts recommended the following actionable measures:

A) Impose strict limits on potable groundwater use in stressed basins
B) Create incentives for low-water cooling technologies or operations
C) Stronger carbon-water impact assessments supported by transparent water usage data (mandate scope 1 and scope 2 water usage by DCs)
D) Drought curtailment clauses
E) Community benefit agreements that support agricultural water security

Germany

To better understand how artificial intelligence (AI) infrastructure intersects with agricultural water security in Germany, five semi-structured expert interviews were conducted between January and February 2025. The respondents represent diverse sectors including digital infrastructure, agroecology, rural development, environmental science, and global water governance. Their expertise spans field-level agricultural realities, AI cooling systems, water-policy implementation, and cross-sector cooperation frameworks. This section synthesizes their insights to characterize emerging conflicts and cooperation pathways between farmers and the rapidly expanding data-center ecosystem.

AI and Data-Center Water Demand: Invisible Pressures (A. Caliwag, personal communication, 2025)

From a technological standpoint, AI workloads — particularly large model training and high-frequency inference — are becoming one of the most resource-intensive forms of computation. Caliwag explained that in temperate climates like Germany, most major data-center operators rely on evaporative cooling, which directly consumes groundwater or municipal freshwater depending on siting conditions. She emphasized that although energy demand receives significant regulatory oversight, water withdrawals remain largely unreported, especially in scope-2 categories linked to electricity generation.

She warned that the geographic clustering of AI compute along major grid interconnections — including Berlin-Brandenburg and portions of Lower Saxony — will intensify water-resource strain specifically in agricultural regions already facing irrigation stress. The most critical problem, she noted, is opacity: without reliable public disclosure of annual cooling-water consumption, rural communities cannot anticipate stress scenarios or influence permitting processes. Her primary recommendation is that water use — both on-site evaporative consumption and off-site water-for-energy impacts — should be regulated and disclosed at parity with carbon reporting.

Agricultural Water Security and Farmer Awareness (A. Maranda, personal communication, 2025)

Providing a farm-system perspective, Maranda described a German agricultural sector already operating under water scarcity, especially in Brandenburg, Saxony-Anhalt, and northern Lower Saxony, where irrigation permits have tightened and shallow aquifers face seasonal depletion. Farmers are adapting through precision irrigation systems, drought-tolerant crop choices, and soil-moisture conservation practices. However, these multi-year adaptation strategies are now threatened by new industrial water users whose presence farmers often learn about only after policy decisions have been finalized.

Maranda stressed that the information asymmetry between municipalities and farmers is one of the biggest sources of anxiety: farmers typically do not know how much water a nearby data center is scheduled to use, nor whether emergency restrictions will affect their growing season before an industrial cooling system curtails operations. She argued that transparent reporting of industrial water withdrawals and return flows would enable proactive farm management, reduce community mistrust, and ensure accountability in water-allocation decisions.

<u>Rural Governance and Uneven Power in Siting Decisions (T. Edria, personal communication, 2025)</u>

From a governance perspective, Edria emphasized that digital-infrastructure siting in Germany often prioritizes economic development over long-term water security. Municipalities may accept large compute-site proposals because they provide tax revenue, land-value appreciation, and short-term jobs. However, the resulting benefits rarely accrue directly to farmers, while the risks concentrate heavily on them — particularly when water permits restrict irrigation before cooling systems are affected.

Edria stressed that public participation in water-allocation processes remains insufficient, especially in rural areas lacking strong administrative representation. Farmers and local citizens are typically consulted reactively, only once siting and permit agreements are nearly final. She advocated for local water-council frameworks where agriculture, municipalities, and digital industries negotiate water allocation before extraction thresholds are set. Without these mechanisms, she warned that water scarcity will evolve from a climate problem into a governance conflict.

<u>Environmental and Ecological Risks From Industrial Water Use (N. Stupak, personal communication, 2025)</u>

Stupak highlighted the ecological implications of industrial water expansion under drought stress. She explained that irrigation in response to groundwater decline can intensify soil degradation, including compaction, salinization, and nutrient leaching. When data centers draw additional water from the same basins, the threshold for ecological tipping points is reached faster: wetlands contract, groundwater recharge slows, and groundwater-dependent ecosystems lose functionality.

A major challenge she identified is that many of the same regions that attract hyperscale operators — due to available land, renewable-energy access, and proximity to fiber backbones — are also the regions with highest ecological vulnerability. Stupak argues that Germany's National Water Strategy (2023) is an important step toward holistic resource governance, but its implementation currently lacks sector-specific safeguards for emerging digital industries. She recommended that environmental permits for data centers include long-term cumulative-impact assessments, explicitly considering aquifer depletion thresholds and groundwater-dependent habitats.

Global Water Governance Lessons for Germany (M. A. Milan, personal communication, 2025)

Bringing a global development lens, Milan emphasized that water conflict between agriculture and industry is not new in global South contexts. She noted that countries with decades of experience regulating water-intensive mining, beverage plants, and power generation have adopted proactive measures such as:

- Mandatory water-use transparency
- Community oversight boards
- Rainwater harvesting requirements
- Industrial water-recycling mandates
- Drought-contingency curtailment rules

Milan argued that Germany can avoid future conflict by applying similar governance principles before agricultural livelihoods are harmed. She was particularly emphatic that digital facilities should never have priority over food production during drought. She also highlighted that AI and digital monitoring tools can support detecting leaks, monitoring irrigation efficiency, and tracking groundwater-table dynamics, but warned that such innovations must not be used to justify industrial over-consumption elsewhere in the system.

Integrated Assessment From Interview Findings

Across all five interviews, several points of consensus emerged:

- Water is becoming the core limiting resource for rural economic stability in Germany.
- Data-center water use is largely invisible, making risks hard to quantify and manage.
- Farmers remain under-represented in water-allocation and siting decisions.
- Ecological thresholds are tightening, especially in areas targeted for digital growth.
- Governance innovation is needed, not just technological adaptation.

Where the interviewees differed was primarily in response scope:

- The digital-infrastructure expert focused on transparency and reporting.
- The agricultural expert emphasized operational fairness and early warning.
- The rural-governance specialist prioritized power redistribution in decision-making.
- The environmental scientist highlighted ecosystem limits and freshwater resilience.
- The international expert insisted on prevention through planning, not reaction.

Conclusion

Across both the United States and Germany, a common pattern emerges: AI-driven data center expansion is colliding with agriculture in regions where water has already become a binding constraint for rural development. In each country, farmers depend on increasingly stressed groundwater and surface supplies, while data centers introduce new blue-water demands and large indirect water footprints through electricity consumption, particularly in drought-prone or agriculturally intensive areas. Despite differences in regulatory style—market-led in the U.S. and more rules-based in Germany—both systems struggle with transparency, fragmented governance across water, energy, and agriculture, and uneven participation of farmers in siting and allocation decisions. In both contexts, the future relationship between AI infrastructure and farming hinges less on technology alone and more on whether institutions can coordinate strategic siting, enforce water reporting, and prioritize food production when scarcity intensifies.

Taken together, these findings show that water scarcity in both countries is no longer only a climate or hydrological variable, but also a question of institutional priorities, economic power, and equity. To prevent AI infrastructure from undermining agricultural water security, experts emphasize that transparency must precede expansion, farmers must become co-decision makers rather than afterthoughts, and ecological thresholds must be embedded into permitting and planning. Digital growth and food production can coexist in both the U.S. and Germany, but only if water allocation is governed as a shared resource rather than a competitive asset.

Recommendations

Policy and governance

- Mandate comprehensive disclosure of both on-site cooling water use (scope 1) and grid-related water footprints (scope 2) for all large data centers, enabling basin-level monitoring and informed local decision-making.
- Establish formal farmer-inclusive water councils or stakeholder forums in regions targeted for hyperscale development so that agricultural voices shape siting, allocation rules, and drought-contingency plans from the outset.
- Integrate water, energy, and agricultural objectives into permitting frameworks by requiring cumulative impact assessments that consider groundwater thresholds, ecological limits, and long-term food security.

Technical and operational measures

- Encourage or require hybrid and dynamic cooling strategies that switch to less water-intensive modes during peak irrigation seasons or declared droughts, even at modest energy or cost penalties.
- Promote spatiotemporal scheduling of AI workloads, shifting non-urgent computation to cooler periods or regions with low water-intensity grids to reduce both local and upstream water stress.
- Use strategic siting criteria that favor locations with lower water scarcity footprints and cleaner, less water-intensive power mixes, avoiding concentration of data centers in the most drought-sensitive agricultural basins.

Farmer-focused and rural benefits

- Tie data center approvals to community benefit agreements that fund on-farm water conservation, such as irrigation modernization, soil-moisture monitoring, and canal or delivery-system upgrades.
- Support pilot projects where treated cooling water or managed aquifer recharge schemes provide additional, reliable supplies for nearby farmers under strict environmental safeguards.
- Ensure that, in both national and regional drought plans, food production and basic rural livelihoods have clear priority over non-essential digital workloads when allocating scarce water resources.

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