

Global Energy and Freshwater Use, 2020-2025: Trends, Data Gaps and Implications for the Water-Energy Nexus

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Abstract - Energy and freshwater are closely connected resources, but the evidence used to track them is updated at very different rates. This study reviews global energy and freshwater-use patterns from 2020 to 2025 using the Energy Institute Statistical Review of World Energy, International Energy Agency (IEA) assessments, FAO AQUASTAT and World Development Indicators, UN-Water reports and World Bank population data. Global total energy supply rose from 536.07 exajoules (EJ) in 2020 to about 600.31 EJ in 2025. This is an increase of 12.0% over the period, equivalent to an approximate compound annual growth rate of 2.3%. Energy supply per person also increased, from 68.26 to 73.07 gigajoules (GJ). The global freshwater record is less current. Comparable AQUASTAT/World Bank observations are consolidated only through 2022, when withdrawals were approximately 3,876 billion m³ in 2020, 3,850 billion m³ in 2021 and 3,853 billion m³ in 2022. Thus, aggregate withdrawals changed very little during the years for which both energy and water data are available, while freshwater withdrawal per person declined from about 493.5 to 482.3 m³ per year. Over the same interval, the descriptive water-to-energy co-use ratio fell from 7.23 to 6.75 billion m³ per EJ. This ratio describes the movement of two economy-wide aggregates and should not be read as the water intensity of energy production. Taken together, the results suggest a limited form of macro-level relative decoupling: energy supply expanded without a corresponding rise in total freshwater withdrawals during 2020-2022. At the same time, regional water scarcity and water stress remain important concerns. The analysis also identifies a significant information gap. Energy statistics extend to 2025, whereas globally harmonized freshwater-withdrawal data lag by several years. More timely water accounting and basin-level reporting would improve the basis for integrated energy and water planning.

Key Words: water-energy nexus, total energy supply, freshwater withdrawals, AQUASTAT, energy transition, water stress, resource efficiency, SDG 6, covid

1. INTRODUCTION

Energy and water are basic inputs to modern economies and to everyday life. They support agriculture, industry, cities, health services and adaptation to climate pressures. Their relationship is two-way. Water systems consume energy for pumping, treatment, distribution, heating, cooling and desalination, while energy systems depend on water for activities such as fuel processing, thermal power-plant cooling, hydropower, bioenergy and manufacturing. Decisions made in either sector can therefore create benefits, costs or risks in the other. The term water-energy nexus is used to describe this interdependence, while broader studies place it within water-energy-food and climate-land-energy-water frameworks (Ding et al., 2020; Purwanto et al., 2021; Vinca et al., 2021).

The period from 2020 to 2025 is especially useful for examining these connections because it combines an abrupt disruption with a rapid recovery. The COVID-19 pandemic reduced travel, industrial activity and energy demand in 2020. What followed was a strong rebound, renewed concern over energy security, sharp movements in commodity prices and faster deployment of solar photovoltaic and other low-carbon technologies. Electricity use continued to expand as well. By 2025, global energy demand was still growing, although at a slower rate than in 2024 and the IEA identified solar photovoltaic generation as the largest individual contributor to incremental energy growth (IEA, 2026).

The water side of the picture is harder to observe with the same immediacy. Global freshwater statistics are assembled from national systems that differ in reporting frequency, measurement practices and sector classifications. The FAO AQUASTAT Water Data Snapshot released in 2025 notes that the reporting cycle conducted in 2024 contains data only up to 2022. A global study ending in 2025 therefore faces a clear timing problem: energy indicators can be assessed almost to the present, whereas comparable freshwater-withdrawal observations stop several years earlier. Rather than estimating the missing years and presenting them as observations, this study treats the reporting lag as part of the methodological problem. That choice is important both for research transparency and for the quality of resource planning.

Against this background, the study addresses four objectives.

- 1) To describe the change in global total energy supply between 2020 and 2025.
- 2) To examine available freshwater-withdrawal observations for 2020-2022 and make the 2023-2025 reporting gap explicit.
- 3) To express both resource measures on a per-capita basis and use a simple descriptive co-use ratio to compare their movement during the common observation period.
- 4) To discuss what these trends imply for energy transition, water scarcity, resource efficiency and statistical governance. The analysis is descriptive; the short global time series is not used to make causal claims.

2. LITERATURE REVIEW AND CONCEPTUAL BACKGROUND

Water-energy research now goes beyond listing physical links between the two sectors and increasingly asks how decisions in one system affect the other. Ding et al. (2020) review the development of the nexus concept and explain why water and energy policy cannot be treated independently. Purwanto et al. (2021) extend this perspective through the water-energy-food nexus, linking sector decisions with wider sustainable-development goals.

Integrated modelling has developed alongside this conceptual work. Vinca et al. (2021) show that climate-land-energy-water models can support Sustainable Development Goal analysis across spatial scales, but they also identify limits created by model complexity, uneven data coverage and accessibility. Chini et al. (2021) reach a similar conclusion in their review of energy-for-water data: availability and standardization remain recurring problems. Better models therefore still depend on primary statistics that are timely and comparable.

A second strand of research concerns efficiency and decoupling. Ke et al. (2022), using longitudinal data for China, report falling water and energy intensities and show how efficiency can moderate resource-demand growth. At the global level, UN-Water reports that water-use efficiency rose from USD 17.4 per m³ in 2015 to USD 20.8 per m³ in 2021, an increase of 19.3%. However, it does not conclude that any region has fully decoupled economic growth from water use (UN-Water, 2024a). Improved efficiency is therefore not the same as evidence that local ecological limits are being respected.

The energy transition adds another dimension because technologies differ greatly in their water requirements. Wind and solar photovoltaic generation generally use less operational freshwater than many thermal pathways, but system-level effects still depend on the generation mix, cooling technology, location, supply chains and storage. Hydropower and bioenergy can also create significant water or land-water pressures. Helerea et al. (2023) therefore argue that transition pathways should be evaluated for water dependence as well as carbon performance.

This study contributes by assembling a concise global picture for the post-pandemic period and by treating publication timing as part of the nexus problem. The issue is not only whether energy and water indicators changed differently, but also whether they can be observed with comparable timeliness. That question matters because integrated policy decisions are often made before all resource statistics for the same year are available.

3. DATA AND METHODS

3.1 Data sources and variable definitions

Total energy supply (TES), measured in exajoules (EJ), is used as the energy indicator. Values for 2020-2024 come from the Energy Institute's 2025 Statistical Review and the 2025 value comes from the 2026 edition. Because historical figures can be revised between editions as national data and methods are updated, small annual differences are not over-interpreted. The IEA Global Energy Review 2026 is used as an independent check on 2025 demand growth and technology trends.

Freshwater use is represented by annual freshwater withdrawals in billion cubic metres per year. Under the World Development Indicators/AQUASTAT definition, the measure covers freshwater abstracted for agriculture, industry and domestic or service uses; desalinated water may be included where important. Withdrawal is not the same as consumption because some abstracted water is returned after use. The AQUASTAT/World Bank international series currently extends through 2022 and the 2025 AQUASTAT Water Data

Snapshot confirms that endpoint. No global values are imputed for 2023-2025.

World population data for 2020-2025 are taken from the World Bank World Development Indicators series distributed through FRED. These figures are used to calculate per-capita energy supply and freshwater withdrawals.

Table -1: Main datasets and coverage used in the study.

Dataset / institution	Indicator used	Unit	Latest year used	Role in analysis
Energy Institute, Statistical Review	Total energy supply	EJ	2025	Primary global energy series
IEA, Global Energy Review 2026	Energy-demand growth and technology context	% / EJ	2025	Independent contextual check
FAO AQUASTAT / World Bank WDI	Annual freshwater withdrawals	billion m ³ /year	2022	Primary global water series
UN-Water	Water stress, water-use efficiency, sector shares	% / USD per m ³	2021-2025 publications	Sustainability context
World Bank WDI / FRED	World population	persons	2025	Per-capita normalization

3.2 Derived indicators

Three additional indicators are calculated from the source data.

- 1) Energy supply per person is obtained by converting TES from EJ to GJ and dividing the result by world population.
- 2) Freshwater withdrawal per person is calculated by converting annual withdrawals from billion m³ to m³ and dividing by population.
- 3) A macro co-use ratio is also calculated for 2020-2022, the years in which both datasets overlap. It is defined as total global freshwater withdrawals in billion m³ divided by total global energy supply in EJ. The measure is deliberately descriptive. Its numerator includes agricultural, municipal and industrial withdrawals that have no direct connection with energy production, so it cannot be treated as an engineering estimate of the water intensity of the energy sector. It is used only to show whether the two global resource totals moved proportionately over the same period.

Change over time is reported as the percentage difference between the first and last available observations. For energy, the six-year series is also summarized with a compound annual growth rate (CAGR). The purpose is to describe direction and scale rather than test a causal model. Formal hypothesis tests are therefore not applied to these short, highly aggregated global series.

3.3 Data-quality protocol

Four rules were followed to reduce avoidable inconsistency. First, the analysis gives priority to recognized data custodians and primary statistical sources: the Energy Institute and IEA for energy; FAO AQUASTAT, the World Bank and UN-Water for water; and the World Bank for population. Second, source definitions are retained rather than converting withdrawals into consumption or combining different energy-accounting conventions. Third, missing global water observations for 2023-2025 are shown as unavailable instead of being extrapolated. Fourth, global results are interpreted alongside their spatial limitations, since a world average can conceal severe water stress in individual countries and river basins.

4. RESULTS

4.1 Global energy supply: recovery after 2020 and continued growth

Global total energy supply recovered strongly after the decline recorded in 2020. TES increased from 536.07 EJ in 2020 to 563.26 EJ in 2021 and reached 571.04 EJ in 2022. The upward movement continued to 580.28 EJ in 2023, 592.22 EJ in 2024 and approximately 600.31 EJ in 2025. Across the full period, energy supply rose by about 12.0%, corresponding to an approximate CAGR of 2.3%. The IEA's 2026 review provides a useful independent check on the final year: it reports a 1.3% increase in global energy demand in 2025, or roughly 8 EJ, compared with a 2% rise in 2024. Solar PV made the largest single contribution to the additional demand supplied in 2025 (IEA, 2026).

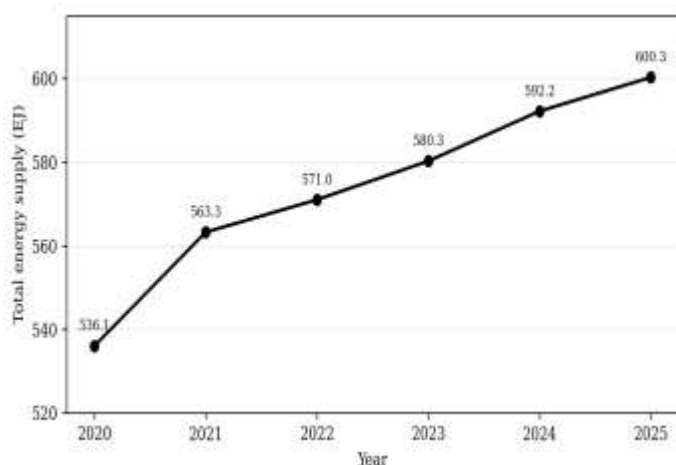


Fig -1: Global total energy supply, 2020-2025. Sources: Energy Institute (2025, 2026).

Energy supply also grew faster than world population. On a per-capita basis, the series increased from 68.26 GJ in 2020 to 73.07 GJ in 2025, a gain of about 7.1%. The result indicates that the rise in aggregate energy supply cannot be explained by population growth alone. Average commercially traded energy availability per person was also higher at the end of the period.

Table -2: Global energy, freshwater and population indicators, 2020-2025.

Year	Energy supply (EJ)	Population (bn)	Energy (GJ/per son)	Freshwater withdrawals (bn m ³)	Water (m ³ /per son)	Macro co-use (bn m ³ /EJ)
2020	536.07	7.854	68.26	3,876	493.5	7.23
2021	563.26	7.920	71.12	3,850	486.1	6.84
2022	571.04	7.989	71.48	3,853	482.3	6.75
2023	580.28	8.063	71.97	n.a.	n.a.	n.a.
2024	592.22	8.141	72.75	n.a.	n.a.	n.a.
2025	600.31	8.215	73.07	n.a.	n.a.	n.a.

Note: Comparable AQUASTAT/WDI freshwater observations were not globally consolidated for 2023-2025 when this analysis was prepared. These years are therefore reported as unavailable rather than estimated or backfilled.

4.2 Freshwater withdrawals: little aggregate change and a recent data gap

The available global freshwater-withdrawal series is much flatter than the energy series. Withdrawals were about 3,876 billion m³ in 2020, 3,850 billion m³ in 2021 and 3,853 billion m³ in 2022. This is a decline of roughly 0.6% between 2020 and 2022, leaving the global total close to 3.85 trillion m³ per year. Such stability at the world level should be interpreted cautiously. Water scarcity depends on where and when withdrawals occur, so an almost unchanged global total can coexist with worsening pressure in particular basins or regions.

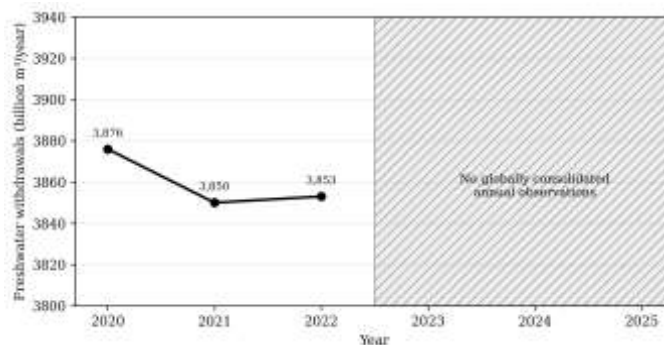


Fig -2: Global annual freshwater withdrawals, observed years and current data-coverage gap. Source: FAO AQUASTAT/World Bank WDI, processed international series; FAO (2025) confirms the latest global reporting cycle covers data through 2022.

Freshwater withdrawal per person declined from approximately 493.5 m³ in 2020 to 482.3 m³ in 2022, or about 2.3%. A near-stable aggregate total combined with population growth is consistent with a falling per-capita measure, although the present data do not identify the drivers of that change. Broader efficiency indicators provide useful context. UN-Water reports that global water-use efficiency improved by 19.3% between 2015 and 2021, increasing from USD 17.4 to USD 20.8 per m³. At the same time, global water stress was

estimated at 18.6% in 2021 and differed widely across regions (UN-Water, 2024a, 2024b).

4.3 Energy and water during the common observation period

The contrast is clearest when the two series are restricted to 2020-2022. Total energy supply increased over these three years, whereas freshwater withdrawals remained close to their 2020 level. With 2020 set equal to 100, the energy index reached 106.5 in 2022 and the water-withdrawal index stood at about 99.4. The macro co-use ratio consequently declined from 7.23 billion m³/EJ to 6.75 billion m³/EJ, a reduction of around 6.7%. In descriptive terms, this pattern is consistent with relative decoupling at the global aggregate level because energy supply grew without a proportional increase in total freshwater withdrawals.

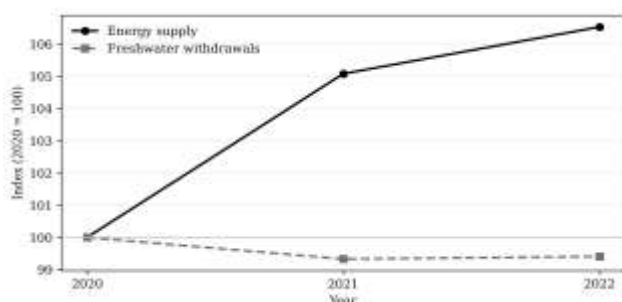


Fig -3: Indexed global energy supply and freshwater withdrawals during the overlapping observation window (2020 = 100).

That interpretation must remain narrow. Agriculture accounts for about 72% of global freshwater withdrawals in the SDG 6 reporting framework, while industrial and service uses account for the remainder. The numerator of the co-use ratio is therefore dominated by activities outside the energy sector. A decline in the ratio could reflect changes in irrigation, economic structure, population, energy efficiency, power-sector technology, hydrological conditions or revisions to the underlying statistics. The indicator is best understood as a measure of economy-wide co-movement, not as a direct estimate of water used to produce one unit of energy.

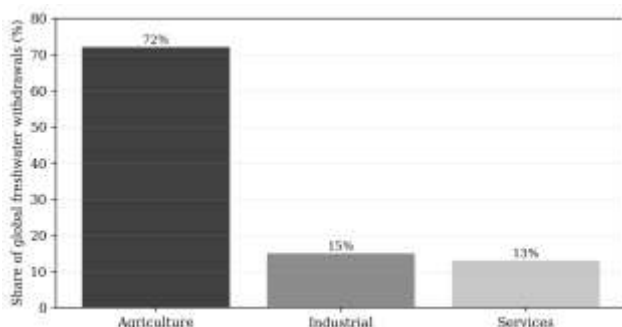


Fig -4: Approximate sectoral shares of global freshwater withdrawals. Source: UN-Water (2024b): agriculture 72%, industrial sector 15%, services 13%.

5. DISCUSSION

5.1 Energy recovered faster than aggregate freshwater withdrawals

The most visible result is the different pace of change in the two global series. Energy supply expanded markedly after the 2020 downturn, whereas observed freshwater withdrawals showed little movement during the years that overlap. There

are several plausible explanations. Improvements in energy intensity can reduce the energy required for a given level of economic activity; changes in electricity technology can alter water requirements; and gains in agricultural or industrial water productivity can limit withdrawals even when output rises. The IEA also points to faster improvements in energy intensity as one reason global energy-demand growth moderated in 2025.

These results are compatible with partial decoupling among resource use, population and economic activity, but the evidence is not sufficient to establish why it occurred. A more demanding analysis would need regional and sector-level information on water consumption, cooling systems, electricity generation technologies, irrigation, industrial structure, prices and climate conditions. Global totals cannot distinguish technological efficiency from shifts in the location of water-intensive production, hydrological variability, statistical revision or delays in national reporting.

5.2 Stable global withdrawals do not imply low water risk

Water scarcity is shaped by place, season and available supply, not only by the total volume withdrawn. One cubic metre taken from a water-abundant basin does not carry the same environmental or social risk as the same withdrawal from an arid or already over-allocated basin. UN-Water reports a global water-stress level of 18.6% for 2021, below the 25% threshold used for aggregate classification, while also identifying regions with high or critical stress and large populations exposed to those conditions. The global average therefore has limited value for decisions that depend on local water availability.

The same spatial logic applies to energy-transition choices. Wind and solar PV can have low operational freshwater requirements compared with many thermal technologies, but their actual water benefit depends on the technology they replace, their location and their supply chains. Recirculating and once-through cooling, dry cooling, nuclear generation, hydrogen production, bioenergy, hydropower and mineral processing each create different patterns of water dependence. For planning purposes, the label 'clean energy' is therefore not enough; water implications need to be assessed by technology and by basin.

5.3 Delayed water statistics as a planning constraint

One of the clearest findings is institutional rather than physical. The Energy Institute and the IEA are able to publish global energy assessments for the immediately preceding year, which makes it possible to discuss 2025 energy conditions in 2026. The 2025 AQUASTAT snapshot, however, reports globally consolidated water data only through 2022. The difference is understandable because water statistics often depend on administrative records, surveys, sector estimates and national reporting cycles. Even so, the result is a multi-year information gap during a period in which climate conditions, infrastructure and demand can change quickly.

This difference in reporting speed matters for integrated planning. Energy investments may be assessed using current information on demand, prices and technology deployment, while the corresponding water assessment relies on older averages or irregular observations. New electricity demand from cooling, industrial production, data infrastructure and electrification can therefore be evaluated with more current energy information than water information. The problem becomes more serious at basin scale, where drought and competition among users are decisive. Better metering, remote

sensing, consistent water accounting and interoperable annual reporting would reduce this mismatch and strengthen the evidence base for energy-transition decisions.

6. POLICY AND MANAGEMENT IMPLICATIONS

Integrated resource planning should begin with basin conditions rather than national averages alone. Appraisal of power and industrial projects should identify the proposed water source, expected withdrawal and consumption, seasonal availability, cooling system, drought exposure and possible competition with other users. These factors affect both project resilience and local social and environmental risk.

Energy-efficiency and water-efficiency measures should also be designed together. Lower energy demand can reduce water requirements in parts of the fuel and power supply chain. In the opposite direction, efficient irrigation, pumping and wastewater treatment can reduce the electricity required to deliver water services. Treating these measures as connected can reveal savings that sector-by-sector planning may miss.

Technology selection should account for water as well as carbon performance. Where conditions allow, low-water generation, dry or hybrid cooling, treated wastewater reuse and process-water recycling can reduce dependence on freshwater. Desalination can increase supply in water-scarce coastal areas, but it brings additional energy demand, cost and brine-disposal concerns. Its sustainability therefore depends in part on the electricity source and on effective environmental management.

Agriculture deserves particular attention because it represents about 72% of global freshwater withdrawals in the latest SDG reporting. Changes in irrigation technology, crop choice, soil-moisture management, scheduling and water allocation can therefore affect the global water balance more than many measures confined to the energy sector. At the same time, statistical agencies should work toward more timely annual water-use accounts, with clear sector definitions, uncertainty information and data-quality flags. Such reporting would make it easier to combine water statistics with energy and climate datasets without disguising missing observations.

7. LIMITATIONS AND RESEARCH PRIORITIES

Five limitations should be kept in mind when interpreting the results.

- 1) First, the energy series follows Energy Institute accounting conventions for commercially traded energy and modern renewables. It is therefore not identical to every measure of primary or final energy used in other databases.
- 2) Second, historical energy values may be revised from one annual edition to the next. The figures used here should be viewed as a harmonized analytical series rather than a permanently fixed data vintage.
- 3) Third, freshwater withdrawal and freshwater consumption are different concepts. Withdrawal data alone do not show how much water is returned after use or the resulting ecological effect.
- 4) Fourth, globally comparable water-withdrawal data end in 2022, so the study cannot present a fully observed annual water series for the complete 2020-2025 period.
- 5) Fifth, global aggregation hides important differences across countries, basins and seasons. The short

aggregate series is suitable for trend description but not for causal inference.

Future work should move toward regional panels that connect power-generation technology and cooling systems with energy supply, agricultural withdrawals, water stress, drought conditions and economic structure. Combining AQUASTAT and SDG 6 information with geospatial power-plant and river-basin datasets would make it possible to examine the location-specific water exposure of different energy-transition pathways. Another useful research direction is to measure the effect of statistical delay itself, including how often investment and policy decisions use water information that is several years older than the energy and economic indicators used alongside it.

9. CONCLUSION

From 2020 to 2025, global energy supply moved from the pandemic-related downturn to a new high. Total energy supply increased from 536.07 EJ to approximately 600.31 EJ, while energy supply per person rose by about 7%. The freshwater evidence covers a shorter period. Globally comparable observations currently extend through 2022 and withdrawals remained close to 3.85 trillion m³ per year between 2020 and 2022. Over the same years, freshwater withdrawal per person declined modestly. Because energy supply increased while the aggregate water total remained almost unchanged, the descriptive water-to-energy co-use ratio fell by about 6.7%.

This result should be viewed as a modest signal rather than evidence that global water use has become sustainable. It shows only that the increase in global energy supply during 2020-2022 was not accompanied by a proportional increase in total freshwater withdrawals. Agriculture remains the largest user of freshwater, water scarcity is concentrated geographically and climate variability is making water availability less predictable in many regions. Two priorities follow from the analysis: resource efficiency and low-water development pathways should continue to improve and water statistics need to become more timely and spatially detailed so that energy and water decisions can be made from evidence covering the same period.

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