
**IAEE Asia-Pacific Energy Economics Network
Webinar**

Global Virtual Water Flows and a Water Resource Curse?

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Paper: Virtual Water in
Global Supply Chains:
Trade Structure,
Industry Composition
and Policy Levers

Talk map: from component-specific virtual-water accounting to the no-generic-curse result

01 Context	Green manufacturing, virtual water, and the resource-curse question
02 Design	Literature gap, hypotheses, and latest manuscript contribution
03 Method	Eora MRIO, green/blue/grey water satellite accounts, and WDI macro variables
04 Facts	Component-specific rankings: advanced-economy inflows and emerging-economy outflows
05 Econometrics	Net/gross outflow models and GDP-growth tests
06 Implications	Supply-chain water risk, policy levers, and future research

Virtual-water flows are component-specific: trade and industrial structure matter more than simple water abundance.

Green / blue / grey

Rainfall, withdrawals, and pollution pressures differ.

Water withdrawal

Predicts blue/grey net outflows and all gross outflows.

Manufacturing

Most clearly associated with grey-water outflows.

Growth / curse

Green/grey are pro-growth; blue is insignificant; no generic curse.

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PART 1

Why water belongs in an energy-economics conversation

The paper is not only about water accounting. It links energy transition, global value chains, and development risk.

Low-carbon energy is not automatically low-water once manufacturing and infrastructure are counted

- **Solar PV manufacturing**

Silicon processing and wafer cleaning rely on large volumes of ultrapure water.

- **Wind and grid infrastructure**

Operational water use is low, but steel, concrete, and composite-material supply chains embed water use.

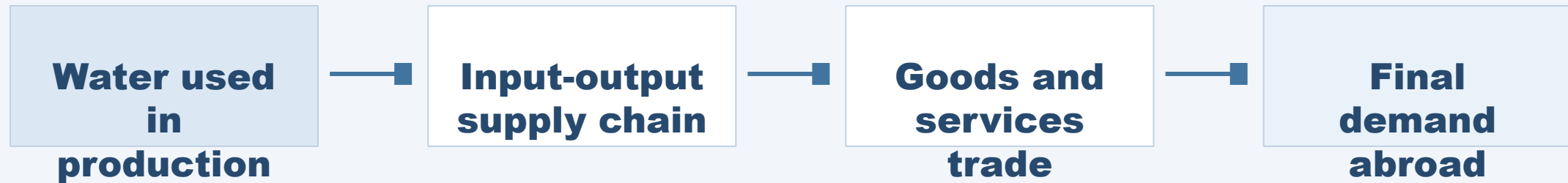
- **Hydropower and biofuels**

These technologies interact directly with basin hydrology, agriculture, and ecological flows.

- **The research question**

If green manufacturing depends on water, could water abundance become a development liability?

Virtual water is the hidden resource transfer embedded in traded goods and services



- The traded object is the product; green, blue, and grey water pressures are embodied in the production process.
- It connects intermediate inputs, final demand, and cross-border supply-chain linkages for each water component.
- **Energy-economics relevance**
Energy equipment, food, chemicals, metals, and services redistribute rainfall, withdrawals, and pollution pressure through trade.

The natural resource curse asks a counterintuitive question: can abundance reduce development?

Price volatility

Resource-price shocks destabilize revenue, investment, and public finances.

Dutch disease

Resource exports can appreciate currencies and weaken manufacturing.

Enclave effects

Dominant resource sectors may stay disconnected from the wider economy.

Rent seeking

Resource rents can strengthen corruption and political capture.

Conflict risk

Control over valuable resources can become a source of unrest.

Water differs from oil, gas, and minerals: it is dispersed, foundational, and harder to convert into a single rent stream

- **Spatially and seasonally distributed**

Water is organized by basins and hydrological cycles rather than by isolated mines or oil fields.

- **Foundational to production**

Irrigation, urban systems, industry, and ecosystems all rely on water; abundance can raise productivity.

- **Embedded in complex trade**

Virtual water appears in agriculture, manufacturing, services, and re-export chains.

- **Policy implication**

High virtual-water outflow does not automatically mean a resource-cursed economy.

Existing water-footprint research measures many flows, but explains too little about global drivers and development effects

- **Narrow empirical scope**

Much work focuses on single countries, regions, crops, food systems, or power sectors.

- **Limited explanatory framing**

The literature often asks where virtual water flows, but less often why countries become net exporters or importers.

- **Resource-curse gap**

Water has been discussed through hydropower projects, but not through a global virtual-water test.

- **This paper's entry point**

Build a 189-country green/blue/grey flow matrix; explain net and gross outflows; test whether water capacity and outflows shape growth.

Six hypotheses in the latest manuscript focus on component heterogeneity, water capacity, and growth.

Hypothesis	Expected relationship	Empirical meaning
H1 Heterogeneity	Green, blue, grey differ	Rainfall, withdrawals, and pollution are distinct
H2 Withdrawal	Blue/grey net; all gross	Mobilizable water matters
H3 Grey water	Manufacturing -> grey outflows	Industrial channel in pollution-related water
H4 Green water	Gross scale; weak net link	Rain-fed land use differs from withdrawals
H5 Growth	Green/grey positive; blue weak	Opportunity costs differ by component
H6 No curse	No lower-growth pattern	Tests oil/mineral curse analogy

PART 2

Data and method: turning global trade into a virtual-water matrix

The method traces water used in production through intermediate inputs and final demand.

Eora MRIO and WDI create a country-year panel for component-specific virtual-water flows.

189

countries/territories in the Eora MRIO system

26

sectors per country in the input-output structure

2010-2021

annual virtual-water result tables used for trends

Q + WDI

water satellite accounts plus macro variables

- **Eora26 Global Supply Chain Database**

Provides intermediate uses, final demand, output, value added, and the environmental satellite account Q.

- **Green, blue, and grey water in Q**

Q reports sectoral water footprints as blue surface/groundwater, green soil moisture, and grey dilution requirement.

- **WDI macro panel**

Adds total water withdrawal, manufacturing value added, natural-resource rents, population growth, trade openness, and GDP growth.

From sector networks to country networks: the MRIO matrix is collapsed into 189 by 189 country flows

01 Raw MRIO

189 countries x 26 sectors plus ROW produce a high-dimensional intermediate-flow matrix.

02 Country aggregation

Sector flows are summed by country to obtain bilateral intermediate and final-demand matrices.

03 Water occupation vector

Q reports green, blue, and grey water footprints; component-specific vectors are retained for regressions.

04 Net and gross flows

Rows and columns of W are summed, excluding own use, to obtain net outflows and gross outflows.

INTERPRETATION

The key intuition is simple: production water use is traced through supply chains to final demand.

The Leontief inverse traces direct and indirect embodied water for each component.

1. Direct requirement coefficients

$$A_{ij} = Z_{ij} X_j^{-1}$$

2. Full requirement coefficients

$$B = (I - A)^{-1}$$

3. Component-specific virtual-water matrix

$$W^s = \text{diag}(q^s) B Y, \quad s \in \{\text{green, blue, grey}\}$$

- **A captures direct inputs**

Inputs sourced in region i per unit of output produced in region j.

- **B captures supply chains**

The Leontief inverse includes all indirect production requirements.

- **W^s_{ij} has a clear meaning**

Component s water used in region i to satisfy final demand in region j.

The latest regression design links component-specific flows, water capacity, structure, and growth.

Role	Variable	Interpretation
Flow outcomes	Green / blue / grey net outflows	Embodied-water exports minus imports; component-specific country-year measures.
Gross outcomes	Green / blue / grey gross outflows	Total embodied-water exports; captures scale even when net balance is small.
Water capacity	Total water withdrawal	Proxy for feasible mobilizable water; WDI lacks universal green/blue/grey split.
Structure	Manufacturing value added; trade openness	Industrial composition and open-economy exposure, not mechanical export/import values.
Controls	Natural-resource rents; population growth	Controls for broader resource dependence and demographic pressure.
Growth test	GDP growth	Tests whether component-specific water positions are associated with development outcomes.

Two reduced-form models: flow determinants first, then the growth / curse test.

Model A: component-specific outflow models

$$\text{VWOutflow}_{i,t}^s = \alpha + \beta \text{Withdrawal}_{i,t} + \gamma \text{Manufacturing}_{i,t} + \delta X_{i,t} + \varepsilon_{i,t}$$

Model B: growth association / water-curse test

$$\text{GDPgrowth}_{i,t} = \alpha + \theta \text{VWOutflow}_{i,t}^s + \varphi \text{Withdrawal}_{i,t} + \lambda X_{i,t} + \varepsilon_{i,t}$$

- **Model A**

Estimated separately for net and gross outflows, and separately for green, blue, and grey water.

- **Model B**

If a generic water curse exists, water withdrawal or embodied-water outflows should predict weaker growth.

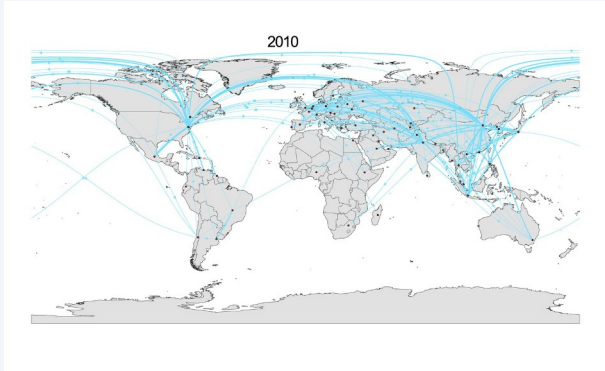
PART 3

Descriptive facts: what the global virtual-water network looks like

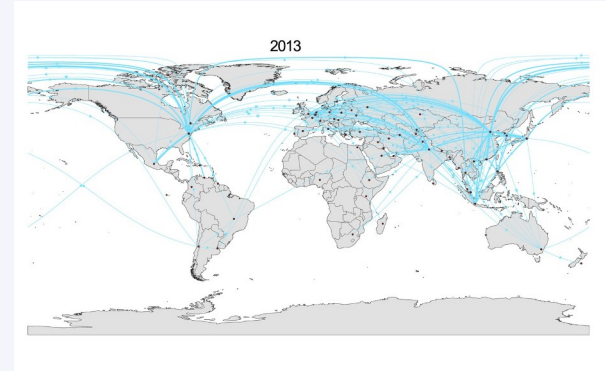
Before interpreting coefficients, the network itself already tells an energy-trade story.

Global virtual-water flows form a stable trade network

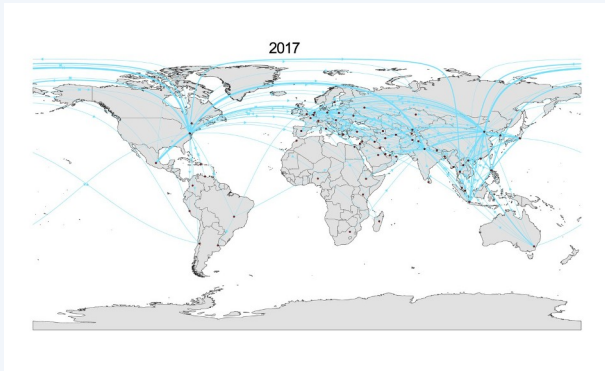
2010



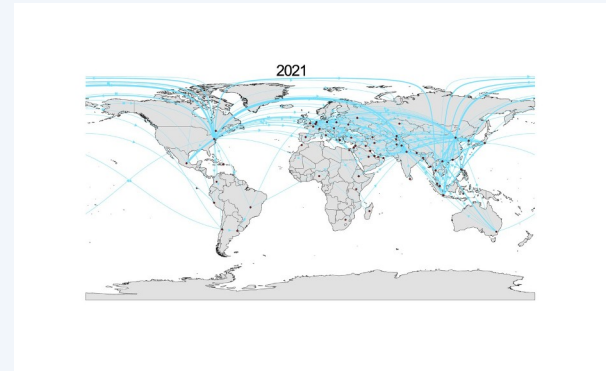
2013



2017



2021



Latest Figure 1: advanced economies are mainly net importers; emerging economies often export green/blue water.

- **Advanced economies are net importers**

The United States, Japan, and Germany are among the largest net importers of embodied water.

- **Emerging economies are key exporters**

India, Ethiopia, Thailand, Indonesia, and Vietnam recur as green- and blue-water net exporters.

- **Regional clustering is visible**

North America, Europe, and East Asia show strong within-region linkages.

- **Grey water is the manufacturing signal**

Grey-water outflows concentrate in manufacturing exporters, with China particularly prominent.

■ FIGURE 1

Component-specific rankings: the latest manuscript no longer supports a single aggregate-country ranking.

Largest net inflows

- Advanced economies and trade hubs
- United States, Japan, Germany
- Singapore and Hong Kong SAR, China

Green / blue outflows

- Emerging and resource-intensive exporters
- India, Ethiopia, Thailand
- Indonesia and Vietnam recur in the rankings

Grey-water outflows

- More concentrated in manufacturing exporters
- China is particularly prominent
- Pollution-related pressure follows industrial structure

Source: latest manuscript, Figure 1. Rankings are reported separately by water component and selected years; units are million m³.

■ COUNTRY PATTERNS

The geography differs by water type, so the talk should not read one old aggregate trajectory.

Advanced economies

Mainly net importers in the latest descriptive results, especially large consumer markets and trade hubs.

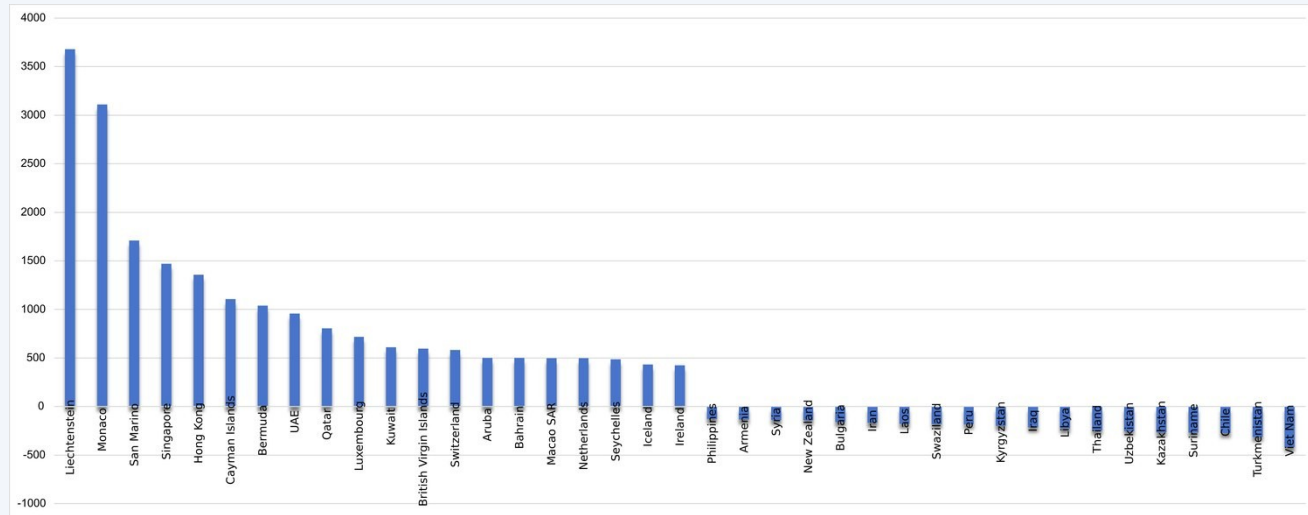
Emerging exporters

Green and blue outflows are recurrent in economies with agricultural or resource-intensive exports.

Manufacturing channel

Grey-water outflows are concentrated where industrial composition creates pollution-related water pressure.

A per-capita view amplifies small open economies and resource-exporting hubs



Per-capita lens (illustrative); latest results are component-specific.

- **Denominator effect**

Small economies such as Hong Kong and Singapore can show high per-capita net flows.

- **Externalizing domestic scarcity**

Resource-exporting economies can use trade revenue and re-export systems to absorb water constraints.

- **Population giants remain central**

India, Indonesia, and Vietnam stand out in both absolute and per-capita terms as green- and blue-water exporters.

Absolute and per-capita flows answer different questions and should not be mixed

Metric	Best used for	How to interpret it
Absolute net flow	Global network position and resource-curse testing	Best for assessing system-level contribution to global redistribution.
Per-capita net flow	Resident-scale exposure and small-economy effects	Best for showing how population size changes rankings.
Gross outflow/inflow	Two-way trade intensity	A country can be both a major outflow and inflow node.
Net value	External dependence or external supply direction	Negative values indicate reliance on water embodied abroad.

INTERPRETATION

The resource-curse question is a macro-development question, so the paper gives more weight to absolute net flows than to per-capita rankings.

Three forces explain the geography: water type, industrial composition, and supply-chain position.

- **Natural resources and agriculture**

The U.S., Australia, and Brazil can export water-intensive products because of agricultural capacity.

- **Position in global value chains**

Manufacturing countries may import water-intensive inputs and export higher-value products.

- **Regional trade costs**

Proximity and trade agreements generate spatial clustering in flows.

- **Industrial upgrading**

Moving from textiles and agricultural goods to machinery can reduce water embodied per export dollar.

PART 4

Empirical results: what drives flows, and does the water curse hold?

Interpret signs, significance, and economic meaning separately. Do not simply read the regression tables aloud.

■ TABLE 4

Table 4: water withdrawal predicts blue/grey net outflows; green-water net outflow is different.

Driver	Latest result	Interpretation
Total water withdrawal	Positive for blue and grey net outflows	Mobilizable water matters for withdrawal-based and pollution-related embodied-water exports.
Green net outflow	Not robustly related to withdrawal	Green water mainly reflects rainfall, soil moisture, land use, and agricultural structure.
Manufacturing value added	Most clearly positive for grey water	Industrial composition is most visible in pollution-related water pressure.
Natural-resource rents / controls	Do not overturn the component pattern	The central result is heterogeneity across green, blue, and grey water.
Bottom line	H1-H3 supported in a component-specific way	Aggregation hides the mechanism; the latest manuscript requires separated components.

Redrawn from the latest manuscript, Table 4. Dependent variable: component-specific net virtual-water outflow.

■ MANUFACTURING

Manufacturing is most clearly associated with grey-water outflows, not with a generic total-water channel.

- **Grey water is the industrial signal**

Grey water captures pollution-dilution requirements, so it is closer to industrial water-quality pressure.

- **Gross outflows strengthen the result**

Manufacturing value added is especially visible when the outcome is gross grey-water outflow.

- **Asia-Pacific relevance**

Export-oriented manufacturing networks can shift pollution-related water burdens across borders.

- **Policy implication**

Cleaner production and supply-chain disclosure matter as much as aggregate water availability.

■ GROSS VS NET

Net balances and gross outflows answer different questions; the latest manuscript estimates both.

- **Net outflow**

Exports minus imports: it identifies whether a country is a net supplier or net absorber of embodied water.

- **Gross outflow**

Total embodied-water exports: it captures export scale even when imports offset the balance.

- **Latest result**

Total water withdrawal is positive and highly significant for gross outflows of all three components.

- **Presentation stance**

Use net results for country position; use gross results for supply-chain exposure and production scale.

■ TRADE OPENNESS

The latest regressions avoid treating raw exports/imports as causal drivers of accounting identities.

- **Why not simple exports/imports?**

Trade values are mechanically embedded in MRIO flow construction, so direct causal claims would overreach.

- **Reduced-form design**

The paper relates component-specific water positions to structure, openness, water withdrawal, and growth.

- **Policy meaning**

Trade still matters, but the claim is about supply-chain position rather than a one-variable export coefficient.

- **Energy-trade insight**

Green equipment, chemicals, metals, food, and services all redistribute different kinds of water pressure.

■ WATER CAPACITY

The latest manuscript uses total water withdrawal as the feasible water-capacity proxy.

- **Why withdrawal?**

Not all renewable water can be mobilized for production; withdrawal is closer to usable water capacity.

- **Blue and grey channels**

Withdrawal is positively associated with blue- and grey-water net outflows.

- **Green-water exception**

Green net outflow does not track withdrawal capacity because it depends on rain-fed land use.

- **Interpretation**

The result is not 'water abundance determines trade'; it is 'mobilizable water matters differently by component.'

The latest H1-H6 results support component heterogeneity and reject a generic macro water curse.

H1 Component heterogeneity

Supported

H2 Withdrawal -> blue/grey net; all gross

Supported

H3 Manufacturing -> grey-water outflows

Supported

H4 Green-water specificity

Supported

H5 Growth heterogeneity by component

**Supported /
nuanced**

■ TABLE 5

Table 5: gross outflows confirm that water capacity scales embodied-water export activity.

Driver	Gross-outflow result	Interpretation
Total water withdrawal	Positive and highly significant for green, blue, and grey	Mobilized water capacity scales total embodied-water export activity.
Manufacturing value added	Strongest and clearest for grey-water outflows	Industrial composition is linked to pollution-related water pressure.
Green water	Gross responds to scale; net is not robust	Rain-fed land-use scale differs from net trade position.
Blue water	Linked to withdrawal, but not to GDP growth	Withdrawal-intensive exports may carry high opportunity costs.
Bottom line	Component-specific pattern is robust	Do not collapse green, blue, and grey water into one total.

Redrawn from the latest manuscript, Table 5. Dependent variable: component-specific gross virtual-water outflow.

Why H6 is rejected: Tables 6-7 do not show a generic macro-level water resource curse.

- **Water withdrawal is mildly pro-growth**

Countries able to mobilize more water appear better able to relax production bottlenecks.

- **Green and grey outflows are positive**

Rain-fed exports and pollution-intensive manufacturing can coincide with short-run GDP growth.

- **Blue outflows are insignificant**

Blue-water export strategies may face high opportunity costs and infrastructure burdens.

- **No oil-like rent concentration**

Water remains foundational infrastructure, not a concentrated mineral-style rent in the aggregate data.

PART 5

Asia-Pacific energy-economics implications

For an IAEE audience, the key question is how energy-transition supply chains redistribute water pressure.

Asia-Pacific is a major virtual-water absorption zone and a central arena for supply-chain water risk

- **Population and demand scale**

India, China, and Southeast Asia pull in water-intensive food, intermediates, and consumer goods.

- **Manufacturing networks**

Viet Nam, Indonesia, Thailand, and China show how production networks reshape net inflows.

- **Energy equipment trade**

Solar, wind, battery, hydrogen, steel, and chemical supply chains transfer water pressure across borders.

- **Regional cooperation agenda**

Virtual water can be added to discussions of green trade, energy security, and industrial resilience.

UCAS angle: the paper connects four fields

Resource & environmental economics

Extends water use from local withdrawal to global embodied flows.

International trade

Uses MRIO to trace resource transfers behind final demand.

Energy economics

Connects green manufacturing, water footprints, and industrial policy.

Development economics

Tests whether water abundance creates a resource-curse pathway.

Green manufacturing policy should track water footprints as well as carbon footprints

- **Supply-chain disclosure**

Solar, batteries, wind, steel, chemicals, and hydrogen equipment can be assessed through product-level water footprints.

- **Trade-policy assessment**

Tariffs, subsidies, and regional agreements reallocate water footprints as well as emissions.

- **Water-risk stress testing**

Energy firms should assess upstream scarcity, flooding, regulation, and supply interruption.

- **Avoid the wrong lesson**

The absence of a water curse does not mean water risk is unimportant.

Contribution, limitations, and next steps

Contribution

A 189-country green/blue/grey MRIO flow matrix; net and gross outflow regressions; GDP-growth tests of a water-curse hypothesis.

Limitations

The evidence is reduced-form and national-level; basin scarcity, governance, seasonality, and climate risk are not fully captured.

Future work

Add basin-level hydrology, scarcity-weighted footprints, causal identification, governance, and climate-vulnerability measures.

Five questions for the Asia-Pacific energy-economics discussion

- **1. Should green industrial policy include water-footprint constraints?**
Especially for solar, batteries, hydrogen, steel, and chemicals.
- **2. How will regional trade agreements reshape virtual-water networks?**
Regional integration may reduce costs while concentrating water pressure.
- **3. How should water risk enter energy-security indicators?**
Beyond scarcity: floods, pollution, basin conflict, and supply-chain disruption.
- **4. How should we read China's prominence in grey-water outflows?**
This is a useful case of industrial upgrading and trade-composition change.
- **5. Should hydropower and water abundance be analytically separated?**
One is a capital project; the other is a resource condition.

Water is a serious constraint for the energy transition, but not a classic global resource curse.

The relevant macro pattern differs across green, blue, and grey water; water capacity itself does not imply lower growth.

Do not collapse rainfall, withdrawals, and pollution pressures into one aggregate water total.

Asia-Pacific manufacturing and demand make the region central to component-specific water-footprint redistribution.

Policy should govern embodied-water risk through cleaner production, efficiency, upgrading, and diversified sourcing.

Backup: expected directions in the latest manuscript

Hypothesis / driver	Expected direction	Intuition
Component heterogeneity	Different signs by green/blue/grey	Each component has a different ecological meaning.
Total water withdrawal	Blue/grey net + all gross outflows	Mobilizable water capacity matters most.
Manufacturing value added	Grey-water outflows	Industrial and pollution-related water channel.
Green water	Gross scale; weak net relationship	Rain-fed land use differs from withdrawals.
Growth tests	Green/grey positive; blue insignificant	No uniform curse pattern.
H6 water curse	Not supported	No generic macro-level water resource curse.

Backup: component-specific country patterns from the latest manuscript

Net inflow pattern

- Advanced economies and trade hubs
- United States, Japan, Germany
- Singapore and Hong Kong SAR, China

Green / blue outflow pattern

- Emerging, agricultural, and resource-intensive exporters
- India, Ethiopia, Thailand
- Indonesia and Vietnam

Grey-water pattern

- Manufacturing exporters
- China particularly prominent
- Industrial composition and water quality pressure

Use this slide for Q&A: it replaces the earlier single aggregate 2021 ranking with the latest component-specific Figure 1 interpretation.