## CLIMAWAT 101: A Global CGE Water Model

Basic Structure, Research Problems and Estimation Challenges

## 5 Key Issues to be Explored with a Global CGE Model Focusing on Water (WCGE)



- 1. Water Scarcity and Allocation: Quantifying the availability and distribution of freshwater resources in different regions, addressing issues like over-extraction, droughts, and the impact of climate change on water availability.
- 2. Water Quality and Pollution: Assessing the impacts of industrial, agricultural, and urban pollution on water quality, including the economic costs of water treatment and the effects on human health and aquatic ecosystems.
- **3.** Impact of Land Use Changes: Evaluating how changes in land use, such as deforestation, urbanization, and agricultural expansion, affect water cycles, runoff patterns, and the overall health of water ecosystems.
- 4. Water-Related Ecosystem Services: Measuring the economic value of services provided by water ecosystems, such as habitat provision, nutrient cycling, flood protection, and recreational opportunities.
- 5. Transboundary Water Management : Analyzing the implications of shared water resources between countries or regions, including the movement of green water from one region to others.



#### 4 Key Hypotheses to be Tested with a Global CGE Model Focusing on Water (WCGE)

- a. Interplay between Climate Change, Water Resources, and Agricultural Productivity: Climate change-induced alterations in water availability will have a significant impact on agricultural productivity, particularly in water-stressed regions.
- **b.** Impact of Water Scarcity on Global Trade Patterns: Regions experiencing water scarcity will see a shift in their trade patterns, with an increase in the import of water-intensive goods and a decrease in their export.
- c. Economic Impact of Water-related Climate Adaptation Strategies: Regions investing in climate adaptation strategies specifically for water resource management will experience less economic volatility and stronger growth compared to regions that do not.
- d. Role of Water in Energy Transition and Economic Shifts: As economies transition to renewable energy sources, the shift in water usage patterns (especially from water-intensive energy sources like coal and nuclear to renewables) will result in significant changes in overall water demand and regional water balances.

### CLIMAWAT 101 Main Construction STEPS

Step	Description	Research Challenges	Estimation Suggestions
1. Conceptual Framework Development	Define scope, objectives, and key components focusing on water.	Balancing comprehensiveness with model manageability.	Use existing models as a reference; consult with experts for a realistic framework.
2. Literature Review and Hypothesis Formulation	Review existing models and approaches; formulate research hypotheses.	Identifying all relevant literature and existing model limitations.	Comprehensive literature survey; engaging with recent research and expert opinions.
3. Data Collection and Preparation	Collect and prepare relevant economic, water usage, and environmental data.	Ensuring data accuracy and compatibility across regions and sectors.	Utilize international databases; harmonize and normalize data for consistency.
4. Model Specification	Decide on model type and specify functional forms, including water dynamics.	Choosing appropriate functional forms and market mechanisms.	Tailor specifications to objectives; use empirical data to inform functional forms.

## Ongoing and Future Activities

Step	Description	Research Challenges	Estimation Suggestions
5. Parameter Estimation	Estimate parameters and calibrate the model using	Accurately estimating behavioral	Use econometric methods for parameter estimation;
and Calibration	baseline data.	relationships and calibrating the model.	calibrate with baseline equilibrium data.
6. Incorporating Water-	Model water supply, demand, transfer, and	Capturing complex water dynamics and	Incorporate hydrological and climate models; consider
Specific Dynamics	environmental aspects.	integrating them effectively.	water management policies.
7. Model Validation and	Validate the model with historical data; test under	Ensuring model validity and sensitivity to	Compare with historical trends; conduct sensitivity
Testing	different scenarios.	various inputs.	analyses.
8. Policy Simulation and	Simulate different policy scenarios and analyze	Predicting realistic outcomes of policy	Use the model to simulate various realistic policy
Analysis	their impacts.	interventions.	scenarios; analyze results comprehensively.
9. Reporting and	Document and disseminate the model and	Effectively communicating complex model	Prepare clear, comprehensive reports; use visualizations
Dissemination	findings.	results.	for better understanding.
10. Model Updating and	Regularly update the model with new data and	Keeping the model relevant and up-to-date	Regularly incorporate new data and insights; adjust model
Maintenance	adapt to changes.	with current data.	assumptions as necessary.

## Main Features of CLIMAWAT 101 from the GTAP and the WIOT Data Base

Component of GTAP	Strengths	Weaknesses
Input-Output (IO) and SAM T	- Provides detailed production and	- Data might not reflect real-time economic
	consumption data Maps monetary	changes Complexity can make interpretation
	transactions between producers and	challenging.
	consumers.	
World Input-Output Tables (WIOT Analytics)	- Consolidated set covering global economy	- Limited to years 1995-2009 May not include
	Includes data from 40 countries and ROW	recent economic developments or emerging
	Disaggregated into 35 industries.	industries.
Regional, Industry, and Agent Data	- Detailed information on intermediate use,	- Requires extensive data processing May not
	final consumption, taxes, transport margins,	capture informal economic sectors.
	and value added Insights into international	
	transactions.	
International Transactions Data	- Details direct purchases by non-residents and	- May not account for all types of international
	abroad by residents Useful for analyzing	financial flows Currency fluctuations can
	global trade patterns.	impact data accuracy.

## Production Block (agent's subscript suppressed for simplicity)

- (1)  $X_{ir}^D = F_{ir}(L_r, \overline{K}_r, H_r, Im_{ir}, In_{ir})$  Production Function for market activities for the ith good in the rth region
- (2)  $S_{nr}^{D} = G_n(S_{nr,t-1}^{D}, X_{ir}^{D}, Im_{ir}, In_{ir})$  Ecoservices and externalities
- (3)  $P_{ir}^{VA} = PD_{ir} \sum_{i} P_{i}a_{jir} td_{ir}$  Value Added Price Definition
- (4)  $P_{ir}^{VA} \frac{\partial X_{ir}}{\partial L_r} = w$ Implicit demand function for labor (5)  $P_{ir}^{VA} \frac{\partial X_{ir}}{\partial H_{ir}} = p_H$

Implicit demand function for land

- (6)  $Im_{ir} = \sum_{j} a_{ijr} X_{ir}^{D} + \sum_{j} c_{ijr} S_{ir}^{D}$  Market demand for material inputs
- $(7) IN_{nr} = \sum_{j} b_{ijr} X_{ir}^{D} + \sum_{j} f_{njr} S_{nr}^{D}$ services

Implicit demand for ecosystem

(8)  $Im_{kr} = \sum_{ik} a_{ikr} X_{ir}^D + \sum_n c_{ikr} S_{nr}^D$ Capital Formation





### Material and Virtual Trade Block

- (1)  $\frac{M_{irs}}{X_{irs}^{XD}} = \left(\frac{PD_{irs}}{PM_{irs}}\right)^{\sigma_{ir}} \left(\frac{\delta_{ir}}{1-\delta_{ir}}\right)^{\sigma_{ir}}$  Demand for Armington Import of region r from region s
- $(2)\frac{N_{irs}}{S_{irs}^{XD}} = \left(\frac{PDN_{nrs}}{PNN_{ins}}\right)^{\sigma_{nr}} \left(\frac{w_{nr}}{1-w_{nr}}\right)^{\sigma_{nr}} Demand for Armington Transfers of Ecoservices from Region r to region s$
- (3)  $PM_{irs} = PWE_iER(1 + tm_{ir})$  Armington Price-World Price relationship
- (4)  $X_{irs}^{D} = A_{irs}^{T} [\gamma_{i} E_{i}^{\varphi_{ir}} + (1 \gamma_{i}) X_{i}^{XD^{\varphi_{ir}}}]^{\frac{1}{\varphi_{ir}}}$  Armington Export -domestic composite assumption
- (5)  $\frac{E_{irs}}{X_i^{XD}} = \left(\frac{PE_{irs}}{PD_{ir}}\right)^{\pi_{ir}} \left(\frac{\gamma_{ir}}{1-\gamma_{ir}}\right)^{\pi_{ir}}$  Demand for Armington export
- (6)  $PE_{ir} = PWE_iER/(1 + te_{ir})$  Armington Price-World Price

### **Consumption Block**

 $(1)C_{ir} = \frac{\beta_{ir}C_r^{Tot}}{P_i}$ Demand for ith consumption  $(2) = C_r^{Tot}(1 - s_r)Y_r$ Demand for total consumption  $(3) Y_r = \sum_i P_{ir}^{VA}X_{ir}^D - DEPR - DIRTAX$ Disposable Income  $(4)DEPR = \sum_j D_{jr}\sum_i P_{ir}h_{ijr}K_{jr}$ Depreciation  $(5)G_{ir} = \beta_{ir}^G C_r^{Tot}$ Government Expenditure  $(6)IN_{ir} = I_{ir0} + \mu_{ir}Y_r$ Investment Function  $(7)S_r = s_r\sum_i P_{ir}^{VA}X_{ir}^D + RG - \sum_i P_i G_{ir} + DEPR + F(ER)$ Savings



## Natural Resource Block

 $\begin{array}{l} (1)C_{nr} = \frac{\beta_{nr}C_{nr}^{Tot}}{P_{nn}} & \text{Demand for final consumptive use of the} \\ nth ecoservice in the r-th region \\ (2) \ D_{nr} = \frac{\alpha_{nr}D_{nr}^{Tot}}{P_{nn}^{D}} & \text{Demand for ecoservice non consumptive use} \\ (3) \ S_{nr}^{Tot} = C_{nr}^{Tot} + D_{nr}^{Tot} = U(Y_r, Q_r) & \text{Total final demand for ecoservice use} \\ (4) \ Q_r = Population \ Size \\ (5) \ G_{nr} = \beta_{nr}^G \ (C_{nr}^{Tot} + D_{nr}^{Tot}) \ Government expenditure for natural resources \\ (6) \ IN_{nr} = I_{nr0} + \mu_{nr}Y_r & Investment function \ for natural resources (e.g., restoration projects) \\ (7) \ IN_r = \sum_{in} b_{nir} X_{ir}^D + \sum_{in} n_{iir} S_{ir}^D & \text{Natural capital Formation} \end{array}$ 

## Potentials and Limitations of the Production Block

COMPONENT	POTENTIALS	LIMITATIONS	ESTIMATION CHALLENGES
Production Function	- Captures diverse inputs in production Reflects real-world production complexity.	<ul> <li>May oversimplify relationships between inputs and outputs Hard to capture dynamic changes in production technology.</li> </ul>	<ul> <li>Accurately measuring input contributions Updating data for technological changes.</li> </ul>
Ecosystem Services and Externalities	<ul> <li>Integrates environmental impacts into economic modeling Highlights the role of ecosystem services in the economy.</li> </ul>	<ul> <li>Difficult to quantify ecosystem services and externalities- May not capture all environmental impacts.</li> </ul>	<ul> <li>Quantifying non-market ecosystem services Balancing economic and ecological factors.</li> </ul>
Value Added Price Definition	<ul> <li>Provides insight into the net economic value of goods Useful for understanding sectoral contributions to the economy.</li> </ul>	<ul> <li>Can be affected by external factors like tax policies and subsidies May not reflect true economic value due to market distortions.</li> </ul>	<ul> <li>Gathering comprehensive pricing and tax data Adjusting for market and policy distortions.</li> </ul>
Implicit Demand Functions (Labor, Land)	<ul> <li>Reflects the value of labor and land in production Useful for labor and land market analysis.</li> </ul>	<ul> <li>Simplifies the complex dynamics of labor and land markets May not reflect non-economic factors affecting demand.</li> </ul>	<ul> <li>Measuring marginal productivity accurately Incorporating non-market influences.</li> </ul>
Market Demand for Inputs	- Captures the interconnectedness of different sectors Useful for input-output analysis.	<ul> <li>Assumes fixed input coefficients, which may not be realistic Ignores potential substitution between inputs.</li> </ul>	- Estimating accurate input coefficients Accounting for input substitution possibilities.
Implicit Demand for Ecosystem Services	<ul> <li>Recognizes the economic value of ecosystem services Can inform sustainable resource management.</li> </ul>	<ul> <li>Challenges in quantifying the demand for non-market services May oversimplify the interaction between economy and environment.</li> </ul>	<ul> <li>Valuing non-market ecosystem services</li> <li>Capturing the dynamic nature of ecosystem services.</li> </ul>

# Potentials and Limitations of the Trade and the Consumption Block

Model Component	Potentials	Limitations	Estimation Challenges
Armington Import and Export Models	<ul> <li>Useful for trade policy analysis</li> <li>Reflects non-substitutability between domestic and foreign goods.</li> </ul>	- The assumption of imperfect substitution might not hold in all cases May oversimplify global trade dynamics.	- Determining the degree of substitutability Incorporating global market complexities.
Consumption and Government Expenditure	- Links economic activity with consumption and government spending Reflects the role of public and private sectors in the economy.	- May not capture the full complexity of consumption behavior Government spending patterns can be hard to predict.	- Modeling diverse consumption patterns Estimating government budget allocations.
Investment Function	- Reflects the role of investment in economic growth Can inform investment-related policy decisions.	- Simplification of investment decisions May not reflect real-world investment dynamics.	- Forecasting investment trends Incorporating various sources and types of investment.
Savings and Disposable Income	- Highlights the relationship between income, savings, and expenditure Useful for macroeconomic analysis.	- Simplifies the complex dynamics of savings behavior May not capture individual or sectoral variations in savings.	- Estimating accurate savings rates Balancing income distribution and spending patterns.

#### Modelling Water in a Global CGE Model

#### 1. Supply of Water

Component	Research Challenges	Data Availability Issues
Natural Water	Estimating renewable water resources under	Limited hydrological data,
	changing climatic conditions.	especially in developing countries.
Man-Made	Assessing the efficiency and capacity of water	Inadequate data on infrastructure
Water	infrastructures like dams and desalination plants.	capabilities and maintenance.

#### 2. Demand for Water

Component	Research Challenges	Data Availability Issues
Agriculture	Understanding the impact of changing agricultural practices and technologies on water usage.	Inconsistent data across regions, lack of detailed agricultural water use data.
Industry	Analyzing industrial water use efficiency and recycling practices.	Industrial water use data often confidential or not systematically collected.
Domestic Use	Projecting changes in domestic water use patterns with urbanization and population growth.	Limited household-level water use data, especially in less developed regions.

# Constructing a water module for CLIMAWAT 101 through a use and supply model (part1)

Feature	Potentials	Research Challenges	Estimation Suggestions
Sector-Specific Water Use	- Tailors water use analysis to specific	- Gathering sector-specific water use data	- Use detailed industry surveys and satellite imagery
Modeling	sectors Can inform targeted policy	Modeling the economic impact of different	for water use data Apply econometric techniques
	interventions.	water use efficiencies.	to assess water use efficiency impacts on
			productivity.
Modeling Evapotranspiration	- Enhances understanding of agricultural	- Accurately measuring evapotranspiration	- Utilize climatic and soil data for evapotranspiration
and Green Water	water sources Accounts for natural	rates Modeling the variability and impact	estimates Employ hydrological models for green
	water cycle impacts on the economy.	of green water.	water assessment.
Blue Water Resources and	- Addresses the management and	- Integrating diverse data on surface and	- Incorporate GIS and remote sensing for mapping
Allocation	distribution of major water sources Can	groundwater resources Balancing	water resources Use optimization models for water
	inform infrastructure and policy	environmental, economic, and social	allocation among sectors.
	planning.	considerations.	
Incorporating "Flying Rivers"	- Expands the understanding of	- Modeling complex atmospheric moisture	- Analyze atmospheric data for moisture flow
	atmospheric water transport Can	patterns Linking atmospheric data with	patterns Use land cover change models to
	improve regional water balance	land use changes.	understand impact on flying rivers.
	predictions.		

## Constructing a water module for CLIMAWAT 101 through a use and supply model (part2)

Feature	Potentials	Research Challenges	Estimation Suggestions
Water Trade and International Policies	- Addresses global water distribution through trade-Can inform international water management policies.	- Quantifying virtual water trade Modeling the impacts of international agreements on water resources.	<ul> <li>Utilize trade databases for virtual water content - Model policy scenarios to assess impacts on water trade.</li> </ul>
Climate Change Impacts	- Projects future water availability and demand- Informs adaptation and mitigation strategies.	- Incorporating reliable climate projections- Modeling dynamic interactions between climate change and water resources.	- Integrate climate models with water resource simulations- Use scenario analysis for future water demand projections.
Feedback Mechanisms	- Captures the interplay between water resources and economic activities- Reflects socio-economic impacts of water changes.	- Establishing accurate feedback loops- Assessing socio-economic responses to water scarcity.	- Develop dynamic models to simulate feedbacks - Incorporate socio-economic surveys for response analysis.
Data Integration and Calibration	- Enhances model accuracy with diverse data sources- Keeps the model relevant with current data.	- Sourcing and integrating local, regional, and global water data- Continuously calibrating the model to reflect changes.	- Aggregate and harmonize data from various sources- Regularly update the model with new data and recalibrate.

## **Modelling Water Transfers in CLIMAWAT 101**

Aspect	Possible Model Solutions
Physical Water Transfers	- Model infrastructures like inter-basin transfers and pipelines. Include international water agreements and treaties.
Virtual Water Trade	- Incorporate water embedded in traded goods. Analyze impacts of trade policies on global water distribution.
Water Pricing Mechanisms	- Implement strategies reflecting water scarcity. Explore market-based systems like cap-and-trade for water rights.
Sectoral Water Use Analysis	<ul> <li>Disaggregate water use by sectors. Model impact of technologies and policies on water use efficiency.</li> </ul>
Policy Scenario Analysis	- Develop scenarios for different water management policies. Analyze long-term implications on global water security.
Data Collection	- Harmonize data from various sources for accurate modeling Utilize satellite data and hydrological models.
Stakeholder Engagement	<ul> <li>Involve multiple stakeholders in water management decisions. Model collaborative governance effects.</li> </ul>

#### Interaction with Natural Resources and Climate Change

Aspect	Model Solutions
Climate Change Integration	<ul> <li>Integrate climate models for water availability projections.&lt;- Analyze impact of climate change on water resources and demands.</li> </ul>
Environmental Impact Assessment	- Assess environmental impacts of water usage and transfers. Consider effects on ecosystems, river flows, and water quality.
Integration with Natural Resource Management	<ul> <li>Link water use with broader natural resource strategies. Model synergies and trade-offs with land and energy use.</li> </ul>
Forest-Water Interactions	- Analyze the impact of forest management on water cycles. Model the role of forests in regional water balance and quality.
Climate Change Mitigation Strategies	<ul> <li>Model the effects of climate change mitigation on water and forests.</li> <li>Analyze policy impacts on carbon sequestration and water cycles.</li> </ul>
Collaborative Governance for Climate and Water	- Involve stakeholders in climate and water management. Model effects of policies on resource sustainability and climate resilience.

#### Water Physical Supply and Use Tables (WPSUT) Main data sources

Data	Source
	Seven Regions according to World Bank classification (total of 221
Regional Classification	Countries):
	EAP, ECA, LAC, MENA, NAM, SAS, SSA.
	- FAO AQUASTAT (200 Countries, data from 1995 to 2020);
Water Supply and Use	- Water Footprint Network (211 Countries, data from 1996 to 2005).
	- UN Statistics Division (97 countries, data from 1990 to 2021);
Evapotranspiration data	- FAO Evapotranspiration DataMap;
	- Other Sources.
	- World Bank Development Indicators;
Other Environmental Data	-National Statistics;
	- Other Sources.

### Aggregate WPSUT Estimates

REGION	WATER IN (Bln m3/year)						WATER OUT (Bln m3/year)								
	Extracted water			<b>D</b> · 1			Supplied to customer				Environmental				
	Surface water	Groundwater	Desalinated water	water (Rainfall)	Total sourced Bul water supp	Bulk supply	Agriculture (irrigation)	Industry	Municipal (residential domestic)	Non Domestic	flows (evapotranspiration )	Own Use	Losses	Total Distribution	Balance
EAP	1,024.49	158.26	13.27	24,177.10	25,373.12		333.99	150.90	183.82	1,671.15	1,127.91	544.55		4,012.32	21,360.80
ECA	373.41	78.08	0.75	14,208.11	14,660.35		221.69	139.52	92.17	1,177.83	9,047.52	30.66		10,709.39	3,950.96
LAC	252.70	66.53	0.22	32,016.86	32,336.31		206.50	35.59	57.28	5,018.61	14,010.00	73.30		19,401.28	12,935.03
MENA	90.41	111.28	7.83	1,350.55	1,560.07		11.63	16.24	41.19	52.88	313.42	250.26		685.62	874.45
NAM	367.73	112.92	0.58	12,334.96	12,816.19		164.78	237.21	63.26	148.80	6.01	15.28		635.34	12,180.85
SAS	549.63	343.95	0.02	4,978.42	5,872.02		9.32	20.20	70.44	1,726.23	142.64	923.53		2,892.36	2,979.66
SSA	38.77	8.07	0.10	19,835.83	19,882.77		65.13	8.65	17.90	1,208.64	2,249.47	37.98		3,587.77	16,295.00

### Summary Country focus aggregated WPSUT

REGION	WATER IN (Bln m3/year)						WATER OUT (Bln m3/year)								
	Extracted water			- · ·			Supplied to customer								
	Surface water	Groundwater	Desalinated water	Received water (Rainfall)	Total sourced water	Bulk supply	Agriculture (irrigation)	Industry	Municipal (residential domestic)	Non Domestic	Environmental flows (evapotranspiration)	Own Use	Losses	Total Distribution	Balance
Bangladesh	7.39	28.48		393.42	429.29			0.77	3.6	0.09	72.55	31.50		108.51	320.78
Egypt		6.5	0.2	18.13	24.83			5.4	10.75	-	2.10	61.35		79.60	- 54.77
Indonesia	188.02	34.61	0.02	5,179.36	5,402.01		177.1	9.13	23.8	-		12.60		222.63	5,179.38
Italy	23.32	10.18	0.2	251.32	251.52		16.85	7.7	9.19	-	148.37	0.15		182.26	102.76
Mexico	54.23	35.31	0.01	1489	1,578.55		66.42	8.55	13.16	19.14	1.05	1.41		109.73	1,468.82
South Africa	17.42	2.89	0.08	603.45	623.84		11.89	4.09	3.11	10.85	268.15	0.10		298.19	325.65

## Potentials and Limitations of the Data for the WPSUT

Data source	Potentials	Limitations	Estimation Challenges		
FAO Statistics	<ul> <li>Useful for water abstraction and distribution, irrigated area and wastewater treatment;</li> <li>Long-term series.</li> </ul>	<ul> <li>Lack of agriculture and industrial disaggregation;</li> <li>Lack of data for forests.</li> </ul>	- Determining the degree of sectorial disaggregation.		
Water Footprint Network	<ul> <li>Useful for green, blue and grey water footprint;</li> <li>Useful for virtual trade water</li> </ul>	<ul> <li>Lack of industrial disaggregation;</li> <li>Lack of water supply data;</li> <li>Data not updated.</li> </ul>	<ul> <li>Determining the degree of industrial disaggregation.</li> <li>Combining with other dataset to homogenize the data</li> </ul>		
United Nation statistics of Evapotranspiration	- Useful for water supply of agricultural activities.	<ul> <li>Data available for small number of countries.</li> <li>Lack of data of water migration among countries</li> </ul>	-Integrating the data with other databases.		