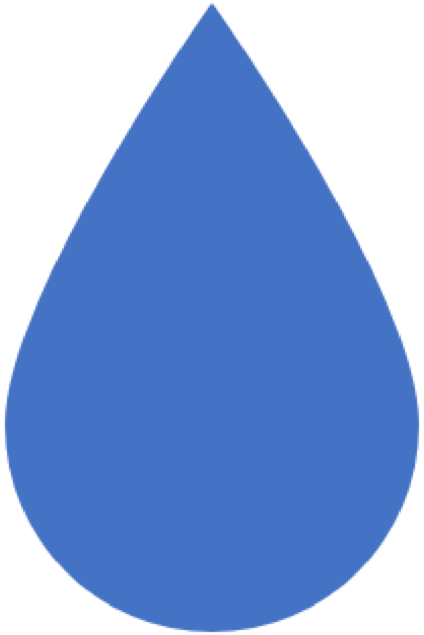
CLIMAWAT 101: A Global CGE Water Model

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 and Calibration	Estimate parameters and calibrate the model using baseline data.	Accurately estimating behavioral relationships and calibrating the model.	Use econometric methods for parameter estimation; calibrate with baseline equilibrium data.
6. Incorporating Water-Specific Dynamics	Model water supply, demand, transfer, and environmental aspects.	Capturing complex water dynamics and integrating them effectively.	Incorporate hydrological and climate models; consider water management policies.
7. Model Validation and Testing	Validate the model with historical data; test under different scenarios.	Ensuring model validity and sensitivity to various inputs.	Compare with historical trends; conduct sensitivity analyses.
8. Policy Simulation and Analysis	Simulate different policy scenarios and analyze their impacts.	Predicting realistic outcomes of policy interventions.	Use the model to simulate various realistic policy scenarios; analyze results comprehensively.
9. Reporting and Dissemination	Document and disseminate the model and findings.	Effectively communicating complex model results.	Prepare clear, comprehensive reports; use visualizations for better understanding.
10. Model Updating and Maintenance	Regularly update the model with new data and adapt to changes.	Keeping the model relevant and up-to-date with current data.	Regularly incorporate new data and insights; adjust model 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 consumption data.- Maps monetary transactions between producers and consumers.	- Data might not reflect real-time economic changes.- Complexity can make interpretation challenging.
World Input-Output Tables (WIOT Analytics)	- Consolidated set covering global economy.- Includes data from 40 countries and ROW.- Disaggregated into 35 industries.	- Limited to years 1995-2009.- May not include recent economic developments or emerging industries.
Regional, Industry, and Agent Data	- Detailed information on intermediate use, final consumption, taxes, transport margins, and value added.- Insights into international transactions.	- Requires extensive data processing.- May not capture informal economic sectors.
International Transactions Data	- Details direct purchases by non-residents and abroad by residents.- Useful for analyzing global trade patterns.	- May not account for all types of international financial flows.- Currency fluctuations can 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) $P_{ir}^{VA} = PD_{ir} - \sum_j P_j a_{jir} - td_{ir}$ *Value Added Price Definition*

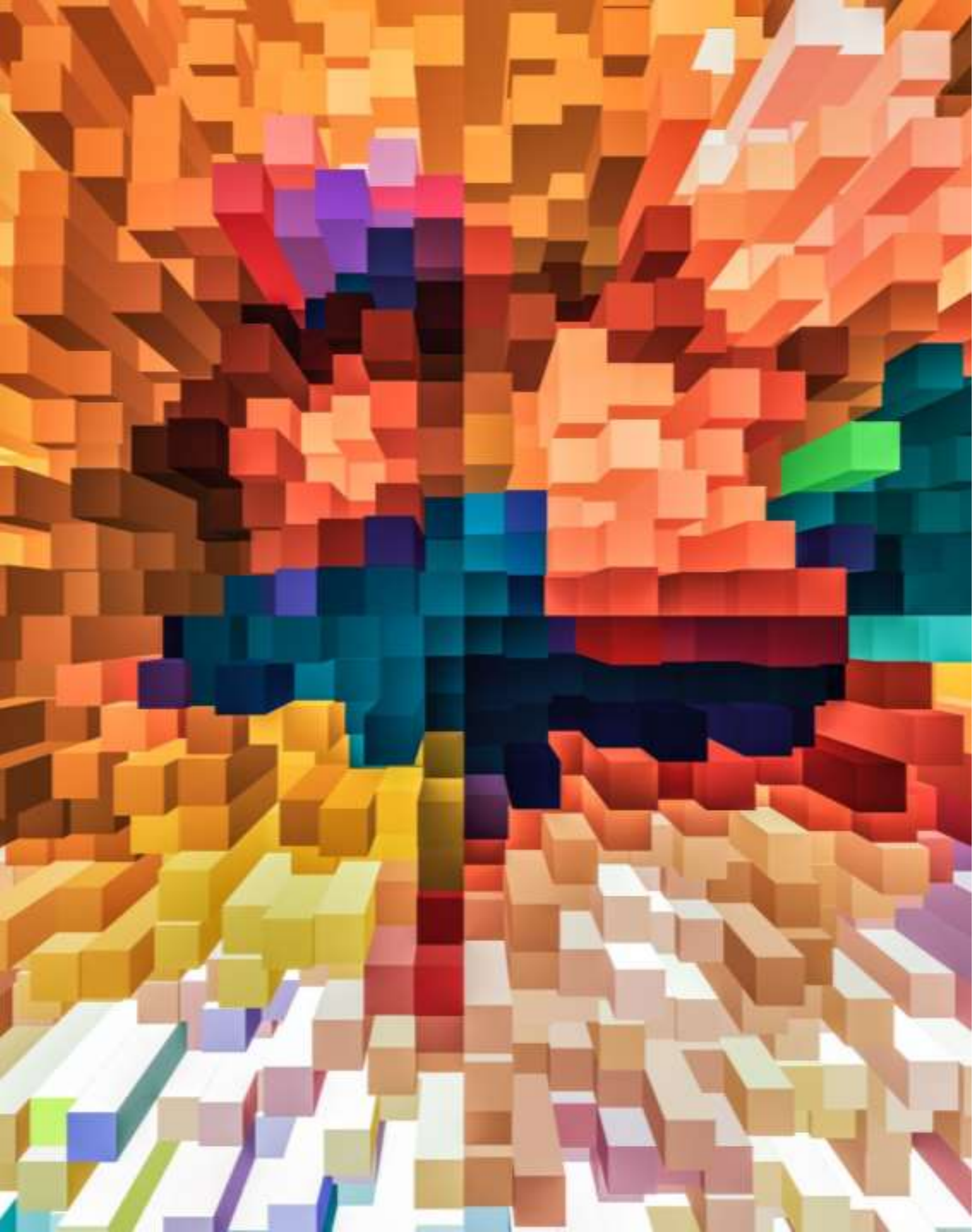
(4) $P_{ir}^{VA} \frac{\partial X_{ir}}{\partial L_r} = w$ *Implicit demand function for labor*

(5) $P_{ir}^{VA} \frac{\partial X_{ir}}{\partial H_r} = p_H$ *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) $IN_{nr} = \sum_j b_{ijr} X_{ir}^{D} + \sum_j f_{njr} S_{nr}^{D}$ *Implicit demand for ecosystem services*

(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) $\frac{M_{irs}}{X_{irs}^{XD}} = (\frac{PD_{irs}}{PM_{irs}})^{\sigma_{ir}} (\frac{\delta_{ir}}{1-\delta_{ir}})^{\sigma_{ir}}$ *Demand for Armington Import of region r from region s*

(2) $\frac{N_{irs}}{S_{irs}^{XD}} = (\frac{PDN_{nrs}}{PNN_{ins}})^{\sigma_{nr}} (\frac{w_{nr}}{1-w_{nr}})^{\sigma_{nr}}$ *Demand for Armington Transfers of Ecoservices from Region r to region s*

(3) $PM_{irs} = PWE_i ER(1 + tm_{ir})$ *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) $\frac{E_{irs}}{X_i^{XD}} = (\frac{PE_{irs}}{PD_{ir}})^{\pi_{ir}} (\frac{\gamma_{ir}}{1-\gamma_{ir}})^{\pi_{ir}}$ *Demand for Armington export*

(6) $PE_{ir} = PWE_i ER/(1 + te_{ir})$ *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

(1) $C_{nr} = \frac{\beta_{nr} C_{nr}^{Tot}}{P_{nr}}$ *Demand for final consumptive use of the nth ecoservice in the r-th region*

(2) $D_{nr} = \frac{\alpha_{nr} D_{nr}^{Tot}}{P_{nr}^{D}}$ *Demand for ecoservice non consumptive use*

(3) $S_{nr}^{Tot} = C_{nr}^{Tot} + D_{nr}^{Tot} = U(Y_r, Q_r)$ *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) $IN_r = \sum_{jn} b_{njr} X_{ir}^{D} + \sum_{jn} n_{ijr} S_{ir}^{D}$ *Natural capital Formation*

Potentials and Limitations of the Production Block

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

Potentials and Limitations of the Trade and the Consumption Block

Model Component	Potentials	Limitations	Estimation Challenges
Armington Import and Export Models	- Useful for trade policy analysis.- Reflects non-substitutability between domestic and foreign goods.	- 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 changing climatic conditions.	Limited hydrological data, especially in developing countries.
Man-Made Water	Assessing the efficiency and capacity of water infrastructures like dams and desalination plants.	Inadequate data on infrastructure 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 Modeling	- Tailors water use analysis to specific sectors.- Can inform targeted policy interventions.	- Gathering sector-specific water use data.- Modeling the economic impact of different water use efficiencies.	- Use detailed industry surveys and satellite imagery for water use data.- Apply econometric techniques to assess water use efficiency impacts on productivity.
Modeling Evapotranspiration and Green Water	- Enhances understanding of agricultural water sources.- Accounts for natural water cycle impacts on the economy.	- Accurately measuring evapotranspiration rates.- Modeling the variability and impact of green water.	- Utilize climatic and soil data for evapotranspiration estimates.- Employ hydrological models for green water assessment.
Blue Water Resources and Allocation	- Addresses the management and distribution of major water sources.- Can inform infrastructure and policy planning.	- Integrating diverse data on surface and groundwater resources.- Balancing environmental, economic, and social considerations.	- Incorporate GIS and remote sensing for mapping water resources.- Use optimization models for water allocation among sectors.
Incorporating "Flying Rivers"	- Expands the understanding of atmospheric water transport.- Can improve regional water balance predictions.	- Modeling complex atmospheric moisture patterns.- Linking atmospheric data with land use changes.	- Analyze atmospheric data for moisture flow patterns.- Use land cover change models to understand impact on flying rivers.

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.	- Utilize trade databases for virtual water content - Model policy scenarios to assess impacts on water trade.
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	- Disaggregate water use by sectors. Model impact of technologies and policies on water use efficiency.
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	- Involve multiple stakeholders in water management decisions. Model collaborative governance effects.

Interaction with Natural Resources and Climate Change

Aspect	Model Solutions
Climate Change Integration	- Integrate climate models for water availability projections.<- Analyze impact of climate change on water resources and demands.
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	- Link water use with broader natural resource strategies. Model synergies and trade-offs with land and energy use.
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	- Model the effects of climate change mitigation on water and forests. Analyze policy impacts on carbon sequestration and water cycles.
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
Regional Classification	Seven Regions according to World Bank classification (total of 221 Countries): EAP, ECA, LAC, MENA, NAM, SAS, SSA.
Water Supply and Use	- FAO AQUASTAT (200 Countries, data from 1995 to 2020); - Water Footprint Network (211 Countries, data from 1996 to 2005).
Evapotranspiration data	- UN Statistics Division (97 countries, data from 1990 to 2021); - FAO Evapotranspiration DataMap; - Other Sources.
Other Environmental Data	- World Bank Development Indicators; -National Statistics; - Other Sources.

Aggregate WPSUT Estimates

REGION	WATER IN (Bln m3/year)					WATER OUT (Bln m3/year)									
	Extracted water			Received water (Rainfall)	**Total sourced water**	Bulk supply	Supplied to customer				Environmental flows (evapotranspiration)	Own Use	Losses	**Total Distribution**	**Balance**
	Surface water	Groundwater	Desalinated water				Agriculture (irrigation)	Industry	Municipal (residential domestic)	Non Domestic					
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			Received water (Rainfall)	**Total sourced water**	Bulk supply	Supplied to customer				Environmental flows (evapotranspiration)	Own Use	Losses	**Total Distribution**	**Balance**
	Surface water	Groundwater	Desalinated water				Agriculture (irrigation)	Industry	Municipal (residential domestic)	Non Domestic					
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	- Useful for water abstraction and distribution, irrigated area and wastewater treatment; - Long-term series.	- Lack of agriculture and industrial disaggregation; - Lack of data for forests.	- Determining the degree of sectorial disaggregation.
Water Footprint Network	- Useful for green, blue and grey water footprint; - Useful for virtual trade water	- Lack of industrial disaggregation; - Lack of water supply data; - Data not updated.	- Determining the degree of industrial disaggregation. - Combining with other dataset to homogenize the data
United Nation statistics of Evapotranspiration	- Useful for water supply of agricultural activities.	- Data available for small number of countries. - Lack of data of water migration among countries	-Integrating the data with other databases.