

Towards the Complete Representation of Water in a CGE Model for Scotland to Assess the Impacts of Water Scarcity

Saba Al Hosni^{1*}, Scott J. McGrane^{1,2}, Gioele Figus¹, Cecilia Tortajada³

¹ Department of Economics, University of Strathclyde, 130 Rottenrow, Glasgow, UK

² Applied Physics, Stanford University, Stanford, CA, 94305, USA

³ School of Social and Environmental Sustainability, University of Glasgow, Dumfries, DG1 4ZL

Keywords

Climate Change, Computable General Equilibrium, Water Scarcity

Abstract

This paper develops a water extended Computable General Equilibrium model that addresses several methodological gaps in literature. Water remains under-represented as an explicit factor of production beyond agriculture-focused applications, as many applications adopt a sector-specific perspective and rarely incorporate multiple water sources to reflect heterogeneous sectoral dependencies. Such modelling decisions affect the realistic representation of water within economy-wide frameworks and influence the macroeconomic and sectoral responses to shocks. This paper extends the AMOS CGE model for Scotland by adding water abstraction as an explicit production factor and by linking sector-specific physical water consumption to the piped supply sector across all sectors represented within the 2019 Social Accounting Matrix. The model is constructed using unique detailed sectoral consumption data from Scottish Water and abstraction data from the Scottish Environment Protection Agency. This model is used to analyse the economy-wide consequences of water scarcity using future climate projections for Scotland.

1. Introduction

Incorporating water resources in Computable General Equilibrium (CGE) models has become increasingly important as climate change, economic and population growth, and competing sectoral demand pressure water systems. CGE models have proven to be powerful tools for analysing the economy-wide impacts of various environmental and water-related topics. However, the integration of water into CGE frameworks is still evolving, with ongoing debates about the representation of water in production functions and the lack of detailed sectoral water use by resource type (surface, ground, or reused water) in these models (Al Hosni et al., 2026).

The literature demonstrates that existing water-CGE models' applications predominantly focus on agriculture, given it's the largest water-using sector, and the one with most detailed water use data (Bardazzi and Bosello, 2021). Other studies focus on a small number of water-intensive industrial sectors, usually modelling water as an intermediate input. While these applications yield valuable sector-specific insights, they offer partial coverage of economy-wide water use, whereas climate driven water scarcity affects multiple sectors simultaneously and intensifies competition for constrained water resources. Consequently, the wider impacts of water shocks may not be completely captured. The literature further notes that modelling water as an explicit production factor in water-CGE remains underdeveloped, mainly due to insufficient data on water quantities, prices and values, along with the methodological challenge of linking physical water use to monetary input-output accounts (Calzadilla et al., 2016).

Despite these concerns, integrating water into CGE models has evolved considerably and are frequently used to model water issues at national, regional, and global scales across different temporal scales. The model has been used to examine topics like changes in the availability of water (Briand et al., 2023), the introduction of new water markets (Koopman et al., 2017), and water-energy-food nexus (Bardazzi et al., 2024).

This paper advances the emerging field of water-CGE modelling by developing the first such framework for Scotland, designed to assess the economic consequences of future water availability changes. A key contribution lies in integrating water abstraction as an explicit factor of production and incorporating sector-specific piped water intensities across 29 sectors. This approach enables a comprehensive representation of abstracted water and main piped-supplied treated water use throughout the Scottish economy, addressing a gap in literature that has largely overlooked detailed, non-aggregated water use outside agriculture and the inclusion of multiple water sources in CGE models (Bryant, 2022). The model also tracks physical water quantities and intensities, enabling the identification of sectoral vulnerabilities and shifts in embodied water use under changing hydrological and economic conditions. This paper will use the water-CGE model developed to analyse future projections of water scarcity impacts in Scotland.

2. AMOS CGE model

To simulate the economy-wide impacts of an exogenous shock, the AMOS (A Macro-Micro Model for Scotland) CGE model is extended to include water resources for Scotland, and coded in GAMS software (Allan et al., 2018; Harrigan et al., 1991). The model is a recursive, dynamic, single-country, multi-sectoral CGE model that follows the standard CGE features, describing production, consumption, and trade as solutions to optimisation problems for each representative agent.

2.1 Production Block

This paper includes water abstraction as an additional factor of production alongside capital and labour within the value-added CES nest in the following manner. The output of the 29 sectors calibrated in this CGE model is produced by combining intermediate inputs with capital and labour as value added, using a nested CES production function for conventional sectors. This allows for substitution between these factors in response to relative price changes. Intermediate inputs are aggregated through a Leontief function, implying fixed input proportions in the base year.

Sectors that abstract include, in addition to capital and labour, water abstraction as an explicit factor of production following the production tree structure of Allan et al. (2018; 2025). This specification allows the model to capture how firms adjust to abstraction supply restrictions and rising scarcity rents through capital and labour depending on sectoral technologies and substitution elasticities, and has been used consistently across water-CGE models applications that explicitly represent water (e.g., (Briand et al., 2023; Lu et al., 2015)). There is one elasticity of substitution parameter that governs the substitutability across all primary factors set as 0.3.

2.2 Water coefficient block

This study links physical water-use data in volume (m³) obtained from Scottish Water with monetary water input values in the SAM to incorporate sectoral water consumption into the CGE model. Adapting the linear method of Jia and Lin (2022) which relates physical energy use to monetary values, water intensities are incorporated into the CGE model via a relationship between physical water use and monetary supply. This allows the model to convert changes in demand or other factors into corresponding changes in physical water consumption, which adjusts over time and to simulate of how shocks affect total and sectoral water use.

3. Data and treatment

This paper uses three databases to build the model. The first is the most recent 2019 Scottish Social Accounting Matrix (SAM), derived from the Scottish Government's input-output (I-O) tables and aggregated from 97 to 29 sectors guided by two criteria: preserving key water-intensive industries, such as agriculture, aquaculture, and manufacturing; and merging industries with minimal water use, such as real estate. Second, sectoral water abstraction data from the Scottish Environmental Protection Agency. Lastly, sectoral water consumption data from Scottish Water.

4. Simulation scenarios

This study draws on projected future water availability estimates reported for the UK Climate Change Risk Assessment, based on UKCP18 river flows projections, to derive the water reduction scenarios used in the CGE model. The report outlines that under a 2°C world, the Q95 river flows will decrease by 0-20% in the UK.

5. Preliminary Results

Water scarcity generates a contraction in the economy under all reduction scenarios in the long run, and particularly under a 20% reduction. However, the impacts are modest as water abstraction constitutes a small share of production costs for sectors. The most significant impact of water scarcity is on water abstraction prices that increase by more than 100% in the long run under a 20% reduction scenario. However, this result is also driven by the current model's closure rule that water abstraction is fixed at the sector level such that each water abstracting sector is endowed with its own exogenously determined abstraction supply and because no reallocation of abstraction across sectors occurs.

6. Conclusions

This chapter extends the AMOS CGE model for Scotland to include water resources for the first time by integrating water abstraction as an explicit factor of production for abstracting sectors and including sector-specific physical water consumption from the piped supply in the model by linking production sectors to the water supply sector for all 29 sectors included in the model using highly detailed sectoral water consumption data.

The present framework provides a basis for analysing the economy-wide water-economy interactions in Scotland. As water abstraction is incorporated as a factor of production, the model can capture the impacts macroeconomic and sectoral impacts of future projections of water scarcity. These preliminary results demonstrate the importance of accounting for water availability in economy-wide assessments and illustrate how this modelling approach can inform resource management, resilience planning and sustainable growth.

7. References

Al Hosni, S., McGrane, S.J., Figus, G., Tortajada, C., 2026. Water in computable general equilibrium models: Review, synthesis and avenues for future research. *Environ. Model. Softw.* 197, 106839. <https://doi.org/10.1016/j.envsoft.2025.106839>

- Allan, G., Comerford, D., Connolly, K., McGregor, P.G., 2025. Improvements in beef cattle productivity can increase economy-wide activity and simultaneously reduce greenhouse gas emissions in Scotland. *Environ. Dev. Sustain.* <https://doi.org/10.1007/s10668-024-05871-0>
- Allan, G., Comerford, D., McGregor, P., 2018. Towards Incorporating Natural Capital into a Computable General Equilibrium Model for Scotland [WWW Document]. URL <https://strathprints.strath.ac.uk/65668/> (accessed 5.1.23).
- Allan, G.J., Figus, G., Pathak, P., 2025. Economic Consequences of Climate-Induced Changes in Crop Yields in a Water-Abundant Region. *Rev. Reg. Stud.* 55, 25–58. <https://doi.org/10.52324/001c.137491>
- Allan, G.J., Lecca, P., McGregor, P.G., Swales, J.K., 2014. The economic impacts of marine energy developments: A case study from Scotland. *Mar. Policy* 43, 122–131. <https://doi.org/10.1016/j.marpol.2013.05.003>
- Bardazzi, E., Bosello, F., 2021. Critical reflections on Water-Energy-Food Nexus in Computable General Equilibrium models: A systematic literature review. *Environ. Model. Softw.* 145. <https://doi.org/10.1016/j.envsoft.2021.105201>
- Bardazzi, E., Standardi, G., Bosello, F., Key Hernández, R.E., 2024. Toward the full implementation of the water-energy-food nexus in computable general equilibrium modelling: methods and macroeconomic implications. *Econ. Syst. Res.* 0, 1–29. <https://doi.org/10.1080/09535314.2024.2349881>
- Briand, A., Reynaud, A., Viroleau, F., Markantonis, V., Branciforti, G., 2023. Assessing the Macroeconomic Effects of Water Scarcity in South Africa using a CGE Model. *Environ. Model. Assess.* 28, 259–272. <https://doi.org/10.1007/s10666-023-09883-4>
- Bryant, W.D.A., 2022. Water and Economy-Wide Modeling: An Overview, in: *Oxford Research Encyclopedia of Environmental Science*. <https://doi.org/10.1093/acrefore/9780199389414.013.611>
- Calzadilla, A., Rehdanz, K., Roson, R., Sartori, M., Tol, R.S.J., 2016. Review of CGE Models of Water Issues, in: Alvaro, C., Katrin, R., Roberto, R., Martina, S., Richard, S.J.T. (Eds.), *The WSPC Reference on Natural Resources and Environmental Policy in the Era of Global Change*. WORLD SCIENTIFIC, pp. 101–123. https://doi.org/10.1142/9789813208179_0004
- Gilmartin, M., Allan, G., 2015. Regional Employment Impacts of Marine Energy in the Scottish Economy: A General Equilibrium Approach. *Reg. Stud.* 49, 337–355. <https://doi.org/10.1080/00343404.2014.933797>
- Harrigan, F., McGregor, P.G., Dourmashkin, N., Perman, R., Swales, K., Yin, Y.P., 1991. AMOS: A macro-micro model of Scotland. *Econ. Model.* 8, 424–479. [https://doi.org/10.1016/0264-9993\(91\)90028-M](https://doi.org/10.1016/0264-9993(91)90028-M)
- Jia, Z., Lin, B., 2022. CEEEA2.0 model: A dynamic CGE model for energy-environment-economy analysis with available data and code. *Energy Econ.* 112, 106117. <https://doi.org/10.1016/j.eneco.2022.106117>
- Koopman, J.F.L., Kuik, O., Tol, R.S.J., Brouwer, R., 2017. The potential of water markets to allocate water between industry, agriculture, and public water utilities as an adaptation mechanism to climate change. *Mitig. Adapt. Strateg. Glob. Change* 22, 325–347. <https://doi.org/10.1007/s11027-015-9662-z>
- Lu, P., Deng, P., He, W.-D., 2015. Assessing the impacts of water policy in Beijing: A computable general equilibrium analysis. Presented at the 2015 IEEE

- International Conference on Information and Automation, ICIA 2015 - In conjunction with 2015 IEEE International Conference on Automation and Logistics, pp. 339–343. <https://doi.org/10.1109/ICInfA.2015.7279309>
- Qu, Y., Swales, J.K., Hooper, T., Austen, M.C., Wang, X., Papathanasopoulou, E., Huang, J., Yan, X., 2023. Economic trade-offs in marine resource use between offshore wind farms and fisheries in Scottish waters. *Energy Econ.* 125. <https://doi.org/10.1016/j.eneco.2023.106811>
- Roson, R., Sartori, M., 2026. Macroeconomic modeling of water resources: Conceptual and methodological challenges in CGE frameworks. *PLOS Water* 5, e0000529. <https://doi.org/10.1371/journal.pwat.0000529>
- Scotland natural capital accounts - Office for National Statistics [WWW Document], 2023. URL <https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/scotlandnaturalcapitalaccounts/2023> (accessed 11.4.25).
- Visser-Quinn, A., Beevers, L., Lau, T., Gosling, R., 2021. Mapping future water scarcity in a water abundant nation: Near-term projections for Scotland. *Clim. Risk Manag.* 32. <https://doi.org/10.1016/j.crm.2021.100302>