The review comments on Kahil et al. “Development of the global hydro-economic model (ECHO-Global version 1.0) for assessing the performance of water management options”

This manuscript presents ECHO-Global, a global hydroeconomic model that integrates physical water flows and economic optimization to assess cross-sectoral water allocation under multiple water management scenarios. The model operates at the scale of 282 basin-country units (BCUs) and captures sector-specific water allocation and use in agriculture, domestic, and industrial sectors, constrained by water availability and infrastructure, while maximizing net economic benefits. The scenario analysis explores supply- and demand-side interventions, including efficiency improvements, land and water reallocation, environmental flow protection, and the use of non-conventional water sources.

The manuscript makes a valuable contribution to the field of global water modeling. ECHO-Global distinguishes itself by combining hydroeconomic balance constraints with economic decision-making across sectors. The application of Positive Mathematical Programming (PMP) to calibrate agricultural land allocation adds credibility to modeled crop choices. Its flexible structure allows for scenario-based assessments aligned with SSP–RCP narratives, providing policy-relevant insights into future water challenges. In this manuscript, the authors demonstrate multiple water management scenarios under the SSP2-RCP6.0 scenario.

The study is timely and addresses an important set of questions regarding the feasibility and trade-offs of water management strategies in the context of climate and socioeconomic change. The model structure is thoughtfully designed, and the manuscript is generally well written and organized.

However, there are some points that I would like the authors to address; Some aspects of the model formulation, scenario design, and interpretation would benefit from further clarification. In particular, additional transparency in how assumptions are specified, how key parameters are derived or constrained, and how results should be interpreted in light of modeling limitations would strengthen the overall contribution. Moreover, the presentation of results could be improved in terms of clarity and consistency, and the structure of the methods section might be adjusted to enhance readability. Some scenario implications may also merit broader contextual discussion.

In summary, this is a promising and ambitious study that contributes to advancing the field of integrated global water resource assessment. With improved clarity in model assumptions, explanation of methods, and framing of results, the manuscript will offer valuable insights to both scientific and policy audiences.

<< Major comments >>

P.6, L140: Although the model equations are defined over time-steps (Section 2.2), monthly water demand inputs are described in Section 2.4.1, and apparently, the total surface water inflow to each BCU is defined as annual value, the model's temporal resolution (e.g., whether it solves monthly or annually) is not explicitly stated. I recommend clearly stating the model time-step and temporal resolution in Section 2.1 or 2.2 to avoid ambiguity.

P.7: While the model includes reservoir evaporation, initial storage levels, and dead storage as components of the reservoir mass balance (e.g., equations 4–7), the description of how these quantities are parameterized remains unclear. For example, evaporation is said to depend on reservoir and climatic features, but no equation or calibration method is provided. Similarly, the sources of initial storage and dead storage values are not described. I recommend that the authors provide additional details on the estimation or data sources for these parameters—particularly for evaporation, which can significantly affect water availability in arid regions.

P.11, L260: While the model optimizes land allocation variables Lag,j,k,t, it remains unclear whether these represent irrigated land area or total crop area. Given their direct link to irrigation water application, they likely refer to irrigated land, but this should be explicitly clarified in the variable definitions.

P.11, L265-267: While the model adopts a Positive Mathematical Programming (PMP) approach to optimize agricultural land allocation, the manuscript lacks a clear description of how irrigated land areas are derived within this framework. Given the importance of irrigated area changes in explaining scenario results (e.g., reductions in agricultural water withdrawal), a more detailed explanation of the PMP calibration steps—including observed activities, cost functions, and land-use constraints—would greatly improve transparency and reproducibility, especially for readers unfamiliar with PMP.

P.11, L265-267: The current modeling framework optimizes irrigated land area based on economic profitability and water availability, but it does not appear to account for key drivers of future land-use change such as shifts in food demand or climate-induced changes in land suitability (e.g., aridification due to a warmer climate, crop viability under warming). These factors can strongly influence future irrigation patterns, and their exclusion limits the applicability of the model under broader climate–socioeconomic scenarios. I suggest that the authors briefly discuss this limitation, particularly in the context of scenarios (e.g., SSP2–RCP6.0) where food trade is expected to play a key role.

Also, the model appears to omit international trade in agricultural commodities. Since the economic decisions in the model depend on crop profitability at the national level, and since global trade flows can substantially influence land allocation and irrigation demand, the absence of trade dynamics may limit the realism of the scenario outcomes. I also suggest the authors to discuss this limitation as well briefly.

P,10 Eq20, P.17 L376-376: The model appears to use fixed crop prices based on historical FAOSTAT averages for 2006–2015 (Section 2.4.3), without projecting changes in agricultural commodity prices under future scenarios. Since crop prices are a major driver of land allocation and water use decisions, omitting price projections may limit the ability of the model to reflect plausible economic dynamics under SSP2–RCP6.0 or other scenarios. A discussion of this limitation and its potential effects on model outcomes (i.e., projection uncertainty) would be helpful.

P.12, L291: The objective function of the model uses a discount rate to calculate the net present value of benefits (Eq. 25, Section 2.2.8), but, probably, the specific value used for the discount rate, and its data source or justification, are not mentioned in the manuscript. Given the central role of the discount rate in determining long-term investment and benefit evaluations, I suggest that the authors specify the discount rate used and explain the rationale behind its selection, particularly in relation to standard assumptions in SSP or IAM frameworks.

P.17: While the model considers 13 major irrigated crops, the manuscript does not provide sufficient detail on how crop composition or land allocation changes under different scenarios. Including a summary table or plot showing crop-specific land area shifts would enhance interpretability.

P18, L400: The manuscript states that the ENV scenario minimizes the use of non-renewable groundwater (p.18). However, it remains unclear how this is implemented in the model. Is this achieved via explicit constraints, penalization in the objective function, or higher supply costs? Since this assumption plays a central role in shaping water allocation outcomes under the ENV scenario, it would be helpful if the authors provided more detailed explanation of the modeling formulation underlying this restriction.

P18, L402-403: The manuscript states that the DM scenario "identifies an optimal allocation of water and land to enhance agricultural water use efficiency" (p.18). However, this statement may be somewhat misleading. The optimal allocation of water and land (driven by economic value) primarily serves to maximize economic benefits, not necessarily to increase water use efficiency. Only the direct increase in irrigation efficiency (i.e., reaching the technical maximum in each basin) leads to a clear and quantifiable improvement in agricultural water use efficiency. I suggest rephrasing this sentence to more clearly distinguish between these different mechanisms.

P.19: The manuscript describes the Demand Management (DM) scenario as involving “optimal allocation of water” among sectors based on the economic value of water use. While this formulation (or expression) may be reasonable within the model, it may appear supply-side oriented to some readers—since it does not directly modify water demand behavior, but rather reallocates supply. I suggest clarifying how this approach qualifies as "demand management" in the context of the scenario narrative, perhaps by distinguishing it from infrastructure expansion or other supply-side interventions. The expression, “Optimal water demand allocation”, may be straightforward?

P.19, Table 2: The scenarios DM, NC, and RES assume that irrigation efficiency will be increased to a “maximum efficiency level” for each basin. However, the definition and source of this maximum value remain unclear. It would improve transparency to clarify whether these maximum values are technically feasible (e.g., drip irrigation), economically viable, or derived from empirical benchmarks (e.g., FAO-AQUASTAT or literature-based potential efficiencies). Furthermore, the estimation method and data sources used to determine these maximum efficiency values are not described. Providing such clarification, including potential regional differentiation or reference benchmarks (e.g., FAO-AQUASTAT or literature-based ranges), would greatly improve the transparency and credibility of the scenario assumptions.

P20. L411-413: The manuscript states that the model was both calibrated and validated for the base year 2010 (Chapter 4, first sentence). ① However, it is unclear how the model outputs for year 2010 prior to calibration were computed, and what metrics were used to assess the calibration’s effectiveness. ② Moreover, performing both calibration and validation on the same year raises concerns regarding overfitting and the robustness of the model’s predictive capacity. I recommend that the authors clarify the calibration procedure and consider including a validation step based on out-of-sample data or a different time period.

P.26, L507: Under the SSP2–RCP6.0 scenario, the reported reduction in irrigated land area warrants further discussion. Does this outcome align with other studies projecting land-use responses under similar scenarios? Including such a discussion would help readers better assess the realism and policy relevance of the model’s scenario results.

P20., L409: Broadly, the scenario results are presented without uncertainty ranges, confidence intervals, or sensitivity analyses. Given the strong influence of parameters like willingness to pay, irrigation efficiency, and non-conventional water costs, this deterministic presentation may limit the policy relevance of the results. Including uncertainty bands or conducting a robustness check across plausible parameter ranges would enhance the credibility of the scenarios for decision-makers.

P28, L568-569: The manuscript states that the domestic sector accounts for 55% of gross benefits in 2010, exceeding those of the industrial sector. This result may seem counter-intuitive, as industrial activities typically generate substantial economic outputs per unit of water use. While the manuscript explains that marginal benefits in domestic use are high for essential needs, the specific parameter values or demand curve assumptions used to generate these results are not clearly shown. I recommend the authors elaborate on the assumptions behind sectoral benefit estimation, especially regarding the benefit functions for the domestic and industrial sectors.

P33, L621: The manuscript states that a combination of water management options can help satisfy water demand. However, under the ENV scenario, both environmental flow requirements and constraints on non-renewable groundwater use are expected to reduce the water available for irrigation. Probably, this leads to substantial decreases in agricultural water withdrawals compared to BAU. It would be helpful for the authors to clarify whether this description is correct and whether these reductions result from unmet water demand due to supply constraints, or from economically optimal decisions under restricted water availability.

P34, L657: While the model provides a detailed representation of water allocation across BCUs within river basins, it does not appear to incorporate institutional or policy-based constraints such as transboundary water treaties or cooperative water management. Similarly, international trade in agricultural products is not modeled, despite its potential impact on regional cropping patterns and water demand. Clarifying these limitations would help define the scope and appropriate applications of the modeling framework.

<< Minor comments >>

P2 L41-46: Would you elaborate or rephase “appropriate water management options … consistent across spatial scales”?

General: I suggest reorganizing Sections 2.2–2.4 so that the spatial delineation and data sources (currently in Sections 2.3 and 2.4) are presented before the model formulation (Section 2.2). This would help readers understand the origins and meaning of key parameters or assumptions—such as willingness to pay and irrigation efficiency—before encountering them in the description on equations. Presenting the data context first would improve the overall readability of the modeling framework.

P.12, Eq. 25: the net present value (NPV) is defined as a summation over time ttt, yet the notation "Max NPV" is somewhat ambiguous. It might be clearer to explicitly show the double summation over both ttt and uuu, and to define NPV as a function of ttt, to clarify that it accumulates time-discounted net benefits across periods.

Figure 3: The colorbar needs unit.

Figure 5(a): Groundwater is shown as a single aggregated category. However, since the model differentiates between renewable and non-renewable groundwater—both conceptually and in terms of cost and sustainability—it would be more informative to distinguish these sources in the figure. This would also better support the interpretation of the ENV scenario, which specifically aims to reduce non-renewable groundwater use. I suggest disaggregating groundwater into renewable and non-renewable components to enhance the clarity and policy relevance of the figure.

Figure 6: Maps appear to be vertically compressed, which may hinder the geographic interpretation of spatial patterns. The aspect ratio does not reflect the natural proportions of the Earth's latitude–longitude grid, making it difficult to compare regions and assess spatial trends accurately. I recommend adjusting the map projection or aspect ratio to improve visual clarity and ensure accurate geographic representation.