Response to Anonymous Referee #2

Summary

The study compares watersheds by assessing causality links of different variables within the Water-energy-food-ecosystem nexus by using Bayesian Network. The framework is applied to two river basins linked to the Aral Sea, to identify factors and strategies that might explain or solve trade-offs among the different sectors and actors. The approach is of interest for the reader of HESS and Innovative. The strength of the framework is to find solutions without assuming the relationship between systems (compared to process-based models); by its design it is stakeholder and data driven. The work is well illustrated with clear figures.

Response: We would like to thank the reviewer for the positive comments and the time invested to review our manuscript. The revised manuscript will follow the reviewer's recommendations.

A Methodology:

It is not clear how this Bayesian Network is constructed, what is optimized or simulated. The authors only clearly describe 2 indicators of causality (VB and MI), and 3 performance indicators (/objectives ?): reliability, total benefits and cooperation, the rest of the framework is vague.

Response: Thank you for raising this point. We admit that the description of the method is not detailed enough. We will add more details about the methodology and revise this section.

A1 The two following describe steps general concept of the framework, however, it is later not clearly explained how those are concretely implemented – with references to the methodology/literature. l 115. "We construct a same WEFE nexus causality structure for the river basins selected in the previous step, which can be represented by a directed graph model such as the Bayesian network" l 121. "we combine the causal structure representing expert knowledge from multiple fields with actual statistics and observation data to update the initial understanding of causality. In this way, the original qualitative causal structure is quantified by actual data, and the originally scattered actual data is closely connected by the causal structure."

Response: Thank you for the insightful comments. We will add relevant references on how to build a Bayesian network in the fields of geography, ecology, hydrology and environment. Usually, expert knowledge is used for the construction of the network structure (to determine the meaning of the selected nodes and the causal logic between them) and the prior setting of the preliminary conditional probability table. In the next step, observation and statistical data are used to update the conditional probability table to get the posterior probability. We will explain in more detail how to combine expert knowledge and observed data in the revised manuscript.

A2 l 196. "The responsibility for exploring the differences between the two river basins mainly relies on the continuous updates of new input cases" What are new input cases? additional data?

Response: Thank you for the insightful comments. The "new" of input cases here corresponds to the "original " of the prior probability distribution. We admit that the description here is unclear and will be revised.

A3 l 208. "The index variance of belief (VB) and the index mutual information (MI) based on the change of information entropy (Barton et al., 2008; Marcot, 2012) - are applied to evaluate the change in strength and uncertainty of the causal relation between the nodes." explain better what those 2 indicators mean, how they can be interpreted ?

Response: Thank you for the insightful comments. They 'respectively' represent the reduction in variance and entropy of the probability distribution of child nodes caused by the determination of the state of the parent nodes. As the value range of the parent node is reduced, the variance or entropy of its distribution is usually reduced. The greater the variance or entropy of the distribution of child nodes that can be further caused by this reduction, the more sensitive the child node is to the parent node which also reflects the stronger causality. We will explain this with more details in the revised manuscript.

A4 l 225. " We utilized the posterior probability prediction function of BN so as to support the decision optimization." how are "posterior probability prediction function" formulated ? – reference ? how is the "optimization" formulated – what are the variables – objective - reference?

Response: Thank you for the insightful comments. We will revise it in the revised manuscript. The prediction function is usually used to infer and predict how one node (D) is likely to change with the distibution of its parent node (A) determined. All nodes that have dependencies between A and D should be included in the calculation. For example, suppose we have the simple Bayesian network for discrete variables with the structure A and D are connected through a dependency of D on C ,C on B and B on A, and we can use the following formula (Heckerman and Breese, 1996) to calculate the probability of D when the state of A is given.

$$P(D|A) = \frac{P(A,D)}{P(D)} = \frac{\sum_{B,C} P(A,B,C,D)}{\sum_{A,B,C} P(A,B,C,D)} = \frac{P(A)\sum_B P(B|A)\sum_C P(C|B)P(D|C)}{\sum_A P(A)\sum_B P(A)P(B|A)\sum_C P(C|B)P(D|C)} \quad (1)$$

Parent nodes are regarded as the independent variables, child nodes are regarded as the objectives. When the state of parent node is given, the beneficial probability distribution change of the child node can be regarded as our optimization goal. We formulated a change measure (ΔP) (Robertson et al., 2009) to assess the impact of a management scenario compared to a base case:

$$\Delta P_{low} = P(X_i|e)_{low} - P(X_i)_{low} \quad (2)$$

$$\Delta P_{high} = P(X_i|e)_{high} - P(X_i)_{high} \quad (3)$$

where e represents the determination of the state of the parent node (management scenario) in the form of hard evidence specifying a definite finding , $P(X_i|e)_{low}$ is the probability of the lowest state for the management scenario, $P(X_i)_{low}$ is the probability of the lowest state for the base case and ΔP_{low} is calculated as the change. The meanings of these variables are the same for the subscripts 'high'.

Reference

Robertson, D. E., Wang, Q. J., McAllister, A. T., Abuzar, M., Malano, H. M. and Etchells, T.: A Bayesian network approach to knowledge integration and representation of farm irrigation: 3. Spatial application, Water Resources Research, 45(2), doi:https://doi.org/10.1029/2006WR005421, 2009.

Heckerman, D. and Breese, J. S.: Causal independence for probability assessment and inference using Bayesian networks, IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 26(6), 826–831, doi:10.1109/3468.541341, 1996.

A5 In general, it is common in the HESS journal that authors if possible, provide the code, software files, so that others can use the framework. It would clearly increase the impact of the work to share the programming tools that were used (in a re-usable way).
Response: Thank you for the insightful comments. We will consider making the model and code available in the "Code/Data Availablilty" section.

B How does the framework guide decision making ?
B1 l 378. "In addition to the widely recognized differences in glacier melting in high mountainous areas, this study shows that the ratio of the upstream reservoir interception water to the total runoff is largely different in these two river basins" Do we need to apply the methodology to reach this conclusion ? is the data on runoff and reservoir capacity not already showing this ?
Response: Thank you for raising this point. We will give the values of the specific ratios, do not regard it as a conclusion, and add relevant references in the revised manuscript.

B2 The rest of the promising solutions presented in sections 5.2 and 5.3 are not based on the framework, at least not to my understanding. If yes, then explained how the framework leaded to find such solutions. If not, why did the framework not help to identify those solutions? How could we improve it to do so?
Response: Thank you for the insightful comments. We will revise this section. The Bayesian network in this manuscript was mainly based on the existing expert knowledge and data only within the Aral Sea basin. It did not incorporate other potential external solutions indirectly based on the framework. But we thought some external measures may also be useful as a complement to the solutions directly based on the framework. These external measures are derived from further consideration of the analysis of differences and optimization measures within the framework. For example, the promotion of drip irrigation we proposed can be seen as a further complement solution for the “reduce water inflow to depressions” in section 4.3. The discussion of the water inflow to depressions is due to the different sensitivity of the ‘water inflow to the Aral Sea’ to the ‘water inflow to the depression’ between the basins and among different periods in section 4.2. Since these factors were not considered in the network structure determined at the beginning or the degree of refinement of the structure was not sufficient to capture these factors. We have included this in the discussion section. For these promising measures in sections 5.2 and 5.3, we will try to explain their indirect connection with the framework to emphersize the logic between the sections more sufficient. For the content of measures that are not related to the framework, we will check and consider deleting them.

B3 l 444. "It might characterize the hidden uncertainty in the decision support." what hidden uncertainty has this study revealed ?
Response: Thank you for the insightful comments. The framework of this article may help decision support mainly in the quantification of the influence of complex causality and more remotely related variables. It may be inappropriate and unclear to be expressed as ‘hidden’

here, and we will revise it to make this more clear.

B4 The limitations of the framework could be more clearly stated. In which cases will the framework fail to identify sources of problems.

Response: Thank you for the insightful comments. We will strengthen the analysis of the limitations of the framework in Section 4.1 and discussion on it in Section 5.1. The newly added discussion content in the revised manuscript may include potential limitations caused by inappropriately selected nodes, lack of consideration of detailed causal processes, lack of expert knowledge, and low data quality/sufficiency. If the selected node variable is inappropriate, it may lead to the failure of the capture of causality. For example, we used the average life expectancy instead of the incidence of specific diseases caused by ecological problems, such as respiratory diseases caused by sand and salt storms. The lack of a more detailed description of causality may cause some detailed but important causality to be ignored, making it difficult for us to discover the differences between river basins. Therefore, the scale to which the structure needs to be refined and when it needs to be refined are what we need to consider carefully when promoting this framework. Lack of expert knowledge often leads to failure when building network structures and when initializing conditional probability tables. Complex networks may often require experts or stakeholders in multiple fields, and their concerns are often different, which may cause conflicts in the setting of the network structure and the initial conditional probability table. River basins in underdeveloped areas may also lack sufficient expert knowledge due to long-term insufficient investment in local related research fields. And weak data support (insufficient in quantity or accuracy) may also weaken the effectiveness of the framework.

B5 Maybe it would be easier to understand if the authors clearly differentiated between two steps: What insights does the framework give when applying the BN to a single river basin (/case) regarding causality and management options? What insights come from the comparison of the causality links between two cases/river basins? How can one basin learn from another by looking at causality links? (what insights cannot be found by looking only at one basin) and also: How does that compare to insights found by process based model as mentioned by the authors ? what are advantages and disadvantages ?

Response: Thank you for the insightful comments. This is a good suggestion. We will rearrange the results and discussion sections in the order of the questions listed by the reviewer. When applied only to a single basin, this framework can help decision makers to re-examine causal and remotely related factors that may have been overlooked before. It also helps to update their empirical knowledge of the probability distribution of some node variables because the previous empirical knowledge may not include the collaborative consideration of the distribution of parent nodes. Compared with process-based models, it may have advantages in the quantification of uncertainty and causality when data-limited and disadvantages in its ability to explain detailed processes or driving mechanisms. When applied to two or more basins, comparing the differences in causal links between different river basins can help local decision makers visualize the possible benefits or risks of new decisions because other river basins may have experienced similar decisions during the development process. We have already pointed out in the original manuscript that care should be taken when building large reservoirs on the Panj

River in the upper Amu Darya to avoid disputes over surplus water downstream caused by the release of upstream reservoirs in winter. Without this experience of the Syr Darya, it will make it difficult to evaluate the downstream conflicts on the possible surplus water that will be caused by the further development of the Amu Darya. Compared with applying the same process-based model in multiple watersheds, it may have advantages in simultaneously and dynamically showing the various causal relationships based on various combined conditions. The new framework may also be able to avoid errors caused by using different parameter groups when applied to two or more basins in the process-based framework because it entrusts the task of discovering differences between river basins to the actual observational data instead of pre-setting or adjusting different parameters of the driving functions in the process-based model. This part will be elaborated in the revised manuscript.

C Data

C1 l 465. The authors state: "The data sources we used in this study have been listed in the main text. Data can also be obtained by requesting the corresponding author." The authors are referred to the guidelines of the journal regarding data: https://www.hydrology-and-earth-system-sciences.net/policies/data_policy.html In table 2, the reference to the data is not precise enough, general websites are indicated. Some links do not work, e.g. https://www.cawater-info.net needs http and not https. The data should be published in a data repository with some decent meta-data level. Seven of the co-authors contribution is solely on data, hence I expect the dataset to be a major contribution of this work, thus special attention should be payed to it.

Response: Thank you for the insightful comments. We will make the data easier to access by checking and modifying data source links or publishing it in a data repository.

D other comments

D1 l 22. Water-energy-food nexus or nexuses ? Inconsistent through manuscript, most literature choose nexus.

Response: Thank you for the insightful comments. Our understanding is that 'es' can be added when representing nexuses in multiple basins. We will check and make it consistent.

D2 l 22-23. the river basins did not cause the Aral sea disaster, but poor water management did.

Response: Thank you for the insightful comments. We will revise it.

D3 l 78. many empirical parameters : give examples

Response: Thank you for the insightful comments. We will revise it. In the original manuscript we described it (line 78): 'However, in order to parameterize these models, we found that many empirical parameters or factors need to be set (Feng et al., 2016; Ravar et al., 2020), which could mask the shortcomings of an insufficient understanding of uncertain and complex processes.' For example, in these two articles, empirical coefficients are used to determine the conversion coefficient of electricity demand for water pumping from different depths, energy demand coefficients of various water sectors (Ravar et al., 2020) and driving functions of water supply, power generation, hydro-ecology (Feng et al., 2016).

References

Feng, M., Liu, P., Li, Z., Zhang, J., Liu, D. and Xiong, L.: Modeling the nexus across water supply, power generation and environment systems using the system dynamics approach: Hehuang Region, China, Journal of Hydrology, 543, 344–359, doi:10.1016/j.jhydrol.2016.10.011, 2016.

Ravar, Z., Zahraie, B., Sharifinejad, A., Gozini, H. and Jafari, S.: System dynamics modeling for assessment of water–food–energy resources security and nexus in Gavkhuni basin in Iran, Ecological Indicators, 108, 105682, doi:10.1016/j.ecolind.2019.105682, 2020.

D4 l 89. the word "superiority" might be overclaimed. It would be also interesting to describe what type of outcomes are available from the different studies.

Response: Thank you for the insightful comments. We will revise it.

D5 l 131. not clear what that "etc." refers to: remove.

Response: Thank you for the insightful comments. We will remove it.

D6 l 227. "we selected the scenarios" - which scenarios are we talking about?

Response: Thank you for the insightful comments. It refers to reducing the water inflow to the depression and improving the planting structure. We will revise it.

D7 l 253. why use "international trade" market prices, what for ecosystems?

Response: Thank you for the insightful comments. We use "international trade" market prices here because when it comes to cross-border cooperative management, different types of benefits (such as upstream hydropower and downstream agricultural products) may need to be weighted and summed. It may be more reasonable to use the universal price of various benefits in the international market to determine the weight. The value of ecological flow can be replaced by calculating the value of the ecosystem services it provides. In this manuscript, we did not use the actual price in this step because actual prices are constantly changing, and there is no uniform method for calculating the value of ecosystem services to determine the weight of ecological flows. But in the practical management, unique values should be given to determine the weight. As a simplified calculation, we normalized the three indicators to 0-1 and sum them with equal weights. We will revise this section to illustrate this clearly.

D8 l 277-279. and Figure 8. "During the period 1980 - 1991, the contribution of most variables has declined, which may be related to the normalization of the maximized agricultural production, leaving only the natural runoff as the main variation contribution. " Should the sum of the contribution of all variables not match a 100%? it is stayed that the runoff becomes the main variation contribution, however also the runoff variable has a decreasing value in the VB ratio. So what is the variable that increases if all the variables showed decrease?

Response: Thank you for the insightful comments. It is normal that the sum of the VB ratio is not 100%. It reflects the sensitivity of the target variable to different parent variables, so the reasonable range of each VB ratio can be 0-1. The decline in the VB ratios of this period may be due to the fact that the inflow to the Aral Sea has been steadily very low during this period.

D9 l 311. reducing flow to depressions is presented as the best solution, but in the previous section it is described as generating trade-off with other sectors and ecosystems – explain.
Response: Thank you for the insightful comments. In the previous section, it specifically refers to the benefits to the lake ecosystem of the depression. In section 4.3, the optimization goal here is focused the inflow to the Aral Sea. We will revise it to make the statement more clear.

D10 l 315. the term "positive" might be misleading, it seems drought have a positive effect on salinization, desertification in the sense "good", "desirable" . . .
Response: Thank you for raising this point. We will revise it.

References

Feng, M., Liu, P., Li, Z., Zhang, J., Liu, D. and Xiong, L.: Modeling the nexus across water supply, power generation and environment systems using the system dynamics approach: Hehuang Region, China, Journal of Hydrology, 543, 344–359, doi:10.1016/j.jhydrol.2016.10.011, 2016.

Heckerman, D. and Breese, J. S.: Causal independence for probability assessment and inference using Bayesian networks, IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 26(6), 826–831, doi:10.1109/3468.541341, 1996.

Ravar, Z., Zahraie, B., Sharifinejad, A., Gozini, H. and Jafari, S.: System dynamics modeling for assessment of water–food–energy resources security and nexus in Gavkhuni basin in Iran, Ecological Indicators, 108, 105682, doi:10.1016/j.ecolind.2019.105682, 2020.

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