Reviewer 3

The authors create a multi-sector system dynamics model, including environmental awareness dynamics and coupled reservoir simulation. The model simulates, among other things, water demand, energy consumption, food production, environmental awareness, and population and GDP growth. The authors apply their model to the Hanjiang river basin and discuss the model simulation results at length. They identify stages of expansion, contraction, recession, and recovery for future water and energy dynamics as well as stages of expansion and stabilization for future food dynamics. The authors conduct a one-at-a-time parameter sensitivity analysis and also show that WEFS (water-energy-food-society) outcomes are strongly impacted by the presence or absence of reservoirs.

While this work aims to contribute in two primary areas – improved understanding of the impact of (1) environmental awareness feedbacks and (2) water supply reservoirs on WEF systems – I believe the work does not achieve these contributions, for the reasons described below:

- It is not clear what exactly about the approach is new. What separates the present study from those WEF studies cited in the introduction, other than the specific context and states modelled? It seems to me that the intended novelty might be coupling a WEF "system-dynamics" model with a detailed reservoir network simulation model, though this is not made clear in the paper. The discussions of model formulation and results do little to emphasize reservoir impacts, though the title suggests that reservoir impacts are central to the paper.

Thank you very much for your insightful and constructive comments on our paper. We will thoroughly revise the paper based on the comments. We believe the current comment can greatly help improve the quality of the paper. Here are the responses to your comments:

We are going to add a new part in Section 4 to study the response of WEFS nexus to environmental awareness feedbacks by setting another two scenarios (i.e., with and without considering the environmental awareness feedbacks, respectively).

And the average annual values of socioeconomic sectors will be counted to contribute to the quantitative assessment on the impacts of environment awareness feedbacks and water resources allocation on WEFS nexus.

- **Socioeconomic model (section 2.1.1, equations (2)-(5)):**

1. The model formulation and justification overlooks well-established growth models subject to resource constraints. Why not use a logistic model for growth?

1 Response:

Thanks for your supportive suggestion. We quite agree with your opinion that logistic model is very popular in growth simulation for socioeconomic sectors. The Malthus growth model adopted in our study is also considered as an effective tool for growth simulation. However, socioeconomic factors in original Malthusian growth model without constraints will explode to infinity in a long-time evolution. Therefore, the growth rates of population, GDP and crop area are assumed to increase with decreasing rates as time goes. And feedback functions as well as environmental capacities of socioeconomic variables are adopted to constrain the infinity evolution of these socioeconomic variables through equation (3)-(5) (Feng et al., 2016; Hritonenko and Yatsenko, 1999). We will add the original Malthusian growth equation in equation (2). And the forms of equations for population, GDP and crop area will be corrected in equation (3)-(5) and interpreted in Section 2.1.2. The equation (4) for GDP simulation is taken as an example here:

$$\begin{cases} \dfrac{dG_t}{dt} = r_{G,t} * G_t \\ r_{G,t} = \begin{cases} r_{G,0} * (1 + \kappa_G * \exp(-\varphi_G t)) + f_2(E) & G_t \le G_{cap} \\ \mathrm{Min}(0, r_{G,0} * (1 + \kappa_G * \exp(-\varphi_G t)) + f_2(E)) & G_t > G_{cap} \end{cases} \end{cases} \quad (4)$$

where G_t is the GDP in tth year; GDP_{cap}, is the environmental capacity of GDP; $r_{G,0}$ is the growth rate of GDP in baseline year, which is observed from history data; $r_{G,t}$ is the growth rates of GDP in tth year; κ_G*exp(-$\varphi_G t$) is used to depict the impacts of technology development on evolution of GDP; E is environmental awareness; f_2 is the feedback function.

2. Each of these growth rates seem likely to be as or more effected by the *actual* resource limitations (i.e., shortages) than by the “environmental awareness” of those limitations. Yet, the physical limitations are not factored into these equations.

2 Response:

Thanks for your supportive suggestion. We totally agree with your opinion that the physical limitations can affect the socioeconomic growth more quickly and directly, which is of great significance for the short-term socioeconomic growth simulation. However, the physical limitations can't describe the process that human sensitivity responds to the environmental degradation within the prevailing value systems. Therefore, we use environmental awareness to describe societal perceptions of the environmental degradation to further drive the feedback on socioeconomic sectors, which is also an informative approach for the long-term socioeconomic growth simulation.

3. I believe rates of change should be proportional to the state at time t, not the initial condition.

3 Response:

Thanks for your supportive suggestion. We totally agree with your opinion. The changing rates for these socioeconomic variables in the paper are indeed considered changing over time. We will improve the forms of equations for socioeconomic sectors as is discussed in "1 Response", to indicate the changing rate explicitly.

4. The impact of technology development is either formulated unrealistically or discussed inaccurately – current formulation/discussion implies that technology suppresses growth.

4 Response:

Thanks for your supportive suggestion. We will give more descriptions for the impacts of technology development on socioeconomic sectors expansion. The exponential terms $\exp(-\varphi_P t)$, $\exp(-\varphi_G t)$ and $\exp(-\varphi_{CA} t)$ in the equations are used to depict the impacts of technology development on the evolution of population, GDP and crop area, and further determine their growth rates. Population, GDP and crop area are assumed to increase but with decreasing rates, as the difficulty for the increases is increasing as time goes, which can be fitly accounted by the exponential term (i.e., $\exp(-\varphi t)$ is non-negative and decrease over time, keeping socioeconomic sectors increasing with decreasing rates).

5. The water quota dynamics are especially unjustified – an exponential growth/decay model seems ill-fit.

5 Response:

Thanks for your supportive suggestion. We will improve the form of equation (6) for water use quota estimation. The exponential term would dampen the decreasing rate of water use quota (rather than water use quota), as the difficulty of saving water by the advances in technology is increasing over time. We will give more descriptions for water use quota simulation in Section 2.1.1. Water use quotas are assumed to decrease with the technology advancing due to expansion economy (Blanke et al., 2007; Hsiao et al., 2007). As the difficulty of saving water by the advances in technology is increasing, the changing rate of water use quota is decreasing in equation (6) (Feng et al., 2019).

$$\begin{cases} \frac{dWQ_{i,j}^{t}}{dt} = WQ_{i,j}^{t} * r_{qwu,t} \\ r_{qwu,t} = r_{qwu,0}(1-\kappa_{qwu} * \exp(-\varphi_{qwu}t)) \end{cases} \quad (6)$$

where $WQ_{i,j}^{t}$ is the water use quota of jth water user in ith operational zone in tth year; $r_{qwu,0}$ and $r_{qwu,t}$ are the growth rates of water use quotas in baseline year and tth year, respectively; κ_{qwu}*exp(-$\varphi_{qwu}t$) is used to depict the water-saving effect of technology development on evolution of water use quota.

- **Water shortage model (section 2.1.2, equations (6)-(7)):**

1. The index for summation is not declared, making the equations difficult to interpret.

6 Response:

Thanks for your supportive suggestion. We will take your valuable suggestion. We will correct the equations for water shortage determination and give more descriptions on it in Section 2.1.2.

Water shortage at demand node should be firstly determined on basis of its water demand and total water supply. The total water supply consists of natural water inflow (i.e., local water availability) and water supply from reservoir. In each sub-time-step (except the first), the average natural water inflow in previous *sts*-1 sub-time-step is estimated as the extrapolated natural water inflow in rest sub-time-steps by equation (7). The water shortage can then be determined by deducting the demand reduction, the total real-time water inflow and the extrapolated natural water inflow from water demand through equation (8). The total water shortage rate can then be determined by equation (9).

$$WE_{i,j}^{sts} = \left(\sum_{1}^{sts-1} WTSup_{i,j}^{sts} - \sum_{1}^{sts-1} WRSup_{i,j}^{sts}\right) * \frac{(Tsts - sts + 1)}{(sts - 1)} \tag{7}$$

$$WS_{i,j}^{sts} = \frac{WD_{i,j}^{ts}(1 - f_{red}) - \sum_{1}^{sts} WTSup_{in}^{sts} - WE_{i,j}^{sts}}{Tsts - sts + 1} \tag{8}$$

$$WSR_{i,j}^{t} = \frac{\sum_{ts}\sum_{sts} WS_{i,j}^{sts}}{\sum_{ts} WD_{i,j}^{ts}} \tag{9}$$

where ts is the current time step; $Tsts$ is the total number of the sub-time-step; sts is the current sub-time-step; $WE_{i,j}^{sts}$ is the extrapolated natural water inflow for jth water use sector in ith operational zone; $WTSup_{i,j}^{sts}$ is the total water supply; $WRSup_{i,j}^{sts}$ is the water supply from reservoir; $WD_{i,j}^{ts}$ is the water demand; f_{red} is the demand reduction factor; $WS_{i,j}^{st}$ is the water shortage; $WSR_{i,j}^{t}$ is the water shortage rate in tth year.

2. The variable definitions are inconsistent and contradictory. Wdem is said to be water demand in line 201, yet WD also appears in equation (7) and is defined as water demand. There is also a Wd variable which is never defined.

7 Response:

Thanks for your supportive suggestion. We will check and correct the variables definitions of all equations to make them clear and consistent.

3. The temporal resolutions (time step and sub time step) are not explained and are therefore confusing.

8 Response:

Thanks for your supportive suggestion. We will add the description about the temporal resolutions of IRAS water resources allocation model in Section 2.1.2. IRAS model runs on a yearly loop. The year is divided into user-defined time step, and each time step is broken into user-defined sub-time-step, base on which water resources allocation conducts. The temporal resolutions of the established WEFS nexus in the study area will also be given in Section 4. The established WEFS nexus runs on a yearly loop. Specifically, as water resources allocation model in water system module takes a monthly time step in the study (and the sub-time-step is the default value: 1 day), the annual water supply and water shortage are firstly determined before outputted to energy system module and food system module, respectively. The annual shortage rates of water, energy and food are then used to determine environmental awareness and further the feedback."

4. The distinction between "natural" and "total" water inflow is unclear.

9 Response:

Thanks for your supportive suggestion. We will add more details to describe the water shortage estimation in water resources allocation model, as is discussed in "6 Response". Specifically, the total water supply at a demand node is composed of two parts, the natural water inflow (i.e., local water availability) and water supply from reservoir. The extrapolated natural water flow at *sts*th sub-time-step indicates that the average natural water inflow in previous *sts*-1 sub-time-steps is adopted as the natural water inflow in the rest *Ttst*-*st*+1 sub-time-steps to further estimate the water shortage.

- **Energy system and Food system modules (sections 2.3 and 2.3, equations (8)-(13));**

1. These modules apply opposite approaches, without justification. The energy module simulates energy demand and takes energy production as an input ("planning energy production"). In contrast, the food module simulates food production and takes food demand as an input (misleadingly named "planning food production"). Why not simulated food demand or energy production?

10 Response:

Thanks for your supportive suggestion. We quite agree with your opinion that energy production and food demand play an important role in WEFS nexus.

The model in the study is proposed for WEFS nexus simulation at basin-scale. However, the imports and exports of energy and food for a basin are always quite complex. For instance, the study area (i.e., the mid-lower reaches of Hanjiang river basin) is considered as an important grain producing area, occupying one of the nine major commodity grain bases in China. The local food demand can always be ensured, and most of food production is exported, the total demand of which is hard to be simulated. For energy production, the energy structure in the study area involves thermal power, hydro power, wind power, solar power and biomass power, which brings a great challenge to the data collection. Moreover, the energy import and export of the study area is complex, as it's under the impacts of Three Gorges (the largest reservoir in China) electric power system, which indicates that the energy production is hard to be determined.

Therefore, as the paper focuses on assessing the impacts of environmental awareness and water resources allocation on WEFS nexus, we simplified the food demand and energy production as the boundary conditions of the model (i.e., planning food production and planning energy production, respectively).

2. No justification is provided for formulating energy demand as a function of water supply, as opposed to population or GDP for instance. Water supply seems like a more important factor for energy production, though energy production is not modelled.

11 Response:

Thanks for your supportive suggestion. Water supply indeed plays a more important role in energy production, rather than consumption. Therefore, we will take this valuable suggestion. We are going to re-build the WEFS nexus model by re-defining the energy consumption in Section 2.2 and the results will be updated.

We will focus on the energy consumption during water supply process to further help investigate the energy co-benefits of water resources allocation schemes (Zhao et al., 2020; Smith et al., 2016). The energy consumption for water heating and water end use will not be included in revised manuscript. Energy consumption is determined by energy use quota and the amount of water supply for water use sectors (Smith et al., 2016). Despite the amount of energy consumption from water supply process is much smaller than the total amount of energy consumption in the study area, it's still an interesting topic to quantitatively assess the trade-offs between water supply and energy consumption under different water resources allocation schemes.

3. I would think that the entire crop yield dynamics are due to technology changes (ignoring water shortage), yet technology change is offered as a single term in equation (11).

12 Response:

Thanks for your supportive comment. We will take the valuable suggestion and improve the equation (20) for crop yield (so as the water use quota and energy use quota). We are going to re-build the model by removing the feedback driven by the changing rate of GDP. And the results will be updated.

$$\begin{cases} \frac{dCY_{i,j}^{t}}{dt} = CY_{i,j}^{t} * r_{pro,t} \\ r_{pro,t} = r_{pro,0} * (1 + \kappa_{pro} \exp(-\varphi_{pro} t)) \end{cases} \quad (20)$$

where $CY_{i,j}^{t}$ is the potential crop yield of *j*th crop in *i*th operational zone in *t*th year; $r_{pro,\ 0}$ and $r_{pro,\ t}$ are the growth rates of crop yields in baseline year and *t*th year, respectively; $\kappa_{pro}*\exp(-\varphi_{pro}t)$ is used to depict the impacts of technology development on evolution of crop yield

4. From the results (Section 4, see especially Tables 2 and 5), it seems that a constant energy production and constant food demand are used to drive the model simulation. This seems unrealistic.

13 Response:

Thanks for your supportive suggestion. We quite agree with your opinion that the energy production and food demand keep changing over time. As is discussed in "10 Response", the energy production and food demand are taken as the boundary conditions of the model in our study. We have given a preliminary sensitive analysis on "planning energy production (PEP)" and "planning food production (PFP)" in Section 4.3. The results indicate that PEP and PFP are the sensitive parameters in the co-evolution of WEFS nexus.

Therefore, we think it's an interesting and important topic to taken time-varying energy production and food demand into account under different policies. However, this paper focuses on impacts of environmental awareness feedback and water resources allocation on WEFS nexus. The time-varying energy production and food demand, and so as their simulations will be taken into account in our further study.

- **Model validation (Section 4.1):**

1. The methods used to develop the observed time series are unclear. For instance, how exactly were the agricultural water demand exceedance frequencies used?

14 Response:

Thanks for your supportive suggestion. The observed time series for population, GPD, crop area, water demand, energy consumption and food production from 2010 to 2019 are collected from the yearbook of Hubei province in China (http://data.cnki.net/). The agricultural water demand depends on not only the water use quota and crop area, but also the precipitation frequency. For simplicity, four frequencies (i.e., 95%, 90%, 70%, and 50%) are used to fit the yearly precipitation frequency series. Four types of agriculture water use quotas under the four frequencies (i.e., 95%, 90%, 70%, and 50%) in the baseline year are collected for water demand projection, which will be added as initial condition setup in Table 2.

2. The observed data is not sufficient to validate the model. The observed data cover a short period during the beginning of the simulation during which all states increase approximately linearly. The effects of shortage and environmental awareness are minimal during this period (as stated by the authors in their interpretations); therefore, the observations offer no validation of the awareness dynamics or feedback. That the model matches observed dynamics under this narrow, early set of conditions does not mean that the model can reliably simulate dynamics under drastically different conditions. For instance, a model which predicts perpetual linear growth in all states would seem to match the observations equally well. Given that the data does not validate the model, the model results are only useful to the extent that the model formulation seems true-to-reality. However, little justification is given for the model formulation, and as described above, there are many problematic elements of the model formulation.

15 Response:

Thanks for your supportive suggestion. We quite agree with your opinion that the numerical calibration of the model with such short data is a challenging work. We believe that sufficient case study examples will emerge as time goes, which could cover a range of gradients, and slowly provide confidence in the WEFS nexus modelling.

Our study focuses on the human sensitivity feedback to the environment degradation, which is assumed to be composed of water shortage, energy shortage and food shortage. As the water and energy availability in the beginning of co-evolution can almost cover the demand from water and energy systems in the study area, environmental awareness indeed stays at a low level. Only the parameters for food shortage awareness and its feedback are calibrated due to the food shortage, while the parameters for environmental awareness and its feedback are poorly calibrated.

However, with the fast socioeconomic expansion, the contradictions between demand side and supply side in water, energy and food systems are going to intensify. The society system will then be more sensitive to environment degradation and seek for environment recovery by constraining socioeconomic expansion as feedback. It worth noting that the forms and parameters of feedback function are not prescribed. The forms and parameters are on basis of previous studies (Feng et al., 2019; Van Emmerik et al., 2014), which is proved with good performance and suitability, and combined with expert knowledge to keep the evolution of socioeconomic variables within rational intervals. As the feedback parameters can be used to indicate the response level of community for environment degradation (i.e., the higher level, the stronger feedback), our work can still offer technique support for managers to avoid severe environment degradation from the planning perspective.

- **Model results (Sections 4.2-4.3):**

1. Most of the discussion of the results (co-evolution of WEF system) is a text description of what is seen in the figures. The discussion does little to draw out and emphasize insights.

16 Response:

Thanks for your supportive suggestion. Based on the trajectory of environmental awareness, the co-evolution processes of water demand and energy consumption can be divided into four phases: expansion, contraction, recession and recovery. We will give more detailed discussion and emphasize the current findings. From the discussion, we found that available water and energy are the vital resources constraining the long-term concordant development of the integrated system in the study area. And more attention should be paid to the time lag of community's response to the deterioration WEFS nexus to prevent the integrated system from collapsing, especially after the fast expansion of water demand and energy consumption, which can provide useful support for policy-makers.

2. The sensitivity discussion does little to add understanding. Most interpretations of sensitivity results are vague, such that the same observations could be stated just from the variable definition and model formulation. For example, in lines 551-553, the effect of lowering the food shortage sensitivity threshold level is obvious from its definition.

17 Response:

Thanks for your supportive suggestion. We will update the figures for sensitivity analysis by replacing the black lines with colored lines and color bars so as to give a more informative sensitivity analysis for identifying the explicit variations of state variables with varying parameters. Sensitive analysis on water demand is taken as an example in Figure 6 here.

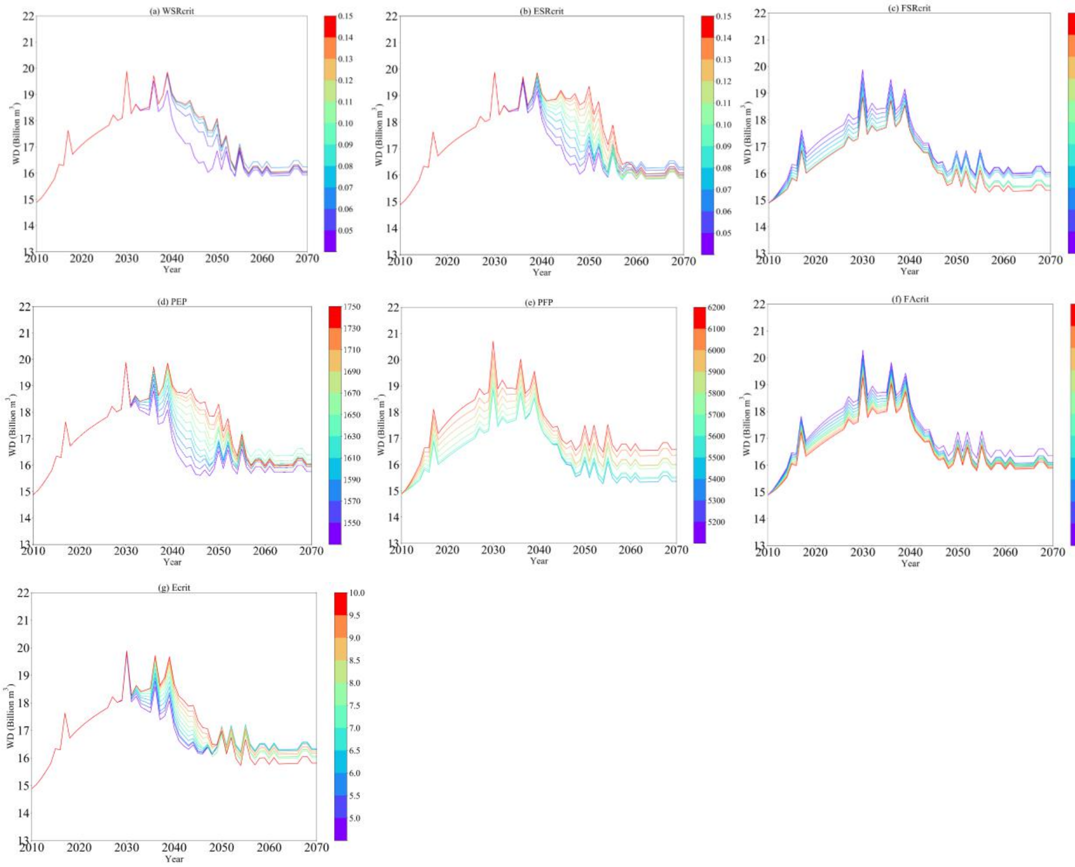

Figure 6. Trajectories of water demand with varied parameters. (Figure 7, 8 and 9 for trajectories of energy consumption, food production and environmental awareness will also be updated)

We find that the co-evolution mode of WEFS nexus functioning strongly depends on the selection of certain parameter values. Rational parameter setting of boundary conditions and critical values is of great significance for managers to keep the socioeconomic sectors from violent expansion and deterioration, especially in contraction and recession phases.

- **Impacts of reservoir system (section 4.4):**

1. The methodology applied here is unclear, what exactly does it mean that one scenario considers allocation and the other doesn't?

18 Response:

Thanks for your supportive suggestion. We will give more details to describe how the methodology applied to the mid-lower reaches of Hanjiang river basin in Section 4. The study area is divided 28 operational zones based on the administrative units and sub-basins. The socioeconomic data (i.e., population, GDP and crop area) for water demand projection are collected based on administrative units, while the hydrological data are often collected on basis of river basins. To ensure the socioeconomic data and the hydrological data consistent in operational zones, the study area is divided into 28 operational zones based on the superimposition of administrative units and sub-basins.

The time resolutions of the model in the study area will also be added to help illustrate how the methodology is applied. The established WEFS nexus runs on a yearly loop. Specifically, as water resources allocation model in water system module takes a monthly time step in the study, the annual water supply and water shortage are firstly determined before outputted to energy system module and food system module, respectively. The annual shortage rates of water, energy and food are then used to determine environmental awareness and further the feedback.

Scenario I considered water resources allocation is based on the real-world reservoir system, while scenario II removes the reservoir system from scenario I, so as to assess the impacts of water resources allocation on WEFS nexus.

2. Nonetheless, it seems that scenario I is running the model with the real-world reservoir network and scenario II is running the model with all reservoirs removed (?). If so, scenario II does not seem like a useful comparison. Is the region considering removing any or all dams in the basin?

17 Response:

Thanks for your supportive suggestion. One of the goals of our study is to assess the impacts of water resources allocation on WEFS nexus, as previous studies haven't considered water resources allocation or significantly simplified reservoirs operational rules in water resources allocation. Compared with scenario I, water resources allocation is removed in scenario II so as to assess the impacts of water resources allocation on WEFS nexus. The results indicate water resources allocation is of great significance in ensuring water supply and further sustaining the WEFS nexus from the planning perspective.

The numbers as well as the operational rules of reservoirs in the study area may change over time in the future. It's also a very interesting topic to investigate the impacts of changing reservoir system on WEFS nexus, which is a very informative study for managers from the planning perspective.

- There are language issues throughout the manuscript – most frequent were typos, poor sentence structure (lots of passive voice that creates confusion about who is the subject and what exactly they are doing), and inappropriate word choice. There are too many to list specifically.

18 Response:

Thanks for your supportive suggestion. We will carefully improve the writing quality in the revised manuscript.

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