water

MDPI

Article

Assessing the Water–Energy–Food Nexus and Resource Sustainability in the Ardabil Plain: A System Dynamics and HWA Approach

Kazem Javan [1,*], Ali Altaee [1], Mariam Darestani [2], Mehrdad Mirabi [3], Farshad Azadmanesh [4], John L. Zhou [1] and Hanieh Hosseini [5]

1 The Department of Civil and Environmental Engineering, University of Technology in Sydney, Sydney, NSW 2007, Australia; ali.altaee@uts.edu.au (A.A.); junliang.zhou@uts.edu.au (J.L.Z.)
2 The Department of Civil and Environmental Engineering, University of Western Sydney, Sydney, NSW 2750, Australia; m.darestani@westernsydney.edu.au
3 The Department of Civil and Environmental Engineering, University of Ferdowsi, Mashhad 9177948944, Razavi Khorasan, Iran; mirabi.mehrdad@gmail.com
4 The Department of Civil Engineering, University of Sajad, Mashhad 9188148848, Razavi Khorasan, Iran; azadmanesh40@gmail.com
5 The Department of Computer and Electronic Engineering, University of Sistan and Balouchestan, Zahedan 9816745785, Sistan and Balouchestan, Iran; hosseini.haniye@gmail.com
* Correspondence: kazem.javan@student.uts.edu.au

Abstract: Ardabil Plain, which holds significant political and economic importance in agricultural production in Iran, has faced various challenges including climate change, economic sanctions, and limited access to global trade. Ensuring food security has become a key priority for the region. The main objective of this research is to identify a suitable crop for this critical region with regard to future climate change conditions. This study employs a new framework of the system dynamics model (SDM) and the Hybrid Weighted Averaging (HWA) method to assess the Water–Energy–Food (WEF) nexus and resource sustainability in the Ardabil Plain under different climate change scenarios (RCP 2.6, RCP 4.5, and RCP 8.5). The research addresses current and future water challenges, emphasizing the need for additional energy and selecting optimal crops. Using the SDM, the study analyzes the impact of water supply fluctuations on agriculture, economic gain, and energy consumption from 2021 to 2050. The results indicate that barley is the most suitable crop for the Ardabil Plain in the near future, based on the overall ranking derived from the HWA method, which is as follows: barley > wheat > soybeans > potatoes > pears. The study highlights the significant challenges in energy supply for agriculture due to declining water levels and the increased force required by pumps to supply water to farms. These findings provide valuable insights for policymakers and stakeholders to make informed decisions in addressing water scarcity and rising energy demands in the Ardabil Plain.

Keywords: Water–Energy–Food nexus; sustainability; system dynamics model; HWA method; crop selection

check for updates

Citation: Javan, K.; Altaee, A.; Darestani, M.; Mirabi, M.; Azadmanesh, F.; Zhou, J.L.; Hosseini, H. Assessing the Water–Energy–Food Nexus and Resource Sustainability in the Ardabil Plain: A System Dynamics and HWA Approach. *Water* **2023**, *15*, 3673. https://doi.org/10.3390/w15203673

Academic Editors: Peiyue Li, Busawan Bidorn and Balamurugan Paneerselvam

Received: 27 September 2023
Revised: 13 October 2023
Accepted: 18 October 2023
Published: 20 October 2023

1. Introduction

Over the next few decades, the demand for freshwater, energy, and food will increase due to population growth, economic development, urbanization, international commerce, food diversity, cultural and technological developments, and climate change [1]. However, in many regions of the world, competition for limited resources will restrict the ability to meet demand because these resources are interconnected [2]. To tackle these challenges, the Water–Energy–Food (WEF) nexus is being developed, providing an opportunity to enhance these aspects by using an interdisciplinary approach that comprehends the trade-offs and synergies involved in resource management [3,4]. Lawford explores multi-sector WEF datasets that can be created and used to support stakeholders and decision makers in the WEF nexus, proposing a generalized and conceptual data information system design [5]. In an educational environment, Hamidov and colleagues examined whether employing sustainability impact assessment protocols could serve as a beneficial method to embrace a holistic, interdisciplinary approach for implementing the WEF nexus in research aimed at sustainable development [6]. The concept of the World Economic Forum is still in its early stages and may take some time to gain universal acceptance. Liu et al. emphasizes the need for an integrated methodology and stakeholder feedback to simulate hydrology, energy, and food systems [7]. Socioeconomic and climatic factors and an expanding population exacerbate the challenges of the WEF nexus, as noted by McCarl et al. [8]. Bazilian et al. suggest that institutional capability is essential in analyzing the complex interconnections of the WEF nexus [9]. For instance, institutional limitations in Pakistan are important to consider when estimating WEF resources accurately [10].

The simulation method, the system dynamics model (SDM), can be used to investigate WEF nexus problems and visualize the non-linear connections and feedback interactions among connected subsystems within the defined boundaries of a system [11]. A review of the existing literature on SDM reveals that most research has concentrated on investigating the connections and interdependencies among WEF systems in different places in the world. Linderhof et al. utilized system dynamics to demonstrate how alternative policy options can help the Netherlands achieve its goals of creating a low-carbon economy [12]. Feng et al. utilized the SDM approach to uncover the dynamics of complex processes in water supply, power production, and environmental systems [13]. Ravar et al. developed a WEF nexus simulation model based on the SDM approach to achieve WEF supply security while considering ecosystem provisioning services [14]. A collaborative approach was taken to create a system dynamics model to identify and evaluate the important connections between water, food, and energy systems in Andalusia, Spain, by González-Rosell et al. [15]. In another study, the authors utilize an SDM approach to simulate the interactions within the WEF nexus. The research is conducted in the green belt of the peri-urban area surrounding the city of São Paulo, situated on the outskirts of the Atlantic Forest, a bio-diverse forest in Southeastern Brazil [16]. An SDM was created to simulate and monitor the progress of the Water–Energy–Food–Society–Economy–Environment (WEF-SEE) system in Hunan Province, China. The model is utilized to evaluate the trajectories of the WEF-SEE system from 2021 to 2035, considering nine policy objectives set by the Hunan Provincial Government [17].

A decision maker requires a tool to make more effective decisions regarding the outlets of SDMs. Multi-criteria decision-making (MDCM) approaches are deemed effective tools for evaluating water resources management and choosing a comprehensive solution [18–20]. The Hybrid Weighted Averaging (HWA) method is one of the MDCM methods [21]. HWA is preferred due to its ability to incorporate multiple criteria, flexibility in assigning weights, consideration of risk attitudes, improved decision accuracy, and increased transparency. HWA allows decision makers to comprehensively analyze various factors, assign weights based on their importance, and account for their risk preferences. HWA provides accurate and robust decision outcomes by combining the strengths of different weighting approaches. Its transparent nature enhances understanding and trust in the decision-making process. HWA offers a flexible and comprehensive framework for decision making that aligns with decision makers' preferences and provides reliable and transparent results [22]. In developing nations, there is a growing emphasis on acknowledging and accurately evaluating the interdependencies and potential conflicts among the water, agriculture, and energy sectors [23]. This recognition is vital for addressing issues like selecting appropriate crops for specific watersheds or determining suitable energy sources for regions. Effectively managing the WEF nexus and successfully navigating these challenges require implementing the HWA approach.

Several nations in the Middle East's arid and semi-arid regions are currently grappling with the challenges of water scarcity and increasing demands for food and energy in the face of climate change conditions. Iran, one of the prominent countries in the region, shares a comparable arid and semi-arid climate context [24]. Having faced climate change, economic sanctions, and limited access to global trade, Iran has placed significant emphasis on food security and self-sufficiency. The concentration of the population in areas heavily reliant on water resources for drinking and agricultural irrigation further accentuates the significance of water in Iran [25]. Agriculture is central to the Iranian economy, contributing around 10% to the gross domestic product, employing 20% of the workforce, and accounting for more than 20% of non-oil exports [26]. However, the country faces critical challenges due to excessive water consumption, particularly within the agricultural sector [27]. Successive droughts due to climate change have placed Iran in an unfavorable position concerning water resources, and previous programs aimed at improving water-saving behaviors have largely focused on economic concerns with limited success [28]. In light of these circumstances, managing water, food, and energy resources requires the consideration of win–win strategies that balance agricultural production, environmental impacts, and social considerations. The WEF nexus approach emerges as a highly effective and integrated framework for sustainable agricultural management [29].

Extensive research has been conducted to explore the WEF nexus in various regions of Iran. Sadeghi et al. studied to implementation of a linear optimization approach for the WEF nexus in the Shazand watershed, Markazi Province, Iran. The focus was on planning 14 crops across orchards, irrigated farms, and rain-fed farms from 2006 to 2014, to maximize the WEF nexus index [30]. A study to develop a conceptual framework and an SD simulation model as a tool for inter- and cross-sectoral policy making to assess and enhance the ecosystem provisioning services in the Gavkhuni basin in central Iran by Ravar et al. was conducted [14]. Radmehr et al. aim to optimize the management of the groundwater, energy, and food nexus in the Neishaboor basin in northeast Iran using an MCDM method. It provides insights into the dependence of economic profit and food production on groundwater availability and energy use, informing effective strategies for integrated planning [31]. Naderi et al. utilize qualitative representation and quantitative system dynamics simulation to analyze the water resources system in the Qazvin Plain, Iran [32]. The research considers the energy intensity of water supply and the interconnected usage of water in various sectors, including urban, industrial, and agricultural sectors. A comprehensive SDM to simulate the interconnectedness of water, energy, and food in the Urmia Lake Basin is created by Bakhshianlamouki et al. [33]. The model assesses the effects of proposed measures for lake restoration, specifically focusing on potential trade-offs.

Ardabil Plain in Iran possesses significant agricultural potential and ranks highly in producing various agricultural products. The province's strategic location, bordering the Republic of Azerbaijan, facilitates the export of agricultural products. Despite its relatively small size, Ardabil contributes significantly to the national agricultural output and employs a large portion of the province's workforce. The region's crops include wheat, barley, potato, fruit trees, and soya, with irrigation exclusively using surface water. However, due to the low annual river discharge, groundwater pumping has increased six-fold since the mid-1980s [34]. Several studies have been conducted on decision-making methods in this region [35–38]; however, an assessment of the WEF nexus specifically for this area has not yet been undertaken.

The manuscript offers a comprehensive study that utilizes an SDM and HWA method to evaluate the WEF nexus and selection of a crop in a semi-arid and arid region. This novel framework of SDM and HWA represents the first application of such an approach in WEF nexus research. This research aims to address how the combination of an SDM and HWA method can be employed to assess the WEF interplay and determine the most appropriate crop for growth in a semi-arid and arid zone, such as the Ardabil Plain, while taking into consideration anticipated climate change conditions. Additionally, it seeks to investigate the potential economic and environmental consequences associated with this methodology. The simultaneous application of the SDM (Vensim model) and

HWA methods offers a pioneering approach to addressing the intertwined concerns of economic and environmental sustainability on a global scale. This novel approach has not been previously employed, emphasizing its innovative nature in tackling these dual challenges.

2. Methods and Data

2.1. Case Study

The research focused on the Ardabil watershed plain in northwestern Iran, bordered by the Caspian Sea, the Republic of Azerbaijan, and the East Azerbaijan province (Figure 1). The Ardabil province has achieved impressive rankings in several agricultural categories, including being the second-largest producer of potatoes, ranking fifth in sugar beet production, and seventh in producing beans, wheat, and barley [39]. The Ardabil Plain offers significant potential for cultivating various agricultural products in the Ardabil province. Large-scale farming has thrived in the region for many years. Moreover, Ardabil's strategic geographic location, with a shared border with the Republic of Azerbaijan, provides advantageous opportunities for exporting agricultural goods. The study area encompasses a plain with a size of approximately 4747 km^2. This region's annual average precipitation range varies between 220.8 and 370 mm, while the annual average temperature is 11.4 °C. Regarding water resources, the average annual evaporation ranges from 1500 to 2300 mm, and the annual average surface runoff is measured at 185 million cubic meters (MCM). Regarding water management, there are 3607 registered wells in the region, and the annual average reduction in groundwater level is reported at 0.3 m. The daily water demand per person for municipal use in 2006 is estimated to be 182 L. Furthermore, water used for municipal purposes accounts for 6% of the total water usage, while the area of land under irrigation covers approximately 132 hectares. The irrigation efficiency in the region ranges from 25 to 38%. Agriculture accounts for 90% of water usage, while the industrial sector utilizes 4% of the water resources [39–41].

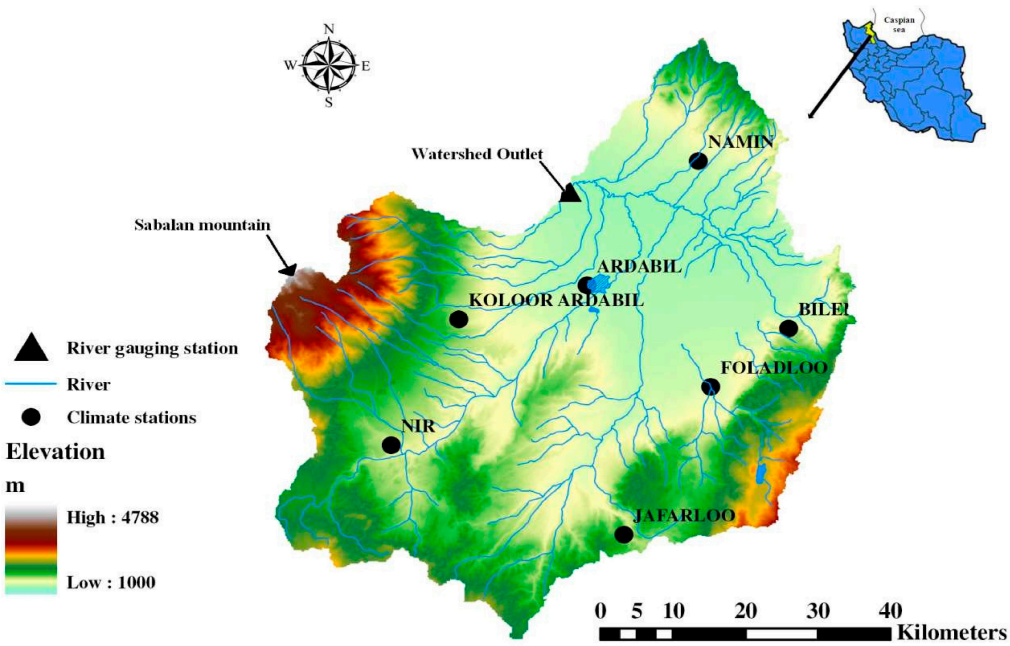


Figure 1. The Ardabil Plain map.

The average energy consumption in the agricultural sector of Iran is three times higher than the global average. According to official data, the majority of fossil fuel consumption in agriculture is attributed to gasoil, accounting for 94% of the total. Additionally, electricity consumption in the sector has witnessed a significant annual growth rate of 45% between 1988 and 2014 [42]. Table 1 shows the stock of agricultural wells connected to electricity in the jurisdiction of Ardabil Provincial Power Distribution Company in 2016 [39,43]. In Ardabil, a wheat production farm with an area of approximately one hectare experienced energy consumption of 6.49% for pumping water and 8.74% for irrigation, accounting for a significant portion of the total input energy [44]. As another example for potatoes, the total energy utilized for different farm activities in the cultivation amounted to 81,624.96 MJ per hectare. The average annual crop yield observed in the surveyed farms was 28,453.61 kg per hectare, resulting in a calculated total energy output of 102,432.99 MJ per hectare in Ardabil [45].

Table 1. Inventory of electrified agricultural wells in the coverage area of Ardabil Provincial Power Distribution Company in 2016.

Month	Number of Wells	Electricity Consumption (MWh)
March	1528	6253
May	1545	19,560
July	1553	20,115
October	1587	13,317
December	1596	4649
February	1610	9064

2.2. Methods

2.2.1. Causal Loop Diagrams (CLD)

In this study, Causal Loop Diagrams (CLDs) are graphical tools that depict the relationships between variables using polarized arrows to represent positive (+) or negative (−) relationships [46]. Stocks in CLDs represent the accumulations and depletions that change over time, while flows indicate the rate at which stocks are modified at any given moment. Additionally, converters, inputs, output signals, and connections are depicted to demonstrate the connections between different system components. CLDs and System Flow Diagrams (SFDs) are valuable tools for quantitatively modeling water resource dynamics systems and simulating the system's behavior [47].

2.2.2. System Dynamic Model (SDM)

SDM is a simulation methodology used to analyze and understand complex dynamic systems. SDMs capture the interdependencies and trade-offs among water, energy, and food systems, enabling the exploration of complex feedback loops and dynamic behavior. By modeling the flows and interactions between sectors, SDMs help to identify the impacts of changes in one sector on the others. They facilitate the evaluation of resource scarcity, quantification of trade-offs, and policy analysis in the WEF Nexus context. SDMs contribute to sustainable resource management by designing integrated strategies, promoting stakeholder engagement, and facilitating informed decision making. Overall, SDMs provide a holistic framework for analyzing the WEF Nexus and developing strategies to address its challenges [32]. Sankey Flow Diagrams (SFDs) are widely used to depict material or energy flows and provide a visual overview of how resources are utilized, transferred, and wasted within a system. The SFD is generated using the system dynamics Vensim software version 9.1.1. Stocks are crucial SDM system variables because they allow the storage or accumulation of material. Flows are the systems that regulate the rate at which material moves into and out of stocks. To summarize, CLDs and SFDs are used to quantitatively depict, assess, and simulate a system in modelling water resources system dynamics [46]. There are several SDM equations in this paper. One of the SDM's components is based on the basin's water balance (Equation (1)) [48]:

$$\Delta v = \left[\left(\overline{P}_{eff} \cdot A_B\right) + Q_{return}\right] - \left[Q_{in} + Q_{do} + Q_{agri} + E_{dam} + E_{land}\right] \quad (1)$$

The average net rainfall in the watershed ($\overline{P}_{eff}$) is measured in meters, and according to Hull's interception ratio, it is estimated that 85% of the rainfall in this study falls on the plain. A_B refers to the total area of the plain in km^2. At the same time, Q_{in} and Q_{do} represent the total consumption of industrial and household water in the plain, respectively, measured in million m^3 [49]. Q_{agri} (million m^3) represents the agricultural water demand, with wheat, barley, potatoes, and fruit trees being the main crops, and all other crops are grouped into one category. The irrigation efficiency for croplands and fruit trees is predicted to be 0.39 and 0.44, respectively [50]. The evaporation from dams is denoted as E_{dam}, and land evaporation is referred to as E_{land} (including fallow land and rain-fed cropland). Q_{return} represents the overall backflow from the residential, agricultural, and industrial sectors using the IWRMC data [51]. To calculate the river discharge to the plain, Equation (2) is used, where Q_{runoff} (million m^3) represents the total runoff. The inflow coefficient is calculated using Farajzadeh's model [52]. The total water consumption returned to surface water is denoted as $(Q_{re})_{surf}$, and the total water consumption from surface water is represented as $(Q_u)_{surf}$.

$$Q_{riv} = [Q_{Runoff} + (Q_u)_{surf} + (Q_{re})_{surf} - E_{dam}] \tag{2}$$

In the Ardabil Plain, Equation (3) is used to calculate the agricultural sector's net economic benefit, where NBe is the irrigated (or rain-fed) network financial profit. A_i is the surface area (ha), Pr_i is original price (\$ kg^{-1}), Y_i is yield (kg), and Co_i is production cost (\$ ha^{-1}) of each crop:

$$(NBe_{irr\ or\ rain}) = [A_i(Y_i \cdot APr_i - Co_i)]_{irr\ or\ rain} \tag{3}$$

Groundwater storage is represented in Equation (4) as the primary stock in the hydrological, wastewater, and water subsystems:

$$GWS = \int_{t_0}^{t_n} [GI(t) + DI(t) - E(t) - GW(t) - GO(t)] \tag{4}$$

The acronym GWS represents groundwater storage, while t represents the period ($t_0 < t < t_n$). GI represents the sum of groundwater inflow and outflow. DI denotes deep infiltration resulting from precipitation, E represents evapotranspiration, GW indicates groundwater withdrawal, and GO represents groundwater outflow from the watershed. Equations (5) and (6) below describe the annual gross water demand for each crop and the annual agricultural water demand, respectively:

$$GWR_i(t) = \frac{NIWR_i(t)}{EI} \tag{5}$$

$$AMD_i(t) = \sum_{i=1}^{n} (GWR_i(t)) \tag{6}$$

The crop's gross water demand is denoted by $GWR_i(t)$, while the crop's net irrigation water requirement is represented by $NIWR_i(t)$. Furthermore, EI represents the irrigation efficiency of the crop for a particular year (t), and $AWD_i(t)$ is the annual agricultural water demand for the current year (t) [32]. Groundwater extraction has been facilitated through the use of wells distributed across the plain. Higher pumping rates lead to a decrease in the aquifer water table, and consequently, more energy is needed to extract water from deeper levels for delivery to consumers. This relationship is established based on the negative causal link between water demand and groundwater table [53]. The amount of energy needed to elevate groundwater was calculated using Equation (7), as presented by Karimi [54].

$$EC = \frac{2.73 \times D \times V}{OPE \times (1 - Tl) \times 1000} \tag{7}$$

The following equation was utilized to determine the energy consumption (EC) in kilowatt-hours (KWh) required to lift groundwater from the wells in the plain, where D represents the height of lifting in meters, V represents the volume in cubic meters, OPE represents the overall pumping plant efficiency, and Tl represents the energy loss due to transmission and distribution. We chose VensimPLE (Personal Learning Edition) 7.3.5 to develop the SDM in this study because it is freely available for academic use and easy to use for various stakeholders, providing necessary information for decision making. A conceptual framework for examining the WEF nexus was also established to identify the processes inherent in the energy, water, and food systems based on causal feedback linkages.

2.2.3. HWA Method

The HWA (Hybrid Weighted Averaging) operator is a method introduced by Xu and Da in 2003 to address the limitations of existing aggregation operators such as the SAW (Simple Additive Weighting) operator and the OWA (Ordered Weighted Averaging) operator. The SAW operator only considers the weights of attributes without considering their ordered positions, while the OWA operator only weighs the ordered positions of attributes without considering their importance [22]. The HWA operator combines attribute importance and value in its weighting process. It uses a weight vector $v = (v_1, v_2, \ldots, v_n)T$, where $v_j \geq 0$ for $j = 1, 2, \ldots, n$, and the sum of all weights is equal to 1. The HWA operator aggregates the attributes according to the following formula:

$$\mathrm{HWA}_{v,w} = (a_1, a_2, \ldots, a_n) = \sum_{j=1}^{n} v_j b_j \tag{8}$$

where v_j is the weight associated with the j-th attribute, bj is the j-th largest value in an ascending ordered set of attribute values, and $w = (w_1, w_2, \ldots, w_n)$ T is the weight vector associated with the criteria a_i ($i = 1, 2, \ldots, n$). The balance coefficient n plays a role in balancing the aggregation process. As the weighted vector $(w_1, w_2, \ldots, w_n)$ T approaches $(1/n, 1/n, \ldots, 1/n)$ T, the vector $(nw_1a_1, nw_2a_2, \ldots, nw_na_n)$ T tends toward $a_1, a_2, \ldots, a_n$, and the HWA operator approaches the OWA operator. The HWA operator considers both the importance of attributes and their values, providing a more comprehensive approach to aggregation. It allows decision makers to incorporate both attribute weights and their ordered positions, leading to more balanced and informed decision-making processes [21,22].

2.2.4. Climate Change Scenarios

The dataset used in this study is based on downscaled GCMs that project future climate scenarios under three different RCP (Representative Concentration Pathways) (RCP2.6, RCP4.5, and RCP8.5), representing different levels of future greenhouse gas emissions. These scenarios consider a range of possible future conditions, depending on future emissions levels. The RCP 2.6 scenario, representing the most optimistic mitigation pathway, projects a peak in global greenhouse gas emissions between 2010 and 2020, followed by a rapid decline. Achieving this pathway will require significant global efforts to reduce emissions [55]. The RCP 4.5 scenario projects emissions peaking around 2040, followed by a decline, reaching 540 parts per million of total forcing by 2100 before stabilizing [56,57]. In contrast, the RCP 8.5 scenario projects gradually increasing emissions throughout the 21st century, reaching 940 parts per million by 2100, and continuing to rise for the next 100 years [58].

2.2.5. Data

The data used for this study on the Ardabil Plain's WEF direct usage were obtained from various sources. The region has a subtropical to moderate climate, as indicated by geographical data and mean climatic data from seven primary synoptic stations between 1985 and 2022. The six categories of data used in this study include energy data, agricultural data, meteorological and hydrological data, demographic data, climate change data, and interview data [39,43,59]. The meteorological and hydrological data, including temperature, evaporation, precipitation, and river input, were obtained from the Iran Water Resource Management Company (IWRMC). Agricultural statistics, such as cropland utilization area, crop yield, production cost, and original crop price, were provided by the Statistical Center of Iran's Ministry of Agriculture. Energy sector statistics, such as the number of electric pumps in the basin, power demand from pumping, total basin agricultural electricity demand, and water demand of various sections, were prepared by the Ministry of Energy. The CMIP5 data from the IPCC official website were used to forecast future temperature patterns. The GCM output from CMIP5 with a grid size of $0.5^{\circ} \times 0.5^{\circ}$ for the near future (2021–2050) was used in this study. However, the poor resolution of GCM output makes it unsuitable for regional studies, and its conclusions should be scaled down before being applied to local cases. Interview data with local specialists provided insights into several questions regarding the Ardabil Plain, including water allocation mechanisms; current and potential river flow restoration scenarios; major social, economic, and environmental issues; and agricultural water use. The data were presumed to be correct, updated, and quality-controlled, although some date back to the mid-1990s and cannot be confirmed. It should also be noted that some of the historical datasets expired in 2021. The responses to interview questions are considered to be objective and truthful.

2.3. Research Framework

The proposed research framework focuses on studying the WEF Nexus in Ardabil Plain by utilizing an SDM in combination with RCPs and HWA method for crop selection decision making. The research begins with an introduction to the WEF Nexus concept and the importance of considering RCP pathways for understanding climate change impacts. Data collection involves gathering relevant information on water availability, energy consumption, food production, climate projections, and other variables specific to Ardabil Plain. The SDM is then developed, capturing the interdependencies of the WEF Nexus and incorporating climate change impacts based on the selected RCP pathways. The SDM is calibrated and validated using historical data to ensure its accuracy in representing the dynamics of the WEF Nexus. Scenarios are designed to represent different RCPs, and simulations are conducted to analyze the long-term behavior and impacts on water, energy, and food systems. The HWA method prioritizes crop selection, considering criteria such as water consumption, energy requirements, economic value, climate change resilience, and sensitivity. Weights are assigned to each criterion, and the HWA method calculates the weighted average for each crop option under the worst RCP scenario. The SDM simulations and HWA analysis findings are interpreted, discussing the implications of different RCP pathways on the WEF Nexus in Ardabil Plain. This research framework provides a comprehensive approach to understanding the WEF Nexus in the Ardabil Plain, considering climate change impacts and incorporating decision making for crop selection. It facilitates informed decision making for sustainable resource management in the region [60]. The study's framework is illustrated in Figure 2.

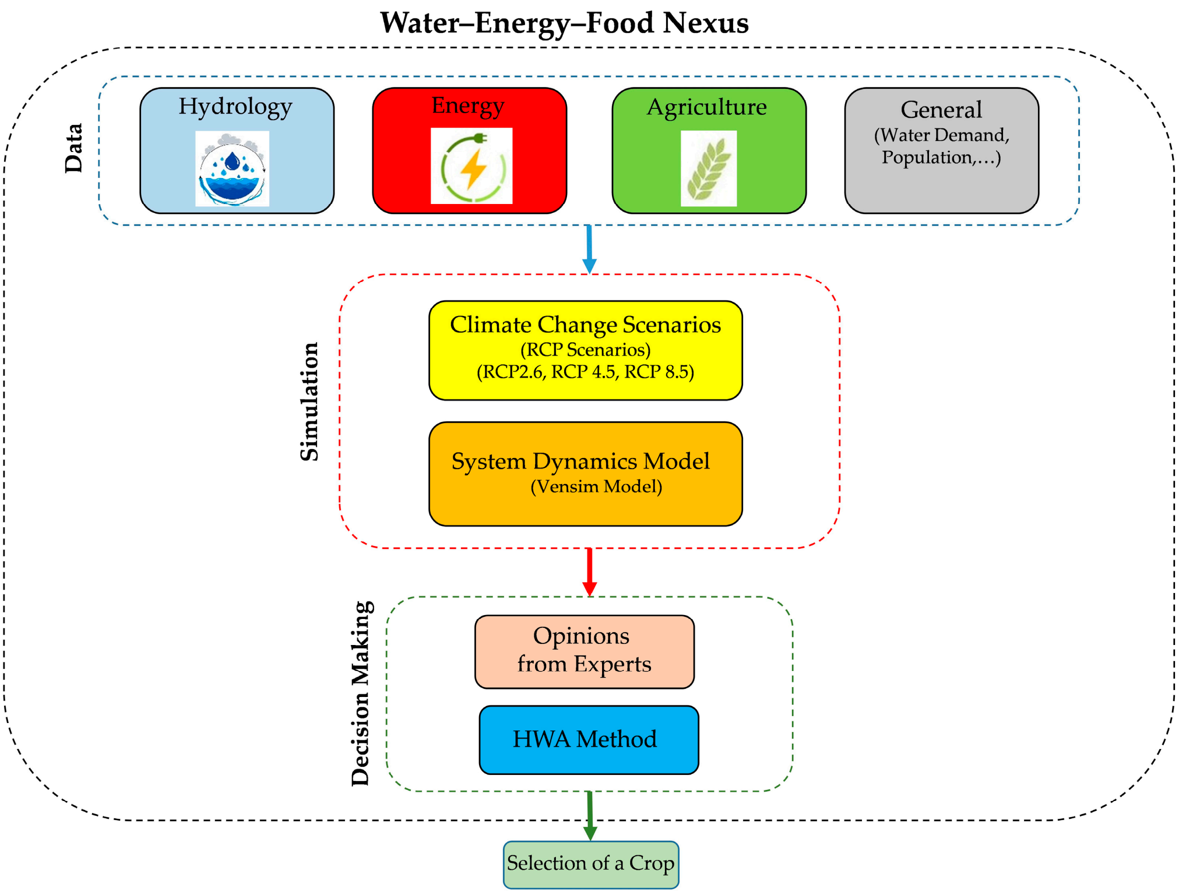


Figure 2. The framework of study.

3. Results and Discussion

3.1. Developed Conceptual and CLD Models

The Ardabil Plain's water, energy, and food nexus is depicted in Figure 3 using a causal loop diagram. These diagrams are utilized to illustrate the feedback linkages and interactions among different subsystems within the Ardabil Plain. This diagram shows the relationships and interconnections between the three sectors, with polarity (+/−) indicating whether a change in one variable leads to an increase (+) or decrease (−) in another. A different colored section represents each sector, and the arrows indicate the key components and connections. The energy sector includes factors such as the total power needed for electric pumps, the impact of groundwater extraction on the number of electric wells, and the energy required for wastewater treatment. The agricultural sector comprises monthly crop water consumption, irrigation efficiency, cropland acreage, and net profit. In the water sector, the primary factors that affect river discharge are infiltration and precipitation into the watershed, total renewable water in the watershed, groundwater storage, evaporation from land cover and groundwater, sectorial water demand, and the return flow of different sectors. For example, an increase in crop water needs would lead to an overall increase in agricultural water demand, resulting in a corresponding increase in energy demand and possibly a decrease in river flow quantities if other factors remain constant. This diagram provides a comprehensive understanding of Ardabil Plain's nexus and enables stakeholders to explore different scenarios and evaluate the impact of management practices and policies on the nexus.

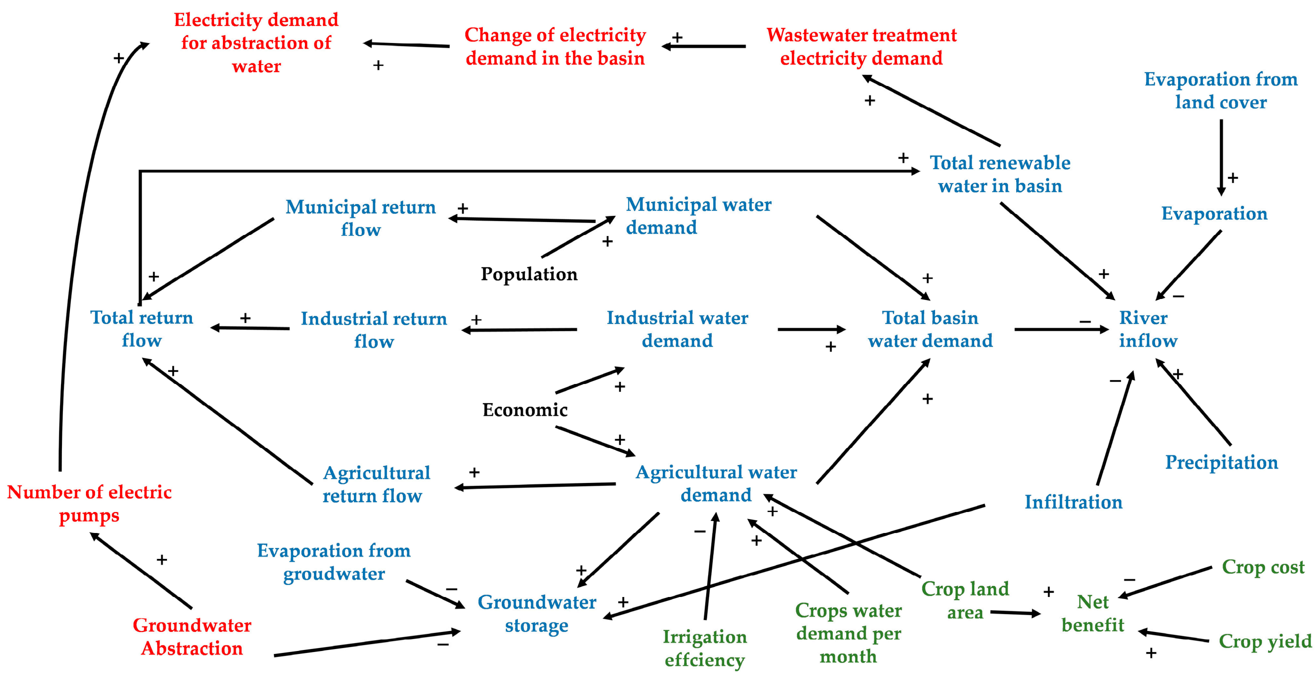


Figure 3. A causal loop diagram—water, energy, and food nexus in the Ardabil Plain.

3.2. Developed SFD Model

The hydrological, wastewater, and water subsystems and the agriculture and energy consumption subsystems are included in the system's simplified SFD (Figure 4). Each stock represents a numerically solved non-linear differential equation, like the Euler technique. The SDM goes through the equations, units, and other features of the SFD in great depth. The Ardabil Regional Water Authority and the Iranian Ministry of Agriculture sent specialists to help with the SFD design process. While developing the CLDs for the subsystems, we spoke with experts to gain a realistic understanding of the system structure and interactions. Stocks are used to describe the system's states, such as groundwater storage, surface water storage, and population, which will alter over time as inflows and outflows change. Pipes with valves going into or out of the stocks symbolize flows. Due to the enormous number of wells, the numerical estimates of the energy consumption for pumping groundwater and distributing it are not included in the SFD of the energy subsystem. Each well's total expected energy consumption is based on yearly groundwater withdrawal. The groundwater table calculates the overall energy consumption to pump and provide groundwater to stakeholders. The two dynamic feedback loops that link the agricultural and population subsystems to the water and wastewater subsystems demonstrate how the water resources sector responds to the demands of regional stakeholders. The area's primary water source, groundwater storage, will thus continue to decline, requiring more energy to treat wastewater and deliver water in the future.

3.3. Calibration and Validation SDM

The model was calibrated using data from 1996 to 2015. Its accuracy was validated for 2016 and 2020 by comparing the model's two main outputs, river intake and discharge, with the observed data (Figure 5). The simulation results for the calibration period are considered satisfactory, with an R^2 value of 0.97 and an RMSE value of 14.5. However, the model underestimates river inflow peak numbers, particularly between 2009 and 2014, where the differences between the estimated and historical data have nearly doubled. The validation results show improved accuracy, with an R^2 value of 0.94 and an RMSE value of 15.08 (Figure 6). The lower correlation between the calculated and observed data during the calibration period might be due to the impact of dams constructed during this time, and the illegal diversion of river inflows to these dams. The calibration and validation results suggest that the model reasonably accurately represents river intake and discharge dynamics. However, the underestimation of peak numbers during the calibration period highlights the need for further refinement to accurately capture the effects of dams and illegal diversions. It is important to note that the model's validation results show an improved level of accuracy, indicating its ability to simulate river intake and discharge more accurately for the validation period. This implies that the model can capture the variations and trends in the river system, providing valuable insights for water resource management and decision making in the study area.

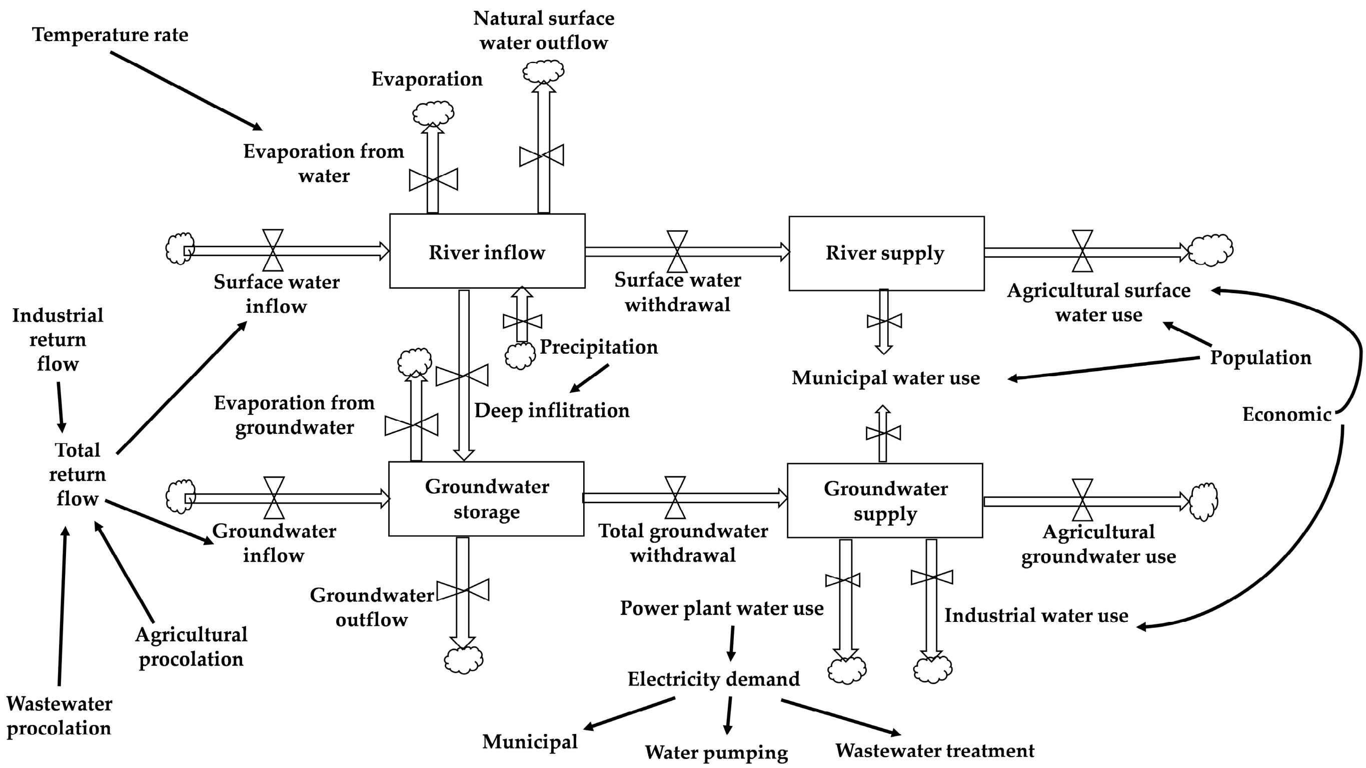


Figure 4. The diagram that illustrates the WEF (Water–Energy–Food) system dynamics model's stock and flow in the Ardabil Plain.

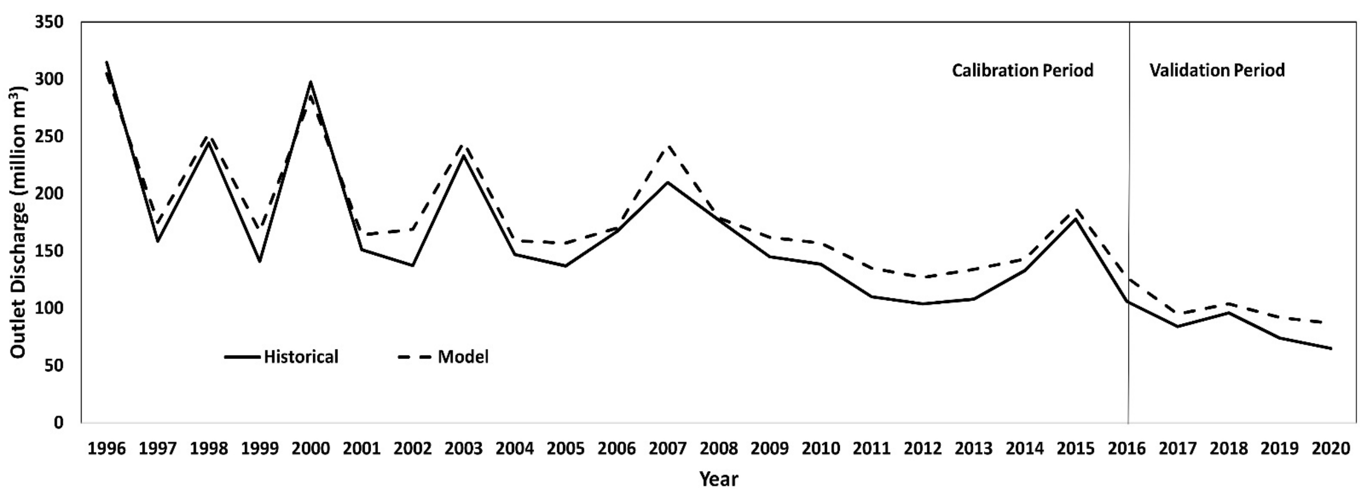
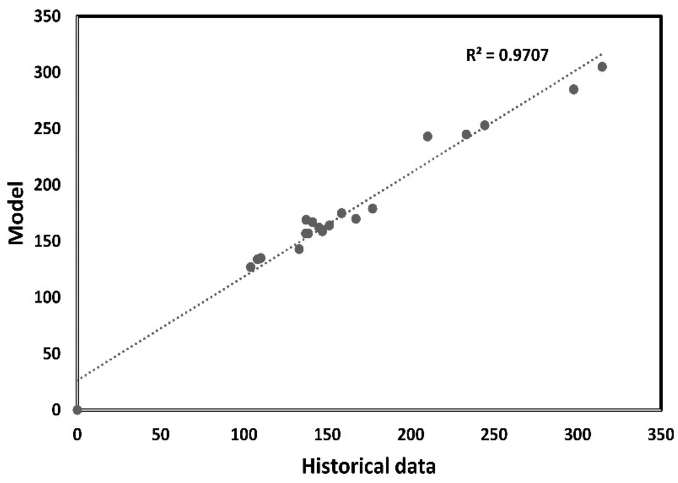
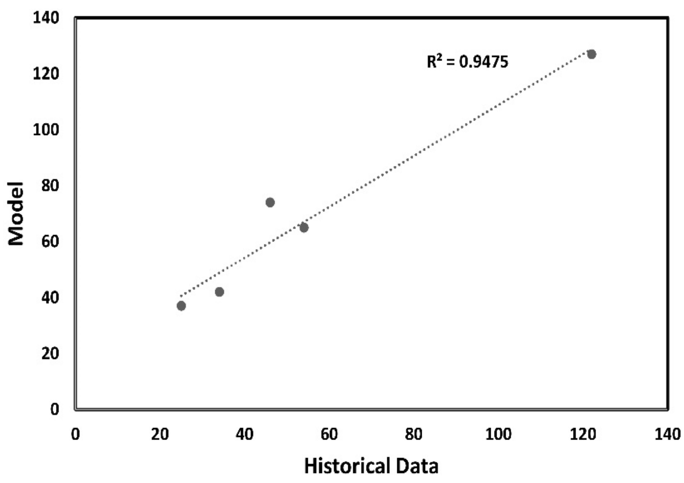


Figure 5. Comparison of the calibrated and validation simulations of river flow for 1996–2015 and 2016–2020 years, respectively.



(a)



(b)

Figure 6. Results from simulations that were calibrated and validated for river flow during the periods 1996–2015 (**a**) and 2016–2020 (**b**), respectively.

Figure 7 depicts the outlet's discharge history and effect of various RCP scenarios on future climate estimates for the Ardabil Plain's outlet discharge. The historical discharge values from 1996 to 2021 show fluctuations in the outlet's discharge, indicating varying water availability. The projected discharge values under the RCP scenarios provide insights into the potential impacts of climate change on the outlet's discharge in the future. RCP 2.6 scenario shows the highest increase in outlet discharge compared to the other scenarios. It is attributed to a slight reduction in global greenhouse gas emissions, leading to a decrease in temperature. The higher outlet discharge indicates potentially increased water availability. Although RCP 4.5 Scenario is somewhat more severe than the RCP 8.5 scenario, it results in lower outlet discharge compared to the RCP 2.6 scenario. This scenario implies a moderate level of greenhouse gas emissions and temperature increase, which may have implications for water availability and agricultural activities. The RCP 8.5 scenario exhibits the lowest outlet discharge among the three scenarios. For RCP 8.5, the inflow outlet in 2021 was around 59 Mm^3 and for 2050 is 23 Mm^3. This scenario shows a decrease in inflow outlets of around 2.5 times from 2021 to 2050. It represents a higher level of greenhouse gas emissions and a significant temperature increase, which can lead to reduced water availability. This scenario suggests potential challenges for water resources and agricultural productivity. Extending the findings more practically reveals significant differences and resource implications. Particularly during the summer months, high evaporation and extreme heat stress on crops such as barley, potato, and wheat could impact the World Economic Forum's security. The analysis emphasizes the potential impacts of climate change on the outlet's discharge in the Ardabil Plain. The variations in discharge levels under different RCP scenarios underscore the need for proactive measures, such as water management strategies and adaptation plans, to mitigate potential challenges and ensure the long-term sustainability of water resources and agricultural activities in the region.

Figure 8 presents the projected changes in the Ardabil basin's electricity consumption over the next two decades, assuming that electric motor pumps will replace diesel pumps. In 2021, the electricity consumption was projected to be 149,237 for all three RCPs. From 2022 onwards, there are varying consumption figures across the different scenarios. Under PCR 2.6, power consumption will increase steadily, reaching 196,354 MWh in 2050. For PCR 4.5, the power consumption exhibits a similar trend, reaching 195,482 MWh in 2050. The highest energy use figures are projected under PCR 8.5, with a peak of 206,475 MWh in 2050. The energy consumption for the year 2050 is around 1.3 times more than 2021. The Policy Water Energy sector research suggests agricultural demand management is necessary to prevent long-term groundwater table decline. While municipal and industrial water usage remains stable due to population growth, the groundwater table will rise in operating wells, requiring less energy to extract water from the aquifer. In the worst-case scenario, continuous groundwater table decline will increase energy demand for groundwater pumping from approximately 150,000 MWh to around 200,000 MWh over the next three decades. RCP 8.5 is the most energy-intensive scenario due to water shortages, assuming the least river flow in the future and requiring farmers to expend more energy to extract groundwater. Additionally, due to lower groundwater tables in these areas, urban and industrial groundwater withdrawal requires more energy per water unit than farming groundwater withdrawal. However, the amount of energy consumed in these sectors is minimal compared to farming, which consumes a significant amount of energy.

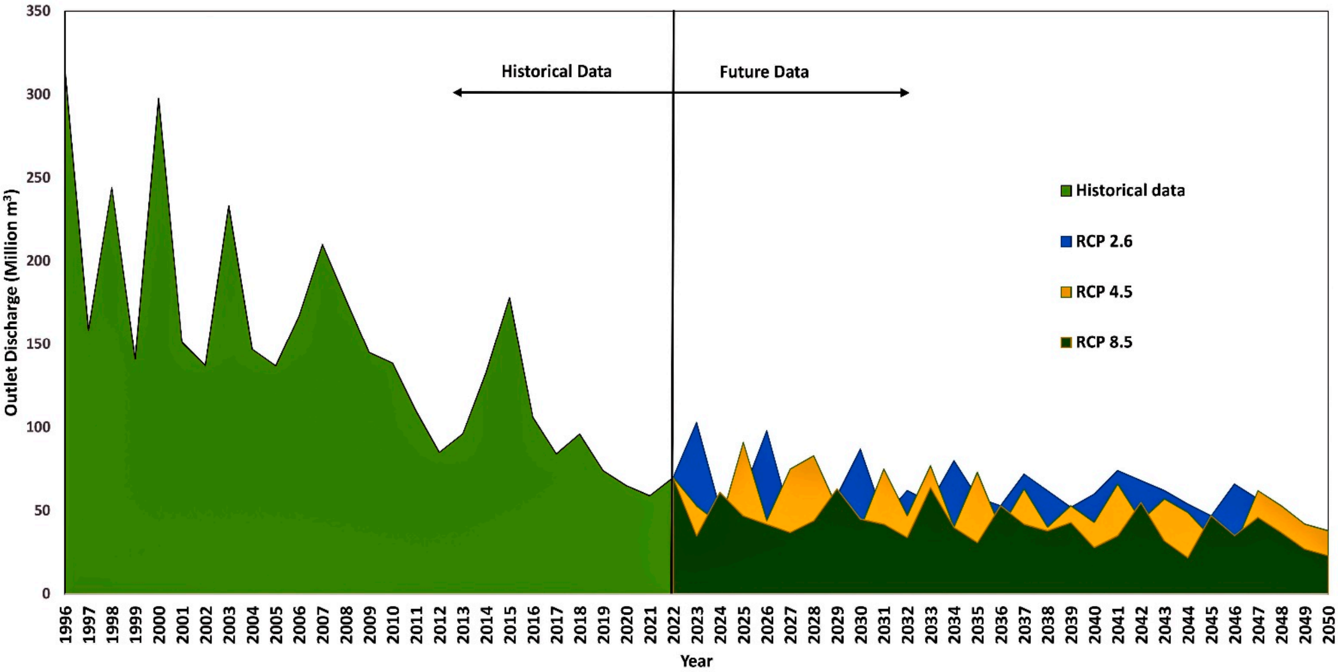


Figure 7. Impact of RCP scenarios on outlet's discharge of the Ardabil Plain.

The power consumption for electrical engines in agriculture in the Ardabil Plain was compared between 2021 and 2050 (Figure 9). Power consumption during the spring (February to April) shows a stable level. Power consumption during the summer (May to July) shows higher values in July compared to May. This can be attributed to increased irrigation demands as the growing season progresses, high temperatures, and evaporation. Electricity consumption in the fall (October to December) severely increased from July to May. October is the most consumed, with around 33,000 MWh. This indicates a severe decrease in surface runoff in this plain using more electricity pumps for irrigation purposes in wells. Energy consumption during the winter (November and January) remains relatively constant, with similar values over the next three months. This suggests a lower demand for irrigation during the winter months, when agricultural activities may be reduced. The power consumption projections for 2050 show higher values in all seasons compared to 2021. This implies an anticipated rise in energy demand for irrigation, likely due to expanding agricultural practices or changing climatic conditions. These scientific findings highlight the seasonal variations and long-term trends in power consumption for electrical pumps in agriculture. The data underscore the importance of efficient energy management strategies to meet the growing irrigation needs and sustain agricultural productivity in the Ardabil Plain. Based on research conducted in Ardabil, the energy requirement for pumping water for one hectare of wheat cultivation is estimated to be around 2.49 GJh^{-1} per year [42]. Considering that the wheat farm area in the Ardabil Plain is approximately 95,031 hectares, the energy demand for wheat production would be approximately 239,627 GJh^{-1}. Furthermore, if these conditions persist under the RCP 8.5 scenario by 2050, the energy requirement for wheat production in the Ardabil Plain would increase to approximately 314,714 GJh^{-1} per year.

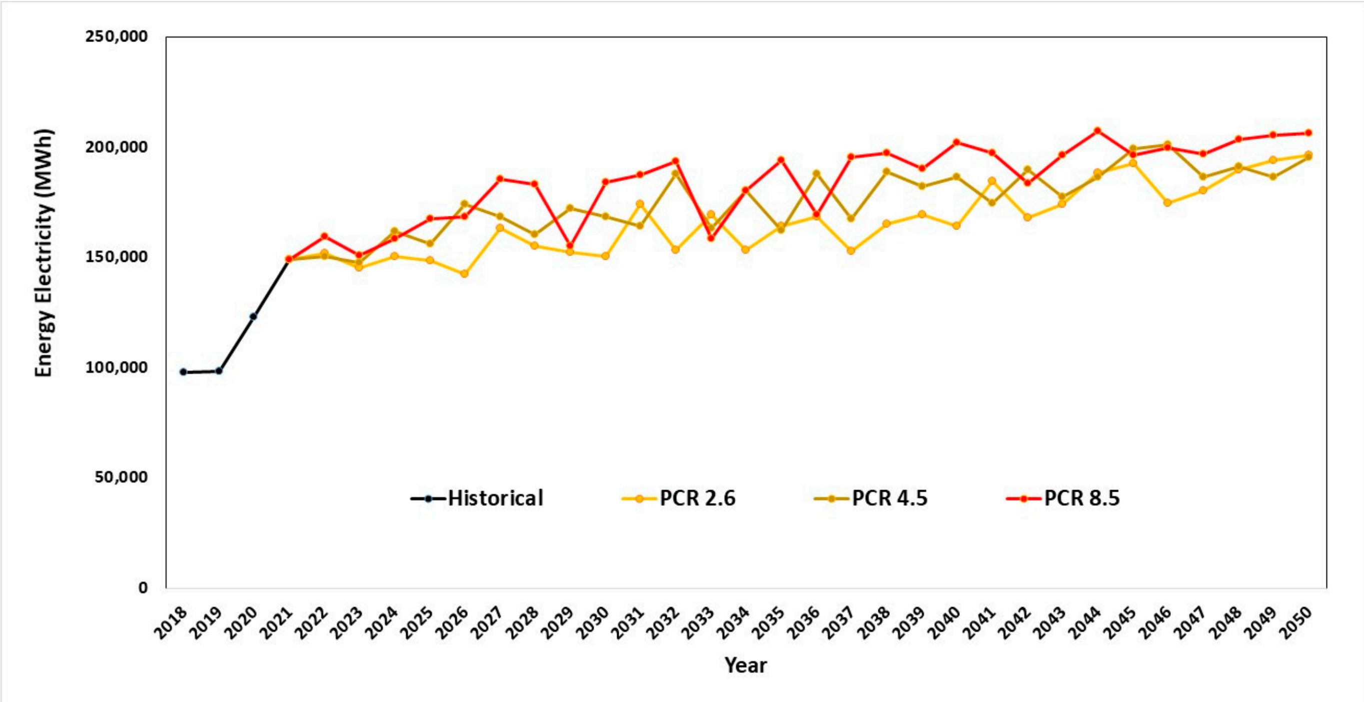


Figure 8. Impact of RCP scenarios on basin power.

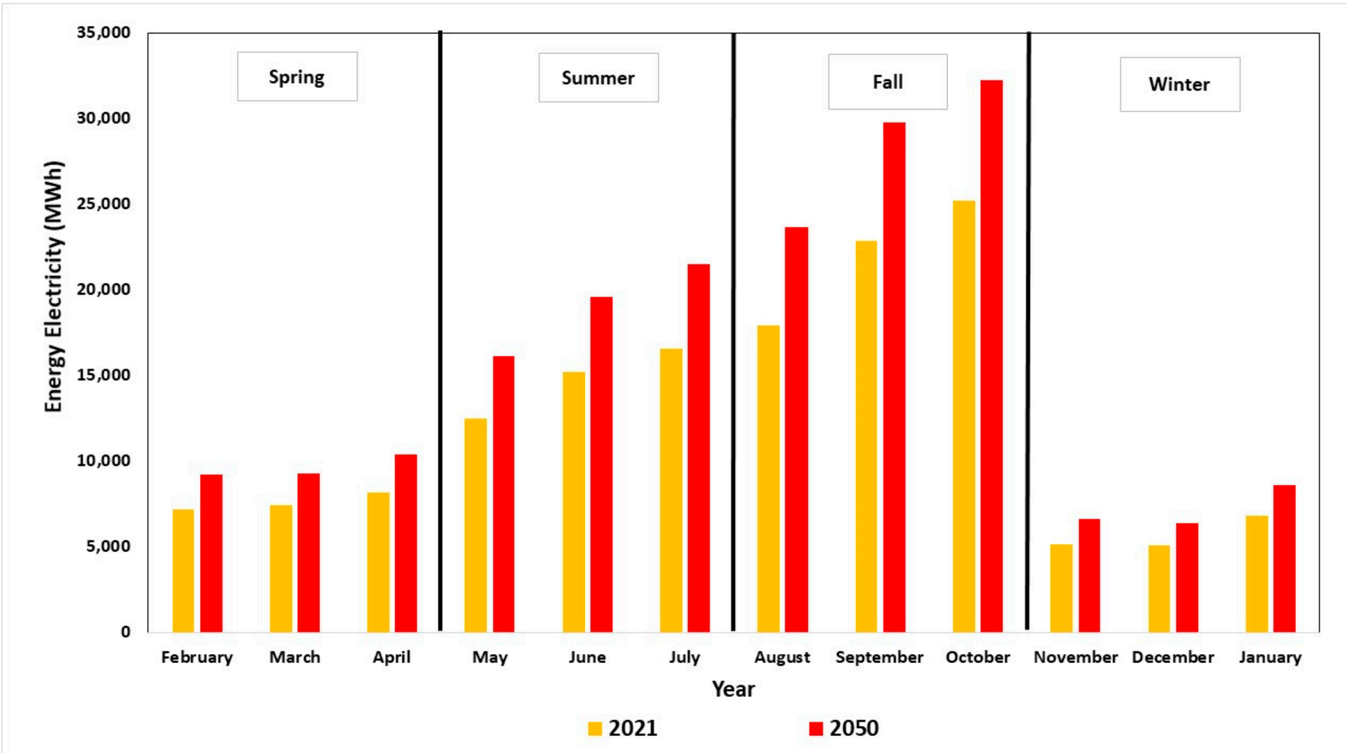


Figure 9. The electricity demand for farming wells on a monthly basis for 2021 and 2050.

3.4. Decision Making for Selection of a Crop Production in the Future

The assigned weights to each attribute signify their relative importance in the decision-making process. Specifically, in the context of the SDM model, emphasis is placed on water and power consumption, and the weights of criteria as indicators for future considerations have been determined. These weights are typically determined based on the specific context and priorities expert and outlet of the SDM model. By multiplying the attribute values with their respective weights and summing them up, a weighted score is calculated for each alternative. This allows for the comparison and evaluation of alternatives based on their performance across different attributes, taking into account their relative importance. Table 2 illustrates the importance of indicators, and the decision matrix can be quantified to determine their relative significance.

Table 2. Degree of the importance of indicators and the decision matrix.

	Risk Prone		**Risk Neutral**	**Risk Aversion**	
	Optimistic	**Fairly Optimistic**	**Neutral**	**Fairly Pessimistic**	**Pessimistic**
Barley	4	5	5	5	4
Wheat	5	4	4	4	5
Soybeans	2	2	3	3	3
Potatoes	3	3	2	2	2
Pears	1	1	1	1	1

In order to assess the impact of risk attitudes of decision makers (DMs) on selecting the best alternative using the HWA method, we conducted a study with three different scenarios: optimism (α = 0.1, 0.5), neutrality (α = 1), and pessimism (α = 2, 10). The HWA operator employed the equation Q(r) = rα, where α represents the risk attitude parameter. The balance coefficient (n = 1) was considered, and the overall value and ranking of alternatives using the HWA operator are presented in Table 3. HWA directly considers the risk attitudes of DMs and the relative weights of criteria to determine the most preferred option for the WEF nexus of the Ardabil Plain. Barley and wheat receive higher ratings (4 and 5) under the optimistic risk attitude, indicating that these crops are favored when taking higher risks. Barley and wheat continue to receive relatively high ratings (5 and 4) under the fairly optimistic risk attitude, indicating their preference for moderately risky conditions. Barley, wheat, and soybeans receive intermediate ratings (5, 4, and 3) under the neutral risk attitude, suggesting that these crops are suitable for neutral risk preferences. Barley, wheat, and soybeans receive lower ratings (5, 4, and 3) under the fairly pessimistic risk attitude, indicating a preference for less risky options. Barley and wheat receive lower ratings (4 and 5) under the pessimistic risk attitude, suggesting a preference for safer options. Barley and wheat consistently receive higher ratings across different risk attitudes, indicating their suitability and popularity in the Ardabil Plain regardless of risk preferences. Soybeans, potatoes, and pears receive lower ratings overall, suggesting that they may be less preferred choices for farming in the region. Given the anticipated challenges of water scarcity, unfavorable economic conditions, and rising energy consumption in the agricultural sector, planting barley emerges as the optimal choice for cultivation in the Ardabil Plain. In general, according to Table 3, the overall ranking of options using the HWA method is barley > wheat > soybeans > potatoes > pears. These scientific results provide insights into the selection of fruits for farming land in the Ardabil Plain based on risk attitudes. Barley and wheat emerge as the more favorable crops, while soybeans, potatoes, and pears are relatively less favored. These findings can inform decision making in agricultural practices, considering risk attitudes and the suitability of different crops for a specific region.

Table 3. Comparison of the final value and rank of each option using the HWA method and different risk levels.

Attributes	Indicator Weight	Water Consumption	Power Consumption	Economic Value	Climate Change
		6	4	7	5
Barley		4	5	3	8
Wheat		5	4	5	7
Soybeans		6	6	8	4
Potatoes		7	7	7	5
Pears		9	8	9	6

Several recommendations are proposed for addressing the challenges in this plain. Considering the Ardabil Plain's specific circumstances, numerous advantages can be anticipated if wheat and barley cultivation continue in the foreseeable future, including reduced energy and water consumption and increased economic profitability. To achieve this, proper planning for land use change and providing necessary support and education to farmers during this crucial period are essential. Alternatively, if farmers persist with their existing crop choices, authorities must address specific conditions and requirements associated with these crops. First, providing long-term financial support to farmers to develop more efficient irrigation systems such as lateral shift, drip, and spray can help conservation. However, it is important to ensure that such savings do not lead to an expansion of irrigated agricultural lands as it may result in a rebound effect on irrigation efficiency, leading to further water scarcity. Moreover, monitoring and managing the abstraction of groundwater is crucial in preventing excessive use and increased energy consumption. Improving pump efficiency can lead to higher agricultural profitability, but it may not necessarily conserve water or reduce demand. Instead, improving irrigation efficiency may be a more practical alternative to expanding surface water development in the agricultural sector, provided that appropriate land management procedures are in place to prevent water from being utilized to irrigate new farmland. Initiatives to conserve water and energy in agriculture are crucial to reduce watershed-level water and energy requirements. While reducing cropland or changing crop patterns can minimize water and energy usage, supporting policies must be re-evaluated to minimize adverse impacts on agribusinesses. Groundwater storage depletion over the next three decades may pose a threat to the long-term sustainability and economic viability of irrigated agriculture and food production. Therefore, limiting the expansion of agricultural land must be appropriately applied and enforced.

The study has limitations due to the lack of data, resulting in simplifying assumptions in the SDM. The model excluded major dam water allocation plans, actual water use and withdrawal in the agricultural sector, and interactions in the WEF nexus. The uncertainties in future climate change forecasts, precipitation, runoff, pan evaporation, and interception coefficient were considered by utilizing various RCPs. The study was not calibrated or tested against the cost of power or water due to the lack of precise and trustworthy data. Additionally, it did not account for unanticipated acreage changes resulting from fluctuations in crop profitability, the socioeconomic effects of international sanctions, and their consequences for irrigation modernization viability.

4. Conclusions

This research's primary goal is to determine the best crop for the Ardabil Plain, taking into account future climate conditions. To achieve this, we have adopted a novel approach that combines an SDM with the HWA method. This approach allows us to evaluate the WEF nexus and resource sustainability in the Ardabil Plain, considering different climate change scenarios (RCP 2.6, RCP 4.5, and RCP 8.5). Our study addresses both current and future water challenges, emphasizing the need for increased energy resources and the selection of optimal crops. Through the SDM, we analyze how fluctuations in water supply will impact agriculture, economic returns, and energy consumption from 2021 to 2050. The results clearly indicate that, considering the HWA-derived overall ranking, barley is the most suitable crop for the Ardabil Plain in the near future, followed by wheat, soybeans, potatoes, and pears.

The study's findings indicate that the watershed will likely face significant challenges in supplying energy to the agricultural sector over the next three decades. These challenges stem from a decrease in subsurface water levels and an increase in the force required by electric pumps used to supply water to farms. Despite variations in management scenarios, all three scenarios project a reduction in water flow in the basin and an increase in power consumption, with the RCP 8.5 scenario representing the most severe conditions. Considering the water and energy constraints, barley and wheat are identified as suitable crops for the future in the Ardabil Plain. In conclusion, this research demonstrates the importance of integrating the WEF nexus approach with a system dynamics model to assess the sustainability of water resources in the Ardabil Plain. It highlights the need for strategic planning, efficient resource management, and informed decision making to address future challenges and ensure the long-term viability of agriculture in the region.

Author Contributions: Conceptualization, K.J. and H.H.; methodology, K.J. and M.M.; data management, K.J.; validation, K.J. and M.M.; formal analysis, K.J., F.A. and M.M.; writing original draft, K.J.; review and editing, A.A., M.D. and J.L.Z.; software, K.J., H.H. and M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data will be made available upon request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. FAO. *The Water-Energy-Food Nexus: A New Approach in Support of Food Security and Sustainable Agriculture*; The Food and Agricultural Organisation of the United Nations: Rome, Italy, 2014.
2. Zhang, X.; Li, H.-Y.; Deng, Z.D.; Ringler, C.; Gao, Y.; Hejazi, M.I.; Leung, L.R. Impacts of climate change, policy and Water-Energy-Food nexus on hydropower development. *Renew. Energy* **2018**, *116*, 827–834. [CrossRef]
3. Pardoe, J.; Conway, D.; Namaganda, E.; Vincent, K.; Dougill, A.J.; Kashaigili, J.J. Climate change and the water–energy–food nexus: Insights from policy and practice in Tanzania. *Clim. Policy* **2018**, *18*, 863–877. [CrossRef]
4. Al-Saidi, M.; Hussein, H. The water-energy-food nexus and COVID-19: Towards a systematization of impacts and responses. *Sci. Total Environ.* **2021**, *779*, 146529. [CrossRef]
5. Lawford, R.G. A design for a data and information service to address the knowledge needs of the Water-Energy-Food (WEF) Nexus and strategies to facilitate its implementation. *Front. Environ. Sci.* **2019**, *7*, 56. [CrossRef]
6. Hamidov, A.; Daedlow, K.; Webber, H.; Hussein, H.; Abdurahmanov, I.; Dolidudko, A.; Seerat, A.Y.; Solieva, U.; Woldeyohanes, T.; Helming, K. Operationalizing water-energy-food nexus research for sustainable development in social-ecological systems: An interdisciplinary learning case in Central Asia. *Ecol. Soc.* **2022**, *27*, 1. [CrossRef]
7. Liu, J.; Yang, H.; Cudennec, C.; Gain, A.K.; Hoff, H.; Lawford, R.; Qi, J.; Strasser, L.D.; Yillia, P.; Zheng, C. Challenges in operationalizing the water–energy–food nexus. *Hydrol. Sci. J.* **2017**, *62*, 1714–1720. [CrossRef]
8. McCarl, B.A.; Yang, Y.; Schwabe, K.; Engel, B.A.; Mondal, A.H.; Ringler, C.; Pistikopoulos, E.N. Model use in WEF nexus analysis: A review of issues. *Curr. Sustain. Renew. Energy Rep.* **2017**, *4*, 144–152. [CrossRef]
9. Bazilian, M.; Rogner, H.; Howells, M.; Hermann, S.; Arent, D.; Gielen, D.; Steduto, P.; Mueller, A.; Komor, P.; Tol, R.S. Considering the energy, water and food nexus: Towards an integrated modelling approach. *Energy Policy* **2011**, *39*, 7896–7906. [CrossRef]
10. Grigg, N.; Foran, T.; Darbas, T.; Kirby, M.; Colloff, M.J.; Ahmad, M.-U.-D.; Podger, G. The water–food–energy nexus in Pakistan: A biophysical and socio-economic challenge. *Proc. Int. Assoc. Hydrol. Sci.* **2018**, *376*, 9–13. [CrossRef]
11. Hjorth, P.; Bagheri, A. Navigating towards sustainable development: A system dynamics approach. *Futures* **2006**, *38*, 74–92. [CrossRef]
12. Linderhof, V.; Dekkers, K.; Polman, N. The role of mitigation options for achieving a low-carbon economy in the netherlands in 2050 using a system dynamics modelling approach. *Climate* **2020**, *8*, 132. [CrossRef]
13. Feng, M.; Liu, P.; Li, Z.; Zhang, J.; Liu, D.; Xiong, L. Modeling the nexus across water supply, power generation and environment systems using the system dynamics approach: Hehuang Region, China. *J. Hydrol.* **2016**, *543*, 344–359. [CrossRef]
14. Ravar, Z.; Zahraie, B.; Sharifinejad, A.; Gozini, H.; Jafari, S. System dynamics modeling for assessment of water–food–energy resources security and nexus in Gavkhuni basin in Iran. *Ecol. Indic.* **2020**, *108*, 105682. [CrossRef]
15. González-Rosell, A.; Blanco, M.; Arfa, I. Integrating stakeholder views and system dynamics to assess the water–energy–food nexus in Andalusia. *Water* **2020**, *12*, 3172. [CrossRef]

16. Francisco, É.C.; de Arruda Ignácio, P.S.; Piolli, A.L.; Dal Poz, M.E.S. Food-energy-water (FEW) nexus: Sustainable food production governance through system dynamics modeling. *J. Clean. Prod.* **2023**, *386*, 135825. [CrossRef]
17. Wang, X.; Dong, Z.; Susnik, J. System dynamics modelling to simulate regional water-energy-food nexus combined with the society-economy-environment system in Hunan Province, China. *Sci. Total Environ.* **2023**, *863*, 160993. [CrossRef]
18. Diaz-Balteiro, L.; González-Pachón, J.; Romero, C. Measuring systems sustainability with multi-criteria methods: A critical review. *Eur. J. Oper. Res.* **2017**, *258*, 607–616. [CrossRef]
19. Bell, M.L.; Hobbs, B.F.; Ellis, H. The use of multi-criteria decision-making methods in the integrated assessment of climate change: Implications for IA practitioners. *Socio Econ. Plan. Sci.* **2003**, *37*, 289–316. [CrossRef]
20. Wang, C.-N.; Nguyen, V.T.; Kao, J.-C.; Chen, C.-C.; Nguyen, V.T. Multi-criteria decision-making methods in fuzzy decision problems: A case study in the frozen shrimp industry. *Symmetry* **2021**, *13*, 370. [CrossRef]
21. Xu, Z.; Da, Q.-L. An overview of operators for aggregating information. *Int. J. Intell. Syst.* **2003**, *18*, 953–969. [CrossRef]
22. Mirabi, M.; Mianabadi, H.; Zarghami, M.; Sharifi, M.B.; Mostert, E. Risk-based evaluation of wastewater treatment projects: A case study in Niasar city, Iran. *Resour. Conserv. Recycl.* **2014**, *93*, 168–177. [CrossRef]
23. Reddy, V.R.; Cunha, D.G.F.; Kurian, M. A water–energy–food nexus perspective on the challenge of eutrophication. *Water* **2018**, *10*, 101. [CrossRef]
24. Borgomeo, E.; Jagerskog, A.; Talbi, A.; Wijnen, M.; Hejazi, M.; Miralles-Wilhelm, F. *The Water-Energy-Food Nexus in the Middle East and North Africa*; World Bank: Washington, DC, USA, 2018.
25. Nabavi, E. Failed Policies, Falling Aquifers: Unpacking Groundwater Overabstraction in Iran. *Water Alternative.* **2018**, *11*, 699–724.
26. Central Bank of Iran. 2021. Available online: https://www.amar.org.ir/english (accessed on 25 September 2021).
27. Azadi, Y.; Yazdanpanah, M.; Mahmoudi, H. Understanding smallholder farmers' adaptation behaviors through climate change beliefs, risk perception, trust, and psychological distance: Evidence from wheat growers in Iran. *J. Environ. Manag.* **2019**, *250*, 109456. [CrossRef]
28. Savari, M.; Abdeshahi, A.; Gharechaee, H.; Nasrollahian, O. Explaining farmers' response to water crisis through theory of the norm activation model: Evidence from Iran. *Int. J. Disaster Risk Reduct.* **2021**, *60*, 102284. [CrossRef]
29. Tan, Q.; Liu, Y.; Ye, Q. The impact of clean development mechanism on energy-water-carbon nexus optimization in Hebei, China: A hierarchical model based discussion. *J. Environ. Manag.* **2020**, *264*, 110441. [CrossRef]
30. Sadeghi, S.H.; Moghadam, E.S.; Delavar, M.; Zarghami, M. Application of water-energy-food nexus approach for designating optimal agricultural management pattern at a watershed scale. *Agric. Water Manag.* **2020**, *233*, 106071. [CrossRef]
31. Radmehr, R.; Ghorbani, M.; Ziaei, A.N. Quantifying and managing the water-energy-food nexus in dry regions food insecurity: New methods and evidence. *Agric. Water Manag.* **2021**, *245*, 106588. [CrossRef]
32. Naderi, M.M.; Mirchi, A.; Bavani, A.R.M.; Goharian, E.; Madani, K. System dynamics simulation of regional water supply and demand using a food-energy-water nexus approach: Application to Qazvin Plain, Iran. *J. Environ. Manag.* **2021**, *280*, 111843. [CrossRef]
33. Bakhshianlamouki, E.; Masia, S.; Karimi, P.; van der Zaag, P.; Susnik, J. A system dynamics model to quantify the impacts of restoration measures on the water-energy-food nexus in the Urmia lake Basin, Iran. *Sci. Total Environ.* **2020**, *708*, 134874. [CrossRef]
34. Abou Zaki, N. *The Role of Agriculture Expansion in Water Resources Depletion in Central Iran*; University of Oulu: Oulu, Finland, 2020.
35. Veisi, H.; Deihimfard, R.; Shahmohammadi, A.; Hydarzadeh, Y. Application of the analytic hierarchy process (AHP) in a multi-criteria selection of agricultural irrigation systems. *Agric. Water Manag.* **2022**, *267*, 107619. [CrossRef]
36. Ashofteh, P.-S.; Golfam, P.; Loáiciga, H.A. Evaluation of river water transfer alternatives with the TODIM multi-criteria decision making method. *Water Resour. Manag.* **2020**, *34*, 4847–4863. [CrossRef]
37. Daneshparvar, B.; Rasi Nezami, S.; Feizi, A.; Aghlmand, R. Comparison of results of flood hazard zoning using AHP and ANP methods in GIS environment: A case study in Ardabil province, Iran. *J. Appl. Res. Water Wastewater* **2022**, *9*, 1–7.
38. Kord, M.; Moghaddam, A.A. Spatial analysis of Ardabil plain aquifer potable groundwater using fuzzy logic. *J. King Saud Univ. Sci.* **2014**, *26*, 129–140. [CrossRef]
39. MAJ (Ministry of the Agriculture Jihad Iran). *The Annual Report of Production Cost of Agricultural Crops*; Physical copy only; MAJ: Iran, 2018. (In Persian)
40. WBW. The World Bank Water in Agriculture. 2022. Available online: https://www.worldbank.org/en/topic/water-in-agriculture (accessed on 9 July 2022).
41. Javan, K.; Lialestani, M.R.F.H.; Ashouri, H.; Moosavian, N. Assessment of the impacts of nonstationarity on watershed runoff using artificial neural networks: A case study in Ardebil, Iran. *Model. Earth Syst. Environ.* **2015**, *1*, 22. [CrossRef]
42. Farajian, L.; Moghaddasi, R.; Hosseini, S. Agricultural energy demand modeling in Iran: Approaching to a more sustainable situation. *Energy Rep.* **2018**, *4*, 260–265. [CrossRef]
43. MOE (Ministry of Energy). *The Annual Report of Energy Balance in Iran*; Physical copy only; MOE: Iran, 2018. (In Persian)
44. Shahin, S.; Jafari, A.; Mobli, H.; Rafiee, S.; Karimi, M. Effect of farm size on energy ratio for wheat production: A case study from Ardabil province of Iran. *Am. Eurasian J. Agric. Environ. Sci.* **2008**, *3*, 604–608.
45. Mohammadi, A.; Tabatabaeefar, A.; Shahin, S.; Rafiee, S.; Keyhani, A. Energy use and economical analysis of potato production in Iran a case study: Ardabil province. *Energy Convers. Manag.* **2008**, *49*, 3566–3570. [CrossRef]

46. Sterman, J. *Instructor's Manual to Accompany Business Dyanmics: Systems Thinking and Modeling for a Complex World*; McGraw-Hill: New York, NY, USA, 2000.
47. Cavana, R.Y.; Boyd, D.M.; Taylor, R.J. A systems thinking study of retention and recruitment issues for the New Zealand army electronic technician trade group. *Syst. Res. Behav. Sci. Off. J. Int. Fed. Syst. Res.* **2007**, *24*, 201–216. [CrossRef]
48. Hornberger, G.M.; Wiberg, P.L.; Raffensperger, J.P.; D'Odorico, P. *Elements of Physical Hydrology*; The Johns Hopkins University: Baltimore, MD, USA, 2014.
49. Hull, A., Jr. Rainfall and snowfall interception of big sagebrush. *ABS Papers Proc. Utah Acad. Sci.* **1972**, *49*, 64–65.
50. IME (Iran-Ministry-of-Energy). *The National Water Master Plan Study in the Aras, Sefidrood, between Sefidrood and Haraz, Atrac and Urmia: Agricultural Water Use Study in Urmia Lake Basin in the Refrence Year (2005)*; IME: Iran, 2014.
51. IME (Iran Ministry of Energy). *The National Water Master Plan Study in the Aras, Sefidrood, between Sefidrood and Haraz, Atrac and Urmia: Final Urmia Lake Basin Water Balance*; Physical Copy Only; IME: Iran, 2014. (In Persian)
52. Farajzadeh, J.; Fard, A.F.; Lotfi, S. Modeling of monthly rainfall and runoff of Urmia lake basin using "feed-forward neural network" and "time series analysis" model. *Water Resour. Ind.* **2014**, *7*, 38–48. [CrossRef]
53. Moazedi, A.; Taravat, M.; Jahromi, H.N.; Madani, K.; Rashedi, A.; Rahimian, S. Energy-water meter: A novel solution for groundwater monitoring and management. In Proceedings of the World Environmental and Water Resources Congress 2011: Bearing Knowledge for Sustainability, Palm Springs, CA, USA, 22–26 May 2011; pp. 962–969.
54. Karimi, P.; Qureshi, A.S.; Bahramloo, R.; Molden, D. Reducing carbon emissions through improved irrigation and groundwater management: A case study from Iran. *Agric. Water Manag.* **2012**, *108*, 52–60. [CrossRef]
55. Van Vuuren, D.P.; Stehfest, E.; den Elzen, M.G.; Kram, T.; van Vliet, J.; Deetman, S.; Isaac, M.; Klein Goldewijk, K.; Hof, A.; Mendoza Beltran, A. RCP2.6: Exploring the possibility to keep global mean temperature increase below 2 C. *Clim. Chang.* **2011**, *109*, 95–116. [CrossRef]
56. Clarke, L.; Edmonds, J.; Jacoby, H.; Pitcher, H.; Reilly, J.; Richels, R. *CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*; US Government Printing Office: Washington, DC, USA, 2007.
57. Thomson, A.M.; Calvin, K.V.; Smith, S.J.; Kyle, G.P.; Volke, A.; Patel, P.; Delgado-Arias, S.; Bond-Lamberty, B.; Wise, M.A.; Clarke, L.E. RCP4.5: A pathway for stabilization of radiative forcing by 2100. *Clim. Chang.* **2011**, *109*, 77–94. [CrossRef]
58. Riahi, K.; Grübler, A.; Nakicenovic, N. Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technol. Forecast. Soc. Chang.* **2007**, *74*, 887–935. [CrossRef]
59. SCI (Statistical Centre of Iran). *The Annual Report of Cost and Original Price of Agricultural Products in Rural Areas of Iran*; Physical copy only; SCI: Iran, 2018. (In Persian)
60. Giampietro, M.; Aspinall, R.J.; Ramos-Martin, J. Addressing the Complexity of Integrated Resource Assessment. In *Resource Accounting for Sustainability Assessment*; Routledge: London, UK, 2014; pp. 23–30.