Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir
Online ISSN: 2821-1669, Print ISSN: 2980-9460
Research Article
DOI: 10.22067/JSTINP.2025.91072.1130
JSTINP 2025; Vol. 4, No. 2

Critical Systems Heuristics for Sustainable Management of Iran's Water-Energy-Food Nexus

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How to cite this article

Ebrahimi, S., Fathi, M. R., Shahbazi, M,. 2025. Critical Systems Heuristics for Sustainable Management of Iran's Water-Energy-Food Nexus, *Journal of Systems Thinking in Practice*, *4*(2), pp.101-127. doi: 10.22067/jstinp.2025.91072.1130. URL: https://jstinp.um.ac.ir/article_46280.html.

ABSTRACT

The Water-Energy-Food (WEF) nexus represents a critical framework for sustainable development, ensuring human survival and ecological balance amidst increasing resource pressures from population growth, urbanisation, climate change, and economic development. While many models aim to address this nexus, they often focus narrowly on specific sectors rather than adopting a comprehensive, holistic perspective. This study employs Critical Systems Heuristics (CSH), a reflective and emancipatory approach, to examine the systemic challenges and underlying assumptions within the WEF nexus in Iran. The research involved 25 experts from diverse fields—energy (n=6), water (n=5), food (n=4), academia (n=6), and systems (n=4)—selected through purposive sampling to ensure diverse perspectives. Using boundary critique, the study examines current realities ("is" states) and ideal visions ("ought" states) through twelve boundary questions that assess sources of motivation, power, knowledge, and legitimacy. Findings reveal fragmented decision-making structures, short-term planning approaches, and insufficient interdisciplinary collaboration as significant obstacles to sustainable resource management. While decision-making authority is concentrated in isolated governmental sectors, the study highlights the need for integrated management frameworks that align with long-term sustainability goals, emphasising public welfare, environmental preservation, and inclusivity. Additionally, the research uncovers a gap in leveraging relevant expertise, with reliance on politically influenced appointments over merit-based inclusions. The study advocates for systemic reforms, including interdisciplinary stakeholder engagement, the establishment of a unified governance body for the WEF nexus, legislative adaptations, and the integration of renewable energy and sustainable agricultural practices. These strategies aim to shift decision-making from short-term political gains to fostering resilience and equity for current and future generations. By addressing the socio-political, technical, and ecological dimensions of the WEF nexus, this research provides policymakers, stakeholders, and researchers with actionable insights, contributing to a more integrated and sustainable approach to resource management in Iran.

Keywords

Alternative roofing, Roof market Analysis, Sustainability, System dynamics, Multi-criteria decision making.

Article history

Received: 2024-12-03
Revised: 2025-01-19
Accepted: 2025-01-27
Published (Online): 2025-06-30

Number of Figures: 2 **Number of Tables: 1** **Number of Pages: 27** **Number of References:35**

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1. Introduction

1.1. Forewords

Sustainable management of interconnected resources, such as water, energy, and food, has become a pressing global challenge as societies (Taghipour et al, 2023) grapple with growing population pressures, rapid urbanisation, and the intensifying impacts of climate change (Taghipour et al, 2024). The Water-Energy-Food (WEF) nexus provides a transformative framework for addressing these interdependencies; however, existing research and policy efforts often remain fragmented, focusing on sector-specific solutions that overlook broader systemic dynamics. In Iran, where water scarcity, energy inefficiency, and agricultural vulnerabilities converge, understanding and managing the WEF nexus is critical for long-term sustainability (Ghaedi et al, 2024).

The integration of supply chain management with environmental aspects is crucial, particularly in resource-constrained contexts like Iran (Gholian-Jouybari et al., 2024). Efficient supply chains enable the optimisation of resource allocation, reducing wastage and improving the resilience of critical systems to external shocks, such as climate change and geopolitical instability (Khazaei et al, 2023). In Iran, water-intensive agricultural practices, energy-inefficient food production, and logistical bottlenecks exacerbate vulnerabilities within the nexus. Addressing these issues through a systems-based supply chain approach can ensure that water, energy, and food are distributed equitably and sustainably across regions (Ramezani et al, 2024). Moreover, aligning supply chain strategies with the WEF nexus framework promotes innovation in resource management, such as integrating renewable energy into food production and transportation, or adopting water-saving technologies in agriculture (Ghaedi et al., 2024).

1.2. Water-Energy-Food nexus

Water, energy, and food are the essential elements that ensure the survival of human and animal life on Earth (Li and Ma, 2020). Global trends indicate a growing demand for water, energy, and food in the coming decades due to factors such as population growth, migration, industrial and economic development, international supply chains, urbanisation, socio-technological disparities, and climate fluctuations (Di Martino et al., 2021). The scarcity and significance of water and energy resources, coupled with inadequate energy provision and escalating water stress, pose a pressing challenge in catering to the food requirements of a burgeoning global population (Kondash et al., 2021).

As consumption pressure on resources mounts and intricate interdependencies between resources come to the fore, the necessity for a novel approach in identifying and analysing these interrelationships to safeguard the invaluable resources of water, soil, energy, and more becomes undeniable. The water-energy-food nexus approach emerges as a viable solution in this context (Garcia and You, 2016).

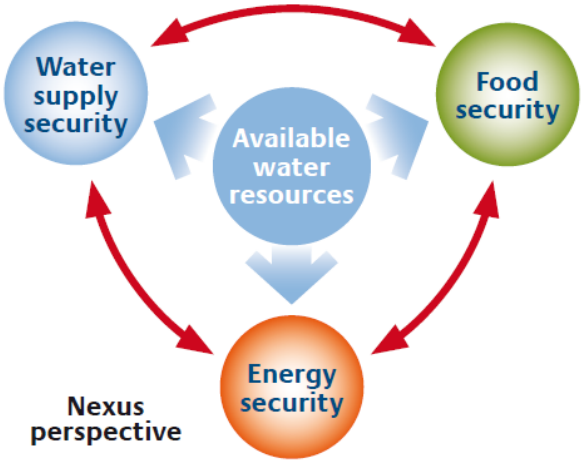

Figure 1. Conceptual framework for depicting resource nexus (Hoff, 2011)

Despite various models being developed to simulate the Water-Energy-Food Nexus, a key issue lies in their partial focus on specific nexus components, whereas the essence of the nexus concept lies in embracing a holistic perspective encompassing its distinct realms (Proctor et al., 2021; Wicaksono et al., 2019).

Significant research has been devoted to examining the water-energy-food nexus through a systemic structural lens, offering conceptual resolutions while critiquing prevailing methodologies. This research underscores the inherent need for systemic experiences in comprehensively analysing intricate problems, emphasising that addressing such challenges mandates a global, holistic systemic approach for crafting enduring solutions. It underscores the inadequacy of short-term solutions, highlighting the necessity for sustained actions and reactions to mitigate crises. The crises at hand are often the result of cumulative events rather than isolated incidents, necessitating a systemic, long-term approach for effective resolution and enhanced system performance.

This study aims to explore and investigate these challenges using a critical systems approach. It seeks to understand how the diverse perspectives of stakeholders shape the way that problems related to the WEF nexus are addressed. Using Critical Systems Heuristics (CSH), this study will explore the “is” (existing realities) and the “ought” (ideal values) states through a set of twelve boundary questions.

Despite the growing recognition of the interconnectedness of the water, energy, and food systems, decision-making remains fragmented, often resulting in short-term solutions that lack the authority to enact meaningful change. This disjointed approach, characterised by a lack of a shared, holistic perspective and collaborative decision-making, undermines the sustainability of the WEF nexus in Iran. This study aims to address this gap by examining how diverse stakeholder perspectives influence the management of the WEF nexus and seeks to propose strategies for fostering integrated and sustainable resource management.

The remainder of this paper is structured as follows: Section 2 delves into the theoretical foundations of the Water-Energy-Food nexus and its relevance to sustainability, drawing insights from existing literature and identifying key gaps. Section 3 outlines the methodology, focusing on the application of CSH and the boundary critique approach to analyze systemic challenges within the nexus. Section 4 presents the research findings, synthesizing expert perspectives to highlight current issues and opportunities for reform. Finally, Section 5 concludes by discussing the implications of the findings, proposing actionable recommendations for policymakers and stakeholders, and identifying future research directions to further advance integrated resource management in Iran's WEF nexus.

2. Theoretical foundations

Water, energy and food are essential for human well-being, poverty reduction and sustainable development. Global projections indicate that the demand for fresh water, energy and food will increase significantly in the coming decades due to population growth, economic development, urbanisation, increasing demand for food and diverse diets, climate change, resource degradation and scarcity (Hoff, 2011). Given the growing demands, the competition for increased use of water and energy resources in agriculture, healthcare, and the environment will intensify, having significant effects on both economic and environmental conditions. Over the past two centuries, the world's fundamental challenges have undergone significant changes, particularly in recent decades (Proctor et al., 2021).

2.1. Water and energy use in agriculture and food production

Even now, the agriculture sector is the largest consumer of water, consuming approximately %70 of the world's total freshwater resources. Water is used for agricultural production and throughout the food and agricultural supply chain, as well as for the production, transport and use of all forms of energy (FAO, 2014). However, food production and supply chains also

consume approximately 30% of total global energy (FAO 2011). Energy is needed for production, transportation and food distribution, as well as for extraction, pumping, lifting, collecting, conveying and water treatment. This situation is expected to worsen in the near future. It is predicted that by 2050, 60% more food will be produced due to increased demand for nutrients and improved quality. Global energy consumption has also been on an upward trend, increasing by nearly 50% by 2035 and by 80% by 2050 (FAO, 2014). As demand increases, there is growing competition for natural resources, including water, energy, agriculture, fisheries, mining, and other sectors. For example, on a macro scale, water infrastructure projects may have synergistic effects for Hydroelectricity generation and water storage provision. But this may have adverse effects on ecosystems and food systems. At the same time, growing bioenergy crops in an irrigated agriculture scheme may improve energy supply, but may also lead to increased water withdrawals and risk compromising food security (Lonbar et al., 2024; Biswas, 2004).

2.2. The Water-Energy-Food nexus as a dynamic system

Each of the water, energy, and food resources is significantly interdependent and intertwined with one another, collectively forming a dynamic system where changes in one sector impact others. Scientifically, these three sectors, which interact with each other, are collectively referred to as the Water-Energy-Food Nexus (Lu et al., 2021). Therefore, it is essential to understand the synergies and interactions in order to develop effective response options that ensure environmental sustainability and people's livelihoods (Lonbar et al., 2024). The aim of Nexus is to ensure sustainability and enhance system performance through a holistic understanding, resource management and reflection of integrated resource management objectives (Biswas, 2004). The Nexus concept acknowledges the need to consider water, energy and food not as separate entities, but as a complex and inseparable entity. This, in turn, allows for more integrated and cost-effective policy-making, planning, implementation, monitoring, and evaluation across the different Nexus sectors. At the same time, the Nexus approach reflects a wide range of perspectives from experts involved throughout the process, which helps to promote dialogue between different sectors and see solutions to challenges as collective efforts (FAO, 2014). Therefore, managing this nexus enhancing the security of the water, food, and energy sectors requires integrated approaches or exploratory tools and conclusions that can identify differences between various sectors, establish effective planning, and provide management strategies and decisions (Yuan and Lo, 2022).

2.3. Existing research and methodological advancements

The following will refer to the research conducted in this field, and subsequently, the gap in the literature will be identified based on the studies conducted. Zhang and Vesselinov (2017) introduced a multivariate socio-economic model. The goal of this model, abbreviated as WEFO, is to minimise the total cost of the system and the link. The costs include the sum of the costs of energy supply, water supply, electricity supply and generation, food production and distribution, and costs of reducing greenhouse gases. In the aforementioned study, a closed area with a certain number of producers and consumers was used, and the equations related to its production and consumption, which mainly considered its economic dimensions, were optimized (Zhang and Vesselinov, 2017). In a similar study, Li et al. (2019) developed an integrated WEFO-like model called AWEFSMI to assist in sustainable agricultural management by Water-Energy-Food Nexus with the aim of maximising net benefits and environmental impacts of food production and processing. This planning model is a nonlinear multi-objective mathematical model that transforms resource availability in the form of fuzzy numbers into a unified computable framework and is capable of considering a wide range of probabilities (Li et al., 2019).

Complementing the above research, Wicaksono et al. (2019) presented a simulation-optimisation model, WEFSIML-apt, related to the water-energy-food Nexus to help major stakeholders of the system make smart and fast decisions regarding sustainable resource management at their national and regional levels. Optimisation in the aforementioned study was developed with two conventional approaches: multi-objective genetic algorithm and single-objective genetic algorithm in order to maximize the user confidence index for the water, energy, and food domains, with special attention to optimizing the priority index and decision-making regarding water allocation (Wicaksono et al., 2019). Studies in this area have also been conducted in the Middle East. Karnib (2017) used an optimal-based simulation tool in a study in Lebanon. In the aforementioned study (the Q-Nexus Model), a type of mathematical model dedicated to simulating the Water-Energy-Food Nexus was used. This model is used for two purposes, including changes related to resource demand or damage reduction and the analysis of scenarios of technological change with greater efficiency (Karnib, 2017). Uen and Rodriguez (2021) conducted significant and comprehensive research in the field of modelling and simulation in Taiwan to optimise power generation and the final storage reservoir. In this study, a three-dimensional and comprehensive plan has been proposed, which combines the benefits of integrating the water, food, and energy nexus by merging short-term and long-term shared

utilisation of a multi-purpose reservoir with irrigation reservoirs in response to urbanisation (Uen and Rodriguez, 2021). Tian et al. (2022) proposed a unified modelling approach to optimize the water, energy, and food nexus with the aim of maximising the net benefit of the system and minimising the pollution emitted from agricultural activities for resource allocation in the water, energy, and food nexus with emphasis on agriculture (Tian et al., 2022).

In the aforementioned study, it is believed that uncertainties such as space-time changes, water availability, and changes and events in river water flows lead to uncertainties in dependent parameters such as the share of land irrigation, access to productive energy, and access to groundwater, due to the complex relationships of the nexus components, and the need to consider a concept such as uncertainty is essential. The research by Rai (2023) emphasises utilising the WEF nexus as a tool to combat environmental destruction, address climate change, and achieve Sustainable Development Goals (SDGs). This article explores the methodological paradigm and application of the WEF nexus within a relevant framework through case studies on water resources, energy efficiency, urban food production, food waste reduction, interdisciplinary perspectives, and circular economy (Rai, 2023).

The objective of the study by Moreschi et al. (2024) is to develop a unified Water-Energy-Food-Climate (WEFC) index using a life cycle approach and to examine its application in the agriculture-food sector, paving the way for decision support tools. After selecting relevant impact categories, a multi-variable optimization was conducted to search for the "best balance" among water, energy, food, and climate issues. Subsequently, a comparative analysis was performed to evaluate the performance of the WEFC index in analysed crops (tomatoes, corn, and chickpeas) in a case study in Italy (Moreschi et al., 2024).

2.4. Gaps and novelties

Research that has addressed the topic under study from a managerial and problem-solving perspective has mostly sought to optimise the current state related to this system or to deal with specific scenarios to reduce risk and uncertainty. In previous research, the existential vacuum of a holistic and systemic approach to creating long-term solutions by considering the interests of all stakeholders is necessary and vital in dealing with such a situation.

3. Methodology

The methodology of the present study is applied in terms of purpose and, considering the chosen methodology, is one of the action research studies that describes the multiple and contradictory

perspectives on the water-energy-food Nexus using the CSH method. This method involves conducting in-depth interviews with stakeholders, using predefined questions (boundary questions) that focus on the target topic, which is explained below. To review and analyse the interviews conducted at CSH, it is first necessary to describe the tools for interpreting these questions and the steps required to analyse the responses obtained in the context of Boundary critique. The stakeholder population for this study comprised a diverse group of 25 experts, selected through purposive sampling to ensure representation across key domains influencing the WEF nexus in Iran. These stakeholders included professionals from the energy sector (6 participants), water sector (5 participants), food sector (4 participants), academia (6 participants), and systems experts (4 participants). This composition reflects a deliberate effort to capture a broad spectrum of perspectives, ensuring insights from both technical and governance domains. Participants were chosen based on their expertise, professional roles, and involvement in decision-making processes related to WEF resource management. The interviews were conducted using a semi-structured format, allowing for both guided discussions based on predefined boundary questions and open-ended responses to capture nuanced insights. Each interview lasted between 60 and 90 minutes and was conducted either in person or via video conferencing, depending on the participants' availability and location. All interviews were recorded with the participants' informed consent to ensure accuracy in data collection and analysis. Detailed notes were also taken during the sessions as a supplementary measure. The recordings were later transcribed verbatim, and the transcripts were coded thematically using qualitative analysis software to identify recurring patterns, systemic challenges, and stakeholder-specific perspectives. Confidentiality and anonymity were strictly maintained throughout the process to encourage honest and uninhibited responses from participants.

3.1. The core principle of CSH

The basic idea of CSH is to support boundary critique—a systematic approach to critically evaluating boundary judgments. Boundary critique may take two primary forms: it can aim at addressing boundary judgments self-critically (reflective practice), or it can utilise boundary judgments for critical purposes against those who may not consider them so self-critically (emancipatory practice). The methodological core idea consists of revealing the unavoidable selectivity of claims in the dual sense of ‘partiality’ explained above (Mirhosseini et al., 2021). Boundary judgments are the perfect target for this purpose, for contrary to what one might think at first, they reflect a claim’s entire selectivity regarding both its empirical and normative

content. It is important to understand that boundary judgments are not merely one (perhaps even minor) among many other sources of selectivity; for example, once the reference system is determined, it is then the specific content of our thinking or discussion that determines how 'partial' they are. Instead, any partiality can and needs to be understood as amounting to boundary judgments for any content we do or do not consider, and the way we consider it implies corresponding boundary judgments. This consequence is the reverse side of the coin of 'clear and valid thinking'; as it were, we cannot meaningfully discuss any aspect of a situation or an issue without implying boundary judgments (Khazaei et al., 2021a).

What a certain aspect means depends on what consequences we anticipate it to have, whose concerns we assume to be affected, what criteria of success or improvement we associate with it (Nayeri et al., 2022), and so on; and all these assumptions and associations embody boundary judgments as to what is to be part of the picture and what is not. Whether these judgments are conscious and deliberate or unintended, the outcome remains the same. Let us now look at the methodological core principle embodied in the concept of boundary critique. As we have understood, the basic requirement for developing the required critical competence is grasping the way judgments of fact as well as of value depend on boundary judgments and are connected through them. CSH explains this through the eternal triangle (Figure 2). Whenever we propose a problem definition or solution or raise any other claim with a practical intent, we cannot help but assert the relevance of some facts and norms over others (Dehghan Nayeri et al., 2021). Which facts and norms we should consider depends on how we bound the reference system, and vice versa; as soon as we modify our boundary judgments, relevant facts and norms are likely to change as well. We are thus caught in an argumentative triangle.

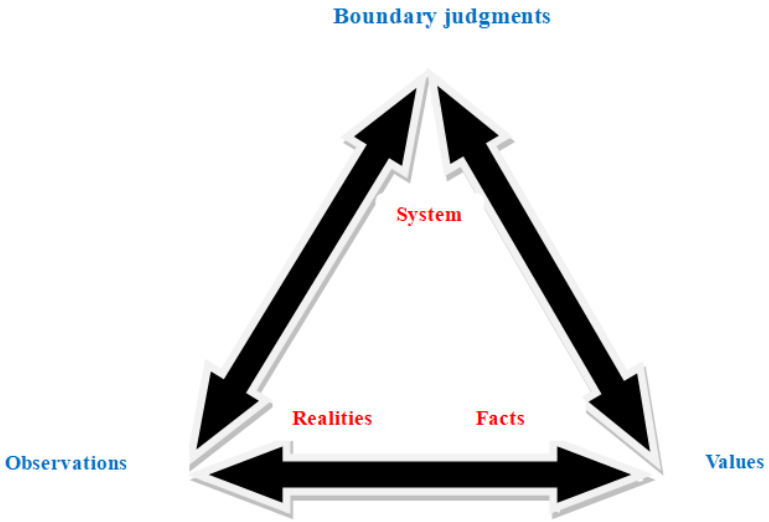

Figure 2. The 'eternal triangle' of boundary judgments, facts, and values Source: Ulrich (2005)

CSH refers to the process of thinking through the triangle as systemic triangulation. It means to consider each corner of the triangle in the light of the other two. For example, what new facts become relevant if we expand the boundaries of the reference system or modify our value judgments? How do our valuations look if we consider new facts that refer to a modified reference system? In what way may our reference system fail to do justice to the perspective of different stakeholder groups? Asking ourselves how the facts that we find relevant, the value considerations we deem adequate, and the context (reference system) that we consider mutually condition one another is highly relevant for developing a sense of modesty regarding our claims, as well as tolerance regarding those of others who appear to have got their facts and values wrong! Next, let us consider the intent of the four basic boundary issues (Dehghan Nayeri et al., 2020). They ask for a claim:

- Basis of motivation – Where does a sense of purposefulness and value come from?
- Basis of power – Who is in control of what is going on and is needed for success?
- Basis of knowledge – What experience and expertise support the claim?
- Basis of legitimacy – Where does legitimacy lie?

Together, the four issues make up a claim's 'anatomy of purposefulness'. Critical heuristics proposes that these four issues are essential for reflective practice in most (if not all) situations of problem-solving, decision-making, or professional intervention (Ramezani et al., 2021). They are essential, as without considering them, we do not truly understand what a claim means and whether or to what extent we should recognise it as valid, that is, as a basis for action. The underlying philosophical position is that of pragmatism.

3.2. Boundary questions

Boundary questions are categorised into four categories, comprising 12 questions (Dehghan Nayeri et al., 2018). As a rule, it makes sense to ask each question both in the 'is' and in the 'ought' mode. Our 'ought' answers always help to clarify the standpoint from which we are assessing a situation or related claim in the 'is' mode. Furthermore, differences between 'is' and 'ought' answers are frequent, not to say the rule; as they point to unresolved boundary issues, they can drive the process of unfolding the selectivity of a claim (Khazaei et al., 2021b). However, the specific way in which we combine the 'is' and the 'ought' mode depends on the particular application of boundary critique in which we are interested. The purpose of critical perceptions is that these four issues are necessary for practising reflection, which is essential in most situations (not always) in problem-solving, decision-making, or professional intervention. Since these four issues are essential, without considering them, we cannot understand what the

meaning (true meaning) of a claim is or to what extent we can recognise it as valid, that is, put it as a basis for actions. The basic philosophical position originates from pragmatism (Ulrich, 2005).

4. Research findings

In the present study, 25 experts were interviewed from various fields, including energy (n=6), water (n=5), food (n=4), academia (n=6), and systems (n=4). This distribution reflects the experts' focus on diverse areas, each of which holds significant importance in sustainable development and societal well-being. It indicates the diversity and depth of expertise among them while emphasising the necessity of interdisciplinary collaboration and knowledge exchange.

Table 1. Summary of interviewees' answers to boundary questions

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
1	Who is the client or beneficiary?	Agriculture sector /Ministry of Energy/Food and Drug Organisation/Ministry of Health	the government	Agriculture sector	Government/Agricultural Jahad/Ministry of Energy/Food and Drug Organization/Water and Wastewater Organization	The government/ Factories, and large industries/the agricultural sector
	Who ought to be the client or beneficiary?	All people	All people and the entire ecosystem	general society	All people	The main body of society that is concerned about health and the future
2	What is the purpose?	Provision of services to the people by the government	Preservation of the status quo	Short-term planning / providing food security at mandated prices	The silence and temporary satisfaction of the people	The government seeks to maintain public cohesion in the short term through policy making
	What ought to be the purpose?	Changing the cultivation pattern according to the climate and guaranteeing the purchase of agricultural products/ moving	Sustainable development from an environmental, economic, social and cultural point of view /balanced distribution of resources	Strategic planning - sustainable food security by preserving basic resources (water, soil, air and environment) with regard to the future generation	Balanced use of water, energy and food resources with a view to the future	Long-term planning (use of renewable energy, cultivation of strategic crops such as cereals and preventing the cultivation of water-intensive crops such

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
		towards the use of renewable energies with land use planning				as beets, cucumbers, watermelons) / the waste should enter the nexus cycle
3	What is the measure of improvement or measure of success?	People's satisfaction	Temporary satisfaction of the people by preventing water, electricity and energy outages	Fake statistics about food production, water and energy consumption	Consumption of water, energy and food	The silence and temporary satisfaction of people with fake statistics, such as the cut-off rate of water and electricity/and setting the market price for food
	What ought to be the measure of improvement or measure of success?	The condition of underground water tables / sustainable energy supply (in all seasons and conditions) /elimination of transgenic products, and healthy products in people's nutrition	The status of underground water tables / the status of providing energy to low-income areas / and the level of people's well-being	The rate of achieving sustainable development indicators	Satisfaction of the current and future generations	The rate of use of renewable energy instead of fossil fuels / the rate of use of waste in the Nexus cycle / the condition of underground water tables
4	Who is the decision-maker?	Ministries of energy, oil, health and agricultural jihad locally and separately	Local trustees locally and separately with a political view	Ministries of energy, oil, health and agricultural jihad locally and separately	Agricultural Jihad, Ministry of Energy, Food and Drug Organisation, Presidential Institution	The government, local representatives such as Imam Juma, and political officials
	Who ought to be the decision-maker?	A reference and an integrated organisation for all 3 areas with a comprehensive view	A non-governmental organization derived from elites and experts in the nexus issue	People's organisations specialised under the supervision of the government	---------	Technical experts who have executive power
	What resources and other conditions of success are controlled by the decision-maker?	All financial, executive and legal resources	Legal and executive sources	Human, financial, legal, and executive resources	All resources are at the disposal of the government	Legal resources and financial resources are available to the government

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
5	What resources and other conditions of success ought to be controlled by the decision-maker?	The integrated organisation that will be created to manage the nexus must have legal and executive power	Access to the media to change the culture with an eye on the environment	Human, financial, and legal resources	Strong legal resources (judiciary)	Executive resources and financial resources should be at the disposal of the government, but the source of legislation should be at the disposal of experts in the field of nexus
6	What conditions of success are part of the decision environment?	Decisions of the Islamic Council	.....	.....	Powerful institutions that are not from the government, but get help from the government in some way	Currently, there are no conditions for the success of the system
	What conditions of success ought to be part of the decision environment?	Using new technologies and up-to-date science in the field of cloud fertilization or cloud guidance	Macro policies of the country from the perspective of strategic management	Long-term planning from the side of governance/changing foreign policy due to sanctions	.....	Absence of sanctions and media problems
7	Who is considered a professional or further expert?	Expert experts working in all 3 areas of water, energy and food, who act locally and separately	Unrelated experts (based on political decisions)	Experts from government departments	Agricultural Jihad, Ministry of Energy, Food and Drug Organisation, Presidential Institution	.....
	Who ought to be considered a professional or further expert?	A working group consisting of three research institutes (water, food energy)	Relevant experts in the field of nexus based on experience, expertise and commitment	Elites and thinkers of society in the field of Nexus	Academic experts who have executive experience in these three fields	A working group consisting of three research institutes (water, food energy)
8	What kind of expertise is consulted?	Currently, the necessary expertise is not used, and appointments are based on relationships	Currently, the necessary expertise is not used, and the appointments are based on relationships and expediency only with a political view	There is no specialization, the appointments are based on the political and governmental view	Management, energy engineering, agricultural and water engineering	Management

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
	What kind of expertise ought to be consulted?	Management, artificial intelligence, data science	land use planning , strategic management	New energy specialist, strategic management	Process knowledge	Trained people in the field of solar/wind and artificial intelligence
9	What or who is assumed to be the guarantor of success?	No one guarantees	No one guarantees	Short-term planning	No one guarantees	No one guarantees
	What or who ought to be assumed to be the guarantor of success?	The support of the government and the parliament for the specialised nexus working group	Macro policy makers/House of Representatives/Government/and Judiciary with a consolidated and combined view	Long-term planning / macro policies /appropriate laws and regulations	.....	Nexus working group
10	Who is witness to the interests of those affected but not involved?	In fact, there is no one	There is no agent	Members of Parliament	In fact, there is no one	There is no agent
	Who ought to be witness to the interests of those affected but not involved?	City Governor/Social Media	NGOs	The real representatives of the people in the NGO Nexus	Having an expert and knowledgeable representative of Nexus in the Islamic Council	Nexus working group, despite having representatives in different strata
11	What secures the emancipation of those affected from the premises and promises of those involved?	Nothing is guaranteed	.....	Nothing is guaranteed	There is no system	Nothing is guaranteed
	What ought to secure the emancipation of those affected from the premises and promises of those involved?	Legal and executive power should be given to the nexus working group	By strengthening the monitoring tools and control mechanisms in the strategic management of Nexus /by giving the necessary powers to Nexus actors.	Phased monitoring based on control mechanisms	.....	To change the method with technical and legal mechanism
	What worldview is determining?	We will face a severe drought	Negative population growth rate	Basic resources (water, soil, and air) will be	Increasing immigration and	By 2050, a strange drought will happen

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
		/more air pollution / and less public health		depleted due to climate change, leading to the loss of vegetation, which in turn will increase fine dust and air pollution.	increasing frustration among people	in Iran
12	What worldview ought to be determining?	The status of underground water tables for future generations/food security / and sustainable energy supply for all people	Increasing food security	Soil protection/protection of all water resources/production of more and quality food in accordance with population growth by preserving basic resources / The waste enters the nexus cycle	Reducing withdrawal from underground water/use of renewable energy	Go to renewable energy

4.1. Energy expert group

The group identifies a fragmented approach to governance and management of the nexus, with separate ministries managing their respective sectors in isolation. This fragmented approach fails to recognise the interdependencies among water, energy and food, potentially leading to policies that optimise one sector at the expense of others. The ideal situation, as articulated by experts, calls for an integrated management organisation that oversees all three areas with a comprehensive and holistic view, recognising the inherent links between these resources.

Currently, the direct stakeholders and decision-makers are identified as various public departments and ministries. However, experts argue for a shift towards considering all people as primary stakeholders. This shift requires policies and decisions that prioritise public welfare and sustainability over sector interests. The recall of an integrated organisation for decision-making reflects a desire to move away from unrestrained decision-making towards a more coherent strategy that can address the complex interdependencies of the nexus. The shift from measuring success by public satisfaction to the state of groundwater and sustainable energy supply highlights a significant shift towards sustainability and long-term environmental health. It suggests that real progress in the nexus cannot be measured solely by immediate public satisfaction but also by the long-term sustainability of essential resources. The responses highlight the current underutilization of relevant expertise and the reliance on appointment-based relationships rather than merit. The government in question is calling for a multidisciplinary working group comprising experts from the water, energy, and food sectors

alongside specialists in management, artificial intelligence, and data science. It acknowledges the complexity of the nexus, which necessitates a broad range of expertise for practical innovation and management. A significant concern is the apparent lack of oversight and accountability mechanisms to protect the interests of those affected by decisions within the intra-nexus but who are not part of the decision-making process. The proposal to involve city governors and the media as representatives and observers represents a move towards greater transparency and accountability, ensuring that the interests of the wider community are considered and protected. The current worldview is pessimistic, predicting severe droughts, increasing air pollution and declining public health.

In contrast, the envisioned vision is one of sustainability, focused on preserving groundwater for future generations, ensuring food security, and providing sustainable energy for all. This vision highlights the pressing need to transition from short-term, reactive measures to long-term, proactive planning and action. The Energy Expert Group's responses provide a clear understanding of the challenges facing Iran's water, food, and energy nexus and propose a forward-looking framework for systemic change. The anticipated overhaul represents a paradigm shift from fragmented, sector-specific governance to an integrated, sustainability-focused approach. It requires not only structural changes in governance and decision-making but also a cultural shift towards valuing expertise, accountability, and long-term social and environmental well-being.

Implementing such comprehensive changes requires broad support from the government, civil society, and the international community, along with significant investment in technology, infrastructure, and human capital.4.2. Water Expert Group

The responses from this group reflect a critical view of the existing system, in which the government is the primary beneficiary and the primary goal is the preservation of the status quo, often measured by temporary solutions such as preventing power outages. This approach has been criticised for being short-sighted and inadequate in addressing the long-term sustainability of resources. Experts propose a paradigm shift towards recognising individuals and entire ecosystems as primary stakeholders, with the goal of sustainable development that encompasses environmental, economic, social, and cultural perspectives. This shift requires a balanced distribution of resources, measured by the well-being of groundwater levels, energy supply in deprived and underprivileged areas, and overall human well-being. One of the most notable points raised by the experts is their critique of the decision-making processes and the actors involved in them. According to the group, the current system suffers from being insular

and a political decision-making process run by local custodians. This process is at odds with the ideal scenario where decision-making is democratic, alongside NGOs composed of elites and experts on the subject of the nexus. It highlights the need for a more transparent and expertise-based approach that can bridge the gap between current practices and sustainable goals. The discussion on resources highlights a fundamental issue in the allocation and control of resources within the current system, pointing to the need for decision-makers to have access to media and other channels for cultural change, with an emphasis on environmental sustainability. It highlights a broader issue of governance and strategic management, where the current system's focus on temporary satisfaction and political expediency is criticised in favour of a long-term, strategic, and holistic approach to resource management. This criticism extends to the area of expertise and specialisation within the system, where current experts are considered irrelevant and appointed based on political decisions rather than their expertise in relevant areas. The call for relevant experts, based on experience, expertise, and commitment, emphasises the importance of specialised knowledge and strategic management in effectively addressing relevant challenges. It is noticeable that the responses also point to systemic guarantees (or lack thereof) for success, indicating a current lack of accountability mechanisms that ensure success. The envisioned system emphasises the role of macro-policymakers, including the House of Representatives, the government, and the judiciary, in ensuring success through an integrated view of related areas. Finally, the worldview and outlook for the system are critically assessed, with the current negative population growth rate perspective replaced to increase food security. This shift reflects a broader perspective that aligns with the Sustainable Development Goals, which emphasise the need for systemic changes that consider the long-term impacts on both the population and the environment. Finally, the responses of the Water Expert Group highlight the deep systemic challenges facing the water-energy-food Nexus in Iran and advocate for a transformative approach that incorporates environmental sustainability, equitable resource distribution, expertise-based decision-making, and strategic and long-term planning. This analysis suggests a multidimensional review of the system that emphasizes the importance of governance, accountability, expertise, and a shift in worldview toward sustainable development and food security.

4.2. Food expert group

The current focus on short-term food security planningprice controls in the agricultural sector is insufficient, experts say. They advocate a shift towards strategic planning, emphasising

sustainable food security by preserving essential resources such as water, soil, air and the environment for future generations and the wider community. This shift in focus is in line to achieveachieving sustainable development indicators, which represent a shift away from relying on inaccurate statistics on food production, water consumption, and energy as measures of progress. Experts also stress the need for changes in decision-making structures and advocate for the involvement of specialist grassroots organisations under government supervision rather than the isolated ministries that are currently responsible. They emphasise the importance of long-term planning, especially in the face of external challenges such as sanctions, which require changes in foreign policy and governance. From a professional perspective, experts also criticise the lack of expertise in current nominations, which are often based on political and governmental views. They emphasise the need for specialists in new energies and strategic management to guide effective decision-making in the food-energy-water nexus. Overall, the group's worldview and vision for the future of the system are based on conserving primary resources, protecting soil and water, and producing more and better quality food in line with population growth. They recognize the potential consequences of inaction, including loss of primary resources and increased environmental degradation. Their vision calls for a holistic approach that embraces the Nexus cycle, reflecting a deep understanding of the interconnected nature of the challenges facing the Food-Water-Energy Nexus in Iran. In conclusion, the Food Expert Group provides a comprehensive and forward-looking perspective on Food-Water-Energy in Iran, highlighting the need for systemic changes in planning, decision-making, and expertise to ensure a sustainable and secure future for all. Their insights provide valuable guidance for policymakers and stakeholders seeking to address complex Nexus challenges in Iran and beyond.

4.3. Academic expert group

They identified the government, especially the Agricultural Jihad, the Ministry of Energy and the Food and Drug Administration, as the main customers or beneficiaries of the system, indicating strong government influence in decision-making. However, they suggested that the people should be the ultimate beneficiaries and stressed the need to shift towards a more people-centred approach. The aim of the system, as the experts understand it, is currently focused on maintaining the status quo and ensuring temporary satisfaction for people. However, they suggest that the goal should be a balanced use of water, energy and food resources, with a focus on sustainable practices for future generations. The experts also emphasised the importance of

measuring progress and success, suggesting that while the current benchmark is based on water, energy, and food consumption, it should instead focus on the satisfaction of current and future generations. This perspective shift reflects a deeper concern for the long-term sustainability of the system. In discussing decision-making, experts noted that current decision-makers include government agencies and institutions. However, they suggested that academic experts should also play a role in the decision-making process. They emphasised the need for strong legal resources, especially the judiciary, to control decision-makers successfully. Experts identified expertise in management, energy and agricultural engineering, and water engineering as essential for the system. They also emphasised the need to involve academic experts with practical experience in these areas in decision-making. Furthermore, they suggested that process knowledge should be further explored to increase expertise in the system. Regarding ensuring success, the experts noted that currently, no one guarantees success in the system. However, they suggested that the presence of an expert and knowledgeable nexus representative in the Islamic Council could ensure success by monitoring and representing the interests of those not directly involved in the process. The experts also emphasised the importance of reducing groundwater withdrawals and increasing the use of renewable energy as a worldview and vision for the system. They suggested that these goals should be prioritized to address key challenges such as increased migration and frustration among the population. Ultimately, responses from a panel of academic experts offer valuable insights into the water-food-energy nexus in Iran, identifying potential areas for improvement and reform. Their suggestions emphasise the need for a more sustainable and people-centred approach, focusing on long-term goals and involving a diverse range of stakeholders in decision-making.

4.4. Systemic expert group

The current stakeholders, primarily the government, factories, and large industries, including the agricultural sector, represent a system skewed towards immediate economic needs and production. However, the proposal that the core body of society concerned with health and the future should be the primary stakeholders indicates a shift towards a more inclusive and sustainable approach. This shift emphasises the need for policies and practices that consider long-term social well-being over short-term economic gains. The current short-term objective of maintaining public cohesion through policymaking is in stark contrast to the long-term planning advocated for, which focuses on sustainable practices, such as the use of renewable energy and the cultivation of strategic crops.

The gap between existing decision-makers (government and political officials) and the proposed technical experts with executive power highlights the need for informed and expert decision-making that prioritizes environmental sustainability and community health. The allocation of legal and financial resources currently under government control suggests a centralized decision-making process. The proposal to place executive and legislative resources under the expertise of Nexus-focused experts represents a move toward decentralisation of power. It ensures that those with the necessary technical knowledge have a say in the legislative and resource allocation processes. This should theoretically lead to more informed and sustainable decisions that align with Nexus objectives. The current measure of success, based on temporary public consent and manipulated statistics, is considered inadequate. A shift toward measuring success by renewable energy use, the inclusion of waste in the Nexus cycle, and the state of groundwater tables represents a more comprehensive and accurate approach to evaluating the health and system progress. This shift highlights the need for transparent and reliable metrics that demonstrate long-term resource sustainability. The current outlook, which projects a "strange drought" by 2050, presents a passive and apocalyptic perspective. In contrast, the proposed shift toward renewable energy represents a proactive, solution-oriented vision that aims to mitigate future crises by embracing sustainable practices today. This perspective shift is crucial for the system preparation to withstand environmental change and ensure the long-term sustainability of the water-food-energy nexus in Iran.

5. Discussion

To bridge the gap between the current state and the desired future of the WEF nexus in Iran, several transformative actions are essential. First, there is a critical need for inclusive stakeholder engagement. Expanding the circle of stakeholders to include the general public, particularly those directly affected by resource mismanagement, necessitates a more democratic and participatory approach to decision-making. This inclusivity not only enhances transparency but also ensures that diverse perspectives, including those from marginalized communities, are considered in policy formulation.

A significant shift in decision-making authority is also necessary. By transferring power from politically motivated entities to technical experts with the capability to implement evidence-based strategies, decisions can be better aligned with scientific knowledge and Nexus sustainability principles. Such a shift would improve the coherence of resource management efforts and reduce the fragmentation that currently hampers the system's effectiveness.

Decentralisation of resource control is another critical aspect. Diversifying resource management by involving Nexus experts ensures that specialised knowledge is leveraged to promote sustainable practices. This decentralisation can help mitigate the risks associated with overly centralised governance, which often prioritises short-term political gains over long-term sustainability.

The adoption of sustainable success metrics is vital for fostering accountability and measuring progress toward long-term goals. Transparent and comprehensive indicators, such as groundwater levels, renewable energy utilisation, and food security indices, provide clear benchmarks for assessing the health and sustainability of the Nexus. These metrics also encourage continuous improvement and informed decision-making across sectors.

Additionally, a proactive and solution-oriented perspective must be embraced. It involves shifting from reactive crisis management to implementing forward-looking strategies, such as integrating renewable energy sources and optimising agricultural practices. Such measures not only enhance resilience but also position the system to better anticipate and address future challenges, including climate change and resource scarcity. The findings from this study underscore the urgent need for systemic changes in the WEF Nexus in Iran. Aligning the system's objectives, decision-making processes, and success measurements with principles of sustainability and inclusiveness can lead to a more resilient, equitable, and sustainable future. By addressing entrenched governance issues and integrating the expertise of diverse stakeholders, Iran can create a Nexus framework that balances immediate resource needs with long-term ecological and social priorities.

The analysis of boundary judgments further highlights the importance of addressing core systemic issues. In terms of motivation, the study identifies a significant gap, with current policies prioritising short-term governmental interests over the well-being of all stakeholders. The "ought" state calls for motivations rooted in long-term sustainability and equity. Regarding power, the research reveals imbalances in decision-making structures, where fragmented governance undermines holistic resource management. Creating interdisciplinary working groups and legislative mechanisms to redistribute power is essential for fostering collaborative and integrated governance. In terms of knowledge, the study identifies a reliance on narrow, sector-specific expertise, which neglects the benefits of interdisciplinary collaboration and capacity building. A shift toward integrating systemic knowledge, incorporating diverse perspectives and local expertise, is necessary to address the Nexus's complexities effectively. Lastly, legitimacy concerns are evident in the exclusion of marginalised voices and

perspectives. Equitable resource allocation and the inclusion of diverse worldviews in shaping solutions are critical to addressing this issue.

6. Conclusion

The responses from various expert groups regarding the water-food-energy nexus in Iran suggest a complex and multifaceted approach to addressing the interconnected sustainability challenges in the country. Each group, from energy and water experts to food specialists, academic scientists, and systems experts, offers unique perspectives that converge on the urgent need for an integrated and sustainable approach to resource management. However, their perspectives differ in terms of priorities, strategies, and implementations, reflecting the depth and breadth of the nexus challenge.

The Energy Expert Group and the Water Expert Group both identify the public sector as the main customer or beneficiary of the current system, but advocate a shift towards all people or the entire ecosystem, indicating a move from a sectoral to a more comprehensive stakeholder framework. They emphasise the importance of sustainable development and the sustainable supply of resources, including energy and water, as key objectives. The need for an integrated . The desire for more centralised organisation to manage this nexus, equipped with comprehensive legal and executive powers, is highlighted. The desire for more centralised and effective governance structures in the energy and water sectors is indicated. The Food Experts Group shifts focus to the agricultural sector and the general public, emphasising the importance of strategic planning for sustainable food security. Like other groups, they criticise short-term planning and advocate for long-term sustainability, emphasising the role of grassroots organisations under government oversight. The group also emphasises the critical need for expertise in new energies and strategic management to overcome complex food security challenges exacerbated by water and energy constraints.

Academic experts present a different perspective alongside representatives from the public, agriculture, energy, and health sectors, who serve as current stakeholders and advocates, advocating for a future in which the broader population benefits. Their vision includes a balanced use of resources and the demand for knowledge in management, energy, agriculture and water engineering to inform decision-making. Their vision includes a balanced use of resources and the demand for knowledge in management, energy, agriculture and water engineering to inform decision-making. Their emphasis on strong, non-public institutions that complement government efforts highlights a call for collaborative, interdisciplinary

approaches. The System Experts Group offers a systemic critique, pointing to a broader societal concern for health and the future as ideal beneficiaries.

They criticise short-term government policies and fake complacency, and advocate long-term planning that includes renewable energy and strategic crop cultivation. The group advocates for decision-making to be entrusted to technical experts with executive authority, reflecting a strong conviction in the necessity of expertise-based governance to address the challenges at hand. In conclusion, while all groups acknowledge the current system's focus on short-term solutions and sector-specific stakeholders, there is a unanimous call for a shift toward comprehensive and sustainable management of the water, food, and energy nexus, with a strong emphasis on long-term planning, renewable resources, and expert decision-making.

The differences lie in their areas of focus on energy efficiency, water conservation, food security, and the role of academia versus technical experts in governance. These responses underscore the complexity of addressing the nexus challenges in Iran and highlight the need for an integrated approach that balances immediate needs with long-term sustainability, engages a wide range of stakeholders and draws on expertise across disciplines to ensure the health and well-being of both the ecosystem and the wider community.

This research employs CSH, a powerful systems thinking approach, to analyze the Iranian WEF Nexus. Unlike previous research, predominantly focused on optimisation and simulation models (e.g., WEFO, AWEFSMI, WEFSIML-apt, Q-Nexus Model, and Tian et al.'s (2022) unified approach), which primarily address economic efficiency and resource allocation, our study delves into the underlying socio-political dimensions shaping decision-making within this critical nexus. These previous models, while valuable in their specific contexts, often overlook the broader societal implications and the diverse perspectives of stakeholders, failing to address the deeply that influence ingrained values and power dynamics that shape resource management.

For instance, the analysis of sources of motivation uncovered a dominant focus on short-term public sector gains, neglecting the long-term ecological and social consequences. Examining sources of power, we identified a concentration of decision-making authority, limiting the participation of diverse stakeholders, particularly marginalised communities. The analysis of sources of knowledge revealed a reliance on fragmented, technical expertise, overlooking indigenous knowledge and interdisciplinary collaboration. Finally, investigating sources of legitimation uncovered a deficiency in accountability mechanisms to protect the interests of future generations and the environment.

These findings, derived from a rigorous application of CSH, illuminate the urgent need for a paradigm shift in the management of Iran's WEF Nexus. The current fragmented, short-term approach, driven by unsustainable practices and power inequalities, must give way to a holistic, integrated, and equitable system. This transformation necessitates:

- **Legislative Reform:** Strengthening legal frameworks to protect long-term sustainability and ensure equitable resource distribution.
- **Interdisciplinary Collaboration:** Fostering collaboration among diverse stakeholders, including experts from various fields, local communities, and government agencies.
- **Capacity Building:** Investing in programs to enhance understanding of the WEF Nexus and build the capacity for sustainable practices.
- **Climate Change Adaptation:** Integrating climate resilience into water management, energy production, and agricultural practices.
- **Long-Term Planning:** Implementing long-term planning that considers ecological, economic, and social dimensions.

This research provides a crucial foundation for policymakers and stakeholders to create a more sustainable and equitable future for Iran's Water-Energy-Food (WEF) Nexus. By adopting a systemic approach that acknowledges and addresses the complex interplay of power, knowledge, values, and interests, Iran can pave the way towards a more just and environmentally responsible management of its vital resources. Future research should focus on operationalising these findings, translating them into concrete policy recommendations, and monitoring the progress toward a truly sustainable WEF Nexus.

The CSH method provides many output analyses but is not considered a decision-making method. Therefore, it is recommended that, in future research, the present method be combined with a decision-making method that can rank and evaluate the obtained options. For future researchers working on issues related to the water, energy, and food nexus, as well as other environmental sustainability concerns, it is recommended that they employ integrated approaches to incorporate diverse and complementary perspectives into their analysis. These approaches can include a combination of systems modelling, critical analysis, and quantitative and qualitative methods to more comprehensively understand and interpret the complexities of the issues under study. Considering uncertainties in data and decision-making processes is a primary challenge in sustainability-related research. The use of fuzzy computing can help researchers manage and analyze these uncertainties more effectively.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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