Journal of Sustainable Development of Energy, Water and Environment Systems

https://www.sdewes.org/jsdewes

Year 2021, Volume 9, Issue 4, 1080355

Exploring the challenges and opportunities in the Water, Energy, Food nexus for Arid Region

***Sameh W.H. Al-Muqdadi* [1*], *Ali Khalaifawi*[2], *Basima Abdulrahman*[3], *Faisal Aziz Kittana*[4], *Khalid Zaki Alwadi*[5], *Mohammed Humam Abdulkhaleq*[6], *Saif Salwan Al Saffar*[7], *Shahda Mazin Al Taie*[8], *Sheelaz Merz*[9], *Reem Al Dahmani*[10]**

[1] Green Charter , Franz-Belzer Str.2 , 76316 Malsch, Germany ; sameh@green-charter.de
[2] Arcadis Consulting Middle East, United Arab of Emirate; a.b@msn.com
[3] KESK Green Building Consulting, Erbil, Iraq; info@keskco.com
[4] Electricite De France, Dubai, United Arab Emirates; faisalazizkittana@gmail.com
[5] IBM, Dubai, United Arab of Emirate; khalidzy11@gmail.com
[6] Civil Engineer, Dubai, United Arab of Emirate; mohammad.humam.ak@gmail.com
[7] Petroleum Engineer, Dubai, United Arab of Emirate; saifalsaffar@hotmail.com
[8] Mechanical Engineer,Dubai,United Arab of Emirate; shahda_altaie@hotmail.com
[9] Sustainability Excellence, United Arab of Emirate; merzasheelaz@gmail.com
[10] Landscape Architect, Abu Dhabi, United Arab of Emirate; rm.aldahmani@gmail.com

[*] Corresponding author: sameh@green-charter.de

Cite as: Al-Muqdadi, S. W. H., Khalaifawi, A., Abdulrahman, B., Kittana, F. A., Alwadi, K. Z., Abdulkhaleq, M. H., Al Saffar, S. S., Al Taie, S. M., Merza, S., Al Dahmani, R., Exploring the challenges and opportunities in the Water, Energy, Food nexus for Arid Region, J.sustain. dev. energy water environ. syst., 9(4) 1080355, DOI: https://doi.org/10.13044/j.sdewes.d8.0355

ABSTRACT

Water, Energy, and Food sectors are interlinked in a nexus wherein actions relevant to one sector can often influence other sectors to a high degree. Globally, there has been a growing focus on ensuring water, energy, and food security in different kinds of frameworks and models. The current research aims to describe the complex interlinks between the three sectors by evaluating the challenges and opportunities in the following domains: policy, management, and technology. The hypothesis is to provide a basic practice framework to secure better outreach to tackle the interlinks and mismatches within the nexus elements. The methods used a dynamic framework through a transdisciplinary team; the team divided the nexus into six sub-sectors and collecting the primary data through fieldwork interviewing 22 stakeholders and secondary data of 211 literature. The approach of complex adaptive systems and evolving mental models have been used to analyse and develop the framework. The results show that interlinks within the water, energy, and food nexus are quite challenging to be identified since each region has different needs. However, the customized framework covered the gaps holistically, which can be used as a fundamental practice guideline. The study also proposed practical solutions and highlighting the opportunities to secure the future of sustainable development goals.

KEYWORDS

Water–energy–food nexus, Sustainable development, Resource management, Governance

[*] Corresponding author

INTRODUCTION

Water, energy, and food (WEF) resources are vital for organisms to live and thrive—they are key to nourishing basic living needs. WEF resources are linked to each other as a nexus with a domino effect, where the action of one sector often impacts one or both of the other areas according to the Food and Agricultural Organization (FAO) of the United Nations (UN) [1]. The global concern about achieving food security while avoiding resource depletion, particularly in the arid regions, as well as adapting to the rapid population growth and population displacement around the globe has increased. Hence, the Sustainable Development Goals (SDGs) were introduced by the United Nations General Assembly in 2015 as a universal call-to-action for all UN member states to protect the planet by improving the WEF nexus. The agriculture sector is a major consumer of water. Water is often required as a source for the production of clean energy. Energy is needed to secure water requirements through pumping, desalination, and other forms. Energy is also required for transportation and distribution. Hence, WEF should be evaluated and analysed collectively rather than looking at each area individually so that long-term sustainable solutions can be fully developed.

Olawuywi [2] developed an institutional challenges profile addressing the WEF nexus fragmentations in the governance approach. The research was identified in the integrative legal framework to cover the WEF nexus shortages. The authors examined the legal and governance aspects and boosted across the WEF sectors. The study recommends improving the legislation levels and elaborating on the institutional principles within the WEF domains. This approach would help to increase the legal knowledge and the systemic, integrated governance for the WEF resources. Siddiqi et al. [3] developed a systematic ,analytical approach based on the quantitative analysis of water and energy ,identifying the key actors employing the concepts from stakeholder's theory that can bridge the inter-organisational networks for water and energy planning. The research applied an in-depth investigation of water and energy resources using Jordan in the Middle East as a case study. The results showing that oil shale development would create new water requirements and new sources might be the desalination of seawater or more wastewater use to fulfil future demand. The technology development will come with an opportunity to save water for the agricultural sector and reuse the municipal wastewater to partially cover the water needs in the energy sector. However, the authors highlighted the challenges in terms of joint cooperation across different local agencies and private sectors, suggesting that such coordination can be managed by boundary-spanning agencies, such as international donors and the Ministry of Planning. Karnib [4] performed a science-based technology-oriented approach for quantitative assessment for WEF nexus and introduced a conceptual framework focused on technology. The study has highlighted the importance of the quantitative assessment and the challenge of a considerable number of interlinked elements within the quantities and production of WEF nexus. The results show the difficulties of collecting all of these elements and adopting them with a technology framework to fill the available gaps. The author was also illustrating the opportunities and practical considerations for further development.Tashtoush et.al. [5] provided analyzing of the current water, energy, and food nexus global status, the author used a conceptual framework relay on understanding the WEF nexus that helps the decision-makers for better informed to secure sustainable solutions. The study highlighted the relationship between the main nexus elements and the fundamental of improving the understanding of the nexus function. The results show that the integration between the WEF nexus elements would guide to achieve the SDGs.Woertz [6] indicated that the Middle East is the world's largest oil-exporting region, and due to the huge amount of food trade imports, they import huge quantities of virtual water. The author assumes that the quantity of the imported virtual water is equivalent to the balance of river Nile water in the region. The author praised the expansion of renewable energy production in the Gulf region, such as Riyadh's King Abdullah City for nuclear and renewable energy and Abu Dhabi's Masdar City hopping to reach 7% share of renewable energies of its installed power generation capacity by 2020. However, the author emphasises that the three nexus elements are highly political commodities. Rising [7] studied the challenges of the long-term development of the WEF nexus, using the integrated assessment models and hydro-economic optimization models. The results show that the integrated assessment models have weaknesses to identify some interlinks, such as the importance of the water infrastructure, the decision-making implications, and the climate change policies. The study recommends that developing hydro-economic models would strengthen the WEF nexus analysis. Kibaroglu [8] provided a scheme for improving the management of the Euphrates-Tigris Basin (ETB) and transboundary water resources. This scheme provides a basis for long-term strategy creation for decision makers to reach agreements and cooperation with riparian countries in terms of the nexus areas. The research highlighted opportunities for Iraq, Syria, and Turkey in terms of food security, energy production, and the ETB as a valuable water resource. Farid et al. [9] identified management opportunities of Energy-Water nexus in the Middle East and North Africa (MENA) region. They proposed adopting a management integration system through four phases: identifying the nexus for power supply, potable water, wastewater distribution system, and the planning of the sustainable phase of the energy-water nexus. The research summarised the implications to identify the opportunities. Rogers [10] performed an intensive study for water security in relationships governing the food-water-energy-climate nexus, indicating how renewable energy is reducing the reliance on fossil fuels and highlighted the loss of water used to grow food. The study shows as well the influences on the imminent challenge of climate change, where all these transitions have major implications for water security both globally and regionally. The author shows optimism for the Arab Middle East region, providing a set of technical fixes such as: developing new water sources, precision irrigation that can save as much as 50% of water applications at the field level, agronomic research applying Yield-Gap (YGA) methods of planning for crop and region choices, modernising the food and value chains and post-harvest losses from farm to fork that can save substantial quantities of water up to 40–50%, improve regulations like pricing and trading and command the water resource. Alhanaee et al. [11] compiled data sets and developed a model from the perspectives of nature, human, and climate to predict interlinks and interactions in the long term. This model would help in the creation of preventive strategies to confront fundamental challenges, such as rapid population growth and resource limitation of the WEF nexus, in particular for the Gulf countries. The research emphasised the cooperation between decision makers and the community to develop practical solutions to minimise challenges. Wa'el et al. [12] developed an integrated model to simulate the interlinks between WEF and household consumption. The authors used primary data based on a field survey of over 400 households during different seasons in Duhok governorate, located in Northern Iraq. The model includes the estimated WEF demand, along with organic and wastewater generation, to assist decision makers and beneficiaries to manage WEF implications. The outcomes showed an agreement with global scenarios. Lange [13]elucidated the impact of climate change on the security of water and energy in the Middle East and North Africa Region and highlighting the challenges of population growth, substantial societal and economical transitions, and political instability of the countries of the region. The author anticipates that in climate change, in particular, the number of heat waves will exacerbate the challenges in terms of providing sufficient amounts of water and energy to the region, where the numbers of dry spells will be increased dramatically. The study emphasised that adaptive strategies for the water-energy nexus must consider integrated technology. Schlör et al. [14] used an integrated assessment model to study the heterogeneity of the food-energy-water nexus. Germany has been chosen as a case study. The study implemented a four-phase approach based on the exponential function of Ridder's method to analyse the food-energy-water nexus against the background of the completely revised sustainable strategy of 2017. The four steps are: A) Interconnections of WEF nexus between natural resources and the socio-economic system; B) management and modern political values; C) identifying the framework or the targeted country; D) Integrating assessment approach where policy process culturally recognised the involvement of learning the government and society. Albrecht et al. [15] provided a competitive study of the WEF nexus methods to foster the available approaches and promote analytical methods. The study reviewed 245 journal articles and book chapters. The results showed some limitations within the used methods and highlighted uncommon methods. There was a limitation in the use of social science methods or in utilising both quantitative and qualitative approaches. The author recommended deriving four key features of nexus analytical tools: innovation, context, collaboration, and implementation. They assume that such a complex mixed method should be incorporated with social and political dimensions of WEF nexus to involve elaborating the stakeholders and decision-makers. Mabhaudhi et al. **[16]** presented the WEF nexus evolution during the last decade to demonstrate the core challenge of the nexus components. Four case studies were developed to review the WEF constrains and the results were elaborated using the concept of the SDGs to balance social, economic, and environmental sustainability. Zarei **[17]** focused on sustainable development of the Middle East countries and have chosen Iraq as one of the case studies that shares transboundary river basins with neighbours, such as Turkey and Iran. The author aimed to investigate the dynamics behind the WEF security concerns in this region. With WEF insecurity and poor management, the results have shown that the WEF index for Iraq is 0.65, which is a lower rate compared to its neighbours. The demand is increasing in line with population growth that could lead to potential conflict over water resources. The research looked for regional solutions and recommended cooperation at different levels to maintain the WEF security challenges. Jemmali et al. **[18]** attempted to examine the dynamic relationship between food-water scarcity, sustainable agriculture, and climate change. The case study was in the MENA region covering the period 1990–2016. The study used two dynamic models and developed the following algorithms: the pooled fixed and pooled random effects along with the Hausman test for model specification. Three proxies have been implemented, one for food poverty and two proxies for water scarcity. The main results indicated that low- and middle-income MENA countries need to increase agricultural sustainability without deteriorating environment and water reserves. Kamrani et al. **[19]** proposed a framework for agricultural water distribution systems based on the WEF Nexus concept. An operational management was developed, adopting a common water shortage scenario; the outcome showed good results when adopting an automatic control system. The Bayesian Network model has been used to help the decision makers in evaluating the performance of the system. The configuration approved that the framework can be employed as a decision support model to develop the agricultural water distribution systems. Weinthal and Sowers **[20]** explored the WEF nexus infrastructure for the Middle East and North Africa and highlighted the importance of planning for a large scale of water-energy infrastructures to foster development. The author examined the water-energy nexus impact on the urban and agricultural sectors. The research demonstrates how the water-energy infrastructure is shaping the security, livelihoods, and socio-economics in the Middle East and North Africa region. Shannak et al. **[21]** developed a comprehensive model to manage the WEF interlinked resources. The model has used an integration method of watershed management and proposed several sub-models to ensure an in-depth understanding of the WEF nexus complexity. The objective is to assist the policymakers in proper planning and decisions. The results show that a limited number of frameworks consider all WEF elements together and even fewer models digging deeply to analyze the nexus. The research also confirmed that each country has it owns strategy to govern their natural resources. Fayiah et al. **[22]** recently provided a comparative study and chosen to review 21 cases to examine the water-energy nexus within the urban systems. The hard challenges were by understanding the water-energy nexus limitations in particular for a certain audience, such as policymakers. The study explicitly identifies the nexus gaps and how bridging them would lead to a significant breakthrough in the nexus arena. The author also ends with a very interesting conclusion: yet there is no single agreed framework or acceptable practice that could be used for the water-energy nexus studies globally.

In a nutshell, this last very recent publication along with the previous literature are linked to the current research hypothesis, where no matter what gaps or how many gaps we have within the WEF nexus, there will be no common framework or best practice approach. In other words, the best practice concept might not be applicable to WEF nexus, where each case should be uniquely customised for the targeted region/country. This is at least due to the following reasons: A) the differences in priorities and demands for each region/country – for example, if country "A" has security concerns, their WEF nexus priorities will be different than country "B", which has energy shortages or the region "C" suffering from water scarcity. B) the high diversity and large number of variables factors within the WEF nexus; C) the sensitivity of the nexus interlinks that complicates the repercussions; D) the limitations of implementing policies or the shortages of decent technology; E) management capacity. However, the hypothesis of the current study is that no matter the challenges the country faces, three sectors at least should be covered and applied as a basic practice and these three sectors are: policy, management, and technology.

The objective of this study was to identify the main challenges of the WEF nexus and propose solutions focusing on three sectors: policy, management, and technology, using a snapshot of the WEF nexus for the developing country Iraq. Insights on the availability of primary freshwater, energy, and food resources were explored, evaluating the existing challenges, threats, solutions, and opportunities. The evaluation and assessment will serve Iraq to: give a heads up for the gaps at the mentioned national plan, increase efficiency, save costs, enhance sustainability, and protect the environment. The goal is to increase the public's awareness on the WEF nexus to its importance in developing countries and spark dialogue on knowledge transfer, expertise, research and development, joint ventures, and investments to overcome challenges and secure the future of the national demand.

METHODS

The teamwork capacity approach used the Think-Tank (transdisciplinary team). Ten researchers have contributed to this study, seven members have covered the three major sectors (water, energy, and food) along with three mentors, one mentor for each group. Nexus was divided into six sub-sectors: water for food, water for energy, energy for water, energy for food, food for energy, and food for water. Each team covered a sub-sector that fits the team background and specialisation. This work is not targeting a commercial purpose instead of scientific demands.

Secondary data from government statistics, industry associations, private sector webpages, modern literature, and reports were collected and analysed during brainstorming sessions for the research teams to arrive at the conclusions. About 211 works of literature, reports, and documents (covering international, regional, and local articles) have been systematically reviewed in depth, including synthesis and desk search as follows: A) focusing on international studies, B) regional studies, and C) finally, zooming in on the local studies and internal reports. Less than 30% of the studies were excluded because they were irrelevant for the current study or did not meet the selection criteria.

The studies have been classified later as follows: A) studies intensively exploring the WEF nexus and SDGs concept; B) informative studies focused on potential common interlinks, challenges, and potential opportunities within the nexus; C) demonstrated comprehensive methodologies and tools; D) modern technology-focused studies; E) knowledgeable studies of governance and policies; F) descriptive studies for integrated management and sustainability. The metrological data, statistics, maps, and supportive documents like executive agreements have been collected from relevant authorities. The team also identified the essential software needed to visualise the outcomes.

One of the vital tools to uncover the WEF nexus' inherent mismatches is by evolving the mental models that we have built during the collecting of secondary data. These mismatches are the results of how the real-world of WEF nexus works and how we think it works. These mismatches are forming our mental models, where the mental models will shape our understanding and initiate our behaviour later to generate real-life consequences. The mental models that we embraced approximate the real world, but they become more accurate depictions and represent the actual situation over time through the feedback processing and fieldwork investigation that gathers new information, learns new facts, or meets new people. The complex adaptive systems and evolving mental models (EMM) approach that was developed by Derek and Laura Cabrera from Cornell University [23] have been used to enhance the mental models that secondary data generated. The EMM will reveal the secondary data paradox, if any, showing the relationships among the variables that WEF nexus is dealing with. It is essential to modify the metaphors that we might have and avoid the biases that might steer the research in the wrong direction, which ultimately would misguide the decision maker later (**Figure 1**).

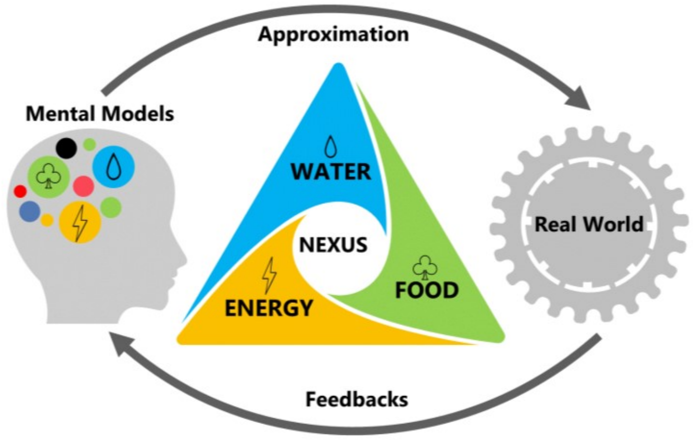
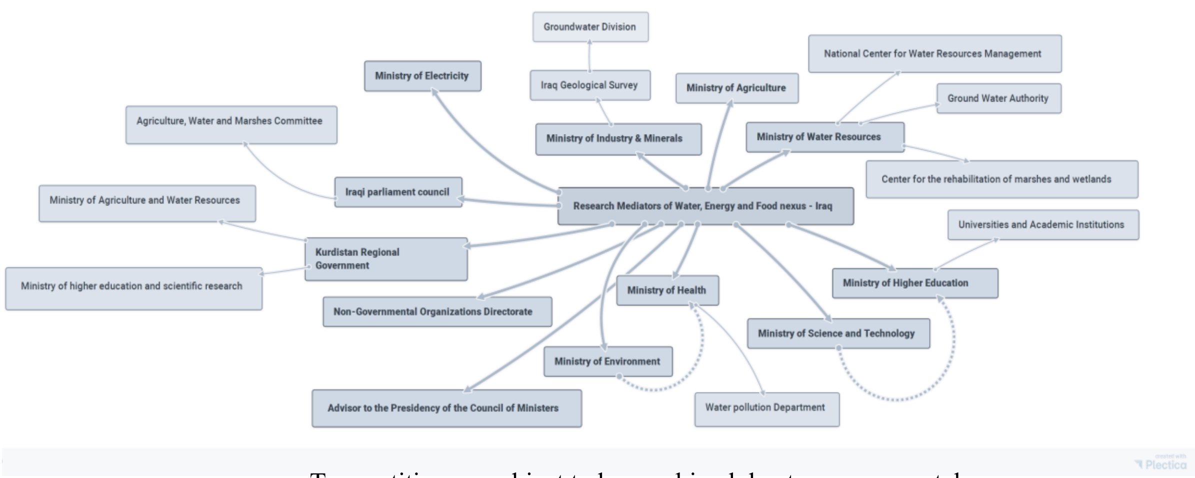


Figure 1. Evolving the WEF nexus mental models

.

To find and bridge the mismatches, we need to have a new pool of information to double check what we had. Twenty-two relevant stakeholders (ministries and governmental authorities and related offices) have been selected across the WEF nexus sectors, followed by a fact-finding mission for 27 days (during Feb 2020) to optimise and validate the secondary data and to get the feedback needed. The technique of focus group discussions with specialists in the fields of water, energy, and agriculture, along with personal interviews with decision makers (Director level) has been taken. Seventeen respondents from different ministries and governmental institutions have been interviewed to take notes and cross-check the information (**Figure 2**).



Two entities are subject to be combined due to governmental restructuring

Figure 2. Research stakeholders of WEF nexus

Generally, the framework went through three stages:

1. The diagnostic stage where a desk review, initial screening, collecting relevant documents, and institutional analysis took place.
2. The WEF nexus were analysed by addressing the key indicators along with potential interlinks and stakeholders.
3. Interpretations and deliverables by having an assessment and tackling the opportunities and challenges.

To deeply understand the WEF nexus, the structure relies on identifying the driven forces at the first stage (external and internal). These driven forces might shape the priority for the WEF nexus and the interactions between the elements. The dynamic loops between the three elements show the collective interaction for each sector upon the other once in a case by case basis. This logic might serve the smooth overlaps and interlinks tackling within the nexus. Moreover, three dependent areas have been employed: policy, management, and technology. They were selected as a response to indicators in-line with the hypothesis of the present study. It has been assumed that such a contextual method would secure the maximum broader coverage to radar the gaps and expand the outreach to reveal the nexus mismatches. The proposed solutions should choose the beneficiaries in advance to ensure better synergies. In this study, the following domains have been chosen to reflect the impact of the solutions: governmental institutions, society, economy, and the environment. The final stage producing outcomes should be aligned with SDGs affected governance and highlight the challenges and possible opportunities **Figure 3** is illustrating in the dynamic framework.

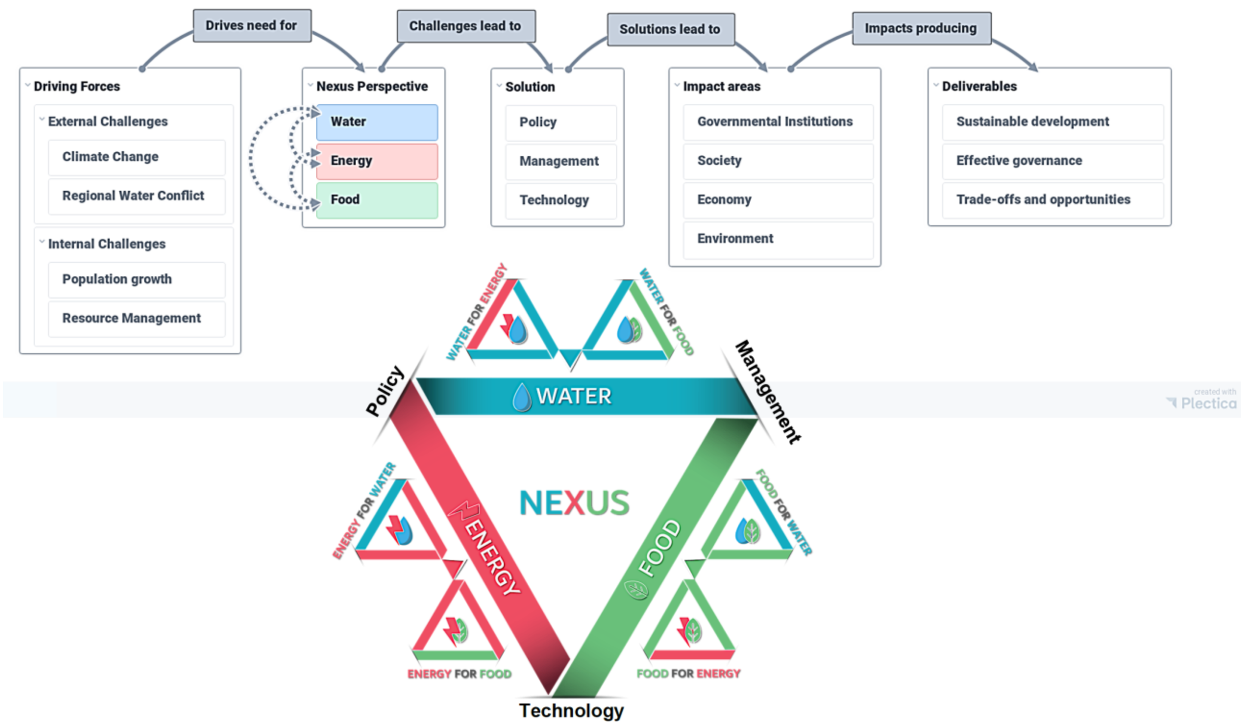


Figure 3. Dynamic framework

Panel discussions and descriptive analysis have been conducted between the research teams. Seven rounds during seven months (Nov.2019 - May 2020) to discuss and present the results for each sector/team, provide feedback, collect comments/suggestions, calibrate the orientation and last but not least ensure consistency. They have included one final co-integration panel to fine-tune the deliverables and collectively evaluate the feasibility of the outcomes.

The open-source Plectica software, developed by professional and scientist group Plectica LLC [24], has been used to visualise and explain the complex mental model methods. Furthermore, the maps have been generated, georeferenced, and classified using ESRI-ArcGIS 10.8, where several layers have been added to the base maps, such as lakes and rivers. The base maps have been downloaded from the World Food Programme by the United Nations Office and the World Bank Group respectively [25], [26].

RESULTS AND DISCUSSION

Iraq, as an arid region with a multidimensional challenge, is the case study of this research; a country shaped by two rivers namely the Euphrates and the Tigris. Over 40% of the country is a desert and 26% is cultivated land [27]. The climate is subtropical semi-arid with rainfall usually during the winter from December to February, with an average precipitation of ~200 mm/year. However, the average rainfall varies between 1200 mm/year in the north to less than 100 mm/year in the south. The summer temperature is extremely hot with daily peak temperatures reaching over 43 °C during July and August [28]. As a downstream country, Iraq is significantly reliant on the water surface from neighbouring countries as over 70% of the water resources in Iraq are consumed by the agriculture sector [29]. The massive dams that were built by the upstream country, Turkey, have severely reduced the water shares and unleashed tension between the riparian countries; however, in 1980s Turkey proposed a comprehensive project to establish a long-term agreement, the project named as "the three-stage" represented by the following: a) creating a joint team; b) studies of the water demands for each country; c) agreeing on water allocations. Unfortunately, the project failed due to political reasons [30]. The limited water has posed multiple threats at different levels, in particular for the agriculture sector that has been severely diminished, with food production decreasing to ~50% over the last two decades [31].

The degradation of water quality and quantity is causing serious local environmental damage; around one-third of water from the rice paddies and fishing grounds is gone. Consequently, this led to the increase of sandstorms [32]. Between 1990 and 2003, the UN embargo caused acute food shortages; the food deficit increased from 12% in 2009 to 48% in 2015. Yet violent civilians and political instability were the key factors in influencing Iraqi food security [33]. After 1990, the human development index (HDI) dramatically decreased [34] and the mortality rate of children under five years of age was three times higher than the rates in neighbouring countries [35].

The 13 years of UN embargo and the reliance on oil revenues, along with climatic fluctuations, led to the absence of national self-sufficiency in terms of food production. The energy sector in Iraq has been suffering for decades, where about two-thirds of Iraq's generation capacity is below the demand. The main sectors in power supply are generation, transmission, and distribution. The total generation capacity was only 16,800 MW in 2012 due to the mismanagement, deterioration, and inefficiency of assets. The relatively old power stations that had been built between 1955 and 1986 were damaged during the 2003 war [36]. The long-term unplanned expansions have led to ~34% losses in the transmission and distribution lines systems, which is considered one of the highest rates in the Middle East [37]. The cost of the underserved power supply is estimated to be USD 40 billion/year [38]. The lack of public awareness is partly due to the power supply failure, with illegal consumption and connection becoming prevalent practices in many parts of the country since 2003 [34]. As a potential sector for alternative energy in Iraq, using solar power could displace over 200,000 metric tons/year of carbon dioxide equivalent emissions, creating over 100 jobs for each 10 MW during the phase of construction and might save ~13,000 barrels/day that Iraq currently uses by generating electricity from fossil fuel [39]. However, others assume that solar power production in Iraq is limited to simple applications, such as water heating for domestic use, lighting streets, and drip irrigation [40].

The absence of regulations, policies, and insightful planning are barriers for renewable energy development in Iraq [40]. One of the major energy challenges is the dispute over natural resources management between the central and regional governments in Kurdistan. This political conflict is embedded in the Iraqi constitution between the states (Article 110–115) [41], where the articles enshrine general principles, such as oil for all Iraqis and the distribution should be equitable. However, these rules require clarification [42]. The UN released the 2030 Agenda for Sustainable Development and SDGs targeting governments, non-governmental organisations, and other stakeholders, including the whole society, aiming to reflect 17 SDGs and 169 targets. The SDGs act as a guide for localisation of the global agenda and provide direction for policy coherence. The global demand for WEF is facing urgent challenges as a result of population growth, urbanisation, economic growth, and environmental stress, such as climate change [29]. The understanding of this chain and evaluations on the local scale are vital for Iraq in the near future to meet the international standards.

Iraq has released documents supporting the SDG localisation process [43] and highlighted the main challenges for implementation. The SDG localisation in Iraq is a crucial process to ensure that government and non-government stakeholders at the sub-national level have clear roles in the formulation, implementation, and monitoring the SDGs progressing. Since early 2016, the Iraq government adopted the 2030 Agenda for Sustainable Development and has started showing serious commitment by conducting a series of workshops and developing a holistic institutional framework to follow up on the SDGs implementation. The report included the National Development Plan 2018 – 2022, the Poverty Reduction Strategy, and the convention on biodiversity. While the Iraqi government pursues an ambitious structural reform program in the coming years, it needs to sustain the networks of collaboration with other stakeholders and develop national policies to support and measure the implementation of the SDGs. The plan admitted and highlighted several strategic challenges and gaps at internal and external levels. The internal challenges are represented by the following: 1) integrating the sustainable development plan at a local level with a national vision and plans within a strategic framework for national development action; 2) the acute need to develop the country and society after generations from war implications; 3) the shortage of stakeholders' awareness from the vision and perception of the sustainable development plan; 4) lack of practical mechanism for communication between the mediators; 5) insufficient data coverage and sorting; 6) political instability in general plays a significant role in carrying out incomprehensive statistical operations to cover and integrate the national database; 7) high rate of population growth where Iraq expected to reach 53 million by 2030; 8) the extreme reliance on oil revenue and the inhibitory environment and policies for the private sector makes the national economy fragile; 9) the weak institutional performance and governance, such as corruption, institutional confusion and poor coordination make it hard to integrate the SDGs into the national plans and policies; 10) financial damages resulting from terrorist actions have been estimated at 63.7 billion USD. The external challenges are summarised by the climate change impact and the geopolitical changes at international and regional levels.

This part of the study is divided into two sections: 1) a deficit analysis 2) discussion of suggestions that might improve the situation. Both parts are organized within the WEF nexus for the three domains policy, management and technology. General observations have been flagged: a) the WEF nexus elements are tightly linked to each other and overlapping to the extent where any shortage of one sector or sub-sector within the nexus lead to consequential influence on the others. b) Limitations of local studies covering the three pillars water, energy and food nexus. c) Data and information were scattered in over 22 local authorities. e) The political decentralization system consumed additional efforts to cover the federal government (Baghdad) and the regional independent government represented by Kurdistan region (Erbil).

Deficit analysis:

The results showing the challenges and gaps within the three domains (policy, management and technology) are as following for each sector and sub-sector:

Water for Food

Water quantity and quality are influencing the country's ability to achieve food security, especially under the pressure of impact on climate change. The following challenges have been observed:

Policy challenges: water is linked to be a political problem back to a century in Iraq, it has been used as a political tool for several time, and internally the Sothern Marshland was a good example, which has been drained for political reasons used as prevention strategy to prevent the insurgents crossing the border between Iraq and Iran during the Iraq-Iran war **[30]**. However, there is also an external influence where the regional tension over water usage and allocation of resources for riparian countries of the ETB has accelerated the damage to potential farmland areas in Iraq **[44]**. Iraq's poor water management system coupled with the Islamic State (IS) seizing control of major water sources has significantly worsened the water crisis in the country **[45]**. The IS has tactically weaponized water facilities, such as dams, to gain strategic military advantages. The flooding of the Fallujah Dam in April 2014 resulted in damage to over 200 km^2 of fertile farmland and loss of the majority of the livestock in the area **[31]**. As such, Iraq imports food products from neighbouring countries like Turkey, Syria, and Iran, which all share the same water resources from the Tigris and Euphrates.

A significant trade-off exists between the water shares allocated for Iraq by these countries and the effect of their food exports to Iraq. This is particularly true for Turkey, which is an upstream country that provides more than one-third of Iraq's food imports, worth approximately USD $3 billion **[46]**. In October 2019, Iraqis began to protest the political and economic situation, especially the significant influence of Iran in the country **[47]**. This unleashed a campaign to boycott imported Iranian goods, as the total imports from Iran reached nearly USD $12 billion in November 2018. The impact of the boycotts resulted in a significant drop in purchasing Iranian goods **[48]**. Consequentially, the gap between the supply and demand for food products was increased and Iraq instead turned to Turkey for these imports. This has increased the water for food challenges in Iraq; the lack of sufficient water supply for sustainable agricultural production in Iraq continues to evolve.

Management Challenges: The varying precipitation rates in Iraq along with the significant reduction in the water shares from the upstream countries have hindered the agricultural sector's growth and heavily reduced the crop production volume. In 2009, Iraq witnessed a major drought period that damaged over 40% of cropland (**Figure 4**) **[49, 50]**. However, by March 2019 Iraq experienced unusual heavy rainfall, which caused flooding across the country **[46]**. This dynamic environment, including the fluctuations between drought and floods periods, creates another challenge for Iraq. No sophisticated and efficient management systems are available that allow the storage of the surplus water during wet periods and the redistribution of water for irrigation purposes during dry periods.

Technology Challenges: As the agricultural sector consumes nearly 70% of Iraq's total water **[29]**, however, approximately 60% of the agricultural water is wasted due to the traditional irrigation methods used by local farmers **[51]**. The existing irrigation schemes are inefficient, with high water losses due to poor distribution systems, infiltration, seepage of water to soil, and leakage **[50]**. Farmers are employing outdated agriculture technologies, keeping production yields at a low **[28]**. Improved irrigation methods are urgently required, as in investing modern technologies to improve production yield and minimize water losses.

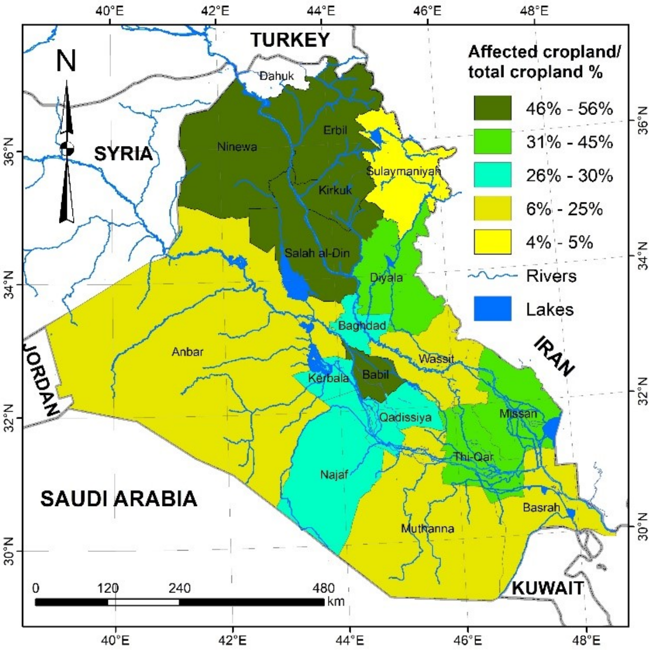


Figure 4. Percentage of crops damaged by drought in 2008–2009 after [50]

Water for Energy

Iraq is suffering from energy efficiency due to the lack of needed power supply. The country is highly in need to expand their outreach to alternatives of renewable energy and hydropower is considered a proper source in this context. In this section, the following challenges have been observed:

Policy Challenges: The massive dam constructed in Turkey by the Southeastern Anatolia Project (GAP) has led to a significant reduction in the surface water flow in Iraq. For Turkey, the GAP dams are considered to be a major source of hydro power and irrigation with a planned installed capacity of 27 billion kW, providing over 45% of the potential hydropower in Turkey [52]. However, GAP poses a major threat to Iraq's water security as the few dams producing energy in the country are facing challenges due to insufficient water levels [53], in addition to other major operational issues. The Mosul dam in Iraq, which has a total installed capacity of 750 MW, is suffering from seepage problems due to the gypsum layers beneath the foundation [54]. The Ilisu dam, commissioned in July 2019 in Turkey, has an installed hydropower capacity of 1200 MW making it the third largest hydroelectric project within GAP, and will increase the water tension over hydropower generation [55].

For decades, the riparian countries (Iraq, Turkey, and Syria) have failed to reach a strategic agreement in terms of water share. Over 45 negotiation meetings have been held between the riparian countries without a settlement [56]. The major reasons behind the lack of a strategic agreement include: limitations in international laws (i.e., the UN conventions for natural resources and the International Watercourses of 1997) [57], lack of identification of rivers and basins (i.e., no agreement over defining the water courses of the Euphrates and Tigris Rivers as either international waters or transboundary water courses), and lack of agreement over water allocation due to challenges in hydropolitical influence, including communication and negotiations gaps [30].

Management Challenges: The lack of long-term strategic planning for dam construction and decommissioning, along with the ineffective implementation of environmental policies, has led to water quality degradation and losses [51]. Climate change, drought, and reduction of renewable water resources, in addition to degraded water infrastructure, have worsened the water shortages [58]. Iraq has 16 dams and barrages (in addition to the Bekhme dam, which is incomplete), most of which were commissioned in the 1980s and designed for the frequent rains and floods of that time [59]. By following good practices for water harvesting, the floods could be used for the internal recharge of groundwater resources, and any surplus might be stored in the current reservoirs to generate clean hydropower from the dams.

Technology Challenges: Hydroelectric power generation in Iraq peaked in 2005, contributing nearly 20% of the total electricity generation [60]. Since then, hydroelectric power generation has steadily declined due to the lack of technology availability and absence of suitable maintenance programs, including challenges regarding the age of equipment, efficiency, lack of maintenance, and continued operations. By 2015, hydroelectric power shares dropped to approximately 3.73% of the total installed power for electricity generation in Iraq (Figure 5) [60]. The current infrastructure is considered to be inadequate and is causing high water losses throughout the distribution network [51]. Iraq's energy grid must be urgently rehabilitated as peak demands can reach around 24,000 MW, or as high as 30,000 MW during the summer heatwaves [51]. The current dams and hydroelectric plants require major refurbishments and retrofits to operate efficiently to meet the energy demand.

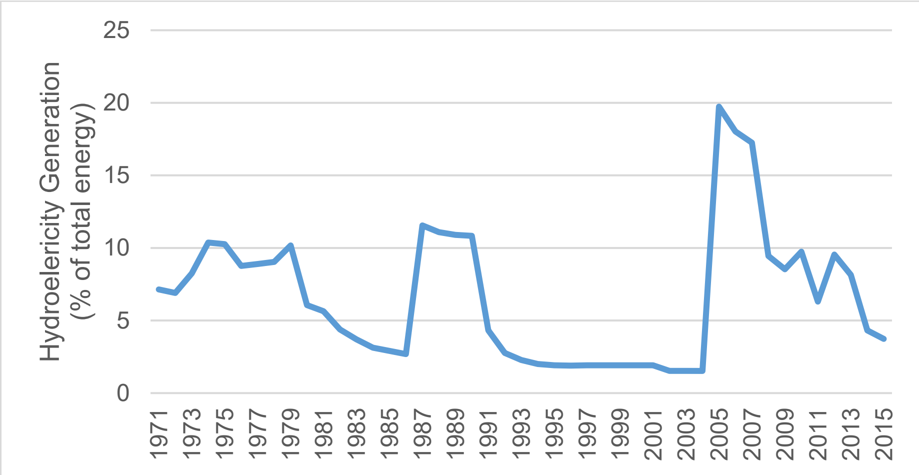


Figure 5. Electricity production from hydroelectric sources (% of total energy) [60]

Energy for Water

Energy and water are inextricably linked. Since Iraq is facing water resource shortages and this gap expected to grow in the future, more energy for the water sector will be needed in pumping and desalinization processes. In this section, the following challenges have been observed:

Policy Challenges: Within the jurisdictional capacity the Iraqi parliament has developed the Energy and Oil Committee that oversee the policies related to oil and natural resources. The water sector falling under natural resources has the involvement of the Ministry of Oil, Ministry of Electricity, and the Ministry of Water in the committee set up by the parliament to tackle the challenges involved. This also includes submitting draft laws to reduce waste of oil and natural wealth and follow up on the rehabilitation and development of projects related to natural resources. Due to the challenging and dynamic political environment in the region, policy makers have been focusing on fast and temporary solutions to address water shortages. The lack of prioritizing efforts and improper planning by the government is the 2019 federal budget, did not allocate funds for the rehabilitation of the water production infrastructure for Mosul province [61]. These areas were the most affected by the political unrest; and therefore, are the most in need of rehabilitation for their power supply and electricity systems. Another internal political challenge that has affected the water supply and the water–energy sector is the lack of clarity on the responsibility of water flow regulation in the Iraqi constitution (article 110 and 114) [41]. This uncertainty and political distrust have escalated the tension between the Kurdistan Regional Government (KRG) and Iraq's Federal Government (IFG).

Management Challenges: A clear framework for water management and communication among the state entities involved is lacking. For instance, although Basrah is suffering from freshwater shortages, the Basrah governorates have failed to maintain efforts for the commissioning of Al Faw Desalination Plants (FDP). The FDP was initially set up in 2011, commissioning was later suspended due to shortages in spare parts, and was only recently fully commissioned. However, the seven year period of suspended work proves a major communication gap between the relevant local authorities [62]. With a high population growth rate in Iraq of about 2.3% [63] and no strategic plans for alternative water sources, the management challenges will only increase over generations. The mismanagement, the bureaucratic practices, and political instability in Iraq are reasons why only a limited number of international investors are currently funding renewable energy projects.

Technology Challenges: Over the past decade, the low water flow in Shat Al-Arab has led to dramatic increases in the salinity rates due to the seawater interaction. However, the salinity levels across the Shat Al-Arab vary depending on the location (Table 1) [64]. Wastewater treatment has not been a priority for Iraq in the past due to the sufficient water resources. However, with the current water scarcity, high-technology solutions are needed for wastewater treatment to meet the water demand while following the international SDG standards. The outdated sewage system requires a major overhaul according to the Ministry of Water Resources [65]. The current wastewater treatment capacity is around 580 million m3/day, which would mean a potential for irrigating over 38,000 ha of farmland from treated wastewater (assuming the quantity of water use for agriculture is ~15,000 m3/ha) [64].

Table 1. Dissolved salt concentration (ppm) in the Shat Al-Arab water for 2008–2009 [64]

Location	**Salinity (ppm)**
Al-Qurna	4330
Al-Maqal	5260
Alseebah	12,300
Fao	14,700

Energy for Food

Lack of access to energy might have several negative impacts on food security, from nutritional choices to cooking methods and storage of food. In Iraq to be specific, load shedding and unscheduled shutdowns of power supply caused eventually a poor nutritional balance. On the other hand, inefficient energy supply can also significantly affect the cooling, drying technologies that enable safe food storage, a vital component to maintain food security. Estimates based on figures from the International Institute of Refrigeration [66] that around one quarter of food loss and waste in developing countries. In this section, the following challenges have been observed:

Policy Challenges: The coordination and communication between the local authorities and public institutions is evidently inefficient, in addition to the absence of a central authority to verify the implementation progress of relevant regulations. The World Food Program (WFP) report, that was approved and published in 2018 by the office of the Secretary General of the General Secretariat for the Council of Ministries—Iraq (GSCM), does not highlight the impact of developing a reliable electricity network on achieving food security [67]. The 13 years of sanctions imposed on Iraq from 1990 to 2003 caused a major degradation in the food and agriculture sector. Whereas the Qatar National Food Security Program recommends using solar technologies as a key component of to provide 80% of the power for water desalination and other operations of Qatar's agricultural sector [68]. Currently, Iraq is unable to meet the national demand for food. The agriculture sector, which provides employment to 20% of the population, is shrinking [69] with no comprehensive plans to develop this sector since 2003 [70]. The 2017 statistics show that only 2% of the power supply is allocated to agricultural purposes [51].

Management Challenges: Iraq generates ~14,000 MW on the national grid, and heavily relies on Iranian gas imports to generate an additional 4000 MW to meet the power demand. As such, over 22% of Iraq's energy consumption is from imported sources [71]. The current political instability along with the previous military operations against the IS have resulted in energy losses of up to 4500 MW, destroying 18% of the transmission and distribution lines [72]. The transmission and distribution losses from the electricity grids make up 30%–40% of the total energy generated [73]. Globally, the demand for food is expected to increase 50% per generation [74]. Supply chain management (SCM) is considered another challenge that influences the efficiency in this sector, severely increasing costs and food losses. The consistency and stability of the power supply is a key factor for achieving sustainability. Iraq, over the last two decades, has been suffering from severe shortages in this context. Load shedding and unscheduled shutdowns of the power supply are hindering the linkage of energy to food as a fundamental part of the SCM. Despite that power consumption and scope of operation are distributed to residential, industrial, or agricultural sectors, the shutdown schedules are inconsistent, and no special allowances are provided for industries or the agriculture sector. This challenge significantly affects all elements of SCM including planning for fuel, food storage, and transportation.

Technology Challenges: Over one-third of the world's energy is consumed to produce food. The lack of an efficient cooling system for the food sector is a big challenge, particularly for the rural areas. There is a global concern that the food sector is highly dependent on fossil fuels. However, the future limitation of fossil fuels might lead to severe food security issues [75]. Iraq is importing ~25 million m3 of natural gas from Iran daily [76] to be used for the gas power plants in Basmaya and Mansuriya, Al-Sadr and Qudus. The challenge is using efficient, clean, and affordable technologies for energy generation, which are not available, particularly in rural areas where energy security is a significant issue [77].

Food for Energy

Iraq faces food security challenges due to water shortages; however, the country also faces a problem with waste management. In this section, the following challenges have been observed:

Policy Challenges: One of the fundamental challenges is the absence of an energy diversification strategy as Iraq mainly relies on fossil fuels [78]. The economy is significantly reliant on revenues from oil and gas as a commodity that is highly variable based on geopolitics as well as supply and demand trends. The country has no policies that provide a direction to diversify the energy mix such as investing in waste-to-energy applications. Efforts on the national scale have been minimal in terms of food waste management practices and segregation of the types of waste for recycling and incineration. It is assumed that Iraq needs a transition time. Because Iraq has oil and gas, the country should make use of it: gas for electrical power (baseload) and building refineries for gasoline, chemical raw material and hydrogen. Recently, Iraq has recognized the urgent need to invest in alternative energy sources. In 2011, Iraq's Ministry of Electricity has started an initiative for renewable energy investment projects; an independent power producer (IPP). However, the initiative did not materialize into a project and the scheme collapsed shortly after its launch due to considerable economic, political, and security risks [79].

Technology Challenges: Iraq has a high potential for using biomass as an energy source, including solid biomass, biogas, liquid biofuel, and municipal solid waste [40]. However, these sources of clean energy, which have higher capital costs, have not been used yet [58]. Iraq is looking into transitioning from conventional energy sources to modern renewable forms through large-scale solar, wind, and biomass facilities aimed at supplying over 10% of the country's energy requirements by 2028. The rate of waste generation in Iraq is over 31,000 tons/day and is expected to rapidly increase in the near future [80].

Management Challenges: Currently, renewable energy sources meet ~13% of the global energy demand, with more promising scenarios predicting that the contribution of renewable energy might grow to ~70% by 2050 [81]. Since renewable energy provides many benefits in rural areas, especially in alleviating energy poverty [82], a strategic plan for securing energy for farming to increase productivity is a potential sustainable approach.

Food for Water

Although agriculture is consuming the lion share of the water resource (~70%), the country is still facing a food security problem. To bridge this gap, water rationing strategies, elaborated with unconventional agriculture techniques, is highly needed to reduce the water consumption in the agriculture sector and to produce food efficiently. In this section, in this section, the following challenges have been observed:

Policy Challenges: Sustainable agricultural production means meeting the current population demands without compromising the needs of future generations [83]. Post-IS studies indicated that up to one-third of Iraq's population still depends on the agriculture sector for their livelihoods, a figure that corresponds to approximately 11 million Iraqis [84]. Iraq is listed as one of the top five countries in the world in terms of vulnerability to climate change, attributed to decreased water and food availability, extreme temperatures, and associated health problems [85]. The estimated cost of environmental degradation in Iraq is USD \$5.5 billion per year, or an average of 6.4% of GDP [86]. Iraq also annually loses around 250 km^2 of arable land to drought, soil salinity, and wind erosion [87]. Iraq's laws prohibit discharging pollutants and wastewater into water resources [88]. The Environmental Protection and Improvement Law No. 27 of 2009, article 14, prohibits the disposal of any home liquid, industrial or serviceable, or agricultural waste into either groundwater or open water resources [89]. Still, local and federal authorities poorly enforce these laws and legislations. Consequently, water streams all the way to Shat Al-Arab have been polluted severely with contaminants from agricultural waste [90]. The large food production gap that led to increased annual food imports caused agricultural policymakers to introduce agriculture input subsidies, which include policies to increase yields of strategic crops in Iraq using chemical fertilizers and pesticides [91]. Despite its positive impact on crop yield, chemical fertilizers and pesticides pose environmental threats from the leaching of pesticides and nutrients into the soil and waterways.

Management Challenges: The main factors affecting agricultural production in Iraq are land quality and water availability. Agricultural land use has traditionally been based on basic assessments of land performance without considering the prerequisites for sustainable agricultural production such as: evaluation of soil, water requirements, terrain to socio-economic factors, market opportunities, and infrastructure availability [92]. Due to performing these assessments mainly rely on conventional methods, from soil surveys to interpolation of analytical results of soil samples, they are costly as much as time consuming [93]. They require considerable human resources that may be delayed significantly due to emerging security and political problems.

Technology Challenges: Another challenge is maintaining the quality of water resources in rivers and lakes that have been affected by negative and irresponsible agricultural practices. Surface water is contaminated by irrigation water discharged from farms due to runoff carrying sediments, dumps, applied nutrients, animal feed and pesticides to rivers [94]. Historically, traditional irrigation practices (such as over-irrigation) and poor drainage systems have contributed to the increase of soil salinity in agricultural land, which is further exacerbated by high evaporation rates. Soil salinity occurs when undrained water evaporates from the soil profile, particularly during summer season, leaving accumulated salts that affect the soil quality causing lower crop yields, especially at the lower reaches of the rivers [95].

Discussion of suggestions:

The following discussion of the suggestions and opportunities that might improve the situation:

Water for Food

The suggested policy development is through_Improving the cooperation in terms of water allocation and water quality with neighbouring riparian countries by reactivating the three-stage project that has been proposed by Turkey in the early 1980s that includes: 1) the formation of a joint technical committee with an outside and independent party to collect hydrogeological data for the riparian countries; 2) the data should be analysed to understand the demand and requirements per country; and 3) finally a sharing formula should be developed to allocate the resources appropriately to each of the sharing countries (i.e., Turkey, Iraq, and Syria) [30]. The three stage project would help to enhance the regional policies in terms of water for food and this will ease the tensions and hydropolitics in the region, with Iraq benefiting from a strategic agreement with the upstream countries, in particular Turkey. The country also should prioritize it efforts to strengthen the water security and considering dam protection zones as a fundamental element of national security.

It has been recognised that developing the national strategy is highly needed to maintain the optimum levels of water allocation in achieving food security. The sanctions against Iraq in 1991 imposed by the United Nations Security Council banned all trades and financial resources and kept it limited to medicine. This led Iraq to give priority for subsidizing the agriculture sector considering self-sufficiency in food production as a prime objective. [96]. However the subsidies have left Iraqi farmers indolent [97]. Post 2003 war, the governmental system has been changed to adopt the decentralization system, instead of the previous firm centralized one, that carried institutional, political and financial issues. This significant change has disrupted the agriculture policies and subsidies scheme that negatively affected the country [98]; solutions would include: (a) developing an import tariff on certain crops that are cultivated locally. The national imports of the agricultural crops and food commodities amounts to about 12.4 billion USD annually, which is over 30% from the total annual national imports. The local sectors have no ability to compete with the imported goods due to the lack of implementation of the customs tariff law [99] . (b) Classifying and re-evaluating the key strategic crops such as wheat, barley, rice, corn and dates, to encourage the national production and cultivation in accord to the lower water footprint, and (c) partially subsidizing or establishing a credit initiative encouraging access to agriculture loans with marginal interest rates that is limited to cover the loan loss reserve between 2007- 2008. Access to credit initiation with substantial funds by ministry of agriculture where about 570 million USD and has been disbursed as loans: the repayment rate was exceeding 95% [100].
From the management perspective, the country in demand to develop a conceptual model to highlight the potential locations of floods and droughts based on historical trends and changing weather patterns. Also developing a mathematical model for water balance is essential (surface water and groundwater) to estimate the water surplus and deficit for each region in Iraq. It needs also to conduct in-depth feasibility study for potential cultivation areas to create a national map depicting the potential strategic cultivation areas.

The technology part could be enhanced by implementing innovative solutions to capture the rainfall that can be integrated back into the irrigation networks. The open drainage system that is widely used in Iraq should be replaced by a modern piping network to reduce water losses due to evaporation, and in situ units can be deployed for water reclamation [101]. This would significantly reduce potential salinity and conserve water resources. There is an acute need to use a modern forecasting tools, sensors, and software platforms to capture real-time information to assist in taking decisions on irrigation frequency and fertilizer needs [102]. On the top of the updated technology the country could adopt the smart irrigation techniques (SITs) that use remote sensing and drones to evaluate the soil conditions and crop health to help improve farming plans [103, 104]. SITs aim to optimize farm productivity and profitability by allowing farmers to reduce the use for unnecessary machinery, pesticides, seeds, and water. Not least by promoting the use of green houses and drought-resistant seeds, the water consumption and associated losses will be reduced, where a national program linked to the government's national subsidies to support farmers can be deployed for this purpose.

Water for Energy

Since the massive dams of GAP were aimed to generate hydropower, these dams were the main reason of water tension; therefore, integrating the policy of water conflict management and transformation tools is recommended to reach win-win agreements [57, 30]. These tools would allow decision makers to identify areas of mutual benefit and avenues for collaboration between the riparian countries in terms of economic prosperity, safety, and capacity building. The tool should clearly define on water shares that adhere to the considerations and needs of each country. It might be useful to evaluating the feasibility of the decommissioning of the Mosul dam, while cooperating with Turkey to use the Ilisu dam as a storage unit and as a source of hydropower due to close proximity to Iraq (within 200 km) [105]. This cooperation would have several benefits for both sides, in particular for Iraq by saving the tremendous maintenance costs associated with the stabilization of the Mosul dam and increasing Iraq's water allocations. This would limit the water capacity storage of the Ilisu dam to ensure that the Hasankeyf ancient town (declared a natural conservation area by Turkey in 1981), which is 100 km away, is not threatened [106]. Conversely, Iraq should move to construct the incomplete Bekhme dam and Makhoul Dam on the upper Zab River, which has the potential to produce as much hydroelectric power as 1500 MW [107].

From the management side, the country need to adopt a flood prevention strategy and considering the March 2019 floods as a reason to evaluate the existing dams. The evaluation should cover the quantity, distribution (geographic presence), and the purposes of the dams. As a result of the evaluation, a map highlighting the potential areas for hydropower production and distribution of dams should be developed. This comprehensive investigation should answer whether Iraq has sufficient dams operating efficiently to produce enough hydropower to meet the national energy and water demands.

To develop the technologies of water for energy, the following suggestions might be proposed: a) Commissioning non-power dams, unlike conventional hydropower that requires significant investment and resources, which do not include hydraulic turbines but rather use the existing foundations of dams. The benefits include flood control and water supply management. The non-powered dams can be powered through the addition of hydropower generation equipment to deliver energy to the grid more efficiently, lowering the construction costs and reducing down time [108]. They are also considered safer and more environmentally friendly. b) Modular hydropower units can be constructed off-site then easily assembled and reconstructed [109]. c) Pumped-storage hydropower (PSH) performs a similar function to a battery by pumping water from the lower to the upper reservoir to be stored during off-peak times. The water can then be released during peak times to turn turbines and meet energy demand. This solution would be suitable for mountainous terrains in Northern Iraq [110]. This modern technology w used recently in the United Arab Emirates for the Dubai Hatta Pumped Storage Hydroelectric Project. Developed by the Dubai Electricity and Water Authority (DEWA), the project was considered the first of its kind in the Arabian Gulf region as part of the Dubai Clean Energy Strategy 2050 [111]. d) Tidal energy could be a good option, in particular for Shat Al-Arab, which captures water at a high tide and releases it at a low tide to create an oscillating motion to drive turbines to generate electricity. However, this method requires at least a ~5 m difference between low and high tides [112], whereas the current Shat Al-Arab tide difference is only ~1–2 m [113].

Energy for Water

To develop the policy and good governance, the country is in need to have a legislative committee by the Iraqi parliament to oversee the natural resources and agriculture; the Technical Committee for Natural Resources (TCNR). The committee is highly recommended to: (a) implement a capacity building program with national awareness campaigns to educate the public on water management and conservation practices for this valuable commodity; (b) secure an annual federal budget for the strategic development of water desalination plants to meet water demands, and (c) provide the parliament with draft laws and federal policies that aim to mitigate the risk of tension between the IFG and KRG and participate in constitution reforms to centralize the energy–water-related challenges for federal decisions.

The management capacity should be developed by setting up a clear implementation plan for the transition from conventional to renewable energy sources, moreover mandating sustainable development practices for all new projects, such as green building codes, the use of low-water-consuming equipment, and waste segregation. It is also important to attract investors by providing them with incentives such as visa waivers, tax waivers for certain number of years, and logistics support. The other development option could be done by adopting the power purchase agreements (PPA) concept to reduce the financial burden on the government; a tool for investors to determine the cost of engineering procurement and construction (EPC) of solar plants can be used to power reverse osmosis (RO) desalination plants.

The technology domain could be enhanced by establishing a desalination system with a capacity of 1 million m^3/day. The competitive technology was implemented in Saudi Arabia and United Arab Emirates, where the climate conditions are similar to those of Southern Iraq, provides robust pre-treatment of water with low energy consumption [114]. It is also essential to evaluate the damage of the distribution system infrastructure, developing new pipelines, and implementing retrofits. Smart monitoring systems should be used to detect any leaks or damage to the infrastructure. An example can be the Aqua-Link system that could be used to detect leaks immediately through online applications and sensors [115]. Since the country also suffering from the shortage in the sewage system, it would make sense to conduct an innovative sewage treatment system that separates sewage from drainage, such as the anaerobic sanitation system [116], where the sludge residue can be transported and used for power generation.

Energy for Food

As in the previous sector of energy for water, policy could be developed by delegating the TCNR to act as the focal point to review and provide regular reports for the decision makers at the GSCM. The committee could implement an intensive national capacity building program for the governmental staff to convey the urgency for them to work together efficiently and improve communication. It would be also important to review and update the electricity tariffs imposed by the Ministry of Electricity by developing progressive rates that encourage end-users to save energy to minimize their costs. The tariff structure can consider (a) different segments for better penetration and coverage: the residential, commercial, industrial, and agricultural sectors; (b) the population density: urban versus rural areas; and (c) peak versus off-peak periods during the day.

Developing the management capacity for the energy for food might be done through different levels, starting with identifying key factors and segments that affect the efficiency of the supply chain management (SCM) to minimize the unnecessary impacts to ensure renewable and sustainable electricity supply is achieved. This may be attained through the use of innovative storing systems, compressing the cycle time, improving the loading and packaging transportation, and employing technology. A systematic evaluation of these segments is also required to measure the progress. The SCM practices could save between 20% and 50% of the operational costs **[117]**. It is also important to encourage an implementation plan that includes several phases **[118]**: a) short-term: providing a clear shutdown schedule, in particular for rural areas, to support the agriculture sector; b) medium-term: subsidizing renewable energy projects for shortlisted successful agricultural efforts; and; c) long-term: implementing a smart metering system can result in energy savings between 5% and 15% **[118]**. Energy optimization is another challenge; the country needs to develop a mathematical model to optimize the energy consumption versus food production to establish a balance between energy and food sectors, reduce water losses, and develop backup energy sources. In this context, Qatar's Sahara forest project has demonstrated success and can be adopted in Iraq. The project used a unique combination of solutions that are integrated in their food production system to maximize opportunities for sustainability in the food, water, and energy sectors in their arid region **[119]**.

Increase investment in renewable energy options such as solar photovoltaic technologies to generate energy for the food and agriculture sector. Iraq's geographical location is favourable for this technology as the photovoltaic power potential ranges between 1534 and 1899 kilowatt hour per kilowatt peak (kWh/kWp). These are average kWh/kWp values for four representative locations **[120]**. Direct normal radiation ranges between 1680 and 2410 kWh/m2 (**Figure 6**) **[121]**.

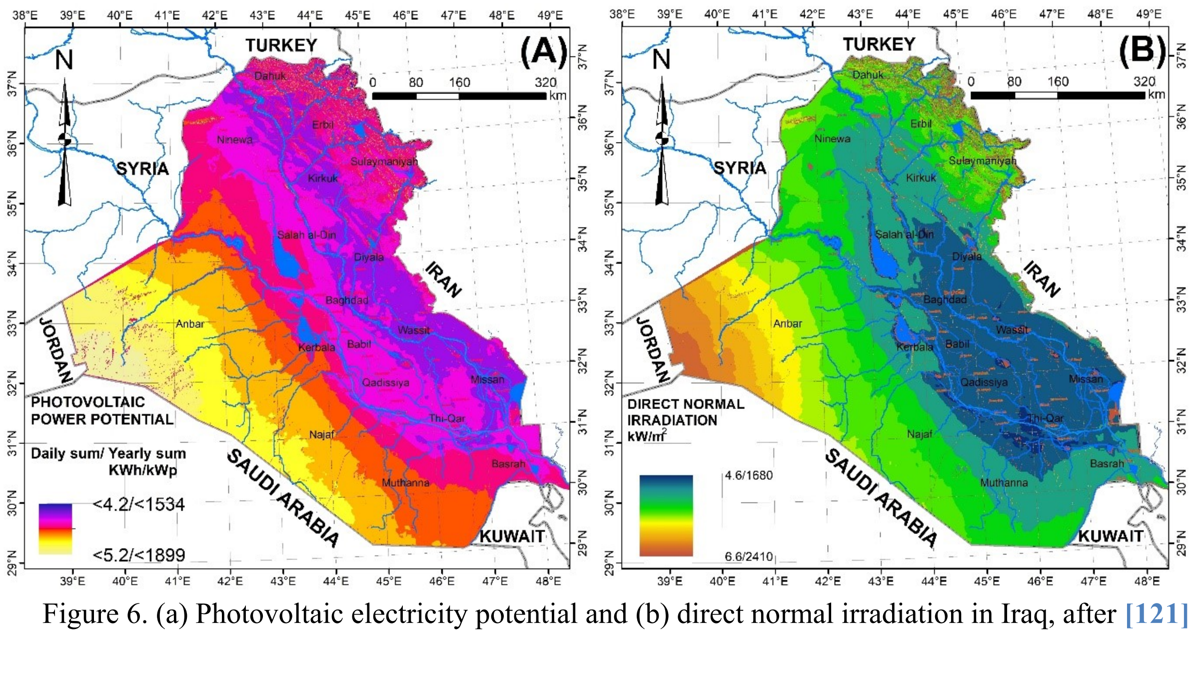


Figure 6. (a) Photovoltaic electricity potential and (b) direct normal irradiation in Iraq, after **[121]**

As such, recommended investments in renewable energy projects include: a) Practice a prevention strategy by reducing consumption of oil and gas products internally, increasing national revenue from oil exports to decreasing dependence on imported gas **[36]**. b) Demonstrating Iraq's commitment to the SDGs by using clean energy sources and decreasing the country's carbon footprint. c) Benefit from supporting private sector businesses, particularly local companies, to create job opportunities, to support agriculture and farming for remote and rural areas, and to generate cheaper energy for food production and storage. d) Promoting the use of efficient and sustainable solutions for the use of energy in greenhouses and warehouses. An example could be replacing conventional lighting with light emitting diode (LED) technologies that reduce energy consumption and increase operational cost savings. The benefits of using LEDs include high energy efficiency, low maintenance cost, longevity, and safety. The cost reduction is expected to be between 25% and 30% compared to conventional lighting [122].

Food for Energy

The waste treatment and its policies is one of the gaps that need to be filled, where implementing a food waste management strategy that promotes minimizing waste production, efficient and safe transport of waste, waste segregation, and recycling. This strategy should be coupled with a road map of clear actions to decrease dependence on fossil fuels and increase the contribution of waste to energy projects to meeting energy demands. In this context, the European Union waste management practices and relevant experience might provide a good example to follow for implementation in Iraq [123]. International standards, such as the World Health Organization codes, can also be adopted to minimize, recycle, and segregate waste [124].

It is important to Iraq to seek for the unconventional sources for energy , hence the management domain proposed to enhance by setting up a nation-wide green energy program to promote the adoption of renewable energy (such as biomass or biofuels) at competitive prices. The government can provide IPPs with tax reduction or other incentives for investing in biomass and biofuel energy projects. The smart energy practices can be also used to meet food–energy demand through integrated food–energy systems (IFESs). IFESs is able enhance the energy efficiency without costly capital investment [125].This approach has been used at the local as well as international scales [75].Examples are plentiful: the dream farm concept in China (organic farming), which minimizes waste and optimizes resources sustainability by using anaerobic digestion, has reduced the energy demand in the region of interest to 14% [126]. The United Kingdom used an integrated cropping system for five years saving about 8% energy compared with conventional cropping, whereas Italy saved ~30% energy using a crop rotation system [127]. Moreover, establishing an intergovernmental renewable energy organization linked to the other local players might be helpful to create (Figure 7). The agency's role would be to optimize the previously lengthy process of decision making and approvals and provide an easy path for investors and interested companies with the support of the International Renewable Energy Agency (IRENA) [128, 79].

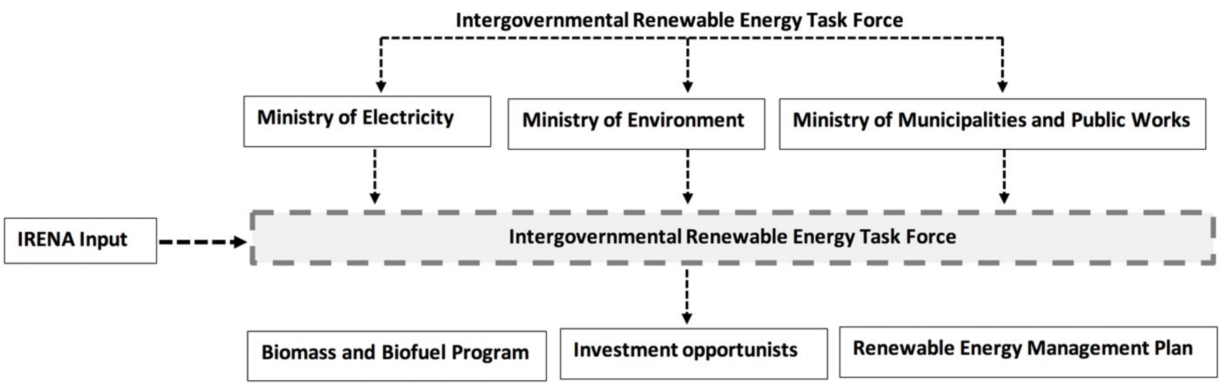


Figure 7. Biomass and biofuel intergovernmental flow

Developing the technology in this context would need to invest in waste to energy projects on the national level. Biomass is a reliable and sustainable substitute for fossil fuels. It is more cost-effective compared to conventional energy sources as it can achieve ~35% savings in energy costs [129]. The other advantages of biomass use include: decreasing the carbon footprint at the local level, providing an additional revenue stream for the government, creating jobs, and reducing landfill costs by 60%–90%. However, biomass plants require sufficient space and investments for a suitable capacity [130]. An example case study is Bee'ah in the United Arab Emirates; the world's largest gasification plant processing as much as 160,000 tons of non-recyclable wastes annually. The added capacity of 35 MW of clean energy supports the country in meeting the rising energy demand while reducing fossil fuel use, environmental related impacts, and use for landfills [131].

Food for Water

This sector is in need to develop a modern policy that encourages new methods of efficient irrigation to achieve optimal crop and livestock production. According to the National Environmental Strategy and Action Plan for Iraq, the transition to sustainable agricultural practices could save ~5%–6% of Iraq's GDP (equivalent to approximately USD $114 billion) and revive the agricultural sector [86]. Another add value suggestion is by limiting the use of chemical pesticides and fertilizers and encouraging farmers to look for alternatives such as the use of bio-pesticide pest control methods and organic fertilizers, which can be subsidized [91].

Evolving the management might need to re-evaluate the land suitability for Iraq's strategic crops by developing a digital land suitability map (DLSM) by means of remote sensing with field work validation using the agro-ecological zoning tool [132]. The map will highlight the feasibility of planting a specific crop by assessing the yield of the value-based crops versus the expected water footprint among other factors [133]. The results can support decision makers when developing plans for increasing agricultural production, improving food security, optimizing investment, and conserving natural resources. Reliable databases and land suitability maps will help farmers promote soil health, minimize water use, and increase profitability, which will, in turn, strengthen the local economy.

The technology part could be developed by controlling the amount of fertilizer and pesticide application to ensure they are optimally absorbed by the crop to avoid any excess to discharge through agricultural runoff [94]. This measure must be applied in parallel to an existing irrigation water management system to prevent over irrigating, and perhaps recovering runoff and tail water. Examples of irrigation systems include precision irrigation, trickle and sprinkler systems, laser levelling, and hydroponic agriculture [87]. These technologies can substantially reduce agricultural water consumption and, ultimately, agricultural water runoff. These solutions will help eradicate soil salinity problems. It is also fundamental to use sustainable agricultural intensification technologies to achieve the following: a) improve water storage in sandy soil with drought-resilient systems (e.g., moister soils), b) use low quality water for agriculture (desalinization, wastewater reuses, saline water, etc.) [134], and; c) invest in greenhouses that allow growing seasons to be extended, providing shelter from excess cold or heat, and inhibit pests.

CONCLUSIONS

This investigation was able to identify the nexus for power supply, water availability and food security chosen a challenging arid region as a case study. A comprehensive exploration for the WEF nexus is vital for any sustainable development plan, as it is currently not only a regional concern but a global one due its scarcity and fears to depletion. The framework used ensured a proper outreach to tackle the mismatches and interlinks within the WEF nexus; it shows the ability to be adopted as a basic practice for other regions after addressing the region priorities. The exploration revealed the gaps and shortages in-between the three main sectors of WEF nexus and the possibility of how to fulfil the framework puzzle to sustain the natural resources to develop long-term socio-economic stability. The study conveyed that it is irrational to look for challenges and opportunities of each WEF nexus separately without considering the strong bonds that link the nexus. This concludes that WEF is interdependent where one influence the other in effect to external and internal related factors.

The influences that effect the WEF are not only environmental but also political and constitutional. Initially the vast water resources in Iraq have changed due to external environmental and political circumstances that led to address the challenges that seemed foreign to country that did not face any of these issues to begin with, to prepare such solutions, as this concept of sustainability was unforeseen in such arable land. Water, energy, and food circumstances have cascaded to one another at national and regional levels that requires the government to step in. The study illustrates that not only the WEF directly affect the livelihoods of the people but influence other aspects making it the driving force in shaping the society and economy. SDGs aim to improve the nexus and Iraq have taken the necessary steps to highlight what needs to be prepared to achieve a desired outcome.

Proposed solutions and opportunities to the evaluated challenges revealed Iraq has the potential to make use of resources using green and renewable energy to reduce a 10% of reliance on fossil fuel. Most of the 70% of water consumed in agriculture is wasted and through renewable technological approaches, this could rapidly repair the situation. Issuing and implementing regulations and policies can assist to practice good governance. Such laws and policies already exist but require enforcement and commitment from the governing bodies to sustain stakeholder collaboration and engagement between the regional governments and riparian countries. As for renewable energy development, new policies and plans are required. Not only will policies and regulations encourage the potential solutions provided in this research but will also interfere in providing jobs and save costs on the social and economic scale. Moreover, the research also managed to work around the current limited circumstances to find optimal solutions to achieve benefits.

This conducted study was able to demonstrate the other studies performed by other experts giving the ability to verify the concern of the nexus to grasp the attention for public awareness and further spark dialogue on knowledge transfer and further elaborated focus-based studies and digital programs. If seen valuable this will attain opportunities for investment as the reaping results will secure the national necessities. Such appealing approach could be integrating models that simulate needed production based consumption within the water energy and food nexus. As a future project, the outcome of this work will be implemented by the system thinking approach to create mantel maps and models for the Iraq WEF nexus gaps and inter-links.

List of abbreviations

DEWA	Dubai Electricity and Water Authority
DLSM	Digital Land Sustainability Map
EPC	Engineering Procurement and Construction
ETB	Euphrates-Tigris Basin
FAO	Food and Agriculture of the United Nations
EMM	Evolving Mental Model
FDP	Al Faw Desalination Plants
GAP	Southern Anatolia Project
GSCM	General Secretariat for the Council of Ministries
IFES	Integration Food Energy System
IFG	Iraq Federal Government
IPP	Independent power producer
IRENA	International Renewable Energy Agency
IS	Islamic State
KRG	Kurdish regional Government
kWh/kWp	kilowatt hour per kilowatt peak
LED	light emitting diode
MENA	Middle East and North Africa
PPA	Purchase Power Agreement
PSH	Pumped-Storage Hydropower
PV	Photovoltaics
RO	Reverse Osmosis

SCM	Supply Chain Management
SDG	Sustaonable Development Goals
SIT	Smart Irrigation Techniques
TCNR	Technical Committee for Natural Resources
UAE	United Arab Emirates
UN	United Nations
WEF	Water Energy Food
WFP	World Food Program
EU	European Union
WHO	World Health Organization
UNGA	United National General Assembly

ACKNOWLEDGMENT

The authors are very thankful for the academic support from Prof.Dr.Broder J. Merkel and Ann Koontz for their kind recommendations and review, to Dr Arsalan Ahmed Othman for his kind scientific contribution by generating figures 3 and 5. The dedication of this work goes to the Iraqi Public Leadership program IPLP (particularly cohort 7), which has been hosted by the American University of Sharjah - UAE and sponsored by Crescent Petroleum. Special thanks go to Prof.Dr. Yass Alkafaji and Majid Jafar for the motivation, unique vision, and generous sponsorship of the IPLP academic program for almost a decade.

FUNDING

This research received no external funding.

REFERENCES

1. (2014). *The Water-Energy-Food Nexus: A new approach in support of food security and sustainable agriculture.* Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-bl496e.pdf (accessed on Dec.01.2019).
2. Olawuyi, D., 2020. Sustainable development and the water-energy-food nexus: Legal challenges and emerging solutions. Environmental Science & Policy, 103, pp.1–9, https://doi.org/10.1016/j.envsci.2019.10.009
3. Siddiqi, A., Kajenthira, A. and Anadón, L.D., 2013. Bridging decision networks for integrated water and energy planning. Energy Strategy Reviews, 2(1), pp.46-58. https://doi.org/10.1016/j.esr.2013.02.003
4. Karnib, A. & Alameh, A., 2020. Technology-oriented approach to quantitative assessment of water–energy–food nexus. International Journal of Energy and Water Resources, 4(2), pp.189–197, https://doi.org/10.1007/s42108-020-00061-w
5. Tashtoush, F.M., Al-Zubari, W.K. & Shah, A., 2020. Correction to: A review of the water–energy–food nexus measurement and management approach. International Journal of Energy and Water Resources,https://doi.org/10.1007/s42108-020-00065-6
6. Woertz, E., 2015, January. The water–energy–food nexus in MENA. In *Oxford Energy Forum* (No. 102). Oxford Institute for Energy Studies.
7. Rising, J., 2020. Decision-making and integrated assessment models of the water-energy-food nexus. Water Security, 9, p.100056, https://doi.org/10.1016/j.wasec.2019.100056
8. Kibaroglu, A. a. (2015). Water–energy–food nexus in a transboundary context: the Euphrates–Tigris river basin as a case study. *Water International*, 40(5-6), pp.824-838. https://doi.org/10.1080/02508060.2015.1078577

9. Farid, et. al. (2016). Opportunities for energy-water nexus management in the Middle East & North Africa. *ELEMENTA Science of the Anthropocene*. https://doi.org/10.12952/journal.elementa.000134
10. Rogers, P., 2017. The triangle: Energy, water & food nexus for sustainable security in the Arab Middle East. In *water, energy & food sustainability in the Middle East* (pp. 21-43). Springer, Cham. https://doi.org/10.1007/978-3-319-48920-9_2
11. Alhanaee, Ghena, Kelly Sanders, and Najmedin Meshkati. "Rising temperatures, rising risks: the food-energy-water nexus in the Persian Gulf." (2017): 4117-4118. https://doi.org/10.1021/acs.est.7b00688
12. Wa'el A, H. M. (2017). An integrated model to evaluate water-energy-food nexus at a household scale. *Environmental modelling & software*, 93, pp.366-380. https://doi.org/10.1016/j.envsoft.2017.03.034
13. Lange, M.A., 2018. The Impacts of Climate Change in the MENA Region and the Water-Energy Nexus. https://doi.org/10.20944/preprints201810.0197.v1
14. Schlör, H., Hake, J.F. and Venghaus, S., 2018. An integrated assessment model for the German food-energy-water nexus. *Journal of Sustainable Development of Energy, Water and Environment Systems*, *6*(1), pp.1-12. https://doi.org/10.13044/j.sdewes.d5.0182
15. Albrecht, T.R., Crootof, A. and Scott, C.A., 2018. The Water-Energy-Food Nexus: A systematic review of methods for nexus assessment. Environmental Research Letters, 13(4), p.043002. https://doi.org/10.1088/1748-9326/aaa9c6
16. Mabhaudhi, T. N. (2019). The Water–Energy–Food Nexus as a Tool to Transform Rural Livelihoods and Well-Being in Southern Africa. *International journal of environmental research and public health*, 16(16), p.2970. https://doi.org/10.3390/ijerph16162970
17. Zarei, M., 2020. The water-energy-food nexus: A holistic approach for resource security in iran, iraq, and turkey. Water-Energy Nexus. https://doi.org/10.1016/j.wen.2020.05.004
18. Jemmali, H., Morrar, R. and Ben Aissa, M.S., 2019. The dynamic nexus between climate changes, agricultural sustainability and food-water poverty in a panel of selected MENA countries. Journal of Water and Climate Change, https://doi.org/10.2166/wcc.2019.309
19. Kamrani, K., Roozbahani, A. and Shahdany, S.M.H., 2020. Using Bayesian networks to evaluate how agricultural water distribution systems handle the water-food-energy nexus. Agricultural Water Management, 239, p.106265, https://doi.org/10.1016/j.agwat.2020.106265
20. Weinthal, E. and Sowers, J., 2020. The water-energy nexus in the Middle East: Infrastructure, development, and conflict. Wiley Interdisciplinary Reviews: Water, p.e1437, https://doi.org/10.1002/wat2.1437
21. Shannak, S., Mabrey, D. & Vittorio, M., 2018. Moving from theory to practice in the water–energy–food nexus: An evaluation of existing models and frameworks. Water-Energy Nexus, 1(1), pp.17–25, https://doi.org/10.1016/j.wen.2018.04.001
22. Fayiah, M., Dong, S., Singh, S. and Kwaku, E.A., 2020. A review of water–energy nexus trend, methods, challenges and future prospects. *International Journal of Energy and Water Resources*, pp.1-17, https://doi.org/10.1007/s42108-020-00057-6
23. Cabrera, D. and Cabrera, L., 2018. Systems thinking made simple.Plectica LLC; 2nd edition p.224.
24. Plectica software, 2020, DSRP, and VMCL are trademarks of Plectica LLC,https://www.plectica.com (accessed on June.03.2020).
25. World Food Programme (2012); Map of Iraq: Percentage of crop damaged by drought in 2008 and 2009. https://reliefweb.int/map/iraq/iraq-percentage-crop-damaged-drought-2008-and-2009 (accessed on Nov.27.2019).
26. ESRI-ArcGIS 10.8 (2020). https://desktop.arcgis.com/en/arcmap/latest/get-started/main/get-started-with-arcmap.htm (accessed on July.20.2020).
27. FAO. 2018. Iraq: Restoration of agriculture and water systems sub-programme 2018–2020. Rome. 110pp. Licence: CC BY-NC-SA 3.0 IGO. http://www.fao.org/3/ca1511en/CA1511EN.pdf (accessed on Dec.29.2019).
28. Bishay, F. (2003). Towards sustainable agricultural development in Iraq. The transition from relief, rehabilitation and reconstruction to development. Food and Agriculture Organization of the United Nations, Rome. SCR 986 OSRO/IRQ/607/DHA, Oil-for-Food Program. http://www.fao.org/3/Y9870E/Y9870E00.htm (accessed on Dec.22.2019).
29. Frenken, K. (2009). Irrigation in the Middle East region in figures AQUASTAT Survey. *Water Reports*, (34).

30. Al-Muqdadi, S.W., 2019. Developing Strategy for Water Conflict Management and Transformation at Euphrates–Tigris Basin. *Water*, *11*(10), p.2037, https://doi.org/10.3390/w11102037
31. Saab, N.W., 2018. More than infrastructures: water challenges in Iraq. https://www.jstor.org/stable/pdf/resrep21320.pdf (accessed on Jan.24.2020).
32. Kitto, M. a. (2004). Aquaculture and food security in Iraq. *Aquaculture Asia*, 9, pp.31-31.
33. Woertz, E. (2017). *FOOD SECURITY IN IRAQ: Politics Matter.* https://doi.org/10.1007/s12571-017-0666-2
34. Koc, M., 2014. Food banking in Turkey: Conservative politics in a neo-liberal state. In *First World Hunger Revisited* (pp. 146-159). Palgrave Macmillan, London, https://doi.org/10.1057/9781137298737_11
35. UNICEF. (2005). The state of the world's children. *Unicef*.
36. Istepanian, H. (2014). Iraq's electricity crisis. *The Electricity Journal*, 27(4), pp.51-69, https://doi.org/10.1016/j.tej.2014.04.006
37. IEA. (2012). *Outlook, WEO-2012 Special Report: Iraq Energy*. Retrieved from https://webstore.iea.org/weo-2012-special-report-iraq-energy-outlook (accessed on Jan.19.2020).
38. Brinckerhoff, P., 2010. Iraq Electricity Master Plan [150_TD $ DIFF]–Executive Summary. *Ministry of Electricity*.
39. Al-Helal, A. (2015). Solar energy as an alternative energy than the conventional means of electricity generation in Iraq. *International Journal of Inventive Engineering and Sciences*, 3(2).
40. Al-Kayiem, H.H. and Mohammad, S.T., 2019. Potential of renewable energy resources with an emphasis on solar power in Iraq: An outlook. *Resources*, *8*(1), p.42, https://doi.org/10.3390/resources8010042
41. Archive, W. (2005). *Iraqi Constitution*. Retrieved from https://web.archive.org/web/20161128152712/http://www.iraqinationality.gov.iq/attach/iraqi_constitution.pdf (accessed on Dec.27.2019).
42. *University of Iraq, Sulaimani, Institute of Regional and International Studies*. Wahab, B. (2014). Iraq and KRG Energy Policies: Actors, Challenges and Opportunities. *The American* https://www.auis.edu.krd/sites/default/files/Iraq%20and%20KRG%20Energy%20Policies%20-%20Bilal%20Wahab.pdf (accessed on Jan.13.2020).
43. United Nation, (2019) Iraq First National Voluntary Review on Sustainable Development Goals, *The Triumph of National Will*,p.94. https://sustainabledevelopment.un.org/content/documents/23789Iraq_VNR_2019_final_EN_HS.pdf (accessed on Dec.17.2019).
44. Tulay Karadeniz, A. A. (2018, June 7). *Turkey halts filling Tigris dam after Iraq complains of water shortages*. Retrieved December 10, 2019, from https://uk.reuters.com/article/uk-iraq-turkey/turkey-halts-filling-of-ilisu-dam-until-july-ambassador-to-iraq-idUKKCN1J3246 (accessed on Feb.04.2020).
45. Price, R.A. (2018) Environmental risks in Iraq, K4D Helpdesk Report. Brighton, UK: Institute of Development Studies.
46. OEC. (2019, December 18). *What does Turkey export to Iraq? (2017)*. Retrieved from The Observatory of Economic Complexity: https://oec.world/en/visualize/tree_map/hs92/export/tur/irq/show/2017/ (accessed on Jan.12.2020).
47. DW. (2019, Nov.). *Iraq: Anti-government protesters hold largest rally since demonstrations began*. Retrieved from https://www.dw.com/en/iraq-anti-government-protesters-hold-largest-rally-since-demonstrations-began/a-51087850 (accessed on Feb.13.2020).
48. The Arab Weekly. (2019, Dec). *Iraq protesters revive 'Made in Iraq' campaign to counter Iranian influence*. Retrieved from https://thearabweekly.com/iraq-protesters-revive-made-iraq-campaign-counter-iranian-influence (accessed on Feb.27.20120).
49. Rick Leblanc. (2019). Different Types of Water Energy. Sustainable Business. Retrieved from https://www.thebalancesmb.com/different-types-of-water-energy-4164332 (accessed on Mar.07.2020).
50. FAO. (2020, January 3). *Iraq at a glance*. (FAO) Retrieved December 10, 2019, from Food and Agricultural Organization of the United Nations: http://www.fao.org/iraq/fao-in-iraq/iraq-at-a-glance/en/ (accessed on Mar.18.2020).

51. Abd-El-Mooty, M., Kansoh, R. and Abdulhadi, A., 2016. Challenges of water resources in Iraq. Hydrology Current Research, 7(4), pp.1-8, https://doi.org/10.4172/2157-7587.1000260
52. Yuksel, I. (2015). South-eastern Anatolia Project (GAP) factor and energy management in Turkey. *Energy Reports*, pp.151-155, https://doi.org/10.1016/j.egyr.2015.06.002
53. UN. (2017, March 25). *Damage to Electricity Infrastructure.* Retrieved from mapping and data portal Mosul: https://reliefweb.int/sites/reliefweb.int/files/resources/170418_Electricity%20Dashboard.pdf (accessed on Mar.11.2020).
54. Cooper, A.H. and Gutiérrez, F., 2013. Dealing with gypsum karst problems: hazards, environmental issues, and planning(pp. 451-462). Elsevier. https://doi.org/10.1016/b978-0-12-374739-6.00106-8
55. Ronayne, M. (2019). *The Ilisu Dam Project in Southern Turkey*. Retrieved from World Archaeological Congress: https://worldarch.org/world-archaeological-bulletin/the-ilisu-dam-project-in-southern-turkey/ (accessed on Feb.27.2020).
56. UN. (1973). In R. 3. General Assembly 28 Session. United Nation: New York, NY, USA.
57. Priscoli, J. D. (2009). Managing and transforming water conflicts. *Cambridge University Press*, https://doi.org/10.1017/cbo9780511551536
58. Chaichan, H. A. (2012). Status and future prospects of renewable energy in Iraq. *Renewable and Sustainable Energy Reviews, 16*, 6007–6012, https://doi.org/10.1016/j.rser.2012.03.058
59. FAO. (2008). Retrieved from http://www.fao.org/aquastat/en/countries-and-basins/country-profiles/country/IRQ (accessed on Feb.05.2020).
60. The World Bank. (2014). *Electricity production from hydroelectric sources (% of total)*. Retrieved December 17, 2019, from The World Bank: https://data.worldbank.org/indicator/EG.ELC.HYRO.ZS (accessed on Mar.12.2020).
61. Turak, N. (2019, Jan. 30). *Iraq's massive 2019 budget still fails to address reform needs, experts say*. Retrieved from CNBC: https://www.cnbc.com/2019/01/30/iraqs-massive-2019-budget-still-fails-to-address-reform-needs.html (accessed on Mar.26.2020).
62. Mawazin. (2018, Sep. 11). *After stopping 7 years in Basra, it announces the operation of the Al-Fao water desalination plant(Arabic)*. Retrieved from https://www.mawazin.net/Details.aspx?jimare=10822 (accessed on Jan.23.2020).
63. Macrotrends. (2019). *Iraq Population Growth Rate 1950-2019*. Retrieved from https://www.macrotrends.net/countries/IRQ/iraq/population-growth-rate (accessed on Apr.16.2020).
64. Yaseen, B.R., Al Asaady, K.A., Kazem, A.A. and Chaichan, M.T., 2016. Environmental impacts of salt tide in Shatt al-Arab-Basra/Iraq. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, *10*(1-2), pp.35-43.
65. Aziz, A. M. (2012). Ministry of Water Resources, Waste Water Production Treatment and use in Iraq, Country report https://www.ais.unwater.org/ais/pluginfile.php/356/mod_page/content/114/Iraq_WasteWaterProduction.pdf (accessed on Jan.12.2020).
66. International Institute of Refrigeration, 2009. The Role of Refrigeration in Worldwide Nutrition–5th Informatory Note on Refrigeration and Food. https://iifiir.org/en/fridoc/109956 (accessed on Dec.22.2019).
67. (ICARDA), R. T. (2008). *National Strategic Review of Food Security and Nutrition in Iraq*. World Food Program. http://54.229.19.198:8080/handle/20.500.11766/9325 (accessed on Jan.14.2020).
68. van Buitenlandse Zaken, M., 2017. Opportunities for Dutch businesses in the Gulf Region-Water Sector-Lo_Res. pdf-Publication-netherlandsandyou. nl. https://www.netherlandsandyou.nl/documents/publications/2017/02/03/opportunities-for-dutch-businesses-in-the-gulf-region-water-sector-lo_res.pdf (accessed on Mar.11.2020).
69. Lucani, P. a. (2012). Iraq: Agriculture sector note. *Food and Agriculture Organisation of the United Nations and The World Bank*, 49. http://www.fao.org/3/i2877e/i2877e.pdf (accessed on Jan.03.2020).
70. UN. (2017, OEC Retrieved from The Observatory of Economic Complexity). Retrieved from https://oec.world/en/profile/country/irq/(accessed on Feb.02.2020).
71. Raya Jalabi. (2019, April 22). *Gas imports to Iraq from Iran will rise in June - electricity ministry*. Retrieved from Reuters: https://www.reuters.com/article/iraq-gas/update-1-gas-imports-to-iraq-from-iran-will-rise-in-june-electricity-ministry-idUSL5N22415V (accessed on Mar.07.2020).

72. RUDAW. (2019, Feb. 8). *Iraq inks deal for another year of electricity imports from Iran.* Retrieved from https://www.rudaw.net/english/middleeast/iraq/080220192 (accessed on Feb.07.2020).
73. Muslim, H. N. (2019). Challenges and barriers in Iraq for solar PV generation: a review. *INTERNATIONAL JOURNAL OF ENERGY AND ENVIRONMENT*, 10(3). https://www.academia.edu/39411654/Challenges_and_barriers_in_Iraq_for_solar_PV_generation_a_review (accessed on Mar.06.2020).
74. Beamon, B., 2014. Sustainability and the Future of Supply Chain Management. *Operations and Supply Chain Management: An International Journal*, *1*(1), p.15, https://doi.org/10.31387/oscm010003
75. FAO. (2011, ENERGY-SMART FOOD FOR PEOPLE AND CLIMATE). Retrieved from http://www.fao.org/3/i2454e/i2454e00.pdf (accessed on Jan.12.2020).
76. Rosenberger, L. (2019). *Economic Statecraft and US Foreign Policy: Reducing the Demand for Violence, https://doi.org/10.4324/9780429026362*
77. Manas Puri. (2016). *HOW ACCESS TO ENERGY CAN INFLUENCE FOOD LOSSES* . Rome: Food & Agricultural Organization of the United Nations. http://www.fao.org/3/a-i6626e.pdf (accessed on Dec.11.2019).
78. Berdikeeva, S. (2019, Mar. 15). *Iraq's Uneasy Road to a Green Economy*. Retrieved from Inside Arabia: https://insidearabia.com/iraq-uneasy-road-green-economy/ (accessed on Jan.14.2020).
79. Power Technology. (2019, May 24). *Iraq hopes third time lucky for competitive IPPs*. (Power Technology) Retrieved December 10, 2019, from https://www.power-technology.com/comment/iraq-solar-energy/ (accessed on Mar.08.2020).
80. Ashraf Yahya Alnajjar. (2019, July 8). Solid Waste Management in Iraq. (EcoMENA) Retrieved December 10, 2019. https://www.ecomena.org/swm-iraq/ (accessed on Feb.16.2020).
81. Mitigation, C. (2011). IPCC special report on renewable energy sources and climate change mitigation. https://www.uncclearn.org/sites/default/files/inventory/ipcc15.pdf (accessed on Jan.08.2020).
82. Ziesemer, J. (2007). Energy use in organic food systems. *Natural Resources Management and Environment Department Food and Agriculture Organization of the United Nations*. http://indiaforsafefood.in/wp-content/uploads/PDF/energy-use-oa.pdf (accessed on Jan.04.2020).
83. GIZ. (2015, Dec.). What is sustainable agriculture? https://www.giz.de/en/downloads/giz2015-en-what-is-sustain-agric.pdf (accessed on Feb.06.2020).
84. FAO, & WB. (2012). Iraq Agriculture sector note. Rome, Italy: FAO. http://www.fao.org/3/i2877e/i2877e.pdf (accessed on Jan.20.2020).
85. Jamal, A. and Wafa'a, A.H., The Role of Technology Transfer in Supporting Climate Change Adaptation the Avenue to Disaster Risk Reduction in the Arid and Semiarid Zones. Open Acc J Envi Soi Sci 1 (1)-2018. *OAJESS. MS. ID*, *105*, https://doi.org/10.32474/oajess.2018.01.000105
86. UNDP; UNEP; WHO. (2012). The National Environmental Strategy and Action Plan for Iraq (2013 – 2017). UNEP. https://www.unenvironment.org/resources/report/national-environmental-strategy-and-action-plan-2013-2017-iraq (accessed on Jan.13.2020).
87. UNEP. (2016). GEO-6 Assessment for West Asia. The Climate and Clean Air Coalition. https://www.ccacoalition.org/en/resources/geo-6-assessment-west-asia (accessed on Feb.07.2020).
88. Ministry of Health and Enviroment, M. (1967). Law No. 25 System of Rivers and Other Water Resources Protection (Include of 45 Pollutants).
89. Ministry of Health and Environment, M. (2009). Law No 27 of 2009 for Protection and Improvement of Environment. FAO. http://www.ilo.org/dyn/natlex/natlex4.detail?p_lang=en&p_isn=89060 (accessed on Mar.02.2020).
90. HRW. (2019). Iraq's Failure to Manage the Water Crisis. Iraq: Human Rights Watch. https://www.hrw.org/report/2019/07/22/basra-thirsty/iraqs-failure-manage-water-crisis (accessed on Mar.05.2020).
91. ICARDA. (2013). Improved livelihoods of smallholder farmers in Iraq through integrated pest management and use of organic fertilizer. Beirut, Lebanon: MEL. https://repo.mel.cgiar.org/handle/20.500.11766/7870 (accessed on Feb.05.2020).
92. Muhaimeed, A.S., Al-Falihi, A.A., Al-Aini$_2$, E. and Taha, A.M., 2014. Developing Land Suitability maps for Some Crops in Abu-Ghraib Using Remote Sensing and GIS. *Journal of RS and GIS*, *2*, pp.2052-5583.

93. Wu, W., Mhaimeed, A.S., Al-Shafie, W.M., Ziadat, F., Dhehibi, B., Nangia, V. and De Pauw, E., 2014. Mapping soil salinity changes using remote sensing in Central Iraq. *Geoderma Regional*, *2*, pp.21-31, https://doi.org/10.1016/j.geodrs.2014.09.002
94. EPA. (2005). Protecting Water Quality from Agricultural Runoff. Washington, DC: EPA. https://www.epa.gov/sites/production/files/2015-09/documents/ag_runoff_fact_sheet.pdf (accessed on Mar.08.2020).
95. World Bank. (2006). Iraq: Country Water Resource Assistance Strategy: Addressing Major Threats to People's Livelihoods. The World Bank. http://documents1.worldbank.org/curated/en/944501468253199270/pdf/362970IQ.pdf (accessed on Mar.11.2020).
96. Roberto Telleria, Abdul Husain El-Hakim, Aden A. Aw-Hassan, Boubaker Dhehibi, Saad Hatem Mohammed, Fadel Rida. (27/7/2014). Agricultural Policies and Institutions in Iraq- A Historical Perspective. Beirut, Lebanon: International Center for Agricultural Research in the Dry Areas (ICARDA),P.22. http://repo.mel.cgiar.org:8080/handle/20.500.11766/8838 (accessed on Dec.04.2019).
97. Los Angeles Times (2003), Subsidies Have Left Iraqi Farmers Flabby, By WARREN VIETH. https://www.latimes.com/archives/la-xpm-2003-jun-16-fg-iraqfarm16-story.html (accessed on Feb.05.2020).
98. Al-Haboby, A., Breisinger, C., Debowicz, D., El-Hakim, A.H., Ferguson, J., Telleria, R. and van Rheenen, T., 2014. Agriculture for Development in Iraq?. Estimating the impacts of achieving the agricultural targets of the national development plan 2013 2017 on economic growth, incomes, and gender equality. https://doi.org/10.2139/ssrn.2483970
99. Rawabet Center,(2020). Food security is threatened in Iraq between low oil prices and the Corona epidemic,by Shatha Khalil. https://rawabetcenter.com/archives/106971 (accessed on June.06.2020).
100. Saade, M., 2012. Iraq Agriculture sector note. Food and Agriculture Organization of the United Nations (FAO).p.72.
101. McCornick, P.G., Hijazi, A. and Sheikh, B., 2004. From wastewater reuse to water reclamation: Progression of water reuse standards in Jordan. *Wastewater use in irrigated agriculture: Confronting the livelihood and environmental realities*, pp.153-62, https://doi.org/10.1079/9780851998237.0153
102. Next Generation Water Tools. (2017, February 10). *Innovative tools and technologies aiding water conservation in agriculture*, https://modernag.org/water-conservation/next-generation-water-tools/ (accessed on Feb.21.2020).
103. Folnovic, T. (2019, December 18). *Technology Essential for Precision Farming*. Retrieved from agrivi: https://blog.agrivi.com/post/technology-essential-for-precision-farming (accessed on Feb.17.2020).
104. Sciforce. (2019, January 14). *Smart Farming, or the Future of Agriculture*. Retrieved from Sciforce: https://www.wur.nl/en/Research-Results/Themes/From-hunger-to-food-security.htm (accessed on Dec.02.2019).
105. Alwash, A. (2016, April 19). *Turning the Impending Mosul Dam Disaster Into Opportunity*. Retrieved from https://www.newsecuritybeat.org/2016/04/turning-impending-mosul-dam-disaster-opportunity/ (accessed on Mar.16.2020).
106. Harte, J., New Dam in Turkey Threatens to Flood Ancient City and Archaeological Sites, 2014. *Forrás: News. nationalgeographic. com [2017. 07. 24.]*. Retrieved from https://www.nationalgeographic.com/news/2014/2/140221-tigris-river-dam-hasankeyf-turkey-iraq-water/ (accessed on Feb.02.2020).
107. By night-Bekhme, G.Z.R., 2014. The Last Free River of Mesopotamia (Doctoral dissertation, Utrecht University).
108. Nawrocki, R. (2017). Greenhouse Gas Emissions Reductions by Powering Non-Powered Dams. *Johns Hopkins*.
109. Drown, P. and French, B., 2017. *French Modular Impoundment: Final Cost and Performance Evaluation* (No. DOE-FDE-0007244). French Development Enterprises, LLC, North Billerica, MA (United States), https://doi.org/10.2172/1364133
110. Immendoerfer, A., Tietze, I., Hottenroth, H. and Viere, T., 2017. Life-cycle impacts of pumped hydropower storage and battery storage. *International Journal of Energy and Environmental Engineering*, *8*(3), pp.231-245, https://doi.org/10.1007/s40095-017-0237-5

111. Energy, N. (2019, Aug 19). *Hatta hydroelectric power station construction contract goes to consortium.* Retrieved from https://www.nsenergybusiness.com/news/hatta-hydroelectric-power-station-contract/ (accessed on Feb.17.2020).
112. Khare, V., Khare, C., Nema, S. and Baredar, P., 2018. *Tidal Energy Systems: Design, Optimization and Control*. Elsevier, https://doi.org/10.1016/c2017-0-02279-6
113. Tide4fishing. (2019, Dec. 28). *Shatt Al-Arab online data*. Retrieved from https://tides4fishing.com/as/iraq/shatt-al-arab/forecast/tides (accessed on Apr.21.2020).
114. GWA. (2019). *Desalination Company of the Year*. Retrieved from https://globalwaterawards.com/2019-desalination-company-of-the-year/ (accessed on Mar.14.2020).
115. AquaLink. (2019). *Water Network Efficincy* . Retrieved from http://www.aqualinksystem.com (accessed on Feb.17.2020).
116. Mulder, K., 2019. Future options for sewage and drainage systems three scenarios for transitions and continuity. *Sustainability*, *11*(5), p.1383. https://doi.org/10.3390/su11051383
117. Alicke, K. and Forsting, M., 2017. McKinsey Supply Chain Segmentation Framework. In *Supply Chain Segmentation* (pp. 15-25). Springer, Cham, https://doi.org/10.1007/978-3-319-54133-4_3
118. Mogles, N., Walker, I., Ramallo-González, A.P., Lee, J., Natarajan, S., Padget, J., Gabe-Thomas, E., Lovett, T., Ren, G., Hyniewska, S. and O'Neill, E., 2017. How smart do smart meters need to be?. *Building and Environment*, *125*, pp.439-450, https://doi.org/10.1016/j.buildenv.2017.09.008
119. Bazoobandi, S. ed., 2014. *The politics of food security: Asian and Middle Eastern strategies*. Gerlach Press, https://doi.org/10.2307/j.ctt1df4hv5
120. Zhang, T. (2017).What's a good value for kWh/kWp? An overview of specific yield. By Solar Power World. https://www.solarpowerworldonline.com/2017/08/specific-yield-overview/ (accessed on Feb.04.2020).
121. Bank, T. W. (2019). *Solar resource maps of Iraq*. The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis. Retrieved from https://solargis.com/maps-and-gis-data/download/iraq (accessed on Mar.17.2020).
122. Khatri, Y. (2016, December 19). *How using LED lights can help you save money*. Retrieved January 3, 2020, from The Economic Times: https://economictimes.indiatimes.com/wealth/save/how-led-lights-can-help-you-save/articleshow/56033284.cms?from=mdr (accessed on Apr.05.2020).
123. Zaman, A.U. and Lehmann, S., 2011. Challenges and opportunities in transforming a city into a "zero waste city". *Challenges*, *2*(4), pp.73-93, https://doi.org/10.3390/challe2040073
124. WHO. (1999). *Waste minimization - World Health Organization.* Retrieved from https://www.who.int/water_sanitation_health/medicalwaste/ch5.pdf (accessed on Jan.23.2020).
125. Bogdanski, A., 2012. Integrated food–energy systems for climate-smart agriculture. *Agriculture & Food Security*, *1*(1), pp.1-10, https://doi.org/10.1186/2048-7010-1-9
126. Matthew, R.A., 2018. Afterward: Closing Thoughts on the Water–Food–Energy–Climate Nexus. In *Water, Energy, Food and People Across the Global South* (pp. 325-332). Palgrave Macmillan, Cham, https://doi.org/10.1007/978-3-319-64024-2_13
127. O Di Nasso, N. B. (2011). Energy efficiency in long-term Mediterranean cropping systems with different management intensities. Energy, 36(4), pp.1924-1930, https://doi.org/10.1016/j.energy.2010.06.026
128. Abass, K. I. (2017). Iraqi Experiment in the Use of Alternative Fuel: A Review. Saudi Journal of Engineering and Technology, 2(4), pp. 171-184.
129. Nunes, L.J.R., Godina, R. and Matias, J.C.D.O., 2019. Technological Innovation in Biomass Energy for the Sustainable Growth of Textile Industry. *Sustainability*, *11*(2), p.528, https://doi.org/10.3390/su11020528
130. Bajpai, P., 2020. Advantages and disadvantages of biomass utilization. Biomass to Energy Conversion Technologies, pp.169–173, https://doi.org/10.1016/b978-0-12-818400-4.00007-4
131. Beeah. (2007). Waste-to-Energy. (Bee'ah) Retrieved December 10, 2019. https://beeah.ae/en/beeah-energy (accessed on Mar.09.2020).
132. Patel, N.R., Mandal, U.K. and Pande, L.M., 2000. Agro-ecological zoning system. A Remote Sensing and GIS Perspective. *Journal of Agrometeorology*, *2*(1), pp.1-13.
133. Anon, 2018. "Virtual water": the importance of "virtual water" in world production and international trade. Journal of Economics and International Relations, (8), https://doi.org/10.26565/2310-9513-2018-8-01

134. McCarthy, N., Lipper, L. and Zilberman, D., 2018. Economics of climate smart agriculture: An overview. In *Climate Smart Agriculture* (pp. 31-47). Springer, Cham, https://doi.org/10.1596/32279

Paper submitted: 22.04.2020
Paper revised: 30.06.2020
Paper accepted:. 25.08.2020