ERF Working Papers Series

Challenges to Iraq's Environment: Applying the Water-Energy-Food Nexus Framework

Bassam Yousif, Omar El-Joumayle and Jehan Baban

Economic Research Forum
منتدى البحوث الاقتصادية

Working Paper No. 1564
August 2022

CHALLENGES TO IRAQ'S ENVIRONMENT: APPLYING THE WATER-ENERGY-FOOD NEXUS FRAMEWORK

Bassam Yousif, Omar El-Joumayle, and Jehan Baban

Working Paper No. 1564

August 2022

Send correspondence to:
Bassam Yousif
Indiana State University
Email: Bassam.Yousif@indstate.edu

First published in 2022 by
The Economic Research Forum (ERF)
21 Al-Sad Al-Aaly Street
Dokki, Giza
Egypt
www.erf.org.eg

Abstract

This paper utilizes research on Water-Energy-Food (WEF) nexus to study the relationships between Iraq's water (requirement and supply), energy (the oil and gas sector), and food production. We survey environmental conditions and note that the quality and availability of water have declined over the last decades, which have posed threats to public health, environmental sustainability, and food security. We next use a variety of data sources to study the interlinkages between these three sectors, including water-energy-food indexes, and explore the state of the agriculture and oil sectors. We point out that water is a key input into both agricultural production and oil extraction, mediating the energy and food sectors and acting to constrain and make rival food and energy outputs. We offer policy recommendations classified into those that seek to overcome internal barriers and others geared towards external constraints.

Keywords: Water-Energy-Food (WEF) nexus, Iraq, environment, sustainability, food security, water resources.

JEL Classification: H4, O3, O5, Q1, Q4, Q5

ملخص

تستعين هذه الورقة بالبحث في العلاقة بين المياه والطاقة والغذاء لدراسة العلاقات بين المياه (المتطلبات والإمدادات)، والطاقة (قطاع النفط والغاز)، وإنتاج الغذاء في العراق. ونقوم بإجراء مسح للظروف البيئية، ونلاحظ أن هناك تراجع في جودة المياه وتوفرها على مدى العقود الماضية، مما شكل تهديدات للصحة العامة والاستدامة البيئية والأمن الغذائي. بعد ذلك، نستخدم مجموعة متنوعة من مصادر البيانات لدراسة الروابط بين هذه القطاعات الثلاثة، بما في ذلك مؤشرات المياه والطاقة والغذاء، واستكشاف حالة قطاعي الزراعة والنفط، وتجدر الإشارة إلى أن الماء هو أحد المدخلات الرئيسية في كل من الإنتاج الزراعي واستخراج النفط، وهو وسيط في قطاعي الطاقة والغذاء ويعمل على تقييد وإنتاج مخرجات منافسة في مجال الغذاء والطاقة. نحن نقدم التوصيات ذات الصلة بالسياسات المصنفة إلى توصيات تسعى إلى التغلب على الحواجز الداخلية وأخرى موجهة نحو القيود الخارجية.

1. Introduction

Since 2015, demonstrations during summer in oil-rich Basra, a city of roughly four million people in southern Iraq, have become a regular occurrence, with a public frustrated at the lack of public services and unemployment (Patel, 2018:1). Protestors demanded, among other things, increased water availability and quality (Davies, 2019), with 120,000 people hospitalized after consuming polluted water, part of Iraq's ongoing water crisis (HRW, 2020).

While the water crisis is most acute in Basra, it is emblematic of conditions in the rest of Iraq, and the result of multiple and ongoing, long-term factors, including reduced flows from Tigris and Euphrates rivers, rising levels of pollution and salination as well as long-term underinvestment or neglect. We argue in this paper that Iraq's water predicament, and its environmental dilemmas more broadly, are best understood when analyzed alongside its energy, mainly oil and gas production, and agricultural sectors rather than separately or independently.

In fact, the relationship between energy and agriculture often has been invoked in discussions of Iraq's economy in various formulations. In the 'Dutch disease' construction, the spending of oil income in the domestic economy results in the appreciation of the real exchange rate and rise in price of non-tradable goods, ultimately making the agriculture and manufacturing sectors less competitive (see Yousif, 2016: 214-215). In parallel, discussions of development in Iraq historically have centered on the notion of investing oil income, with the Development Board established in 1950 to spend oil revenues in productive (non-oil) activities that generate income in future when the oil resource and revenues run out. A large literature concerned with issues of reinvestment of revenues, from sales of non-renewable resources into renewables, has provided theoretical buttress for this (see, for example, Hartwick, 1977; Hotelling, 1931). The latter construction is concerned primarily with issues of income rather than ecological sustainability.[1] Missing in both formulations are accounts of the links and interactions between energy and food production domains, and the natural environment.

We thus draw on the Water, Energy and Food (WEF) nexus framework to assess the substantial environmental challenges in Iraq. The WEF nexus is a relatively new body of literature that emphasizes the importance of evaluating the interconnectedness of water, energy and food resources (see Leck et al., 2015; ESCWA, 2015). According to the OPEC Fund for International Development (OFID, 2017: 11):

> In its simplest form, the [WEF nexus] relationship can be characterized as follows: food production needs water and energy; water production needs energy; and energy production needs water.

[1] For example, following a methodology proposed by el-Sarafy (1989), Yousif (2009) in his study of income sustainability finds that investment in physical capital offset Iraq's oil extraction in the period from the 1950s through the 1980s. However, such studies are highly sensitive to method and specification: Hamilton and Clemens (1999) use a method whereby it is virtually impossible for oil producers to avoid declining real wealth.

Similarly, Simpson and Jewitt (2019: 2) state that the WEF nexus is:

> . . . the study of the connections between these three resource sectors, together with the synergies, conflicts and trade-offs that arise from how they are managed, i.e., water for food and food for water, energy for water and water for energy, and food for energy and energy for food.

Thus, the WEP nexus stresses the relatedness of resources and how policies that appear optimal viewed in isolation in one sector may generate inefficiencies elsewhere, because "policy remains organized along sectoral lines" and often lacks coordination (ESCWA, 2015: 8). For example, bio-energy growth originally thought to mitigate the reliance on hydrocarbons has put pressure on water and land, reducing bio-diversity (Zhang et al., 2018: 626). And Salam et al. (2017) point out that the WEP approach is relevant to the assessment of economic growth, especially in situations where food production competes directly with energy, and water is a limiting resource. In short, the WEF nexus offers us an opportunity to examine various aspects of environmental challenges and their consequences typically not considered in conventional analyses.

We show that water availability and quality in Iraq mediates the energy (or oil and gas) and food (agriculture) sectors, acting to constrain and make rival food and energy outputs. This is consistent with other WEF studies where "changes in the framework center dominate the state of other related sectors through their interlinkages directly" (Zhang et al., 2018: 627).

We thus organize this article as follows. Section 2 provides a short overview of environmental conditions in Iraq. Section 3 presents the water, energy and food nexus as framework for the analysis. Section 4 is the main part of the study and explores the state of water, energy and food (including food security) nexus, their interlinkages and related indexes, including studies of the agriculture and oil sectors, pointing to water as a central sector. The last section concludes and offers brief policy recommendations.

2. Overview of environmental conditions

There are multiple, and interconnected, reasons for environmental deterioration in Iraq, including aspects that are specific to Iraq, regional factors and global systemic dynamics.

<u>First</u>, conflict since 1980—notably the Iran-Iraq war (1980 to 1988), the 1991 war that ejected Iraq from Kuwait as well as subsequent conflict since 2003—has damaged Iraq's environment. Unexploded ordinance and land mines proliferate in war-affected regions of the country and these have resulted in the deaths of tens of thousands of people (Library of Congress, 2006: 6). Indeed, according to Mine Action Review (2020: 144), "Iraq remains the world's most mine-

contaminated country with no credible baseline estimate of the extent of mined area," despite attempts at mine clearing. Relatedly, the destruction of military and industrial infrastructure, and release of heavy metals and hazardous chemicals from spent bombs has polluted the air, soil, and groundwater. UNEP (2017: 2), for example, details the environmental damage resulting from war with the Islamic State, including the 11 million tons of debris created in Mosul and the burning of oil wells and Sulfur that have created toxic clouds. Water contamination has occurred because of oil spills; for example, the largest oil spill in history occurred during the 1991 Gulf War when oil from tankers was deliberately discharged in Gulf waters (Alhanaee et al., 2017: 4117). An extreme example perhaps of the effects of conflict is the draining of large portions of Iraq's marshes by the Iraqi government in the 1990s. This was a ploy to deny perceived political opponents of the Iraqi government refuge, and damaged both local ecosystems and the means of livelihood of local residents (Schwartzstein, 2015). Likewise, Rubaii (2020) shows the effects of past and ongoing conflict on health outcomes vis-à-vis rising cancer rates and birth defects.

Second, the actions of regional neighbors has reduced water availability and quality in Iraq in recent decades, with important Implications for agriculture. In the context of lack of legally enforceable international water rights treaties (see Zarei, 2020), Turkey and Syria, starting in the 1970s and 1980s, have diverted Euphrates and Tigris waters to generate electricity and enhance irrigation and hence cropped area in their own countries, reducing flows of water downstream to Iraq (Kibaroglu and Iba Gürsoy, 2015). Especially in the case of the Euphrates, the return flow of water from irrigation upstream in Turkey and Syria as well as poor wastewater treatment and return flow within Iraq have resulted in increased water pollution and salinity in Iraq (World Bank, 2017: 98). In Iraq's marshlands area, reduced flow from Tigris and Euphrates rivers as well as salination pose renewed threats to the marsh ecosystem, even though allowing water from those rivers to flow into the marshes after 2003 partially has restored the area (Schwartzstein, 2015). Consequently, a number of scholars have pointed to declining water quantity and quality (Al-Ansari, 2013; Alwash, 2020; Zarei, 2020: 84). Relatedly, the International Energy Agency (IEA, 2019: 39) reports that, because of increasing salination, continuing discharge of industrial wastewater sewage, agricultural runoff and, declining freshwater flows, the quality of drinking water has now fallen below safety standards set by the World Health Organization.

Third, global climate change has aggravated Iraq's problems of water scarcity and salination. According to the World Bank (2017: 99) the average annual temperature rose by 1 to 2 °C between 1970 and 2004. This has been accompanied by changes in rainfall patterns, with large declines in rainfall in Iraq's west, of 5.93 mm per month per century, and more modest rise in rainfall, of 2.4 mm, in the northeast, since the 1950s (USAID, 2017: 2). Hameed et al.'s (2018) report of increased intensity of droughts in the period 1948 to 2009 confirms this. The upshot is heightened water evaporation and hence more soil salinity, and net reductions in arable land and desertification, which threatens 92 percent of the country. This has important and negative implications for food security, with one of out every nine Iraqis classified as food insecure (USAID, 2017: 3-4).

These multiple factors have occurred at a time of deterioration of water management infrastructure and decline in Iraq's institutions more generally. Iraq's agricultural sector accounts for most of the water the country uses, but suffers from decades of under-investment and deterioration in critical infrastructure such as irrigation pumping stations, water canals and irrigation networks (Levkowitz, 2018; Mohammed, 2018). Mirroring Iraq's institutional decline elsewhere (see Yousif et al., 2020), the capacities of the Ministries of Agriculture and Water Resources to provide services to the water sector have declined over the past two decades, according the World Bank (2017). Parallel to this, underinvestment and institutional decay have resulted in deterioration in the quality of potable water. Most wastewater remains untreated before discharge to the environment, with 250,000 tons of raw sewage dumped into the Tigris each day, elevating water-borne disease and child mortality (Aenab and Singh, 2012: 534 & 536). Chemical spills and poor hazardous waste management have contaminated groundwater aquifers (Al-Sudani 2019), undermining the suitability of groundwater for irrigation and drinking water.

3. Water, Energy and Food nexus (WEF) framework of analysis

As noted, the WEF nexus aims to deal with interactions of the three sectors, as Zhang et al. (2018: 626-627) state: "As the failure in one sector may exert pressures on the other two sectors, requiring a holistic management among these sectors." There is broad agreement about inter-relationships of sectors and concern over disciplinary 'silo thinking' (OFID, 2017: 20), but also disagreement within the WEF framework about how concepts ought to be applied, with terms often used in competing or ambiguous ways by differing authors (Simpson and Jewitt, 2019: 2). How the WEF nexus is applied is thus a matter of researcher choice rather than agreed upon method. In an in-depth survey of WEF nexus research, Zhang et al. (2018: 627) argue that nexus analysis often involves the identification of a nexus sector that has more linkages with other sectors, for example water when that is a key input into energy and food. In contrast, Simpson and Jewitt (2019: 3) argue that WEP analysis, unlike earlier Integrated Water Resources Management analyses, [2] treats water, energy and food sectors as equals.

Simpson and Jewitt (2019) note also some of the criticism of the WEP paradigm, including that it represents an extension and re-packaging of earlier work on sustainable development and related research rather than a novel paradigm. Indeed, consistent with earlier concerns of Ecological Economics, de Andrade Guerra et al. (2021: 112) call for ". . . technological innovations and techniques to increase resilience of critical infrastructure . . . " Objections about re-branding of earlier work notwithstanding, Simpson and Jewitt (2019) argue that the WEP nexus nonetheless provides a better way of addressing contemporary development challenges. Another criticism, paradoxically given its association with sustainable

[2] The Integrated Water Resources Management "is a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment" (Global Water Partnership, 2018).

development, is that WEP’s focus on securing supplies of resources ends up neglecting livelihoods and even the broader environment in the process (Simpson and Jewitt, 2019: 5). What is generally agreed, however, is that there is a potentially huge role for government to exploit the synergies between energy and food production along with water availability (de Andrade Guerra et al., 2021; OFID, 2017; Simpson and Jewitt, 2019).

Zhang et al. (2018: 627-629) distinguish between internal and external impact analysis, as well as evaluating the system performance as a whole. Internal analysis concerns interactions between the sectors (water, energy and food production), which can be a one-sided assessment of how change in one sector affects other sectors or a more comprehensive ‘interactive impact analysis’ that studies the shared inter-relationships of sectors. We adopt the latter. External analysis results from a change in the external environment that affects one or more of the sectors; these can be analyzed according to their source (physical or social) as well as based on length of time that it takes for change to be recognized (acute or chronic). Finally, system performance assesses broader issues such as ability to recover from an external shocks (Zhang et al., 2018). For national-level analysis, Zhang et al. (2018: 630) propose, among other ways, Computable General Equilibrium (CGE) and econometrics to quantify WEP linkages, while Endo et al. (2015) suggest a variety of quantitative methods, including Physical Models, Benefit-Cost analyses, and Optimization Management techniques. Some of these rely on high quality data and (notably CGE and econometric methods) are appropriate for the study of how change in one or a limited number of variables affect WEF nexus outcomes, not in more extensive and generalized discussions of interactions between sectors. As Zarei (2020: 88) notes, quantitative studies often require a “significant number of inter-sectoral data, e.g., quantities of water used in energy production, energy used in water production, and water and energy used in food production, etc., which are generally lacked or difficult to access and collect.”

Consistent with the diversity of use elsewhere, the WEF framework has been applied in various ways to the Middle East region. In addition to Kibaroglu and Iba Gürsoy (2015) noted above, Siderius et al. (2019) apply the WEF nexus to Kuwait. They argue that while an analysis on the domestic level indicates little trade-off between the WEF sectors, a study on the international level reveals that oil wealth protects Kuwait against domestic food insecurity but exposes Kuwait to water insecurity and other countries to food insecurity. In contrast, Siddiqi and Andon (2011) conduct a country-level quantitative assessment of the water-energy nexus and show how water availability in the Gulf region is highly energy-dependent. Daher and Mohtar (2015) develop a modelling tool, which provides a platform to identify sustainable resource allocation strategies and evaluate different scenarios on national level that they apply to Qatar. Zarei (2020) investigates the dynamics behind the WEF security concerns in Middle East region. While the author explores the WEF nexus as a holistic approach to seek regional solutions to common challenges in Turkey, Iraq and Iran, he concludes that most countries in the region are facing WEF resource insecurity owing to weak planning or management strategies.

The present study will add to this literature, providing a national (and to a lesser extent regional) level WEF nexus study of Iraq; following Zhang et al. (2018), we apply an internal 'interactive impact analysis' to study inter-relationships. We explore the linkages between water, agricultural production, and gas and oil output, Iraq's main export and source of revenue. Because of the requirements of reliable data and the need to consider multiple and interlinked elements and variables, we are unable to follow the quantitative methodology that Zhang et al. (2018) suggest for national-level studies. We instead highlight the noted linkages in the WEF nexus, using the analysis to explore environmental issues facing Iraq.

4. The three sectors

We apply the WEF nexus approach to Iraq in this section. As noted, following Zhang et al. (2018), we apply an internal 'interactive impact analysis' to study the linkages between water, agricultural output and oil (and gas) production, touching upon, when possible, the impact on the people livelihoods.

In respect to the ***Water Sector***, flood control was one the most important challenges for Iraqi policy-makers before the 1950s. According to the International Bank for Reconstruction and Development (IBRD) (1952: 183), "the storage of the flood waters of the Euphrates and Tigris and their tributaries is the foremost problem." Hence, the large investment allocations that Iraq's Development Board made to flood control and water projects in the period 1950 to 1958 (Alnasrawi, 1994: 26). In fact, the construction of dams and other flood control projects on the Tigris and the Euphrates had been a policy priority for many decades and until the 1980s (for a list of dams see Al-Ansari, 2013: 673; Al-Ansari et al., 2014: 1080).

In contrast, Iraq today confronts the opposite situation, namely a shortage of water, especially in central and southern regions such as Basra (IOM, 2020; Human Rights Watch, 2020), along with declining water quality. Population pressures have increased demand for water, energy and food. Iraq's population was 40 million in 2020 and growing at 2.4 percent annually (or a rise of one million per year), one of the highest growth rates in the world; the population is predicted to increase to 50 million by 2030 and to more than 70 million in 2050 (Macrotrends, 2021; Alwash, 2020). Rural to urban migration has steadily made Iraq more urbanized. According to Iraq's the Central Statistics Organization (CSO) (2014: 6), two-thirds of the total population is urban. Interestingly, declining water quality has aggravated rural to urban migration: in 2019, the lack of water along with high water and soil salinity led to the internal displacement of 21,314 persons from central and southern areas of Iraq, according to the International Organization for Migration (IOM), 2020: 6). In the 2015 to 2020 period, the urban population grew by more than the rural, suggesting rural to urban migration for the period (CIA, 2021), as rural birth rates historically have exceeded urban.

The FAO (2019: 247) defines total renewable water resources, expressed in Table 1 in cubic meters (m3) per capita, as "the sum of internal renewable water resources and external renewable water resources" or the "maximum theoretical yearly amount of water available for a country at a given moment." This statistic shows a marked decline between 1997 and 2017. This is consistent with Knoema's (2021) report that total renewable water resources per capita of Iraq declined from 8,477 cubic meters per inhabitant per year (m3/inhab/year) in 1972 to 2,393 in 2017. Iraq's Ministry of Water Resources likewise estimates that river levels have dropped by up to 40 percent in the last two decades (IEA, 2019: 14). Kibaroglu and Iba Gürsoy (2015) view these as the effects of (uncoordinated) decisions taken at national levels, that is, trans-national shocks, on the WEP dynamics in Tigris-Euphrates basin countries of Iraq, Syria and Turkey. Freshwater withdrawal, or the proportion of total renewable water resources that is withdrawn in a given year (FAO, 2019: 241), declined between 2007 and 2017; Zarei (2020: 93) attributes this fall to greater withdrawals in Syria and Turkey, leaving less available to withdraw in Iraq.

Table 1: Water per capita and withdrawal in Iraq 1997, 2007 and 2017

Iraq	1997	2007	2017
Population, total (mill.)	21.4	27.9	38.4
Rural population, total (mill.)	6.8	8.8	11.6
Employment in agriculture (%)	25.2	22.0	19.0
Total renewable water resources per capita (m3)	4178	3165	2348
Freshwater withdrawal (%)	60.5	73.4	42.9

Source: FAO (2019: 132).

As noted, a complicating factor in regards to Iraq's access to this resource is that most of Iraq's water originates outside its borders: only 1,042 m3/inhab/year (close to 1,000, or the World Bank's definition of water stress level) out of 2,200 is generated inside Iraq (World Bank, 2017: 98). Indeed, as Table 2 shows, water demand is expected to exceed supply by 2030, with agriculture alone projected to consume 95 percent of supply. This is consistent with Water Resources Minister Mahdi Al-Hamdani's pronouncement that Iraq will face a water shortage of 10.5 billion m3 of water by 2035 (Kullab and Yahya, 2020). In sum, although Iraq had renewable freshwater availability that was double the regional average in 2017, growth in demand for water and overuse in agriculture threatens to reduce this gap at a time when its water institutions have been declining (World Bank, 2017: 96-7).

Table 2: Estimated Water Demand and Supply in 2030 (in Cubic kilometers)

Domestic Use	5.0
Industrial	3.15
Evaporation from Dams	8.4
Restoring Marches	11.0
Agriculture	42.0
Total estimated Demand	**69.55**
The estimated Supply	**44.00**

Source: Alwash et al (2018: 14).

While there is some divergence in estimates of extent of water deficit (see for example Al-Ansari et al, 2014:1067-1068), there is general agreement that water deficiency is a serious issue. Water deficiency has important implications for Iraq's agricultural and oil sectors, acting to constrain potential increases in agricultural output and oil extraction as we discuss in details later. The following illustration is basic: for example, it assumes that the same water can be used to produce wheat or extract oil, which we query later; nonetheless, it is illustrative. Ewaid et al (2019) estimate that on average 1,876 cubic meters (m3) of water is required to produce one metric ton of wheat in Iraq, with some variation depending on location. Average wheat output in 2016 through 2021 in Iraq was 4.193 million tons per annum[3], which still necessitated imports to satisfy domestic demand; Iraq has been a net importer of wheat for decades. However, a ten percent rise in wheat output for Iraq (and its rising population) requires 787 million m3 per annum or roughly 13.55 million barrels per day (MBD) of water, which, alternatively, is needed to produce about 9 MBD of oil, as we explain later.

One available option to counter Iraq's water deficiency is seawater desalination, perhaps as a solution to the severe drinking water crisis in southern Iraq generally and the city of Basra in particular or (more limitedly) in oil production. Presently, desalination plays a negligible role but has the potential provide up to 10 percent of water supply by 2030 (IEA, 2019: 38- 39). However, desalinization is energy-intensive. Mohtar and Daher (2012:2) provide estimates of energy consumed, depending on the technology used, of 2.58 - 8.5 kilowatt-hour to deliver one cubic meter of clean water (kWh/m3) from seawater, much higher than the 0.37 kWh/m3 required to deliver lake or river water or 0.48 kWh/m3 for groundwater. As the agricultural sector is the biggest consumer of water, it is unlikely that desalinated water will be a cost-effective solution for irrigation (Alwash 2020). Although the IEA (2019: 38) expects the use of desalinated water to rise, the effects of water shortage on energy and agriculture sectors remain and are discussed in the next sections.

By *Energy Sector*, we mean the production (or extraction) of oil, natural gas and electricity. As Iraq is an oil producing country, exploring the inter-connectedness of energy and water is essential, because the extraction of fossil fuels (oil and gas) is water-intensive, requiring water for exploration, drilling, and pumping (Keulertz et al., 2016: 3).

Over the last century, Iraq has changed from an agricultural country exporting mainly grains and dates to an oil-producing nation (Yousif, 2012: 59- 62). Oil was found in Iraq in 1927, and output rose steadily until the early 1970s (El-joumayle, 2017: 4). After the nationalization of oil in June 1972, there was a significant increase in both production and exploration activity, including expanded refinery capacity and petrochemical projects, coinciding with rising oil prices in the aftermath of October War in 1973 (Mahdi, 2007: 12). According to OPEC (2008), production increased from 1.46 million barrels per day (MBD) in 1972 to 3.47 MBD in 1979. By 1979, the share of oil in Iraq's gross domestic product (GDP) had risen to 63 percent (UNEP, 2007: 15). However, with the outbreak of the Iraq-Iran War in 1980, average daily

[3] Calculated from Indexmundi.com (2022).

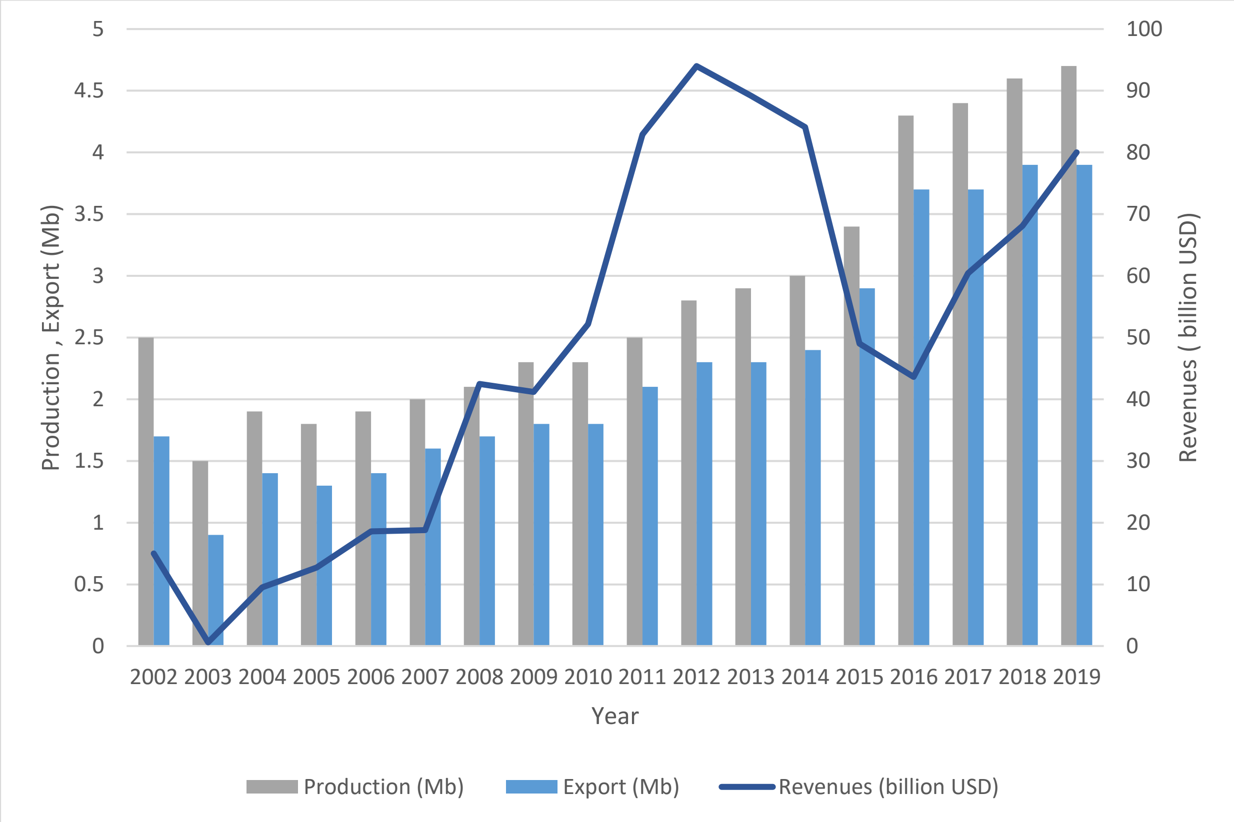
production collapsed, recovering only gradually. Comprehensive UN economic sanctions were imposed on Iraq after its invasion of Kuwait in 1990, followed by war, disrupting oil production and exports. Figure 1 shows the extent of fluctuations in GDP that resulted from oil production and price variations, connected to armed conflicts and UN sanctions. In post 2003 era, policy-makers have sought rapid increases in production volume, mostly from the southern oil fields. In fact, Iraq has succeeded in achieving substantial rises in output, with production capacity reaching 5 MBD in April 2020, according to Iraq's Ministry of Oil (Saadi, 2020), thus reclaiming its previous rank as second-largest crude oil producer in OPEC after Saudi Arabia.

Figure 1: Price Per Barrel, GDP, and Rate of Production (1970-2019)

Source: OPEC (2019), EIA (2020), BP (2020), UNCTAD (2020).

Figure 2 below illustrates oil production, exports and revenue trends for the period of 2002-2019. Declining oil revenues after 2014 are the result of collapsing global oil prices and occur despite higher output and exports. Oil production requires water injection in oil fields to maintain enough reservoir pressure in the wells to maximize output from the oil field. In fact, Iraq has relied on water injection since the 1960s, especially in the south and central oil fields (IEA, 2019). While the international average is 1.3 to 1.5 barrels of injected water needed to produce one barrel of oil, Iraq's southern oil fields require about 1.5 barrels of water to produce one barrel of oil (IEA, 2019: 14 &.24), with aging oil wells requiring rising amounts of water (Siderius et al, 2019: 17). Achieving Iraq's ambitious oil production targets thus require more injected water: a crude oil production volume of 12 MBD requires up to 18 MBD of water, and 14 MBD of water is needed to produce 9 MBD of oil (Schuber, 2018: 6). However, not all water sources are suitable for water injection into oil fields; for example, seawater contains suspended solids and dissolved oxygen and thus requires treatment before it is injected into oil fields, otherwise the amount of oil or gas that can be extracted from the field would be reduced (Robinson, 2010). The need for more water to increase oil output is in conflict with the reality of dwindling supplies of water, needed for agriculture and other uses. Iraq thus intends to treat and transport seawater from the Gulf in the Common Seawater Supply Project to supply the water needed in its southern oil fields. The project is estimated to cost four to six $US billion and plans to supply 7.5 MBD of water initially, increasing to 12 MBD (IEA, 2019).

Figure 2: Daily Oil Production and Exports, and Annual Revenues (2002-2019)



Sources: Gollob & O'Hanlon (2020), IEA (2019), OPEC (2019).

An important by-product of oil extraction is natural gas. Although Iraq imports natural gas, most of the gas generated from oil extraction is burned or flared because of the lack of infrastructure required for its utilization; the remaining amounts are either re-injected into the oil field, to increase the productivity of the oil field, or used in power-generation at the oil field site (Louis Berger, 2012: A-12). In fact, the volume of flared gas has been rising along with higher oil extraction rates. Ibrahim et al (2019) report that the volume of flared gas rose from 11,976 million standard cubic meter (mcm) in 2012 to 17,714 and 16,639 in 2016 and 2017 respectively. According to Jiyad (2018: 260), the proportion of gas generated from oil extraction that is flared has increased from 51 percent in 2009 to 69 in 2015. Indeed, the US Energy Information Administration (EIA, 2021: 5) reports that Iraq ranked the second highest natural gas-flaring country after Russia, flaring 632 Billion cubic feet of natural gas in 2019. Estimates of the economic loss associated with flaring gas are high, but nonetheless vary depending on appraisals of flared volume and its market price. USAID (2012: A-12) estimate the value of flared gas at roughly $1.8 billion per year or about $5 million per day. Maniruzzaman and Al-Saleem (2017: 41) report that 55 percent of Iraq's gas production, or 16 billion cubic meter a year, is flared due to lack of appropriate infrastructure and facilities, for an annual loss of $2.5 billion. There are also costs to the environment and human welfare as a result of flaring: 30 million tons of carbon dioxide emissions are released to the atmosphere because of gas flaring (IEA, 2019: 14). Rubin and Krauss (2020) have recently documented the horrendous consequences on the lives of residents near oil production/gas-flaring in the village of Nahran Omar in southern Iraq, where the local sheikh states: "Imagine that in the town you come from every family has someone who has cancer." Iraq is now in the early stages of prioritizing the re-capture of natural gas instead of flaring, but the legacy of flaring remains (IEA, 2019). A recent article reports that the cost of environmental degradation resulting from the industrial sector as a whole, which includes the oil and gas sectors, is estimated to have been 6.4 percent of Iraq's GDP in 2008, or US$ 5.5 billion (Ibrahim et al 2019: 5). Assessments of costs of oil production do not usually include the replacement cost of flared gas, let alone the associated human and environmental costs, with the result that Iraq emerges as one of the world's lowest cost producers (see Wall Street Journal, 2016).

Returning to the topic of energy-water interplay, water also indirectly plays a role in electricity generation, with most energy produced by burning oil and gas as shown in Table 3. In fact, the relative contribution of natural gas to total electricity production rose from 1990 to 2018, while relative contribution of hydroelectric power declined; the contribution of solar energy is negligible throughout the period. Rising electricity imports have supplemented increasing domestic output since 1990, so that domestic supply actually quadrupled from 1990 to 2018. However, electricity losses are huge in comparison to total produced and among the highest in the world (IEA, 2019: 17). Losses result from inefficient transmission (called technical loss) as well as energy that is delivered to consumers but not charged, e.g. due to theft (known as non-technical loss) (IEA, 2019: 43). Because electricity losses are high and rising, final consumption in 2018 is only 50 percent higher than in 1990, which represents a per capita decline as population increased by even more. As we shall see next the use of water for oil production has consequences for the agriculture sector too.

Table 3: Electricity generation in Iraq for select years (in Gigawatt hours (Gwh))

Electricity	1990	1997	2007	2017	2018
oil	17638	23963	14565	53712	39691
Natural Gas	3762	5795	12936	31477	40940
Hydro	2600	581	5736	2176	1818
Solar PV	--	--	--	57	57
Total production	24000	30339	33236	87422	82506
Domestic Supply	24000	30339	35433	99210	104299
losses	1200	1179	13605	52765	55472
Import	--	---	2196	11787	21793
Final consumption	29800	29160	21828	39992	43501
Industry	9053	11443	3304	5160	5030

Source: IEA (2020).

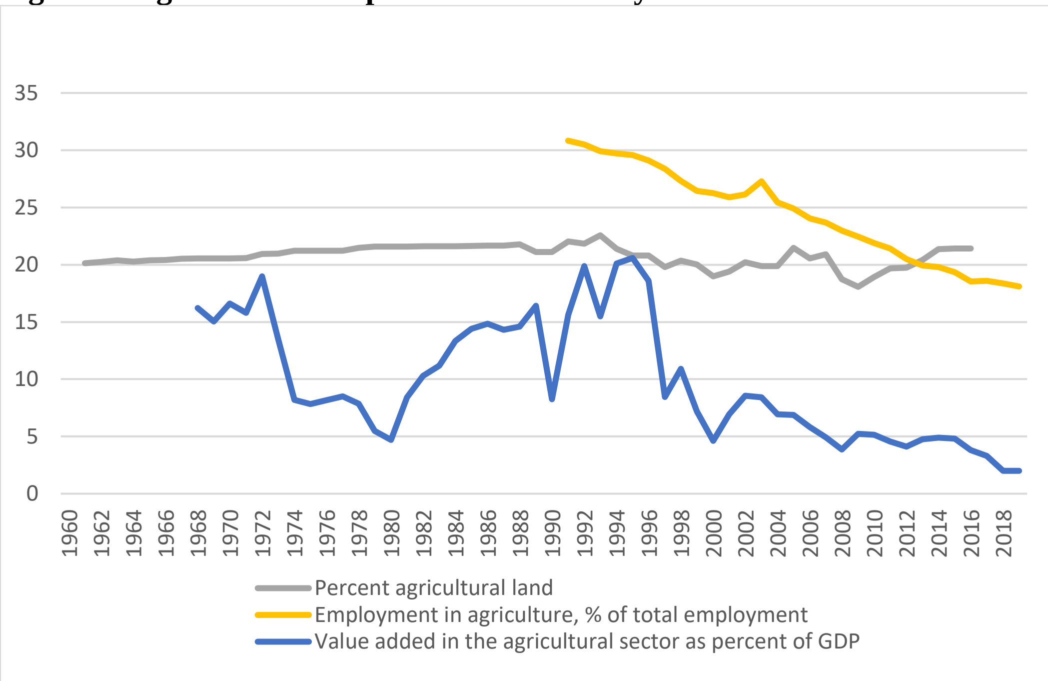
We turn next to the concept of ***Food and Food Security***. There is considerable variation over the definition of food security/insecurity. The definition developed by FAO in 1996 and 2002 (quoted in Willis et al. 2016: 11) states:

> Food security [is] a situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Similarly, according to USAID (2020), Food security is having "both physical and economic access to sufficient food to meet dietary needs for a productive and healthy life." The issue of food security is thus linked to Iraq's agricultural and energy sectors. Food insecurity need not be the result of producing insufficient food, as food also can be purchased in world markets. Thus, both domestic oil output, and hence revenues to import food, and agricultural activities can contribute to food security—or insecurity.

A discussion of food security necessarily involves an analysis, albeit brief, of the agricultural sector. Figure 3 indicates declining employment in agriculture as proportion of the total as well declining, if fluctuating, contribution to overall GDP, since the 1960s. The figure may overstate the decline in employment during the 1990s, as Iraqi census data show the opposite, namely a rise in agricultural employment at that time, the result of sanctions-induced labor flows in the macro-economy (see Yousif, 2016: 221-2). Nevertheless, the overall trend is unmistakable and confirmed by FAO (2021: 7) data that shows the contribution of agriculture to GDP declining to 4.8 percent and employment to 18.7 percent of active workforce in 2018. Digging deeper into the data, we note the relative decline of agriculture's contribution to GDP during the 1970s and its rise in the 1980s. This is only slightly due to changes in agricultural output (see Yousif, 2012) and has more to do with rising oil prices and exports, and hence contribution to GDP, in the 1970s, and disruption of exports and lower prices, and hence stagnant contribution to GDP, associated with the Iran-Iraq war in the 1980s. The rise in agricultural value added during the 1990s is of interest and associated with comprehensive economic sanctions, when oil output and exports collapsed: Iraq was unable to earn foreign currency and domestic prices of imports, including food, rose rapidly. Although agricultural land remained roughly unchanged in the 1990, Gibson et al (2012: 889-890) use satellite data to conclude that cultivated land area increased by 20 percent in the 1990s, as farmers sought to expand output likely on marginal land. This period also was characterized by the deterioration of irrigation networks, rising salinity and reduced productivity, as cash-strapped Iraq attempted to increase agricultural output on the extensive margins, i.e. with more land and labor inputs rather than improved productivity. Cultivated land declined after 2003 when sanctions were removed and exports of oil resumed, but the legacy of sanctions vis-à-vis depleted agricultural infrastructure and damaged and neglected irrigation networks mostly remain.

Figure 3: Agricultural Output and Productivity



Source: theglobaleconomy.com: accessed October 19, 2020.

Although Iraq was at war with Iran during most of the 1980s, it was able to pay for food imports to achieve food security for its population; in fact, per capita caloric availability increased in the 1980s (Yousif, 2012) and was among the highest in the Middle East region by 1990 (Jaradat, 2003: 160). In contrast, economic sanctions deprived Iraq of the means to pay for imports of food in the 1990s, until the oil-for-food program came into effect in the late 1990s, which at any rate was limited in scope (see Yousif, 2016: 222-3). However, the removal of sanctions and renewal of oil exports and rising capacity to invest did not presage a revival in agriculture. As Table 4 illustrates food output in constant US $ declined from 1997 to 2017. In the same period, dependence on food imports, notably cereals, has exploded. Elevated food imports are possible to finance with oil exports but any disruption to output or decline in oil price potentially makes food imports vulnerable.

Table 4: Food supply, hunger dimensions and net trade

	1997	2007	2017
Food Supply			
Food production value (2004-06 (constant) US $ million)	2611	2711	1981
Agriculture value added (% GDP)	15	5	3.4
Food (excluding fish) exports (US$ million)	16	43	67
Food (excluding fish) imports (US $ million)	1280	2563	9696
Hunger dimensions			
Prevalence of undernourishment (% of Pop).	28.5	30.0	29.0
Net trade: exports -imports (mil USD)			
Cereals, flours and grains	-647	-1254	-2575
Fruits and vegetables	-15	-314	-2192
Meat	0	-178	-1010
Dairy products (milk equivalent)	-11	-111	-964
Fish	-1	-22	-148
Total	**-674**	**-1879**	**-6890**

Source: FAO (2019:132)

Despite record levels of food imports and a public distribution (rations) system to which almost all Iraqis qualify, undernourishment remains high, reaching 29 percent of the population in 2017. Declining capacity of Agriculture and Water ministries (World Bank, 2017: 96); continued conflict that disrupts food distribution; climate change and soil and agricultural infrastructure deterioration that disproportionately affects the rural poor; and low water quality and sanitation all work to diminish the effects of oil facilitated rise in agricultural imports on food security. As a result, four million Iraqis—one in nine in 2017—are "vulnerable to food insecurity" according to USAID (2017: 4).

Because wheat and rice are water-intensive crops, importing these crops represent a dual dependence: on wheat itself and on the 'virtual water' that those imports imply, or the water embedded in the food trade; equally, the export of crude oil implies the export of water. Wheat is the main cereal produced in Iraq, accounting for two-thirds of total cereal production (FAO, 2021:13). According to Naima (2020: 23-27), wheat and to a lesser extent barley production fluctuated but generally increased from 2000 to 2014, while the output of rice remained roughly constant. Hence the rise in the imported quantities of both of wheat and rice shown in Table 4 where net trade (exports – imports) exploded from 1997 to 2017. Recent data from FAO (2021:13) reveals that domestic production capacity is 70 percent of the total demand for wheat, which is six million tons annually.

Water scarcity is a binding constraint on food production and indirectly food security. The latter has been compounded by policy distortions and wasteful irrigation methods. Longstanding Ministry of Agriculture policy paid producers of wheat, rice and maize prices that exceed international prices and provided subsidized inputs (FAO, 2021: 13). This policy of subsidizing water-intensive crops has contributed to the water shortage. As Alwash (2020) states: “Farmers have little incentive to take a more long-term view on water management, since the subsidies essentially make wastage profitable for them.” Moreover, flood irrigation, a technique used by 58 percent of wheat farmers in Iraq (see FAO, 2021: 16) tends to waste water, in comparison to say drip irrigation, which however would require large investments in irrigation networks. Farmers blame both the Iraqi government for not modernizing irrigation networks and projects in Syria and Turkey that restrict water flows (CBS, 2018). Yet, the extensive use of flood irrigation tends to over-use water and contribute to soil salinity (Sleet, 2018; Levkowitz, 2018), reducing water availability for other purposes. The World Bank (2017: 96-97) reports that declining quantity and quality of water has resulted in salinization in 70 percent of cropped areas and made 40 percent of irrigated areas unusable. Water salinity, in turn, contributes to reduced land productivity: increased salinity cuts wheat and barley yields, key crops in Iraq, by and 55 and 50 percent respectively, and by even more for maize (ICARDA, 2012: 30-31). The lack of water has forced the Iraqi government to change its agricultural plans by reducing cultivated areas. Thus in July 2018 the Iraqi government banned corn production and restricted rice planting because not enough water was available (Sleet, 2018).

While scarce water resources affect agricultural production, food also requires energy to produce. No data specific to Iraq are available, but FAO estimates show that 4 to 8 percent of the final energy consumption was taken-up by agriculture in developing countries in 2000 (Willis et al, 2016: 2). We consider water to be the important central sector, acting as a binding constraint for both energy and food production. Indeed, as discussed earlier, there is a tension between the continued uses of water in food production in addition to oil extraction, given present methods employed in Iraqi agriculture such as flood irrigation. Iraq’s plans for expansion of oil production in effect prioritize the use of water for oil production over agriculture, and essentially imply utilizing revenues from the sale of oil to purchase food on international markets; this in fact reinforces an existing trend as evinced in rising food imports over time. The increasing dependence of Iraq, like many other oil-exporting countries, on rising food imports implies nexus trade-offs in food producing areas to accommodate rising demand. The increased demand for food also makes food importing countries vulnerable to supply shocks in food producing regions, with spikes in global food prices precipitating higher food costs for consumers in importing as well as producing countries (as has occurred in the case of wheat prices in the context of the Russia-Ukraine conflict). Because the poor (in Iraq and elsewhere) devote a larger portion of their incomes to the purchase of food items, they are likely to be especially affected by such price changes.

We next supplement our discussion of Iraq’s WEF nexus with the use of two integrated indexes. The use of these is a recognized method in WEF nexus research and can provide valuable information for policy planning (Zhang et.al, 2018: 633); Endo et al. (2015: 5818-5819) argue WEF indexes can be helpful in understanding the general characteristics of the nexus. There are difficulties too involved in using an integrated index, including the construction of a rational and unbiased index (Zhang et.al, 2018: 633).

We summarize the findings of two available *__WEF nexus indexes__*: the Pardee-Rand Food-Energy-Water Security Index developed in 2016 and WEF nexus index developed in 2019 with the support of South African and Dutch governments. The Pardee-Rand index covers 166 countries and is divided into three sub-indices: Food, Energy and Water, where scores range from 0 (lowest) to 1 (highest). Each sub-index consists of two or more indicators related to *availability* and *accessibility*; the first reflects the notion that human development depends to some extent on the availability of resources, and the second that it is not only the amount of resources but also their distribution that accounts for development (Willis et al, 2016: 9). In addition, for the water sub-index, *adaptive capacity* represents the potential for cultivating new sources of water with domestically available sustainable resources (Willis et al, 2016: 25). In contrast, the WEF Nexus index is an indication of a country's level of equitable access to and availability of the three resources. Covering 170 nations, this index is divided into sub-pillars of water, energy and food, each composed of relevant indicators with scores ranging from 0 (lowest) to 100 (highest). Norway scores highest (80.9/100), while Chad is lowest (27/100). Iraq's scores on both indexes are shown below.

Table 4: WEF nexus Indexes for Iraq

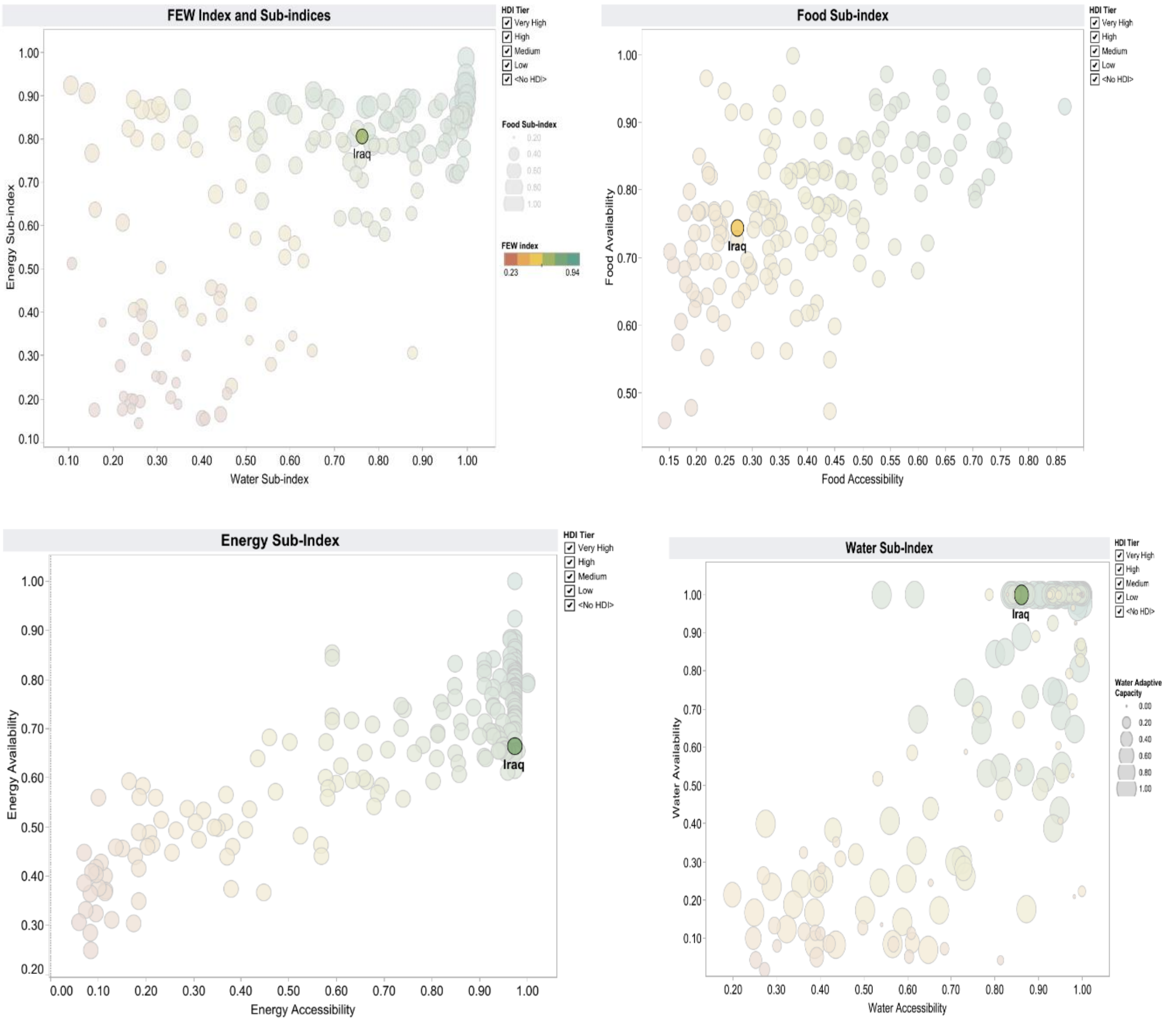
The Pardee-RAND Food-Energy-Water Security Index	**0.65**	**Water-Energy-Food nexus Index**	**46.8**
__Water Sub-Indices__	***__0.76__***	***__Water Sub-Index__***	***__41.1__***
Water Accessibility	0.86	Iraq ranked 147th out 170.	
Water Availability	1.00		
Water Adaptive Capacity	0.52		
__Food Sub-Indices__	***__0.45__***	***__Food Sub-Index__***	***__40.4__***
Food Accessibility	0.27	Iraq ranked 140th out of 170.	
Food Availability	0.74		
__Energy Sub-Indices__	***__0.80__***	***__Energy Sub-Index__***	***__59.0__***
Energy Accessibility	0.97	Iraq ranked 57th out of 170.	
Energy Availability	0.66		

Sources: Willis et al., (2016); The Water, Energy, Food security Platform (2019).

A few observations from the table are pertinent. First, on terminology, the Pardee-RAND index refers to food-water-energy, while the other refers to water-energy-food; in Table 4, we follow the water-food-energy sequencing. The Pardee-RAND index gives Iraq a score of 65, somewhat higher than the WEF nexus index of 46.8; the latter is 7 percentage points below the international average value of 54. On the WEF index, Iraq ranks 121st out of 170 countries assessed; 41.1, 40.4 and 59 for water, food and energy sub-indexes. It is beyond the scope of this paper to go into detail about these numbers, but we note that contrasting methodologies and data sources account for the divergence in the indexes. Nevertheless, food sector scores lowest of all sub-indexes in both indexes, indicating stress in the sector, and consistent with the earlier discussion of high food insecurity among Iraqis.

We focus on the Pardee RAND index to illustrate crucial aspects of the FEW nexus in Iraq, with results of the index shown below in comparison to other countries that are studied. In general, the country-specific values of the integrated index are correlated with the corresponding country-specific indicators of human development such as Human Development Index (HDI) (Willis et al, 2016: 35). This applies to Iraq, where the value of the Pardee-Rand FEW Index is 0.65, while HDI value is 0.64 (Willis et al, 2016: 45). Another remarkable finding for Iraq is the huge disparity between food availability and accessibility (0.74 versus 0.27), indicating that while food is widely supplied on aggregate it is unequally distributed. This reinforces the point made earlier concerning stubborn levels of malnourishment despite increasing aggregate supplies of food and is consistent with research that stresses the weak correspondence between hunger and food supply (See for example Sen, 1981). The dislocations of conflict (with the Islamic State, 2014 to 2017) likely account for this, and low food accessibility reportedly exists despite Iraq's food rationing system that has near universal coverage. With respect to energy, access exceeds availability (0.97 versus 0.66), which is consistent with the complaints of almost all Iraqis about the lack of electricity. Willis et al. (2016: 36-37) note two further findings. First, the FEW Index is more highly correlated with the HDI than with the income portion of the HDI, suggesting that the level of development, rather than income, is more closely associated with access to economic resources. Second, while there is a correlation between HDI and the FEW Index, there is no one to one correspondence, meaning that resources place different limits to development across countries.

Figure 4: The Pardee RAND Food-Energy-Water Index and Sub-indices for Iraq.



Source: Pardee RAND Food-Energy-Water (2016).

Concluding Remarks

UN Water (2021) states that:

> The inextricable linkages between these critical domains [of water, energy and food] require a suitably integrated approach to ensuring water and food security, and sustainable agriculture and energy production worldwide.

Accordingly, we study the inter-relationships and conflicts between these three sectors. We show that declining levels of water quality and quantity pose grave dangers to Iraq's agriculture as well as oil and gas industries, necessitating radical rethinking and restructuring. Agriculture, while declining, still employs one in five to one in six Iraqis, and oil contributes most of GDP and almost all government revenues.

The policy recommendations that emanate from this study are extensive and varied. What we do below is classify and list them rather than entering into detailed discussion. We thus follow Giovanis and Ozdamar (2021) in conceptualizing policies that are designed to overcome internal barriers and others that are designed to alleviate external barriers. The former include solutions that are in principle possible to generate domestically, including more efficient and effective use of available resources and governance. Within these internal barriers, we can distinguish between technical solutions and administrative (or managerial) (see Perera and Zhong, 2017). In Iraq, water use in agriculture remains wasteful and subsidy policy irrational, adding to the water shortage; gas flaring in oil production adds to Iraq's already polluted natural environment. Technical solutions—drip irrigation techniques, changes to crop subsidies and hence output mix, water desalination, improved environmental controls in the oil industry, better wastewater treatment, increased use of solar power, rainwater and wastewater harvesting, which is relatively inexpensive and less capital intensive than desalination (see Perera and Zhong, 2017: 66), and more—are needed. This requires investments in new technologies in sustainable green solutions, in efficient and effective modern systems of water resources management to mitigate and adapt to climate change, and in re-claiming land and expanding green areas and wetlands. In addition to technical, there are administrative measures that might be useful, such as improved coordination between regulatory and administrative units at the national and provincial levels. Given Iraq's present financial difficulties, ongoing conflict and long-term institutional decline, including that of its key ministries, these technical and administrative measures will not be easy to undertake.

Policies that are geared towards overcoming external barriers require Iraq to constructively engage with neighbors, notably Turkey, in discussions over the drastic downstream declines in water flow from the Tigris and Euphrates. The UN ratified Law of Non-Navigational Uses of International Watercourses came into force in 2014; although Iraq and Syria have ratified the convention, Turkey has continued to oppose ratification (Giovanis and Ozdamar, 2021: 3). Representatives of these countries have met, but have yet to reach formal agreement on rights to water. Even with Turkey's political and economic upstream leverage over water rights, it is possible, albeit difficult, for Iraq and Syria to engage with Turkey on the basis of joint interests. Popular protest for improved environment and services should improve the prospects for action and change and provide an added impetus to achieving both internal and external measures.

References

Aenab, Allaa M. and Singh, S. K. (2012), 'Evaluation of Drinking Water Pollution and Health Effects in Baghdad,' Iraq, *Journal of Environmental Protection*, 3, 533-537.

Alnasrawi, A. (1994). *The economy of Iraq: Oil, wars, destruction of development and prospects, 1950-2010.* Westport: Greenwood.

Alwash. Azzam, Istepanian. Harry, Tollast, Robert and Al-Shibaany. Zeyad,Y., (2018). Towards sustainable water resource management in Iraq. London: Iraq Energy Institute.

Alwash, Azzam (2020). Iraq's Climate Crisis Requires Bold Cooperation. The Century Foundation. Available at https://tcf.org/content/report/iraqs-climate-crisis-requires-bold-cooperation/?session=1, accessed on 1 January, 2021.

Al-Sudani, Hussein. (2019). Salinity Pollution of Groundwater in South of Iraq, *Journal of University of Babylon for Engineering Sciences* 27 (3): 13-23.

Alhanaee, Ghena, Sanders, Kelly, and Meshkati ,Najmedin (2017). Rising Temperatures, Rising Risks: The Food-Energy-Water Nexus in the Persian Gulf. *Environmental Science and technology*, 51, 4117-4118. Available at https://pubs.acs.org/doi/pdf/10.1021/acs.est.7b00688; accessed March 2, 2021.

Al-Ansari, Nadhir (2013). Management of Water Resources in Iraq: Perspectives and Prognoses. *Engineering*, 5 (8): 667-684.

Al-Ansari, Nadhir, Ali, Ammar A., Knutsson ,Sven (2014). Present Conditions and Future Challenges of Water Resources Problems in Iraq**.** *Journal of Water Resource and Protection*, 6 (12): 1066-1098. Available at http://dx.doi.org/10.4236/jwarp.2014.612102; accessed May 17, 2021.

British Petroleum (2020). Available at http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/oil/oil-prices.html, accessed May 24, 2020.

CBS (2018). What will happen to our lands?': Iraq bans farming summer crops amid water shortage. Available at https://www.cbc.ca/news/world/iraq-bans-farming-summer-crops-water-shortage-turkey-1.4734611, accessed on May, 18 2021.

CIA (2021) The World Fact book. Available at www.cia.gov/the-world-factbook/countries/iraq/#people-and-society; accessed April 24, 2021.

Central Statistic Organization (CSO) (2014). Environment in Numbers. Baghdad: Central Statistic Organization.

Daher, Bassel T. and Mohtar, Rabi H. (2015) Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making, *Water International*, 40, 5-6, 748-771.

Davies, Kitila (2019). 'Water Insecurity in Southern Iraq Presents Problems for Mahdi.' Available at https://hidropolitikakademi.org/en/article/28216/water-insecurity-in-southern-iraq-presents-problems-for-mahdi, accessed April 20, 2021.

de Andrade Guerra, Jose Baltazar Salgueirinho Osorio et al. (2021), A literature-based study on the water–energy–food nexus for sustainable development, *Stochastic Environmental Research and Risk Assessment, 35*, 95–116.

Endo et al. (2015). 'Methods of Water-Energy-Food Nexus', *Water*, *7*, 5806-5830.

El- Joumayle, O.A.M (2017). Oil production and abrupt institutional change: the multi-cyclic Hubbert model and the case of Iraq, *Contemporary Arab Affairs*, 10(2), 256-285.

El Serafy, Salah (1989). 'The Proper Calculation of Income from Depletable Natural Resources', in *Environmental Accounting for Sustainable Development*, World Bank, Washington DC, 10-18.

ESCWA (2015). 'Conceptual Frameworks for Understanding the Water, Energy, and Food Security Nexus.' Available at http://css.escwa.org.lb/SDPD/3581/WP1A.pdf; accessed December 26, 2020.

Energy Information Administration (EIA) (2021). Country Analysis Executive Summary: Iraq. Available at www.eia.gov/international/overview/country/IRQ, accessed May 24, 2021.

Ewaid, Salam H., Salwan A. Abed, and Nadhir Al-Ansari (2019). "Water Footprint of Wheat in Iraq" *Water* 11 (3): 535. Available at https://www.mdpi.com/2073-4441/11/3/535/htm, accessed April 22, 2022.

Food and Agriculture Organization (FAO), (2019). Statistical Pocketbook. Available at http://www.fao.org/3/ca6463en/ca6463en.pdf, accessed May 9, 2021.

Food and Agriculture Organization (FAO), (2020). Iraq: Humanitarian Response Plan 2020. FAO Emergency and Resilince División. Rome.

Food and Agriculture Organization (FAO), (2021). Agriculture value chain study in Iraq: Dates, grapes, tomatoes and wheat. Baghdad.

Gibson, Glen R., Campbell, James B. and Randolph H. Wynne (2012). Three Decades of War and Food Insecurity in Iraq. *Photogrammetric Engineering & Remote* Sensing, 78 (8): 885–895.

Giovanis, Eleftherios and Ozdamar, Oznur (2021). 'Dams as Drivers of Droughts and Water Pollution: Evidence from the Euphrates-Tigris Basin in Turkey and Iraq.' ERF Policy Brief No. 61. Available at https://erf.org.eg/publications/dams-as-drivers-of-droughts-and-water-pollution/, accessed April 10, 2022.

Global Water Partnership (2018), Global Water Partnership South Asia. Available at https://www.gwp.org/en/gwp-SAS/ABOUT-GWP-SAS/WHY/About-IWRM/, accessed May 3, 2021.

Gollob, Sam and O'Hanlon, Michael E. (2020). Iraq Index: Tracking variables of construction and security in post Saddam Hussien Iraq. Brookings institute

Hameed, M., Ahmadalipour, A., & Moradkhani, H. (2018). Apprehensive drought characteristics over Iraq: results of a multidecadal spatiotemporal assessment. *Geosciences*, *8* (2), 58. Available at http://www.mdpi.com/2076-3263/8/2/58; accessed March 3, 2021.

Hamilton, Kirk and Clemens, Michael (1999). 'Genuine Savings Rates in Developing Countries,' *World Bank Economic Review*, 13 (2), 333-56.

Hartwick, John (1977). 'Intergenerational equity and the Investing of Rents from Exhaustible Resources,' *American Economic Review*, 67 (5), 972-4.

Hotelling, Harold (1931). 'The Economics of Exhaustible Resources,' *The Journal of Political Economy*, 39 (2), 137-75.

Human Right Watch (2020). Basrah is Thirsty: Iraq's Failure to Manage Water Crisis. Available at https://www.hrw.org/report/2019/07/22/basra-thirsty/iraqs-failure-manage-water-crisis, accessed May 1, 2021.

Ibrahim Y M, Hami N and Othman S N (2019) 'Assessing of Imbalance among Economic, Environmental and Social Sustainability: Evidence from Oil and Gas Industry in Iraq,' *Journal of Physics*: Conf. Series 1294. Available at https://iopscience.iop.org/article/10.1088/1742-6596/1294/7/072006/pdf, accessed April 17, 2021.

Jaradat, A. A. (2003). Agriculture in Iraq: Resources, potentials, constraints, research needs and priorities. *Food, Agriculture & Environment* 1(2): 160-166.

Kapita (2020). 'Iraqi Agriculture Sector Review.' Available at http://www.kapita.iq/content/issue/iraqi-agriculture-sector-overview, accessed March 5, 2021.

Indexmundi.com (2022). Available at https://www.indexmundi.com/, accessed April 23, 2022.

International Bank for Reconstruction and Development (IBRD) (1952). *The Economic Development of Iraq*. The Johns Hopkins Press.

International Centre for Agricultural Research in the Dry Areas (ICARDA) (2012), 'Managing Salinity in Iraq's Agriculture,' Report 1: Situation Analysis. Available at https://repo.mel.cgiar.org/handle/20.500.11766/9487, accessed February 18, 2021.

International Energy Agency IEA (2020). Data and statistics: Iraq. Available at https://www.iea.org/data-and-statistics/data-tables?country=IRAQ&energy=Electricity&year=2018, accessed January 10, 2021.

International Energy Agency IEA (2019). Iraq Energy Sector: A roadmap to a brighter future. Paris: International Energy Agency.

International Organization for Migration (IOM) (2020). 'Water Quantity and Water Quality in Central and South Iraq: A Preliminary Assessment in the Context of Displacement Risk.' Available at https://iraq.iom.int/publications/water-quantity-and-water-quality-central-and-south-iraq-preliminary-assessment-context; accessed May 20, 2021.

Keulertz, Martin. Sowers.Jeannie, Woertz. Eckart, and Mohtar, Rabi. (2016). The Water-Energy-Food Nexus in Arid Regions: The Politics of Problem sheds in The Oxford Handbook of Water Politics and Policy *Edited by Ken Conca and Erika Weinthal* Subject: Political Science, Regional Studies Online.

Kullab, Samya and Yahya. Rashid. (2020). Minster: Iraq to face severe shortage as river flows drop. Available at https://apnews.com/article/9542368977c9ee0ae97fd2cc88933198, accessed on 2 November, 2020).

Kibaroglu, Aysegül and Iba Gürsoy, Sezin (2015) Water–energy–food nexus in a transboundary context: the Euphrates–Tigris river basin as a case study, *Water International*, 40:5-6, 824-838.

Knoema (2021). Iraq - Water resources » Total renewable water resources » Total renewable water resources per capita. Available at https://knoema.com/FAOAQST2019/aquastat?tsId=1083690; assessed in May 17, 2021.

Leck, Hayley; Conway, Declan; Bradshaw, Michael; Rees, Judith (2015). 'Tracing the Water–Energy–Food Nexus: Description, Theory and Practice,' *Geography Compass*, 9, 445– 460.

Levkowitz, Joshua (2018). 'Iraq wilting: How creeping drought could cause the next crisis.' *Middle East Institute*. Available at http://www.mei.edu/content/article/iraq-wilting-how-creeping-drought-couldcause-next-crisis, accessed February 20, 2021.

Library of Congress (2006) Country Profile: Iraq. Available at https://www.loc.gov/rr/frd/cs/profiles/Iraq.pdf; accessed February 14, 2021.

Macrotrends (2020). Iraq population 1950-2021. Available at www.macrotrends.net/countries/IRQ/iraq/population (assessed in 2 January, 2021).

Maniruzzaman, A.F.M. and Al-Saleem, K. (2017).The Energy and Environment Dilemma: Sustainably Developing Iraqi Oil and Gas in International Law and Policy - Prospects and Challenges., *Oil, Gas & Energy Law Intelligence* volume 15 issue 3.

Mine Action Review (2020), *Clearing the Mines 2020*, Available at http://www.mineactionreview.org/documents-and-reports/clearing-the-mines-2020 (accessed February 28, 2021).

Mohammed, Shwan (2018), The Importance of Fixing Iris's Irrigation, *1001 Iraqi Thoughts*. Available at https://1001iraqithoughts.com/2018/07/06/the-importance-of-fixing-iraqs-irrigation/; accessed February 20, 2021.

Mahdi, K. (2007), 'Neoliberalism, conflict and an oil economy: The case of Iraq', *Arab Studies Quarterly*, 29: 1, pp. 1–20.

Naima, Haider (2020). Economic Challenges of Grains trade under the International trade agreement of World Trade organization (In Arabic). Baghdad: Ministry of Trade.

Organization of Petroleum Exporting Countries (OPEC) (2008), *Annual Statistical Bulletin*, Public Relations and Information Department, Vienna: Austria.

OPEC (2019), *Annual Statistical Bulletin*, Public Relations and Information Department, Vienna: Austria.

OPEC Fund for International Development (OFID) (2017), 'The energy-water-food nexus: Managing key resources for sustainable development,' OFID Pamphlet series 41, Vienna.

Pardee RAND Food-Energy-Water (2016). Available at https://www.prgs.edu/pardee-initiative/food-energy-water/interactive-index.html. Accessed April 14, 2020.

Patel, David Siddhartha (2018) 'How Oil and Demography Shape Post-Saddam Iraq.' Crown Center for Middle East Studies, Brandeis University. Available at https://www.brandeis.edu/crown/publications/middle-east-briefs/pdfs/101-200/meb122.pdf, accessed April 12, 2021.

Perera, Pradeep and Zhong, Lijin (2017). 'Water-Energy nexus in the People's Republic of China and emerging issues.' Asian Development Bank. Available at https://www.adb.org/sites/default/files/publication/384291/water-energy-nexus-prc.pdf, accessed April 17, 2022.

Raphaeli, Nimrod (2009). Water Crisis in Iraq: The Growing Danger of Desertification, MEMRI. Available at https://www.memri.org/reports/water-crisis-iraq-growing-danger-desertification#_ednref6, accessed on 21 February, 2021.

Robinson, David (2010). 'Oil and gas: water treatment in oil and gas production—does it matter? *Filtration Separation*. Available at https://www.filtsep.com/water-and-wastewater/features/oil-and-gas-water-treatment-in-oil-and-gas/, accessed May 30, 2021.

Rubaii, Kali (2020) 'Birth Defects and the Toxic Legacy of War in Iraq,' *Middle East Report Online*. Available at https://merip.org/2020/09/birth-defects-and-the-toxic-legacy-of-war-in-iraq/; accessed February 14, 2021.

Rubin, Alissa J and Krauss, Clifford (2020) Southern Iraq's Toxic Twilight: Burning Gas and Poisoning the Air, New York Times. Available at www.nytimes.com/2020/07/16/world/middleeast/iraq-gas-flaring-cancer-environment; accessed September 8, 2020.

Saadi, D. (2020), Iraq's OPEC+ cuts will need IOCs contribution, but at what cost? Available at www.spglobal.com/platts/en/market-insights/latest-news/oil/041920-iraqs-opec-cuts-will-need-iocs-contribution-but-at-what-cost, assessed 22 April, 2020.

Salam, P. A., Pandey, V. P., Shrestha, S., and Anal, A. K. (2017). 'The need for the nexus approach,' in *Water-Energy-Food Nexus: Principles and Practices*, eds. P. Abdul Salam, S. Shrestha, V. Prasad Pandey, and A. K. Anal (Washington, DC: John Wiley and Sons), 1–10.

Schuber, Barik (2018). On the consequences of poor planning and failure to manage Oil Service Contract: the seawater injection projects as a model (in Arabic), Iraqi Economists Network.

Schwartzstein (2015). 'Iraq's Famed Marshes are Disappearing Again.' *National Geographic* Available at https://www.nationalgeographic.com/news/2015/07/150709-iraq-marsh-arabs-middle-east-water-environment-world/; accessed February 12, 2021

Sen, Amartya (1981). *Poverty and Famines: An Essay on Entitlement and Deprivation,* Oxford University Press.

Siderius, Christian; Conway, Declan; Yassine, Mohamed; Murken, Lisa. Lostis; Pierre-Louis (2019) 'Characterising the Water–Energy–Food Nexus in Kuwait and the Gulf Region.' LSE Middle East Centre Paper Series no.28, London: LSE Middle East Centre Middle. Available at http://eprints.lse.ac.uk/102852/1/Siderius_characterising_the_water_energy_food_nexus_published.pdf, accessed April 11, 2021.

Siddiqi, A. and Andon, L.D. (2011), "The water-energy nexus in Middle East and North Africa", *Energy Policy*, 39 (8), 4529-4540.

Simpson, Gareth B. and Jewitt, Graham P. W. (2019), 'The Development of the Water-Food-Energy Nexus as a Framework for Achieving Resource Security: A Review,' *Frontiers in Environmental Science,'* 7, Article 8, 1-9.

Sleet, Phoebe (2018). Ravaged by Conflict, Corruption and Water Scarcity, Iraq's Food Security Remains Vulnerable. Future Direction Org. Available at https://www.futuredirections.org.au/publication/ravaged-by-conflict-corruption-and-water-scarcity-iraqs-food-security-remains-vulnerable/; accessed in May 1 2021.

The Water, Energy, Food security Platform (2019). Available at https://wefnexusindex.org/IRQ, assessed in April 5, 2021.

United Nations Conference on Trade and Development (UNCTAD) (2020),'UNCTADstat', Available at http://unctadstat.unctad.org, accessed May 24, 2020.

United Nations Environment Programme (UNEP) (2007).UNEP in Iraq: Post-Conflict Assessment, Clear-Up and Reconstruction, Nairobi: United Nations Environment Programme.

UN Water (2021) Water, Food and Energy. Available at https://www.unwater.org/water-facts/water-food-and-energy/, accessed May 31, 2021.

UNEP (2017). Technical Note: Environmental issues in areas retaken from ISIL: Mosul, Iraq. Rapid Scoping Mission July – August 2017. Nairobi: United Nations Environment Programme. Available at https://postconflict.unep.ch/publications/Iraq/Iraq%20Technical%20Note_September2017.pdf; accessed March 1, 2021.

US Energy Information Administration (EIA) (2016). Country Analysis Brief (April, 2016).

USAID (2012). Assessment of current and anticipated economic priorities in Iraq. A Report prepared by Louis Berger Group, Inc.

USAID (2017), Climate Risk Profile: Iraq, March 2017. Available at https://www.climatelinks.org/sites/default/files/asset/document/2017Mar3_GEMS_Climate%20Risk%20Profile_Iraq_FINAL.pdf; accessed February 14, 2021.

USAID (2020), USAID website. Available at https://www.usaid.gov/what-we-do/agriculture-and-food-security; accessed February 20, 2021.

Wall Street Journal (2016). 'Barrel Breakdown.' Available at http://graphics.wsj.com/oil-barrel-breakdown/; accessed May 24, 2021.

Willis, Henry H., David G. Groves, Jeanne S. Ringel, Zhimin Mao, Shira Efron, and Michele Abbott,(2016). 'Developing the Pardee RAND Food-Energy-Water Security Index: Toward a Global Standardized, Quantitative, and Transparent Resource Assessment.' Santa Monica, CA: RAND Corporation. Available at https://www.rand.org/pubs/tools/TL165.html; accessed April 19, 2021.

World Bank (2017). Iraq - Systematic Country Diagnostic (English). Washington, DC: World Bank. Available at http://documents.worldbank.org/curated/en/542811487277729890/Iraq-Systematic-Country-Diagnostic; accessed January 15, 2021.

World Bank (2020). Oil rents (% of GDP). Available at https://data.worldbank.org/indicator/NY.GDP.PETR.RT.ZS, accessed in March, 21, 2021.

Yousif, Bassam (2009). 'Non-renewable resource depletion and reinvestment: Issues and evidence for an oil-exporting country.' *Environment and Development Economics, 14*(2), 211-226.

Yousif, Bassam (2012). *Human Development in Iraq: 1950-1990*. New York. NY: Routledge.

Yousif, Bassam. (2016). 'Iraq's stunted growth: human and economic development in perspective.' *Contemporary Arab Affairs*, 9, 2: 212-236.

Yousif, Bassam; Morrar, Rabeh and el-Joumayle, Omar (2020) 'Conflict, Institutions and the Iraqi Economy, 2003-2018' *Economic Research Forum* working paper 1367. Available at https://erf.org.eg/publications/conflict-institutions-and-the-iraqi-economy-2003-2018/; accessed February 14, 2021.

Zarei, Mohanna. (2020). The water-energy-food nexus: A holistic approach for resource security in Iran, Iraq, and Turkey. *Water-Energy Nexus*, 3: 81–94.

Zhang, Chi; Chen, Xiaoxian; Li, Yu; Ding, Wei and Fu, Guangtao (2018). 'Water-energy-food nexus: Concepts, questions and methodologies,' *Journal of Cleaner Production*, 195, 625-639.