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Exploring the Water-Energy-Food nexus in context of conflict in Iraq

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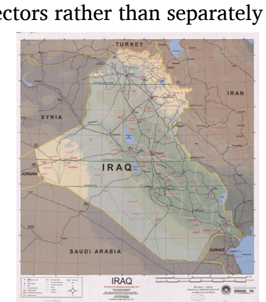
ABSTRACT

This article applies the Water-Energy-Food (WEF) nexus to explore the relationships between Iraq's water (demand and supply), energy (oil, gas and electricity), and food production, moving beyond sector-specific studies. Thus, this is a WEF analysis of a country that is emerging from years of conflict and instability and is among the first WEF applications to Iraq at the national (as opposed to regional or metropolitan) level. We utilize various open-source data, peer reviewed and grey literature to survey environmental conditions, setting the ground for the study of WEF interrelationships. We note the decline in the quality and availability of water, focusing on it as a key input into both agricultural and oil production. We argue that the declining quality and availability of water over many decades is unable to sustain both present agricultural practices and rising oil output, highlighting the difficulty of increasing the outputs of these sectors. As such, the article underlines the need for a multi-sectoral approach in dealing with the present challenges of water, energy and food production and argues that a radical restructuring of the relations between the sectors is required. We offer policy recommendations that seek to overcome internal barriers, constraints that exist and are potentially solvable within Iraq, and other measures geared towards external barriers, including the actions of neighbors.

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, including clean water and electricity, and unemployment ([55]:1). With 120,000 people hospitalized after consuming polluted water in 2019 [24], protestors demanded, among other things, increased water availability and quality [15]. The lack of water, in turn, has important effects for food production; with one of out every nine Iraqis classified as food insecure ([76]: 3-4), the implications for food security are immense. Poor services and inadequate water have been associated with rising political and social instability.

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 the Tigris and Euphrates rivers, rising levels of pollution and salination as well as underinvestment or neglect. We posit that Iraq's water predicament, and its environmental dilemmas more broadly, are best understood when analyzed alongside its energy, including oil and gas production, and agricultural sectors rather than separately or independently.



Source: United States National Mapping Agency [78].

Indeed, the relationship between energy and agriculture often has been invoked in discussions of Iraq's oil 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 the prices of non-tradable goods, ultimately making the agriculture and manufacturing sectors less competitive (see [85]: 214-215). However, this is concerned mainly with the spending of oil revenues rather than oil extraction process, which involves use of water

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to extract oil among other environmental implications, as we shall see. In parallel, discussions of development in Iraq historically have centered on the notion of income sustainability or investing oil income into productive (non-oil) activities that generate income in future when the oil resource runs out [4].[1] Missing in such accounts are the inter-sectoral relationships, including the competing uses of scarce water resources in agriculture and, alternatively, in oil production.

In this article, we seek to explore two inter-related questions. First, and after decades of conflict and political instability, what are the interconnections between the three sectors of food production, energy and water in Iraq's oil economy? What are the tensions and tradeoffs of production in these sectors? In examining these, we sought to apply a methodology that considers these sectors together and to avoid examining any of the sectors in isolation. We thus apply the WEF nexus framework to examine the relatedness of these sectors for Iraq as a whole (see [40,17]). As we state below, we utilize WEF nexus concepts to study sector interactions at the national, rather than local or industry, level in a country recovering from the accumulated effects of conflict and instability.

Simpson and Jewitt ([68]: 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.

The WEF nexus framework 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 ([17]: 8). Salam et al. [61] point out that the WEF 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 or a central sector.

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

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

The OPEC Fund for International Development ([52]: 11) states:

> 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.

There is agreement about the importance of studying the interactions of the three sectors ([87]: 626-627) as well as concern over disciplinary 'silo thinking' ([52]: 20). However, there is some disagreement within the WEF framework about how concepts ought to be applied, with terms often used in competing or ambiguous ways by differing authors ([68]: 2). How the WEF nexus is applied is thus partly a matter of researcher choice rather than agreed upon method. In an in-depth survey of WEF nexus research, Zhang et al. ([87]: 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 ([68]: 3) argue that WEF analysis treats water, energy and food sectors as equals. Still, there is mostly agreement over the potentially huge role for government to exploit the synergies between energy and food production along with water availability [52,68].

Zhang et al. ([87]: 627-629) distinguish between internal and external impact analysis, as well as evaluating the system performance as a whole. The internal impact analysis concerns interactions between the sectors (water, energy and food), which can be a one-sided assessment of how a change in one sector affects other sectors or more comprehensive 'interactive impact analysis' that studies the shared inter-relationships of sectors. We apply an internal 'interactive impact analysis' to study nexus inter-relationships, exploring the linkages between water, food production, and energy (electricity, gas and oil output). Because of the requirements for reliable data and the need to consider multiple and interlinked elements and variables, we are unable to follow quantitative methods. They 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" ([86]: 88). Instead, we use numerous open-source data, and peer reviewed and grey literature, along with existing WEF indexes, to assess WEF interrelationships.

This study complements the existing WEF literature on Iraq and the Middle East by providing a national-level WEF analysis of Iraq, a major oil exporter. It also adds to the growing literature on the importance of the WEF framework in relation to understanding conflict. In respect to the first, the existing work on Iraq tends to focus on specific cities or locales or tends to concentrate on particular industries. Thus, based on survey data, Hussien, Memon and Savic [25] develop a model that assesses the interaction between WEF components by households, estimating demand for various sectors (water, energy and food), organic waste, and wastewater generation in the city of Duhok in northern Iraq. They follow up [26] with a study of the impact of seasonal variability on the consumption of water, energy and food in the same city. Yasin et al [82] examine the food production and consumption, energy production and CO2 output in food processing in Baghdad. Al-Muqdadi et al [3] apply WEF nexus framework to Iraq, focusing on the problems of adopting new technologies in the WEF sectors.

As concerns conflict, there is a growing literature on how domestic and international conflict and water, food and energy resources interact. Abbot et al [1] show a positive correlation between inadequacy of WEF resources and the incidence of domestic and international conflict, including in the Middle East region. Examining the case of conflict in Darfur, Bromwich [11] argues that post conflict governance has been key in the management of environmental scarcities. Zarei [86] investigates the dynamics behind the WEF security concerns, focusing on the transboundary river basin issues in neighbouring countries of Turkey, Iran and Iraq. Likewise, Kibaroglu and Iba Gürsoy [38] show how, starting in the 1970s, the diversion of waters of the Euphrates and Tigris, to generate electricity and increase irrigation and cropped areas in Turkey and Syria, has reduced flows of water downstream to Iraq.

In respect to oil exporters, Siderius et al. [66] apply the WEF nexus to Kuwait and argue that, despite water scarcity, there is little trade-off between the WEF sectors at the domestic level; at the international level though, Kuwait's oil wealth allows it to purchase water-intensive food grains. This protects Kuwait against food insecurity, but may increase water insecurity, and hence food production difficulties, in food exporting countries. In contrast, Siddiqi and Andon [67] conduct a country-level quantitative assessment of the WEF nexus showing that water availability in the Gulf region as a whole is highly energy-dependent. Daher and Mohtar [14] develop a modelling tool, which provides a platform to identify sustainable resource allocation strategies and evaluate different scenarios on the national level that they apply to Qatar. Keulertz and Mohtar [36] apply the WEF nexus framework to Libya, United Arab Emirates, Egypt and Iraq; they argue that while these countries have a high potential for solar power and feedstock sourced energy, water resources and food production capacities

[1] For example, [83] studies income sustainability vis-à-vis investment in physical capital to offset asset liquidation implied in oil extraction in Iraq.

are limited.

3. Overview of environmental conditions

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

First, multiple conflicts, since 1980, have damaged Iraq's environment. Unexploded ordnances and land mines proliferate in war-affected regions of the country and these have resulted in the deaths of tens of thousands of people ([42]: 6). Indeed, despite attempts at mine clearing, Mine Action Review [[46]: 144] reports: "Iraq remains the world's most mine-contaminated country with no credible baseline estimate of the extent of mined area." Relatedly, the destruction of military and industrial infrastructure, and the release of heavy metals and hazardous chemicals from spent bombs have polluted the air, soil, and groundwater. Water contamination has occurred, including from oil spills; the largest oil spill in history occurred during the 1991 Gulf War with the discharge of oil from tankers in Gulf waters ([8]: 4117). UNEP [[74]: 2] details the environmental damage resulting from war with the so-called 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. Rubaii [58] tracks the effects of past and ongoing conflict on health outcomes vis-à-vis rising cancer rates and birth defects. A poignant example of the effects of conflict is the draining of large portions of Iraq's marshes in the 1990s by the Iraqi government, to deny its perceived political opponents refuge, damaging both local ecosystems and the means of livelihood of residents [63].

Second, the actions of regional neighbors have reduced water availability and quality in Iraq in recent decades, with huge implications for agriculture. In the context of a lack of legally enforceable international water rights treaties (see [86]), Turkey and Syria, as noted, have redirected Euphrates and Tigris waters to generate electricity and increase irrigation and cropped areas in their own countries, reducing flows of water downstream to Iraq [38]. Especially with 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 ([89]: 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 [63].

Thus, the International Energy Agency ([32]: 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. 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 ([2]: 534 & 536). In addition, chemical spills and poor hazardous waste management have contaminated groundwater aquifers [7], undermining the suitability of groundwater for irrigation and drinking water.

Third, global climate change has aggravated Iraq's problems of water scarcity and salination. According to the World Bank ([89]: 99) the average annual temperatures rose by 1 to 2°C between 1970 and 2004; they are expected to rise by a further 2.5°C by 2050 ([81]: 4). 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 ([76]: 2). The upshot is heightened water evaporation and hence soil salinity, and net reductions in arable land and desertification, which threatens 92 percent of the country.

All these changes have occurred at a time of decline in water management infrastructure and in Iraq's institutions and state capacity more generally [16,85]. As concerns water, Iraq's agricultural sector accounts for most of its use but suffers from decades of under-investment and deterioration in critical infrastructure such as irrigation pumping stations, water canals and irrigation networks [41,47]. In respect to energy, dependence on oil, dilapidated oil infrastructure along with weakened state capacity have together provided little incentive for polluters to clean up their activities. For example, Iraq's Environment ministry has attempted to impose fines on oil companies (domestic and international) that pollute through gas flaring (discussed later in detail), only for those companies to dodge regulations or even pay the fines, which is often cheaper to do than invest in pollution control [65].

4. The water, energy and food sectors

With respect to the *Water Sector*, flood control was a chief challenge for Iraqi policymakers before the 1950s. According to the International Bank for Reconstruction and Development ([30]: 183): "the storage of the flood waters of the Euphrates and Tigris and their tributaries is the foremost problem." Hence, large investment allocations were devoted to flood control and water projects in the 1950s ([4]: 26); the construction of dams and other flood control projects remained a policy priority until the 1980s (for a list of dams see [9]: 673; [10]: 1080).

In contrast, Iraq today confronts the opposite problem: a shortage of water and decline in its quality, especially in central and southern regions such as Basra [24,34]. Population growth has increased the demand for water, energy, and food. Iraq's population was 40 million in 2020, growing at 2.4 percent annually (or one million per year), and is predicted to increase to 50 million by 2030 and to more than 70 million by 2050 ([44,6]). Rural-to-urban migration has steadily made Iraq more urbanized. According to Iraq's Central Statistics Organization [[13]: 6], two-thirds of the total population is urban. Interestingly, declining water quality has aggravated rural-to-urban migration, with water scarcity and water (and soil) salinity inducing the movement of 21,000 people to urban areas in 2019 ([34]: 6). In the 2015 to 2020 period, the urban population grew by more than the rural, suggesting rural to urban migration for the period [12], as rural birth rates historically have been higher.

According to Table 1, total renewable water resources, or the "maximum theoretical yearly amount of water available for a country at a given moment" ([19]: 247) declined markedly between 1997 and 2017. Likewise, Knoema [39] reports that the total renewable water resources per capita of Iraq declined from 8,477 m3 per inhabitant per year (m3/inhab/year) in 1972 to 2,393 in 2017. Iraq's Ministry of Water Resources reckons that river levels have dropped by up to 40 percent in the last two decades ([32]: 14). Kibaroglu and Iba Gürsoy [38] characterize such changes as trans-national shocks to WEF dynamics, the results of (uncoordinated) decisions taken at national levels in Tigris-Euphrates basin countries of Iraq, Syria and Turkey. Freshwater withdrawal, the portion of total renewable water resources withdrawn in a given year ([19]: 241), declined between 2007 and 2017; Zarei ([86]: 93) attributes this fall to greater withdrawals in Syria and Turkey, leaving less available to withdraw in Iraq.

A complicating factor regarding access to water 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 originates inside Iraq ([89]: 98). However, as Table 2 shows water

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

Category	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 ([19]: 132)

demand is rising and predicted to exceed supply by 2030, with agriculture accounting for three-fifths of demand. Although slightly more pessimistic, this is broadly consistent with former Water Resources Minister Mahdi Al-Hamdani's estimate of a water shortage of 10.5 billion m3 of water by 2035 [37]. Iraq's renewable freshwater availability was double the regional average in 2017, but growth in demand for water and overuse in agriculture threaten to reduce this gap at a time when water institutions have been declining ([89]: 96-7).

While there is some divergence in estimates of the amount of water deficit (see for example [10]:1067-1068), there is agreement that water deficiency is a serious issue, with implications for Iraq's agricultural and oil sectors, constraining potential increases in agricultural output and oil extraction. The following illustration is simple (e.g. it assumes that the same water can be used to produce wheat or extract oil) but clarifies the trade-off between oil and wheat production. Ewaid et al [18] estimate that on average 1,876 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 was 4.193 million tons per annum;[2] with Iraq a net wheat importer for decades, this still necessitated imports to satisfy domestic demand. A 10 percent rise in wheat output for Iraq (and its rising population) requires 786 million m3 per annum or roughly 13.55 million barrels per day (MBD) of water, needed, alternatively, to extract about 9 MBD of oil. This refers to only wheat of course; increases in outputs of other agricultural commodities would require additional amounts of water.

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, or (more limitedly) in oil production. Desalination presently plays a negligible role but has the potential to provide up to 10 percent of the water supply by 2030 ([32]: 38- 39). However, desalinization is energy intensive. Mohtar and Daher ([88]:2) estimate that 2.58 to 8.5 kilowatt-hours of energy are needed 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 [6], although the IEA ([32]: 38) expects the use of desalinated water to rise.

By ***Energy Sector***, we mean the production/extraction of oil, natural gas and electricity. Oil (and associated gas extraction) requires water for exploration, drilling, and pumping activities ([35]: 3). Over the last century, Iraq has changed from an agricultural country exporting mainly grains and dates to an oil-producing nation ([84]: 59- 62). Oil was found in Iraq in 1927, and output rose steadily until the early 1970s ([16]: 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 ([48]: 12); production increased from 1.46 million barrels per day (MBD) in 1972 to 3.47 MBD in 1979 ([50]). By 1979, the share of oil in Iraq's gross domestic product (GDP) had risen to 63 percent ([73]: 15). However, with the outbreak of the Iraq-Iran War in 1980, average daily production dwindled, recovering only gradually, and comprehensive UN economic sanctions, imposed on Iraq after its invasion of Kuwait in 1990, followed by war, disrupted oil production and exports. In post-2003 era, Iraq has succeeded in achieving substantial rises in output, mostly from the southern oilfields, with production reaching 5 MBD in April 2020, according to Iraq's Ministry of Oil [60].

Fig. 1 illustrates oil production, exports and revenue trends for the period of 2002 to 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. Iraq has relied on water injection since the 1960s, especially in the south and central oil fields [32]. 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 ([32]: 14 & 24), with aging oil wells requiring rising amounts of water ([66]: 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; 14 MBD of water is needed to produce 9 MBD ([62]: 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 [57]. Providing more water to increase oil output is in conflict with the reality of dwindling water supplies, needed for food production and other uses shown in Tables 1 and 2. To supply the water needed (7.5 MBD initially, increasing to 12 MBD) to its southern oil fields, Iraq plans to treat and transport seawater from the Gulf in the Common Seawater Supply Project, with an estimated cost of four to six $US billion [32].

An important by-product of oil extraction is natural gas, most of which is burned or flared because of the lack of requisite infrastructure to utilize it; 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 ([75]: A-12). Iraq is now in the early stages of prioritizing the re-capture of natural gas instead of flaring, but the legacy of flaring remains [32]. In fact, the volume of flared gas has been rising along with higher oil extraction rates. Ibrahim et al [27] report that the volume of flared gas rose from 11,976 million standard cubic meters (mcm) in 2012 to 17,714 and 16,639 in 2016 and 2017 respectively. Estimates of the economic loss associated with flaring gas are high and vary depending on appraisals of flared volume and its market price. USAID ([75]: A-12) estimates the value of flared gas at roughly $1.8 billion per year or about $5 million per day. Maniruzzaman and Al-Saleem ([45]: 41) report that 55 percent of Iraq's gas production or 16 billion cubic meters a year is flared, for an annual loss of $2.5 billion. There are also costs to the environment and human welfare from flaring: 30 million tons of carbon dioxide emissions are released into the atmosphere because of gas flaring ([32]: 14). Rubin and Krauss [59] 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." Assessments of costs of oil production do not usually include the replacement cost of flared gas, vis-à-vis natural gas that is imported, let alone the associated health and environmental costs, with the result that Iraq emerges as one of the world's lowest-cost oil producers [79].

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 that of hydroelectric power declined; the contribution of solar energy is negligible throughout the period. Rising electricity imports (non-existent during economic sanctions, 1990 to 2003) have supplemented increasing domestic output since 1990, so domestic supply actually quadrupled from 1990 to 2018. However, electricity losses are huge in comparison to the total produced and among the highest in the world ([32]: 17).[3] 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 the population increased by even more.

Water is relevant too to the issue of ***Food and Food Security***. There is

[2] Calculated from Indexmundi.com [29].

[3] Losses result from inefficient transmission (called technical loss) as well as the energy that is delivered to consumers but not charged, e.g., due to theft (known as non-technical loss) ([32]: 43).

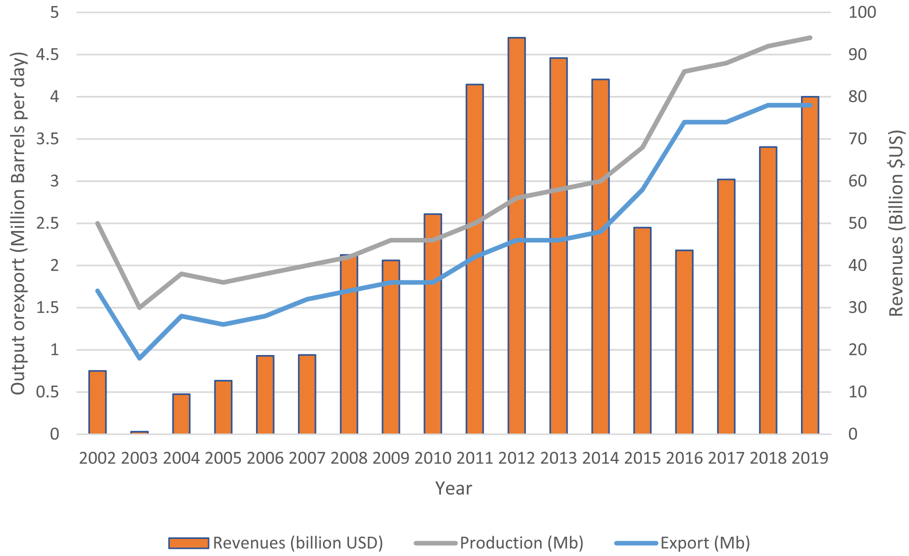

Fig. 1. Oil Production, Exports, and Revenues (2002-2019).
Sources: Gollob & O'Hanlon [23], IEA [32], OPEC [51]

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

Category Demand/Supply (cubic kilometers)
Domestic Use 5.0
Industrial 3.15
Evaporation from Dams 8.40
Restoring Marshes 11.0
Agriculture 42.0
Total estimated Demand 69.55
The estimated Supply 44.00

Source: Alwash et al ([5]: 14).

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

Category	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
Consumption of Industry	9053	11443	3304	5160	5030

Source: IEA [33]

variation in the definition of food security/insecurity. The definition developed by FAO in 1996 and 2002 (quoted in [80]: 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, USAID [77] defines food security as "both physical and economic access to sufficient food to meet dietary needs for a productive and healthy life." Food insecurity need not be the result of producing insufficient food, as food also can be purchased in world markets. Both domestic oil output, and hence revenues to import food, and agricultural activities can contribute to food security—or insecurity. Food security is thus linked to Iraq's agricultural and energy sectors.

Fig. 2 indicates declining employment in agriculture as a portion of the total and 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 associated with sanctions-induced labor flows in the macro-economy (see [85]: 221-2). Nevertheless, the overall trend is unmistakable and confirmed by FAO ([20]: 7) data that show the contribution of agriculture to GDP declining, to 4.8 percent and employment to 18.7 percent of the workforce in 2018. 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 sharply. Gibson et al ([21]: 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 decade also was characterized by the deterioration of irrigation networks, rising salinity and reduced land productivity, as cash-strapped Iraq attempted to increase agricultural output on 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 remain.

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 [84] and was among the highest in the Middle East region by 1990 ([28]: 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 [85]: 222-3). The removal of sanctions, renewal of oil exports and hence of investment funds did not presage a revival in agriculture. As Table 4 illustrates food output in constant $US declined from 1997 to 2017, while dependence on food imports, notably cereals, increased. Elevated food imports can be financed with oil exports but any disruption to output or decline in oil price potentially makes food imports vulnerable. The declining capacities of Agriculture and Water Resources ministries ([89]: 96); continued conflict that disrupts food distribution; climate change and soil and agricultural infrastructure deterioration that disproportionately affects the rural poor; as well as low water quality and sanitation all work to diminish the effects on food security of the oil facilitated rise in agricultural imports since 2003. Thus, four million

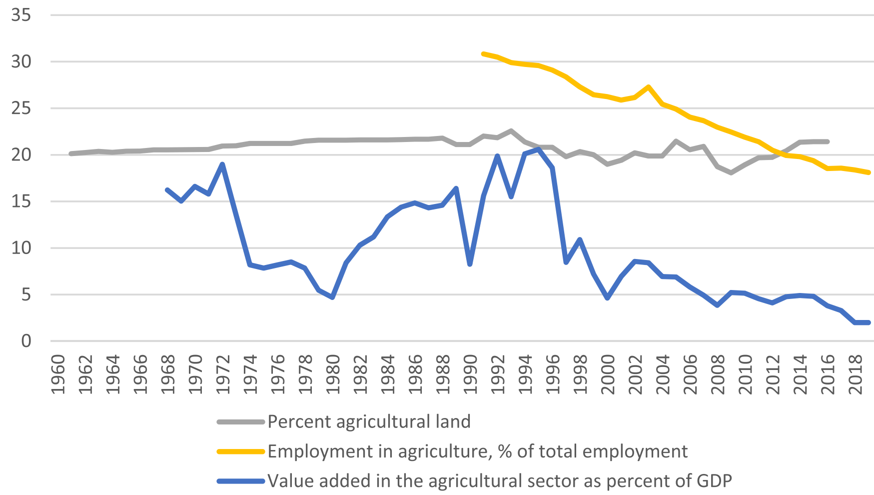

Fig. 2. Agricultural Output and Employment.
Source: theglobaleconomy.com; accessed October 19, 2020.

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 ([19]: 132)

Iraqis in 2017 are “vulnerable to food insecurity” ([76]: 4).

Because wheat and rice are water-intensive crops, importing these crops represents an import of ‘virtual water’ 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 output ([20]:13). According to Naima [[49]: 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 wheat and rice shown in Table 4 between 1997 and 2017. Domestic output capacity is 70 percent of the total wheat demand, which is six million tons ([20]:13).

Water scarcity has been compounded by policy distortions and wasteful irrigation methods; it is a binding constraint on food production and indirectly food security. Longstanding Ministry of Agriculture policy paid producers of water-intensive wheat, rice and maize prices that exceed international prices and provided subsidized inputs ([20]: 13), thus contributing to the water shortage. As Alwash [6] 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 [20]: 16) tends to waste water, in comparison to say drip irrigation, which however would require large investments in irrigation networks. Yet, the extensive use of flood irrigation tends to over-use water and contributes to soil salinity [41,71], reducing water availability for other purposes. The World Bank ([89]: 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 between 55 and 50 percent respectively, and by even more for maize ([31]: 30-31). The lack of water has forced the Iraqi government to change its agricultural plans by reducing cultivated areas: in July 2018, the Iraqi government banned corn production and restricted rice planting because of insufficient water [71].

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 ([80]: 2). 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 the utilizing of revenues from the sale of oil to purchase food on international markets, continuing the long-term trend of 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 recently evinced in the context of the Russia-Ukraine conflict).

We supplement our discussion with the use of two integrated WEF nexus indexes: the Pardee-RAND Food-Energy-Water (FEW) Security Index developed in 2016 and the WEF nexus index launched in 2019 and calculated on an annual basis. An obstacle to applying the WEF nexus approach is the lack of uniform data at the national level [43,53]. The development of a composite index using common measures is one way to overcome such difficulties of data and represents a practical response to moving from ‘nexus thinking’ to ‘nexus action’ [69]. Specifically with respect to the present study, changes in the value of sub-indexes uncover important changes in these sectors of water, energy, and food.

The Pardee-RAND FEW Security Index and the WEF nexus index are summarized in Table 5. 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

Table 5
WEF nexus Indexes for Iraq*

The Pardee-RAND Food-Energy Water Security Index (2016)* *	0.65	Water-Energy-Food nexus Index (2019)	48.2 Ranked 142/181	Water-Energy-Food nexus Index (2020)	50.3 Ranked 138/181	Water-Energy-Food nexus Index (2021)	49.3 Ranked 142/181
Water Sub-Indices		*Water Sub-Pillar*	*47.1*	*Water Sub-Pillar*	***51.9***	*Water Sub-Pillar*	*55.4*
Water Accessibility	*0.76*	Iraq ranked 151^{th} out of 181.		Iraq ranked 124^{th} out of 181.		Iraq ranked 114^{th} out of 181.	
Water Availability	0.86						
Water	1.00						
Adaptive	0.52						
Capacity							
Food Sub-Indices		*Food Sub-pillar*		*Food Sub-pillar*		*Food Sub-pillar*	
Food Accessibility	*0.45*	Iraq ranked 160^{th} out of 181.	*39.0*	Iraq ranked 153^{th} out of 181.	*40.8*	Iraq ranked 169^{th} out of 181.	*33.6*
Food Availability							
	0.27						
	0.74						
Energy Sub-Indices	*0.80*	*Energy Sub-pillar*	*58.6*	*Energy Sub-pillar*	*58.1*	*Energy Sub-pillar*	*58.9*
Energy Accessibility	0.97	Iraq ranked 75^{th} out of 181.		Iraq ranked 86^{th} out of 181.		Iraq ranked 85^{th} out of 181.	
Energy Availability	0.66						

*) The Pardee-RAND index refers to food-water-energy, while the other refers to water-energy-food; we follow the water-food-energy label in Table 4.
**) Although work on an update is forthcoming, no update to this index is available at this time.
Sources: Willis et al., [80]; WEF Nexus Index Organization [72].

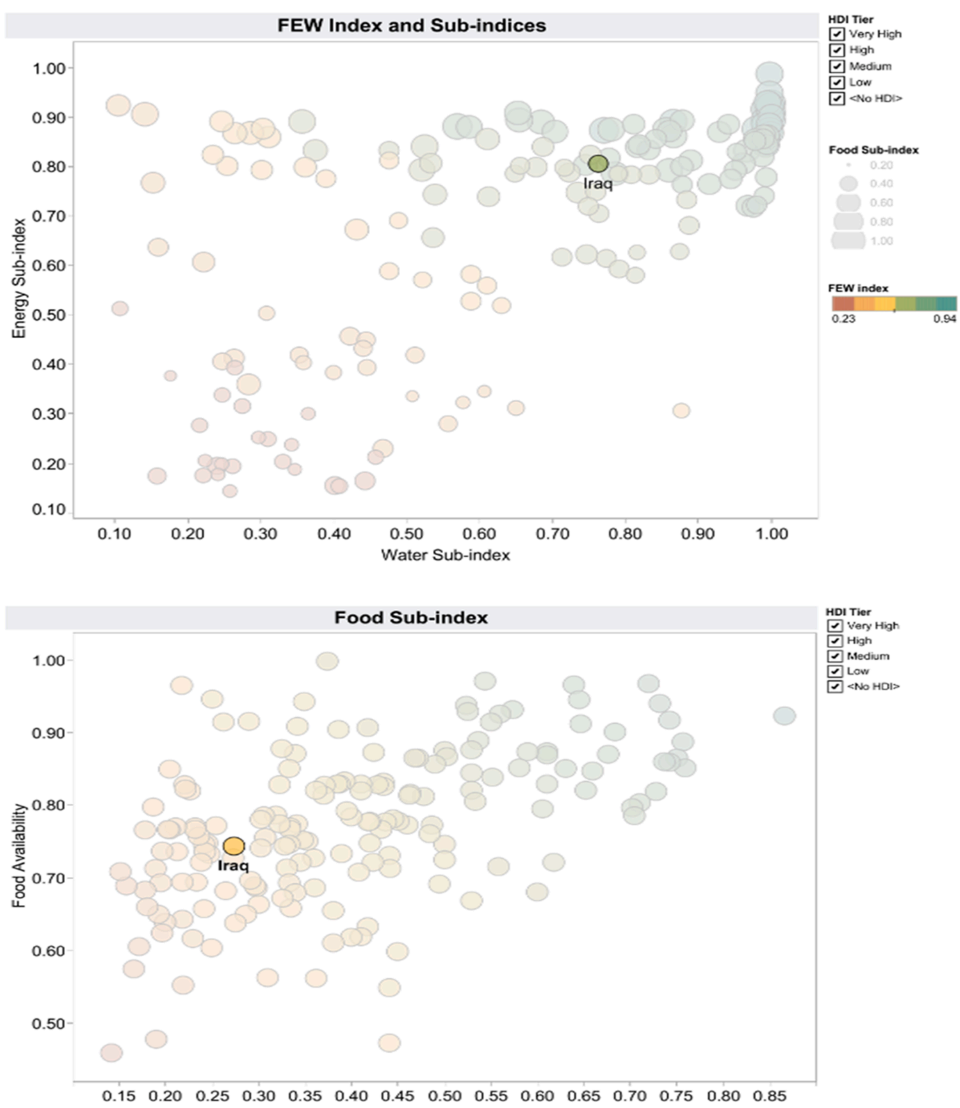

Fig. 3. The Pardee RAND Food-Energy-Water Index and Sub-indices for Iraq: FEW Index and Sub-indices; Food Sub-index; Energy Sub-index; and Water Sub-index. Source: Pardee-RAND Food-Energy-Water [54].

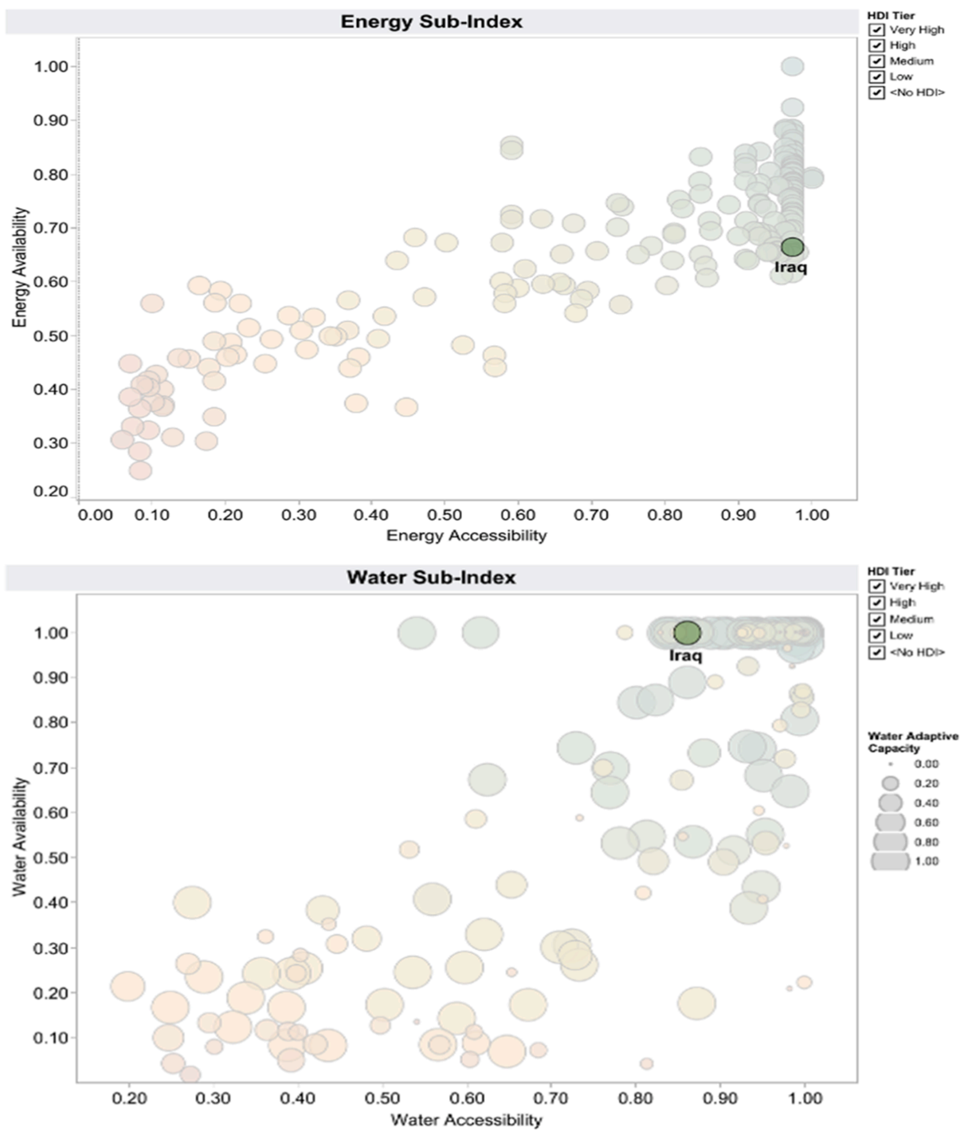

Fig. 3. (*continued*).

reflects the notion that human development depends to some extent on the availability of resources, and the second that it is not only the quantity of resources but also their distribution that accounts for development ([80]: 9). In addition, for the water sub-index, *adaptive capacity* represents the potential for cultivating new sources of water with domestically available sustainable resources (see [80], for detailed methodology). In addition, the WEF nexus index is an indication of a country's level of equitable access to and availability of the three resources. Covering 181 nations, this index is divided into three sub-pillars of water, energy, and food, each composed of relevant indicators, with scores ranging from 0 (lowest) to 100 (highest) (see Simpson et. al, [70], for detailed methodology).

We report Iraq's scores on the available indexes: the FEW Pardee-RAND Index for 2016 and the WEF nexus index for 2019, 2020 and 2021. The Pardee-RAND index gives Iraq a score of 0.65 out of one, 0.76, 0.45 and 0.80 respectively on water, food and energy sub-indexes. The WEF nexus indexes are 48.2 out of 100 for 2019, 50.3 for 2020 and 49.3 for 2021; for 2019, Iraq ranks 142 out of 181 countries overall, scoring 47.1, 39.0 and 58.6 for water, food, and energy sub-indexes; for 2020, Iraq ranks 138 out of 181 countries overall, scoring 51.9, 40.8 and 58.1 for the same sub-indexes; for 2021, Iraq ranks 142 out of 181 countries overall, scoring 55.4, 33.6 and 58.9. While beyond the scope of this paper to detail, we note that contrasting methodologies and data sources account for the divergence in the indexes. Within the WEF index, the improvement between 2019 and 2021 in the water sub index is likely due mostly to better access to drinking water and sanitation services, given the specific composition of the index (see [72]), while the decline in the food sub-index is associated with a spike in malnourishment from 2020 to 2021, and possibly covid-19 related. This decline within the WEF index underlines our earlier discussion of food insecurity in Iraq; indeed, both indexes throughout all years score the food sub-index lowest.

A deeper look at the Pardee-RAND index illustrates an important aspect of this food insecurity. In general, the country-specific values of the integrated index are correlated with the corresponding country-specific indicators of development, such as the Human Development Index (HDI), as shown below in Fig. 3. ([80]: 35); the Pardee-RAND FEW Index for Iraq is 0.65, while its HDI is 0.64 ([80]: 45). An important 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 accessed. This underlines the point about the relatively poor performance of the food sector, as well as the point made earlier concerning stubborn levels of malnourishment despite increasing aggregate supplies of food and is consistent with research that highlights the weak correspondence between hunger and aggregate food supply (see [64]). 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. In contrast in energy, access exceeds availability (0.97 versus 0.66), which is consistent with the complaints of almost all Iraqis about electrical power outages. Willis et al. [[80]: 36-37] note two further findings. 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. And, while there is a correlation between HDI and the FEW Index, there is no one-to-one correspondence, meaning that resources place different limits on development across countries.

5. Concluding remarks

Two chief points emerge in this article. First, given declining levels of water quality and quantity, increases in production of both food and oil are unsustainable with present production methods. Diminishing water for food production implies the necessity for rising oil output, and hence revenues, to pay for imports of food, although the analysis above of the Pardee-RAND index highlights how conflict can hinder food security (or accessibility) even when revenues are able to purchase food imports (or availability). Proposed increases in oil output will thus have to consider water availability as a limiting factor. Without drastic changes in agricultural methods and technology (impossible in the short term), redirection of water from agriculture to oil is likely to induce reductions in agricultural output as well as employment, with agriculture continuing to engage a large portion of the labor force. In short, it is no longer possible for policy to be "organized along sectoral lines" that lacks coordination ([17]: 8). Second, there is growing evidence that the water issues in Iraq have been contributing to political instability, with protesters demanding clean water and deficient water contributing to rural to urban migration. That is, both structural and political factors necessitate a radical rethinking and restructuring of the relationships between water, energy and food production.

In what follows we categorize and briefly note potential policies to address Iraq's WEF predicament. We follow Giovanis and Ozdamar [22] in conceptualizing policies designed to overcome internal barriers to water scarcity and others 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, we can distinguish between technical solutions and administrative (see [56]).

In Iraq, as we show water use in agriculture remains wasteful and subsidy policy irrational, adding to the water shortage; gas flaring in oil production is wasteful and adds to Iraq's already polluted natural environment. Technical solutions are needed, including 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, and rainwater and wastewater harvesting (inexpensive and less capital-intensive than desalination) (see [56]: 66). This requires long-term investments in new technologies, sustainable green solutions, efficient and effective modern systems of water resources management to mitigate and adapt to climate change, and in reclaiming 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 fluctuating oil prices and hence oil revenues and long-term institutional decline, including that of Iraq's ministries, these technical and administrative measures will be challenging to undertake.

Policies geared towards overcoming external barriers require Iraq to engage constructively with neighbors about downstream declines in water flow from the Tigris and Euphrates. The UN Law of Non-Navigational Uses of International Watercourses came into force in 2014; Iraq and Syria have ratified the convention, but Turkey has continued to oppose it ([22]: 3). Even with Turkey's political and economic upstream advantage over water rights, it is possible, for Iraq and Syria to engage with Turkey based on joint interests; popular protest and political instability in downstream countries are surely of concern to Turkey.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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