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Characterising the water-energy-food nexus in Kuwait and the Gulf region

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KUWAIT PROGRAMME

Grantham Research Institute on Climate Change and the Environment

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Abstract

Economic challenges as a result of the recent fluctuations in oil prices have exposed unprecedented risks to Kuwait and the other Gulf Cooperation Council (GCC) states, including securing long-term sustainable access to and use of water and food resources. The strong interlinkages between the availability of water, energy, and food resources have been termed the Water–Energy–Food (WEF) nexus. Here, we characterise the nexus for Kuwait across different spatial scales, reviewing available literature and focussing on empirical data from the most widely used global and regional databases on water, energy and food. While there are certainly issues of water scarcity, trade-offs between sectors at the domestic level are limited. At the international scale, high oil export revenues shield Kuwait from the immediate impacts of higher prices in food imports, but they expose Kuwait to water scarcity and food production risks in other countries. At the global scale, we consider climate change mitigation linkages with Kuwait's WEF nexus. Whilst there is great uncertainty about future international climate policy and its implications for oil and gas revenues in Kuwait, our analysis illustrates how implementation of policy measures to account for the social costs of carbon could be significant.

Water, Energy and Food Security in the Gulf Region

Despite the economic prosperity that Kuwait and the other Gulf Cooperation Council (GCC) states enjoy, economic challenges as a result of the recent fluctuations in oil prices have exposed unprecedented risks, including securing long-term sustainable access to and use of water and food resources. The GCC includes Kuwait, Saudi Arabia, the United Arab Emirates, Qatar, Bahrain and Oman, and is characterised by a hyper-arid climate. These states rank among the lowest in the world in terms of freshwater resources and soil fertility, but among the highest in water, energy and food consumption, and emissions of greenhouse gases (particularly CO2). In recent years, lower oil revenues have highlighted the vulnerability of GCC countries and their reliance on a single export product. Although some of the decline in net oil export revenue is a result of a decrease in production and exports, the decrease in crude oil prices accounted for most of the decline.[1] This has led to significant budget deficits in recent years in several GCC states, including Kuwait, where the government's deficit reached 16.5 percent of its Gross Domestic Product (GDP) in 2016.[2]

None of the GCC states is self-sufficient in food and water; all rely heavily on imports (food products and virtual water in food products) from other countries and seawater desalination to sustain their needs. Harsh climatic conditions and scarce water resources have been major impediments for the development of the agriculture and water sector. In Kuwait, with a current population of about 4 million, the total renewable water resources are as low as 5 m^3/capita-year. In comparison, a country with renewable water reserves below 1000 m^3/capita-year is considered 'water scarce' under widely used definitions. None of the GCC states have water resources greater than 500 m^3/capita-year. To meet their freshwater needs, GCC states have developed into world leaders in the application of seawater desalination technology with an installed desalination capacity in 2012 of 18 million m^3 per day of freshwater in operation (planned to expand by 40 percent by 2020). Seawater desalination is, in turn, highly energy intensive and a costly process that requires 2.6–8.5 kWh/m^3 depending on the desalination technology used.[3]

Food security through conventional domestic agriculture has been deemed unsustainable and an unattainable goal due to environmental and water resource constraints.[4] Any meaningful attempt to support domestic agricultural production is thus strongly dependent on the availability of energy (i.e., burning more oil, and in the future possibly solar) to desalinate seawater for irrigation, using highly controlled environmental conditions in closed agricultural systems. Desalinated seawater and brackish groundwater have been

[1] 'Country Analysis Brief: Kuwait', *US Energy Information Administration, EIA* (2016). Available at https://www.eia.gov/beta/international/analysis.php?iso=KWT (accessed 27 November 2019).

[2] 'CIA World Factbook', *CIA Public Library* (n.d.). Available at https://www.cia.gov/library/publications/the-world-factbook/geos/print_ku.html (accessed 27 November 2019).

[3] 'Renewable Energy in the Water, Energy, and Food Nexus', *International Renewable Energy Agency, IRENA* (January 2015). Available at https://www.irena.org/publications/2015/Jan/Renewable-Energy-in-the-Water-Energy--Food-Nexus (accessed 9 December 2019).

[4] 'FAOSTAT statistics database', *Food and Agriculture Organization, FAOSTAT* (n.d). Available at http://www.fao.org/faostat/en/#country/118 (accessed 9 December 2019).

extensively used for supplemental irrigation in protected greenhouse production, which locally has contributed to soil salinisation,[5] but the techniques are currently too expensive to be used for staple crops. GCC states therefore secure food resources by importing food from international markets, made possible by their ability to maintain their economic wealth through oil exports.

While oil export revenue has been decreasing, energy consumption of GCC residents has steadily increased. According to the World Bank, in 2014, five out of six GCC states were in the top 12 highest energy consumers on a per capita basis, with Kuwait the world's seventh highest. Kuwait's average consumption of 14.9 MWh/capita is equivalent to 9,708 kg/capita of oil per year.[6] About 34 percent of the national energy is generated using natural gas fuel which Kuwait started importing a few years ago to cope with peak electricity demands, while the remainder is generated using crude oil. Insufficient domestic production and imports of natural gas to meet peak electricity demand in the summer months have resulted in frequent blackouts and led to the power sector relying on more expensive heavy fuel oil and crude oil to generate electricity.

The deep interlinkages between the availability of water, energy, and food resources have been termed the Water–Energy–Food (WEF) nexus. The term WEF nexus describes interdependencies and the way activities and/or policies in one sector affect others (see Figure 1, modified for the Middle East and Kuwait contexts). At the core of nexus debates are natural resources scarcities and the recognition that water, energy, food and other resources are interlinked, with resource use and availability being interdependent.[7] As a result of these interdependencies, decision-makers face the significant challenge of accounting for synergies and potential trade-offs between water, energy, food and the environment at multiple spatial and temporal scales.[8] A nexus approach can help focus on increasing resource use efficiency by seeking to maximise the benefits of the scarcest resource and through cooperation produce cross-sector benefits.[9]

[5] 'AQUASTAT statistics database', *Food and Agriculture Organization, AQUASTAT*. (n.d.). Available at http://www.fao.org/nr/water/aquastat/countries_regions/KWT (accessed 9 December 2019).

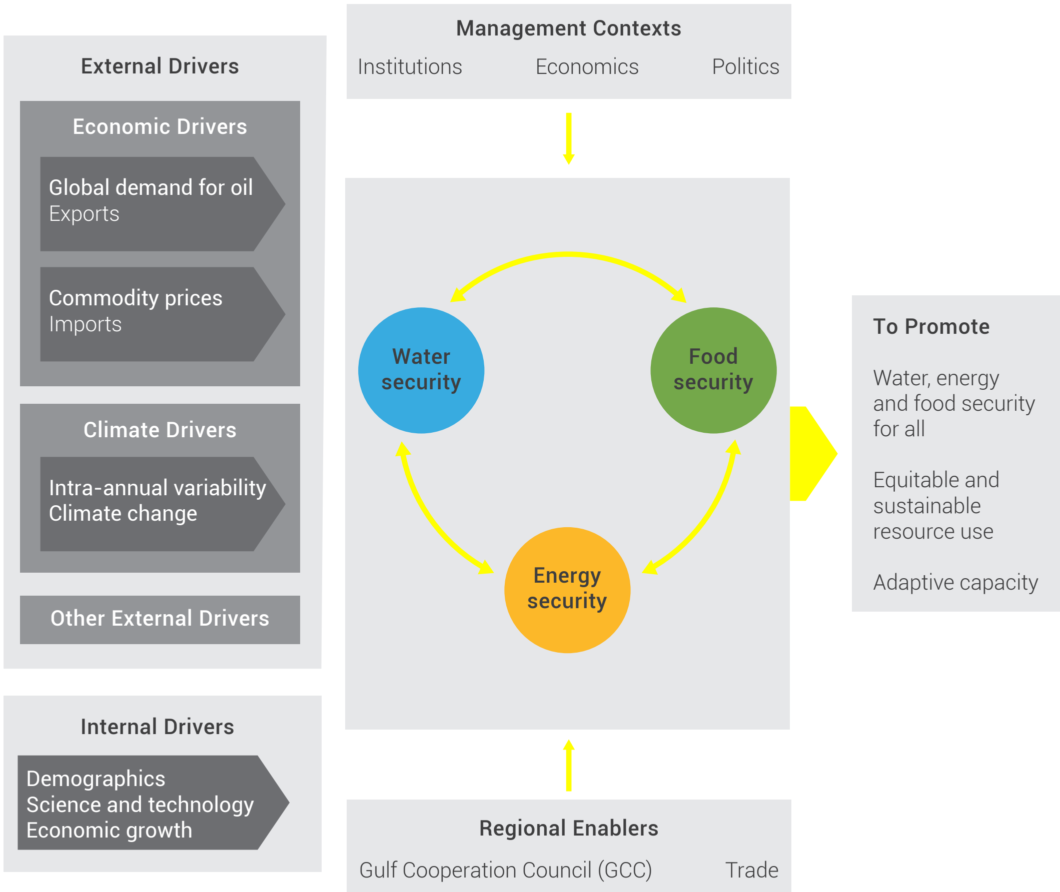
[6] 'World Bank Database', *World Bank*. (n.d.). Available at https://data.worldbank.org/country/kuwait (accessed 9 December 2019).

[7] Mairi Dupar and Naomi Oates, 'Getting to grips with the Water–Energy–Food "nexus"', *Climate and Development Knowledge Network* (2012). Available at https://cdkn.org/2012/04/getting-to-grips-with-the-water-energy-food-nexus (accessed 10 July 2015); Hayley Leck, Declan Conway, Michael Bradshaw and Judith Rees, 'Tracing the water–energy–food nexus: description, theory and practice', *Geography Compass* 9/8 (2015), pp. 445–60.

[8] Mark Howells and H-Holger Rogner, 'Water-energy nexus: Assessing integrated systems', *Nature Climate Change* 4/4 (2014), p. 246; Jianguo Liu et al., 'Systems integration for global sustainability', *Science* 347/6225 (2015).

[9] Claudi Ringler, Anik Bhaduri and R. Lawford, 'The nexus across water, energy, land and food (WELF): potential for improved resource use efficiency?', *Current Opinion in Environmental Sustainability* 5/6 (2013), pp. 617–24.

Figure 1. Modified version of the nexus framework of Conway et al.,[10] based on Hoff,[11] integrating global drivers with fields of action related to the GCC.[12]



Aims and Methodology

The aims of this working paper are to; (1) investigate existing approaches to assess the WEF nexus and their relevance for understanding the nexus in Kuwait and the GCC; (2) highlight the unique characteristics of the nexus in the GCC; and (3) characterise in a quantitative fashion the WEF nexus for Kuwait.

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10 Declan Conway et al., 'Climate and southern Africa's Water–Energy–Food nexus', *Nature Climate Change* 5/9 (2015), pp. 837–46.

11 Holger Hoff, 'Understanding the nexus. background paper for the Bonn2011 Conference: the water, energy and food security nexus', *Stockholm Environment Institute* (Stockholm, 2011).

12 Here, important drivers are global demand, price of oil and prices of other imported commodities. This is considered as a specific 'trade scale' in our analysis. GCC climate drivers are, for example, prolonged heat waves affecting energy usage and water demand.

Results are based on a literature review of 26 review and conceptual papers, out of a total sample of 473, expanded with both peer reviewed and grey literature on the Gulf and, to cast the net wider, the Middle East (n=22). To quantify Kuwait's nexus, global and regional datasets such as UNComtrade, Aquastat and the IEA World Summary Energy Balance were complemented with national reports on resource use.

To date, nexus interlinkages have been poorly characterised for the GCC states; one likely reason being the abundance of oil which obscures any shortages in other sectors. As a result, there exist significant knowledge gaps in the way the WEF nexus of each state in the GCC is **domestically** dependent on its economic performance, **regionally** interdependent on each other's WEF nexus and **globally** affected by the impact of climate variability and change on the world's food producers. A more detailed assessment of trade-offs and synergies could highlight opportunities for more sustainable resource use.

A New Paradigm: The Water–Energy–Food Nexus

In recent years, the WEF nexus concept has become a dominant framework to assess resource use, scarcity and interconnectedness. With its roots in the debate of the 1970s on 'The Limits to Growth', the nexus concept has gained traction after a major WEF nexus conference in 2011 in Bonn adding new momentum to earlier debates on resource scarcity. In parallel, the Planetary Boundaries framework emerged,[13] which puts resource scarcity in a global perspective by proposing quantitative global limits to the anthropogenic perturbation of crucial Earth system processes. While the Planetary Boundaries concept is not mentioned explicitly in the 2030 Agenda for Sustainable Development goals (SDGs), all nine of its system processes are addressed in the SDGs in some way, either as the focus of a goal or included in specific targets.[14] Where Planetary Boundaries set the thresholds that should not be exceeded for a 'planetary safe operating space' and SDGs prioritise and set ambition levels starting from the global level, the nexus concept specifically addresses the trade-offs and synergies that arise at the more regional and domestic levels. Generally, there is no one global definition of the nexus. It can be seen as an analytical approach, a governance framework or a discourse.[15] And while the conceptual debate on the nexus advances, its quantification and application as a management and decision-making tool are still in their early stages.

Which **elements** best describe the nexus and where to draw its boundaries are still topics of discussion. Many approaches and reviews on quantification of the nexus synthesise results for linkages in two sectors, i.e. water–energy, energy–food etc (see Figure 2).

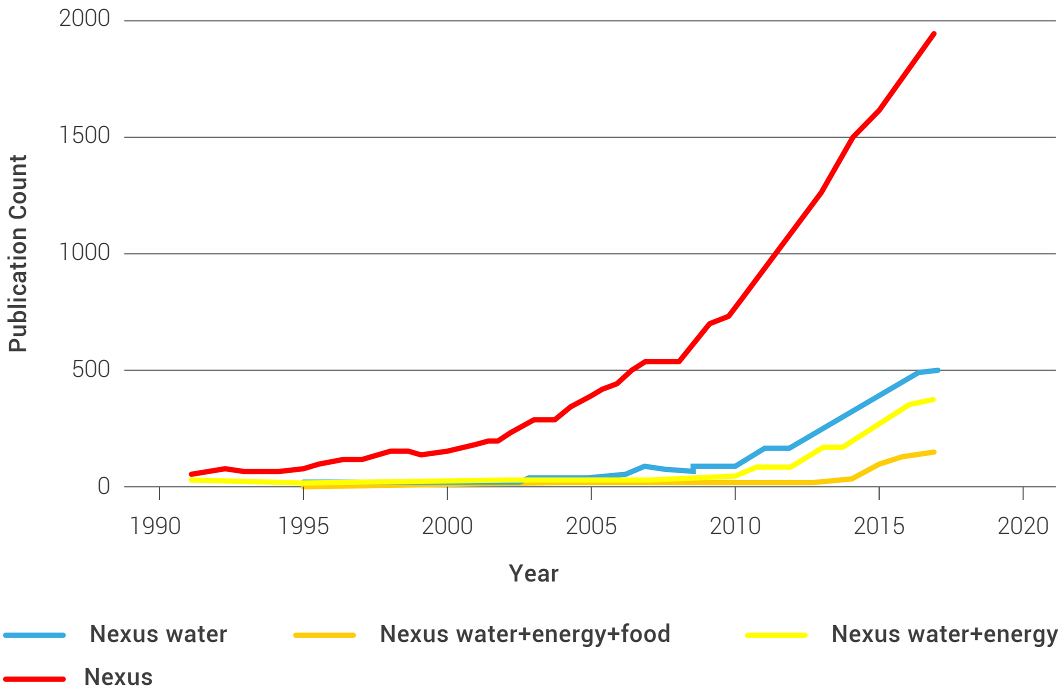
[13] Johan Rockström et al., 'Planetary boundaries: exploring the safe operating space for humanity'. *Ecology and Society* 14/2 (2009), p. 32.

[14] Tiina Häyhä, et al., 'From Planetary Boundaries to national fair shares of the global safe operating space — How can the scales be bridged?', *Global Environmental Change* 40 (2016), pp. 60–72.

[15] Marko Keskinen et al., 'The Water–Energy–Food Nexus and the Transboundary Context: Insights from Large Asian Rivers', *Water* 8/5 (2016).

Albrecht et al.[16] found from 245 papers reviewed, only a few examples of more holistic methods analysing a nexus of more than two elements, like the 'Water–Energy–Food nexus'. While the term 'Water–Energy–Food nexus' has by far received the most attention and traction, alternative versions of nexus sectors notably include climate change, land and soil, or water quality aspects. Allan adds the WASH supply chain (water and sewage services) to the nexus.[17] Several studies caution that terrestrial–marine linkages are often overlooked,[18] which can be important, since coastal ecosystems and fisheries are influenced by flows of nutrients, sediment and salt. Especially the latter, the link between desalination, climate change and increased salinity in the Gulf, gets increased attention.

Figure 2. Development of interest in the nexus, based on count of publications per year (SCOPUS)



[16] Tamee A. Albrecht, Arica Crootof and Christopher A. Scott, 'The Water–Energy–Food nexus: A comprehensive review of nexus-specific methods', *Environmental Research Letters* (2018).
[17] Tony Allan, 'Water, Food and Trade as an Element of the Water–Energy–Food Nexus in the MENA Region', in Adnan Badran et al. (eds), *Water, Energy & Food Sustainability in the Middle East - The Sustainability Triangle* (Springer, 2017), pp. 45–56.
[18] Aiko Endo et al., 'A review of the current state of research on the water, energy, and food nexus', *Journal of Hydrology: Regional Studies* 11 (2017), pp. 20–30.

Broader **scales** beyond Water–Energy–Food have also been identified. Allan, Keulertz and Woertz[19] describe the conceptual emergence of the nexus along the lines of two 'sub-nexuses' on water–food–trade and energy–climate change, merging into the 'grand nexus' of Water–Energy–Food, in which the proportions of energy and water used in different economic sectors across the globe, in regions or for individual countries, could be identified. Key differences between these two sub-nexuses are their supply chains and the type of stakeholders involved: smallholder farmers are often central in the water–food–trade nexus while big oil companies dominate the energy–climate change nexus. To fully consider energy requires quantifying not only energy consumption or supply, but also the CO2 emissions generated.[20] Some studies include climate as a separate, fourth nexus element[21] and some also model its impacts on the WEF nexus.[22]

A number of review studies are motivated by the question of the **nexus' added value**. They find the nexus approach driven by increasing competition for resources and rising scarcity, which intensifies resource linkages.[23] Other explanations for adoption of nexus approaches include the insufficiency of single sector-focused resource management strategies.[24] Comparing a nexus with non-nexus approaches using linear optimisation, a study by El-Gafy et al.[25] finds that considering the full nexus leads to better cropping pattern results than policies focused on one sector only. Increasingly WEF nexus goals are linked to the SDGs,[26] adding value by linking to major policy processes.

With regards to its **integrative power**, many place the nexus approach in the tradition of other integration approaches such as Integrated Water Resource Management (IWRM), which – as its name suggests – was primarily water-centred. Some are critical, seeing the nexus approach as a mere continuation of the formerly failed IWRM paradigm.[27] However,

[19] Tony Allan, Martin Keulertz and Art Woertz, *The water–food–energy nexus: an introduction to nexus concepts and some conceptual and operational problems* (Taylor & Francis, 2015).

[20] Andre Daccache, et al., 'Water and energy footprint of irrigated agriculture in the Mediterranean region', *Environmental Research Letters* 9/12 (2014).

[21] Caroline King and Hadi Jaafar, 'Rapid assessment of the water–energy–food–climate nexus in six selected basins of North Africa and West Asia undergoing transitions and scarcity threats', *International Journal of Water Resources Development* 31/3 (2015), pp. 343–59.

[22] Yi-Chen Ethan Yang et al., 'Modeling the Agricultural Water–Energy–Food Nexus in the Indus River Basin, Pakistan', *Journal of Water Resources Planning and Management* 142/12 (2016).

[23] Mohammad Al-Saidi and Nadir Ahmed Elagib, 'Towards understanding the integrative approach of the water, energy and food nexus', *Sci Total Environ* 574 (2017), pp. 1131–39.

[24] Mike Muller, 'The "Nexus" as a Step Back towards a More Coherent Water Resource Management Paradigm', *Water Alternatives* 8/1 (2015), p. 20.

[25] Inas El-Gafy, Neil Grigg and Reagan Waskom, 'Water-Food-Energy: Nexus and Non-Nexus Approaches for Optimal Cropping Pattern', *Water Resources Management* 31/15 (2017), pp. 4971–80.

[26] Holger Schlör, Jürgen-Friedrich Hake and Sandra Venghaus, 'An Integrated Assessment Model for the German Food-Energy-Water Nexus', *Journal of Sustainable Development of Energy, Water and Environment Systems* 6/1 (2017), pp. 1–12; Carlo Giupponi and Animesh Gain, 'Integrated spatial assessment of the water, energy and food dimensions of the Sustainable Development Goals', *Regional Environmental Change* 17/7 (2016), pp. 1881–93.

[27] Dennis Wichelns, 'The Water–Energy–Food nexus: Is the increasing attention warranted, from either a research or policy perspective?', *Environmental Science & Policy* 69 (2017), pp. 113–23.

most studies do acknowledge the clarity of the nexus approach when it comes to boundaries of integration.[28] In the GCC, and specifically in Kuwait, IWRM has probably had less appeal due to the provision of water being more a technical water supply and reuse challenge rather than a resource management issue. Framing water challenges alongside energy and food challenges opens up new perspectives on sustainability.

Understanding the Nexus Concept in the Gulf Region

The low number of nexus studies focusing on the Middle East highlights the limited development of the nexus concept for the region. Allan[29] states that the nexus concept is not yet widely used for the Middle East region (or elsewhere) and that it needs to be effectively linked to market systems and supply chains to provide greater analytical strength.

As regards the **energy component** of the nexus, oil naturally plays an important role in the region and especially in the Gulf states. Focus on the nexus has been primarily food and water driven, though, which can be explained by the fact that those are the region's two major scarce resources. For Saudi Arabia, Grindle et al.[30] present data on the water embedded in different agricultural products. They highlight that energy use for agricultural production via water would increase dramatically when shifting from groundwater pumping to desalination or brackish water, as treatment of water would be much more energy intensive. Siddiqi et al.[31] illustrate the water requirements of oil production and energy generation, as well as the energy need for water pumping and desalination. Keulertz and Woertz explicitly address the importance that the energy exports had for directing GCC countries towards food imports as an alternative to improving their water, energy and food resource management.[32] With energy (such as diesel oil) being such an important cost for producing food in many agricultural systems globally[33] and thereby an important factor in the price of food commodities, this creates an interesting feedback between the GCC states' oil exports and their food imports.

A general observation is that **the trade scale of the nexus**, mainly in the form of virtual water as a solution to nexus challenges, is more pronounced and important in the Middle

[28] Ximing Cai et al., 'Understanding and managing the food-energy-water nexus – opportunities for water resources research', *Advances in Water Resources* 111 (2018), pp. 259–73.
[29] Allan, 'Water, Food and Trade as an Element of the Water–Energy–Food Nexus in the MENA Region'.
[30] Arani Kajenthira Grindle, Afreen Siddiqi and Laura Diaz Anadon, 'Food security amidst water scarcity: Insights on sustainable food production from Saudi Arabia', *Sustainable Production and Consumption* 2 (2015), pp. 67–78.
[31] Afreen Siddiqi and Laura Diaz Anadon, 'The water–energy nexus in Middle East and North Africa', *Energy Policy* 39/2 (2011), pp. 4529–40.
[32] Martin Keulertz and Eckart Woertz, 'Financial challenges of the nexus: pathways for investment in water, energy and agriculture in the Arab world', *International Journal of Water Resources Development* 31/3 (2015), pp. 312–25.
[33] Morgan Bazilian et al., 'Considering the energy, water and food nexus: Towards an integrated modelling approach', *Energy Policy* 39/12 (2011), pp. 7896–906.

East sample compared to the general WEF nexus literature.[34] This can be explained with the relative importance of agricultural imports for the region and the severe water scarcity many Middle Eastern countries already face. Grindle et al.[35] approach virtual water from an agricultural perspective, looking at virtual water embedded in food trade. They compare food trade and virtual water imports with direct foreign investment in land for agricultural development, which they see as promising for optimising sustainability of global food production, but also as a potential source of conflict. A more complete picture of virtual water in the Middle East region is presented by Antonelli and Tamea,[36] who use FAOSTAT data to analyse historic trade over a 25-year period for 309 products and calculate their virtual water content based on a global assessment for the water content of commodities.[37] They distinguish between green and blue virtual water[38] and find that green water imports are especially important for the Middle East region in the form of food commodities, whereas virtual water exports from Middle East countries contain important amounts of blue water. This study also looks at virtual water through an agriculture lens, largely neglecting the energy use associated with virtual water.

Climate can affect both availability and demand for resources and it will impact Kuwait and the GCC directly and indirectly; through continued warming and through the effects of action on global mitigation. Attempts to reduce climate emissions in order to achieve the ambitions to combat climate change as expressed in the Paris Agreement or to account for the social cost of carbon will influence demand for oil – or its price. This is likely to have a strong influence on synergies and trade-offs in the WEF nexus in the GCC. Apart from some mention of possible impacts on resource availability in the Gulf, especially water,[39] we did not find any Middle East nexus study explicitly addressing this climate mitigation

[34] Allan, 'Water, Food and Trade as an Element of the Water–Energy–Food Nexus in the MENA Region'; Kajenthira et al., 'Food security amidst water scarcity'; Marta Antonelli and Stefania Tamea, 'Food-water security and virtual water trade in the Middle East and North Africa', *International Journal of Water Resources Development*, 31/3 (2015), pp. 326–42.

[35] Grindle et al., 'Food security amidst water scarcity'.

[36] Antonelli and Tamea, 'Food-water security and virtual water trade in the Middle East and North Africa'.

[37] Mesfin Mekonnen and Arjen Ysbert Hoekstra, 'The green, blue and grey water footprint of farm animals and animal products', *UNESCO-IHE Institute for water Education Delft* (2010); Mesfin Mekonnen and Arjen Ysbert Hoekstra, 'The green, blue and grey water footprint of crops and derived crop products', *Hydrology and Earth System Sciences* 15/5 (2011), pp. 1577–600.

[38] Green water originates from precipitation, stored in the root zone of the soil and evaporated, transpired or incorporated by plants. It is particularly relevant for agricultural, horticultural and forestry products. Blue water has been sourced from surface or groundwater resources. It can be evaporated, transpired or incorporated by plants, but part will be returned to a (ground)water body at a different time. Irrigated agriculture, industry and domestic water use can each have a blue water footprint.

[39] Allan, 'Water, Food and Trade as an Element of the Water–Energy–Food Nexus in the MENA Region'; Rana El Hajj et al., 'Enhancing regional cooperation in the Middle East and North Africa through the Water–Energy–Food Security Nexus', *Policy Brief* (2017), pp. 331–40; Peter Rogers, 'The Triangle: Energy, Water & Food Nexus for Sustainable Security in the Arab Middle East', in Adnan Badran et al. (eds), *Water, Energy & Food Sustainability in the Middle East - The Sustainability Triangle* (New York: Springer International Publishing, 2017), pp. 21–44.

component. Swain and Jägerskog touch upon it,[40] placing climate change impacts in a broader security perspective, and address the risks from shifts in the global supply of oil and gas (i.e. new gas explorations in the Mediterranean and elsewhere) and how this might threaten the income sources that most of the Gulf states currently rely on. However, they do not make a direct connection between climate mitigation and the search for alternative renewable sources of energy.

In comparison with the main empirical sample analysed, **methodologies** applied to the nexus in the Middle East use relatively more qualitative approaches and discuss the nexus conceptually.[41] Regarding the use of data, the Middle East literature sample contains few studies that use time-series data beyond the merely descriptive. Where quantitative methods are applied, it is often a simple quantification of two sector linkages.[42] Descriptive reports summarising available data[43] and results of conferences are also presented,[44] which provide insights on the current nexus debates in the Middle East region. More elaborate quantitative analyses include a life cycle analysis (LCA) model,[45] which is based on several sub-system life cycle inventory (LCI) models. Grindle et al. use a water footprint approach with energy input analysis, combined with assessments of virtual water trade and foreign direct investment for food production.[46] The WEF Nexus Tool 2.0 has been developed as a scenario-based, integrated framework and applied to Qatar.[47]

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[40] Ashok Swain and Andres Jägerskog, *Emerging security threats in the Middle East: the impact of climate change and globalisation* (Lanham, Maryland: Rowman & Littlefield, 2016).

[41] Allan, 'Water, Food and Trade as an Element of the Water–Energy–Food Nexus in the MENA Region'; King and Jaafar, 'Rapid assessment of the water–energy–food–climate nexus in six selected basins of North Africa and West Asia undergoing transitions and scarcity threats'; Keulertz and Woertz, 'Financial challenges of the nexus'; Rogers, 'The Triangle'; Aysegül Kibaroglu and Sezin Iba Gürsoy, 'Water–energy–food nexus in a transboundary context: the Euphrates–Tigris river basin as a case study', *Water International* 40/5-6 (2015), pp. 824–38; Najmedin Meshkati et al., 'People-Technology-Ecosystem Integration: A Framework to Ensure Regional Interoperability for Safety, Sustainability, and Resilience of Interdependent Energy, Water, and Seafood Sources in the (Persian) Gulf', *Hum Factors* 58/1 (2016), pp. 43–57; Nadim Farajalla, Patricia Haydamous and Rana El Hajj, 'Water, Energy, Food Nexus: An outlook on public institutions in Lebanon', *AUB Policy Institute* (2016).

[42] Siddiqi and Anadon, 'The water–energy nexus in Middle East and North Africa'; Samer Talozi, Yasmeen Al Sakaji and Amelia Altz-Stamm, 'Towards a water–energy–food nexus policy: realising the blue and green virtual water of agriculture in Jordan', *International Journal of Water Resources Development* 31/3 (2015), pp. 461–82.

[43] Maria Martens, 'Food and Water Security in the Middle East and North Africa', *NATO Parliamentary Assembly Special Report* (2017).

[44] Thinesh Kumar Paramasilvam, 'Report: Emerging issues facing the water–energy–food nexus in the Middle East and Asia', *International Journal of Water Resources Development* 32/6 (2016), pp. 1016–9; 'Emerging Issues Facing the Water- Energy-Food Nexus in the Middle East and Asia', *King Abdullah Petroleum Studies and Research Center* (2016); 'Dialogue Snapshot - The Water Energy Food Nexus: An Integrated Approach to the Middle East Water Challenge', *The Holling Centre* (2016).

[45] Tareq Al-Ansari et al., 'Integration of greenhouse gas control technologies within the energy, water and food nexus to enhance the environmental performance of food production systems', *Journal of Cleaner Production* 162 (2017), pp. 1592–606; Tareq Al-Ansari, 'Development of the Energy, Water and Food Nexus Systems Model in Department of Earth Science and Engineering', *Imperial College London* (2016).

[46] Grindle et al., 'Food security amidst water scarcity'.

[47] Bassel T. Daher and Rabi H. Mohtar, 'Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative

Our review suggests that preferences and **economic decision-making** processes need to be more adequately represented in models and approaches.[48] Incorporating stakeholders' decisions and human behaviour in models is a major challenge.[49] In process systems engineering, multi-stakeholder models have been developed to address this problem, often using game-theoretic approaches.[50] For energy systems' impacts on water consumption and food production, Bieber et al. develop and apply an agent-based model, which does incorporate human behaviour and decisions.[51] In this context, the distinctive character of Kuwait's political economy as a 'super rentier state',[52] where the economy relies predominantly on rents from oil extraction and both taxation and political representation are largely absent, needs to be recognised as it strongly determines nexus resource allocations within sectors and society, and skew the political economy of decision-making.[53] The role of resource subsidies in the social contract (cheap water, energy and food) in legitimising non-democratic governance constrains the political incentives and decision-making space for WEF choices.

Finally, **institutional and governance aspects** of the nexus remain under-researched,[54] even though many studies highlight the need for such research.[55] Calls to better connect the results of nexus assessments to policy goals, for instance the SDGs,[56] are beginning to appear.[57] An interesting observation is that governance and policy seem to receive more attention in the Middle East nexus literature compared to the global sample. A range of studies discusses geopolitical implications and regional security issues,[58] political relations between countries and stakeholders,[59] the local context of the nexus[60] and the

resource planning and decision-making', *Water International* 40/5-6 (2015), pp. 748–71.

48 Catherine L. Kling et al., 'Integrated Assessment Models of the Food, Energy, and Water Nexus: A Review and an Outline of Research Needs', *Annual Review of Resource Economics* 9 (2017), p. 21.

49 Paul Faeth and Lars Hanson, 'A research agenda for the energy, water, land, and climate nexus', *Journal of Environmental Studies and Sciences* 6/1 (2016), pp. 123–6.

50 Daniel J. Garcia and Fengqi You, 'The Water–Energy–Food nexus and process systems engineering: A new focus', *Computers & Chemical Engineering* 91 (2016), pp. 49–67.

51 Niclas Bieber et al., 'Sustainable planning of the energy-water-food nexus using decision making tools', *Energy Policy* 113 (2018), pp. 584–607.

52 Courtney Freer, *Rentier Islamism: The Influence of the Muslim Brotherhood in Gulf Monarchies* (New York: Oxford University Press, 2018).

53 Ibid.

54 Valeria Jana Schwanitz, August Hubert Wierling and Payal Shah, 'Assessing the Impact of Renewable Energy on Regional Sustainability—A Comparative Study of Sogn og Fjordane (Norway) and Okinawa (Japan)', *Sustainability* 9/11 (2017).

55 AJ Veldhuis and Aydong Yang, 'Integrated approaches to the optimisation of regional and local food–energy–water systems', *Current Opinion in Chemical Engineering* 18 (2017), pp. 38–44.

56 Carey King and Michael Carbajales-Dale, 'Food–energy–water metrics across scales: project to system level', *Journal of Environmental Studies and Sciences* 6/1 (2016), pp. 39–49.

57 Schlör et al., 'An Integrated Assessment Model for the German Food-Energy-Water Nexus'; Giupponi and Gain, 'Integrated spatial assessment of the water, energy and food dimensions of the Sustainable Development Goals'.

58 Keulertz and Woertz, 'Financial challenges of the nexus'; Swain and Jägerskog, *Emerging security threats in the Middle East*.

59 Kibaroglu and Gürsoy, 'Water–energy–food nexus in a transboundary context'.

60 Meshkati et al., 'People-Technology-Ecosystem Integration'; Talozi et al., 'Towards a water–energy–food nexus policy'.

need for stakeholder consultation.[61] Particularly comprehensive is the governance analysis for the whole Arab region conducted by Chnais et al.[62] They qualitatively analyse the institutional landscape that governs the nexus at the national and regional scales in Arab countries and identify challenges and opportunities. The findings largely reflect the general governance trends also detected in the global sample on the nexus; a multitude of institutions are responsible for managing (parts of) the nexus in Arab countries, with so far little cooperation and overlapping competencies, as well as silo thinking. These issues could be addressed through existing regional consultation mechanisms or collaborations, for instance in the water sector, to advance nexus thinking and implementation. In a policy paper El Hajj et al. build on this analysis and recommend a set of actions to improve regional cooperation on the nexus, for instance through increased knowledge building and sharing, private sector mobilisation for financing, and integration of existing institutions.[63] More fundamental shortcomings, for instance in the form of many vacant positions in departments and lengthy administrative procedures remain barriers to integration. The social welfare, public sector employment and other rentier benefits that skew the political economy of decision-making in Kuwait, as in the other Gulf states, create very specific conditions for WEF stakeholder consultation.

Water–Energy–Food Nexus for Kuwait

We illustrate the nexus for Kuwait below, at three scales: the domestic nexus; the international nexus, with exports and imports adding an extra scale of analysis that links Kuwait's nexus to those in the countries it imports from; and, finally the global scale, by adding a climate change mitigation angle to Kuwait's nexus.

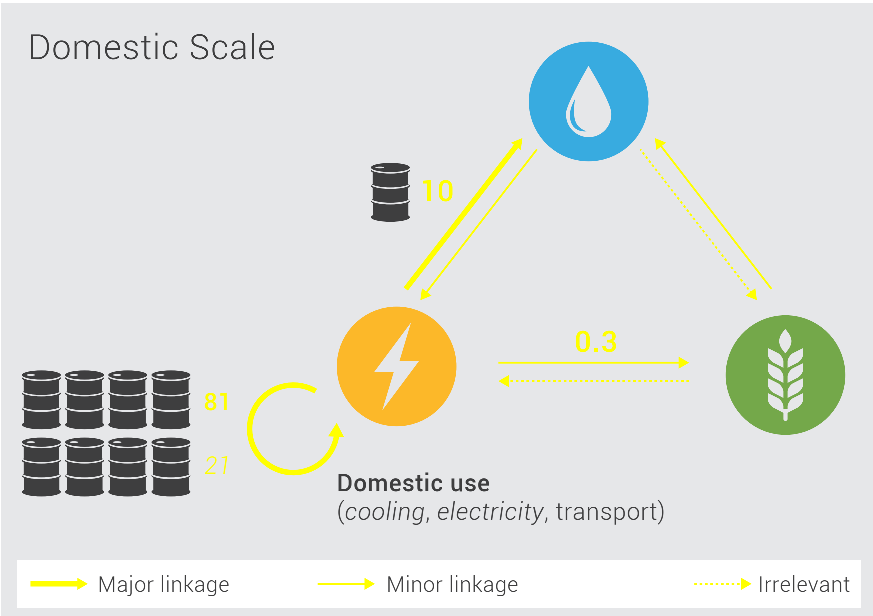
One common problem with quantifying the nexus, and with many nexus studies, is that the sectors are measured in different and, to some extent, non-commensurate units and are therefore rarely compared directly. To address this issue, we convert and present the nexus flows in comparable units – barrel of oil equivalents (BOEs).[64] For some linkages that cannot be expressed in BOE, their relative importance is presented (see Figure 3). Values presented relate to the 1992–2015 period.

[61] King and Jaafar, 'Rapid assessment of the water–energy–food–climate nexus in six selected basins of North Africa and West Asia undergoing transitions and scarcity threats'.
[62] Elie Chnais, Nadim Farajalla and Rana El Hajj, 'Water, Energy, Food Nexus: An outlook on public institutions in the Arab World', *AUB Policy Institute* (2016).
[63] El Hajj et al., 'Enhancing regional cooperation in the Middle East and North Africa through the Water–Energy–Food Security Nexus'.
[64] The barrel of oil equivalent (BOE) is a unit of energy based on the approximate energy released by burning one barrel (42 US gallons or 159 litres) of crude oil.

The Domestic WEF Nexus

Kuwait is the world's 7th highest energy consumer on a per capita basis and has a considerable total domestic energy use of 91 million BOE (mBOE), with energy use for water – mostly through desalination and a fraction used to pump groundwater or treat wastewater – requiring a significant amount (10 mBOE, against 81 mBOE for other uses). Cooling and electricity are other important energy users, at 21 mBOE, about 20 percent of total domestic energy use. Considerably less energy is used for food production, here approximated by the energy requirements for groundwater pumping (0.2 mBOE) and treating wastewater (0.1 mBOE) (ignoring any fuel cost for machinery or cooling costs of greenhouses), reflecting the small domestic agricultural sector.

Figure 3. Kuwait's domestic WEF nexus, with numbers representing mBOE



There is no conflict between land used for food production and that used for water harvesting or energy generation. The production of biofuels, an important cause of trade-offs between food and energy production elsewhere, is non-existent in Kuwait. Using land to harvest water is equally rare in Kuwait's desert, where only a few wadis fill temporarily after rains in winter and spring. Above all, with its hyper-arid climate and sandy soils, there is hardly any land suitable for food production to compete with in the first place. Specialised production in greenhouses and tree crops like date palms requires relatively little space.

With rainfall almost absent, annual renewable water resources are minimal, mostly consisting of groundwater inflow from Saudi Arabia, estimated at about 20 million cubic meter (MCM)[65] to 45 MCM per year.[66] Whilst agricultural production is limited, and only a relatively small volume of water is used for food production, this still amounts to an estimated 200–500 MCM per year, mainly irrigation from brackish groundwater and reuse of wastewater. Agriculture represents more than a third of all water use, with domestic use and the oil production industry being the other main consumers, and its groundwater extraction exceeds the aquifer's capacity.[67] Net water use estimates for the oil sector are rare (the sector is generally ignored in scientific papers or official documents discussing Kuwait's water demand), but using water use per barrel of oil intensity estimates from the Kuwait Institute for Scientific Research[68] and research by Siddiqi and Anadon,[69] a range of 30 MCM to 200 MCM per year is derived, part groundwater, part seawater and with an unknown part recycled. With the aging of oil fields, more water is needed to extract oil through enhanced recovery processes, which is a reason for concern. Most cooling of thermal power plants is done using seawater.[70] Domestic drinking water demand is almost fully met by seawater desalination. While renewable water resources are obviously very limited in Kuwait, there is clearly a challenge to use less and reuse more, but overall nexus trade-offs between sectors are limited.

International Trade Dominates Kuwait's WEF Nexus

More important is Kuwait's international nexus, with limited domestic food production compensated by imports and financed by oil (i.e. energy) exports (see Figure 4). At 710 mBOE the exports dominate the nexus. Food imports represent a value of 35 mBOE (calculated by converting the amount of food imported, and its price, into oil equivalent); which at 4 percent of total oil export revenue is relatively small. In years with low oil and high food prices, however, the food import–oil export proportion increases, reaching 8 percent in 2014.

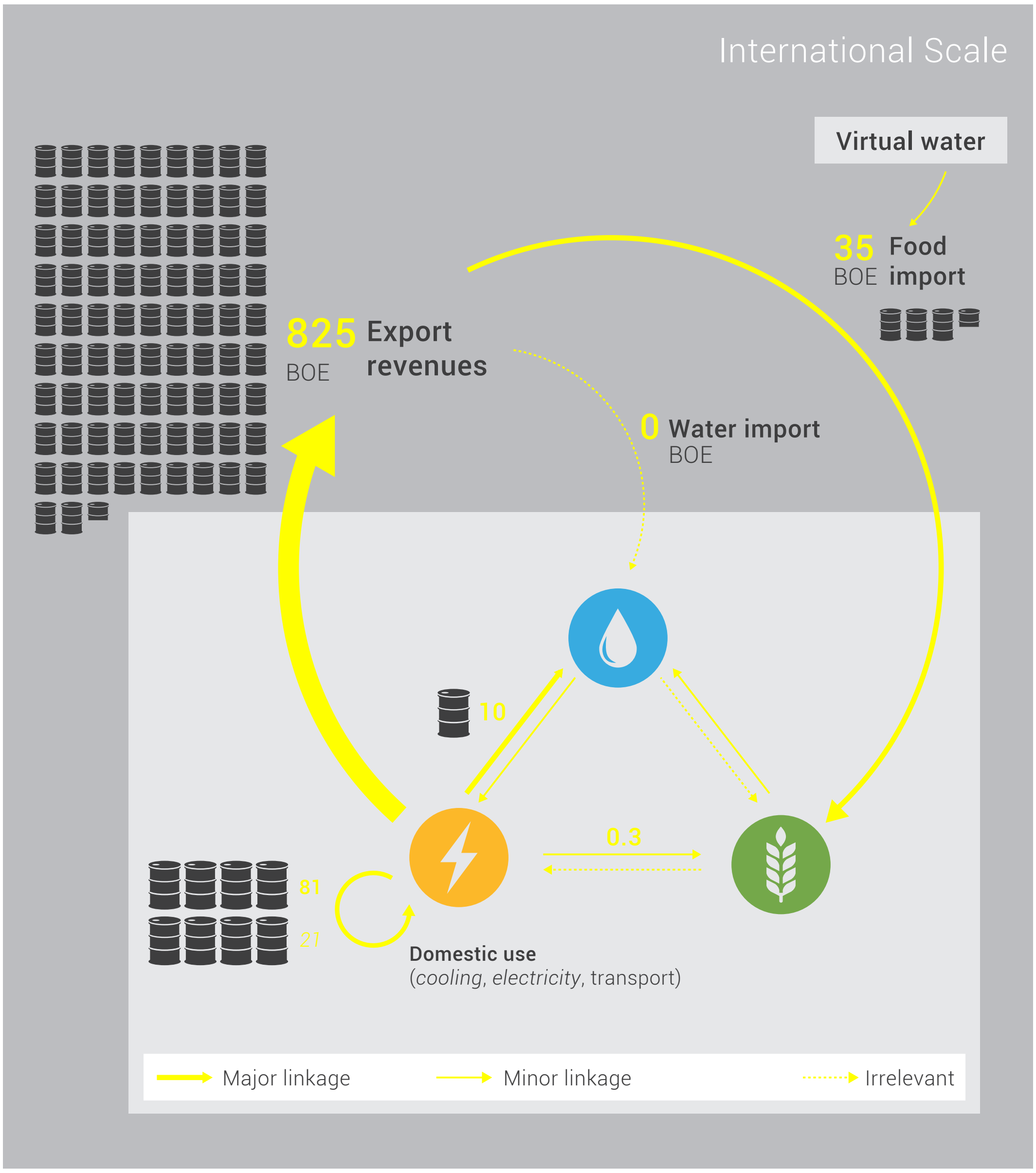
Imported food requires land, water, energy and nutrient resources in other parts of the world. The reliability of food imports, and their price, will depend to some extent on sustainable management of these resources. Importing food thereby means exposure to nexus trade-offs elsewhere. The sustainable use of water, and the amount of embedded water, also called 'virtual water', has lately received increasing attention. About 90 percent of Kuwait's rice imports come from India (2015 values),[71] a country that has abundant water resources seasonally, but that suffers from declining groundwater levels due to over

[65] AQUASTAT statistics database, *Food and Agriculture Organization*.
[66] Amr Fadlelmawla and Muhammad Al-otaibi, 'Analysis of the Water Resources Status in Kuwait', *Water Resources Management* 19/5 (2005), pp. 555–70.
[67] Ibid.
[68] Pers. Com. KISR – Petroleum Research Center, estimating about 1/6 of a barrel of water for each barrel of oil produced. Part seawater, part recycled, with amounts increasing when going to enhanced oil recovery practices.
[69] Siddiqi and Anadon, 'The water–energy nexus in Middle East and North Africa'.
[70] Ibid.
[71] Based on UN COMTRADE, visualised by https://atlas.media.mit.edu/en/visualize/tree_map/hs92/import/kwt/show/1006/2016/ (accessed 9 December 2019).

abstraction especially in rice growing such as the Punjab. With increasing competition for water from industry and households, greater stress and nexus trade-offs should be expected in Pakistan and India, and elsewhere. Wheat is mainly imported from Australia and Canada, two countries with – in normal years – a large food surplus from crops grown mainly under rainfed conditions. Threats to imports from nexus trade-offs play less of a role here, though changes in global demand – i.e. reduced production elsewhere – might still affect prices. Vegetables are imported from a variety of places, from India to the Netherlands, limiting exposure. The most important meat and dairy import is poultry, with almost 80 percent of poultry meat coming from Brazil, a country with abundant land and water resources, but also strong nexus trade-offs between using land for food production, biofuels and maintaining essential ecosystems services of the Amazon forests and surrounding areas.

The international nexus highlights resource interdependencies, which play out both inwards, as a domestic challenge for Kuwait (e.g. an increasing part of the budget is spent on food imports) and outwards, affecting sustainable use of resources in source countries. The outward impact should be nuanced, though, and goes beyond the direct impact on the nexus in exporting countries. Exports to the Middle East provide valuable foreign currency for poorer countries that have sovereignty in choosing with whom to trade. The most severe impacts of any shock to the nexus in exporting countries (or global prices) are more likely felt in low/middle income countries reliant on imports, where rising food import prices directly translate into higher costs (proportion of income) for consumers.

Figure 4. International scale of the WEF nexus, with units expressed in barrel of oil equivalent (BOE). One depicted barrel is 1 mBOE.



Adding Climate Change to the Nexus: The Social Cost of Carbon

A third scale links Kuwait's nexus to the global, via climate change mitigation efforts. Emissions from burning fossil fuels are contributing to rising temperatures globally, affecting weather patterns and the environment. This is expected to lead to a wide range of negative impacts, as summarised by the Intergovernmental Panel on Climate Change (IPPC).[72]

The social cost of carbon (SCC) tries to account for the costs of these impacts. Using common estimates on the cost of impacts and the emissions from a barrel of oil[73] suggests that the social cost of carbon should be $42 (per ton CO2) at 5 percent discount rate, representing 30 percent of the current price of a barrel of oil (see Figure 5). Much higher estimates of the SCC exist.[74] Society will still be willing to accept some of these costs because of the benefits of burning fossil fuels, while other will have to be accepted because of the difficulty of reducing emissions rapidly (i.e. we are committed to impacts). In addition, in the future, increasing amounts of atmospheric CO2 might be sequestrated by combining bioenergy with carbon capture and storage (BECCS), either through engineering solutions or reforestation. This will limit social costs and allow greater exploitation of the fossil fuel resource base globally. An alternative estimate of the price of carbon is based on the notion of a limited total carbon emission budget still left under a maximum acceptable temperature rise, currently agreed at 2 °C above the pre-industrial mean;[75] this gives the marginal costs of keeping global warming below this level. Assessing a range of modelled scenarios, a median price of $31/tCO2 in 2020 was reported by Dietz et al.[76] A more ambitious maximum 1.5 °C temperature level,[77] considered safer, would raise this price to $105/tCO2, with another model intercomparison suggesting a median carbon

[72] 'IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 (Energy)', *Intergovernmental Panel on Climate Change (IPPC)* (Switzerland, 2006). Available at https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html (accessed 23 November 2019).

[73] Among the state-of-the-art contemporary estimates of the Social Cost of Carbon (SCC) are those calculated by the US Environmental Protection Agency. The latest figures equal to $12, $42 and $62 per tCO2 emitted in 2020 for 5, 3 and 2.5 percent discount rates, respectively. See Ricke et al, 'Country-level social cost of carbon'. Carbon dioxide emissions per barrel of crude oil are determined by multiplying heat content times the carbon coefficient, times the fraction oxidised, times the ratio of the molecular weight of carbon dioxide to that of carbon. The average heat content of crude oil is 5.80 Metric Million British thermal unit (MMBtu) per barrel. The average carbon coefficient of crude oil is 20.31 kg carbon per MMBtu (EPA 2017). The fraction oxidised is 100 percent. This gives 0.43 metric tons CO2/barrel. Taking the lower discount rate of 2.5 percent then gives a social costs of $27 per barrel. At an average price of oil of $61 per barrel, this means SSC is 43 percent of the price per barrel. See 'Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015, Annex 2, Table A-40 and Table A-49', *U.S. Environmental Protection Agency (EPT)* (Washington, DC, 2017). Available at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2015 (accessed 23 November 2019).

[74] Katharine Ricke et al., 'Country-level social cost of carbon', *Nature Climate Change* 8/10 (2018), p. 895.

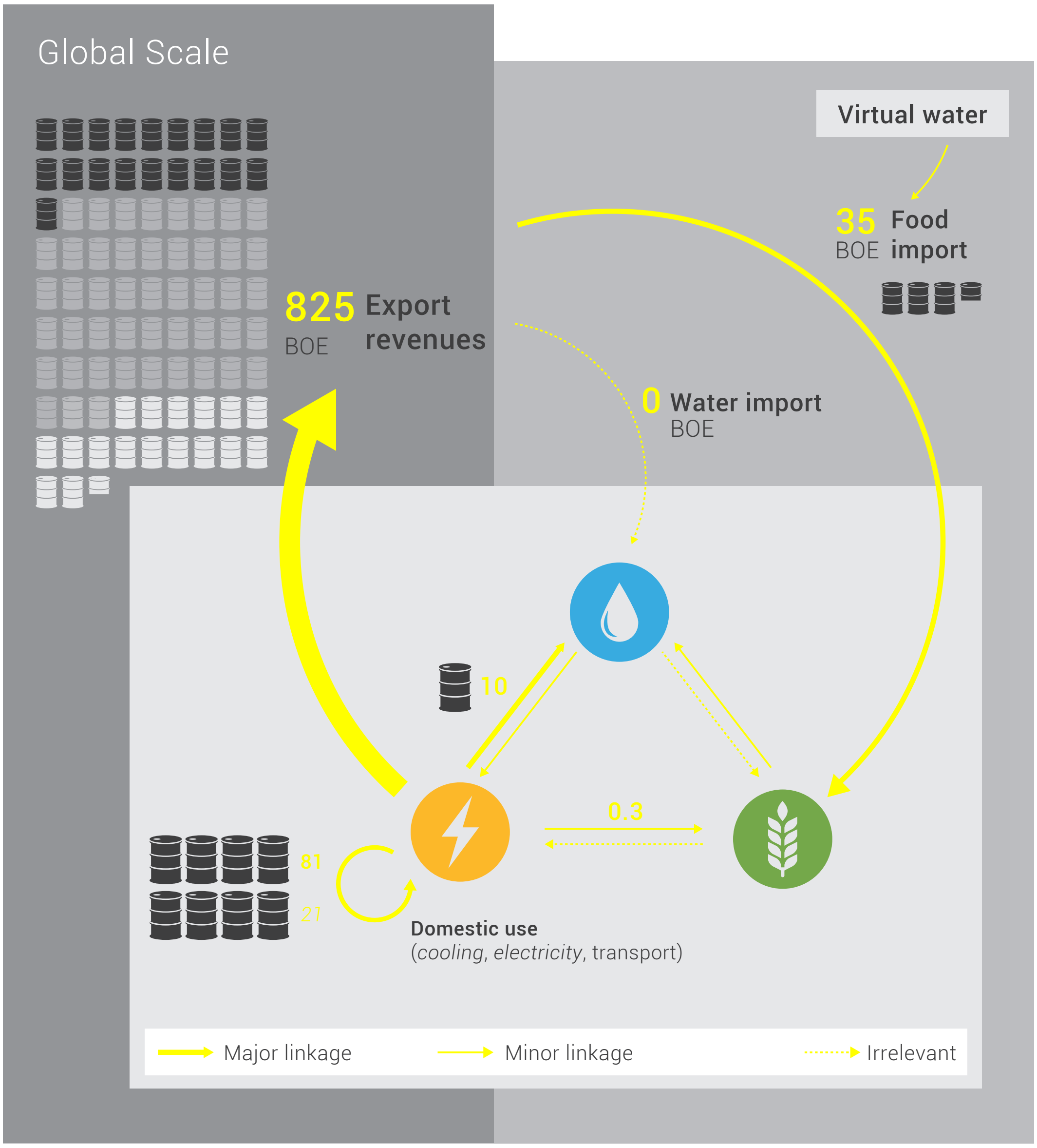
[75] 'Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009', *UN Framework Convention on Climate Change* (2010).

[76] Simon Dietz et al., 'The Economics of 1.5 °C Climate Change', *Annual Review of Environment and Resources* 43/1 (2018), pp. 455–80.

[77] 'The Paris Agreement', *United Nations* (2015). Available at https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed 9 December 2019).

price in the same order,[78] of $137/tCO2 in 2030. However, the price of carbon will not be constant; it needs to rise steeply to drive further mitigation and maintain temperatures within both 2 °C and 1.5 °C.[79]

Figure 5. Same as Figure 4, but depicting the marginal cost of carbon as a fraction of oil export revenues, with in lightest grey an estimate of the marginal cost of carbon (in 2020) to keep global temperature increase below 2 °C and in dark grey the additional costs estimated for a 1.5 °C target.[80]



[78] Joeri Rogelj et al., 'Energy system transformations for limiting end-of-century warming to below 1.5 °C', *Nature Climate Change*, 5/6 (2015), p. 519.

[79] Dietz et al., 'The Economics of 1.5 °C Climate Change'.

[80] Ibid.

With global progress on international commitments to reduce fossil fuel use slow, and carbon prices still very low in those countries that have implemented emission trading schemes, the comparison in Figure 5 is primarily illustrative. Moreover, a price on carbon cannot be translated one-to-one into a future reduction in revenues as demand is not fully elastic. Reduced demand will not impact producers equally; Kuwait for example has a comparative cost advantage, with large reserves easily exploitable. Any reduction in demand is likely to first reduce production from more costly sources, like Canada's tar sands, or limit expensive new exploration, like in the arctic. McGlade and Ekins have looked at the remaining ultimately recoverable resources, when countries would commit to a 2 °C maximum increase in temperature above pre-industrial levels.[81] Globally, over 430 billion barrels of oil and 95 trillion cubic metres of gas currently classified as reserves should remain unburned by 2050.[82] The Middle East possesses over half of the unburnable oil globally (and half of unburnable global gas reserves) leaving over 260 billion barrels in the ground, almost 40 percent of its oil reserves,[83] but with coal and production in other regions being phased out first. This is under the assumption that countries and consumers behave in an economically rational fashion.[84]

Apart from costs, timing is important. The 1.5 °C ambition requires a decarbonisation of energy supply that is more rapid and profound than in 2 °C-consistent scenarios. Dietz et al. indicate that an energy-system transformation with about 50 percent additional decarbonisation compared to a 2 °C scenario is needed, starting sooner.[85] Early CO2 reductions in 1.5 °C-consistent scenarios are achieved through early reductions in the power sector,[86] but by 2050 most of the supply-side mitigation potential is already used – also when aiming to keep warming to 2 °C. Moving to 1.5 °C relies on much stronger emission reductions on the end-use sectors such as industry and, in particular, transport and buildings,[87] which are sectors consuming most oil. Again, this suggest there is some time left to adjust Kuwait's economy to changes in oil demand, but with a 1.5 °C target, impacts will be felt sooner.

[81] Christophe McGlade and Paul Ekins, 'The geographical distribution of fossil fuels unused when limiting global warming to 2 °C', *Nature* 517 (2015), p. 187.

[82] Based on the scenarios significant carbon capture and storage (CCS). Assumptions on CCS determine total production, with the deployment of CCS permitting wider exploitation of the fossil fuel resource base on a global level. Due to low costs of production in the Middle East compared to other regions, fewer CCS seems to mostly affect other producers rather than a producing country like Kuwait (assuming perfects markets). See McGlade and Ekins, 'The geographical distribution of fossil fuels unused when limiting global warming to 2 °C'.

[83] Ibid.

[84] Models used often assume optimal conditions, i.e. perfect markets. The fossil fuel sector is heavily subsided and might remain subsidised with countries interfering because of national security considerations or protecting employment, which would undermine the assumption that Kuwait will not be affected in the short run by a reduced demand because of its cost advantage as other countries might protect their producers.

[85] Dietz et al., 'The Economics of 1.5 °C Climate Change'.

[86] Rogelj et al., 'Energy system transformations for limiting end-of-century warming to below 1.5 °C'.

[87] Ibid.

There will also be some synergies. Kuwait's high energy use for cooling, being one of the hottest cities on earth,[88] creates a vicious circle; higher average temperatures globally means more extreme and prolonged heatwaves in the Gulf region. This means more cooling and even more emissions, rising non-linearly due to lower efficiencies of air conditioning devices at high temperatures. As climate change mitigation will limit the expected rise in temperatures this will have a (modest) effect on domestic oil consumption. Renewable energy could play an increasing role in mitigating Kuwait's own emissions, further reducing the costs of energy use. The potential for both solar and wind energy is high, which makes the renewable energy target of up to 15 percent of Kuwait's electricity consumption needs by 2030 realistic and entirely achievable.[89]

Finally, climate change will have an impact on the amount of food produced elsewhere – e.g. in Australia's grain belt or on rice production in the Indo-Gangetic Plain, affecting global food availability and prices. Not only gradual changes in production will matter, but also the volatility; major food price spikes in 2007–8 illustrate that even a perceived shortage due to compounding climate impacts in multiple food producing regions can lead to strong responses in restrictions on trade with impacts on prices. Compared to poorer importing countries, e.g. in sub-Saharan Africa, Kuwait is still well endowed to buffer any shocks, but a lack of alternative sources of food production will keep it exposed.

Conclusions and Recommendations

A comprehensive application of the water, energy and food nexus concept to Kuwait and the Gulf region has been lacking. Here, we explored the nexus for Kuwait, reviewing available literature and focussing on empirical data from the most widely used global and regional databases on the WEF sectors.

At the **domestic scale**, WEF trade-offs are modest. Kuwait's domestic nexus can be characterised as 'energy-dominated'. We find, like others in the Middle East and North Africa region, that while there are certainly issues of water scarcity, trade-offs between sectors at this level are relatively small because water scarcity limits agricultural production and surplus fossil fuel resources compensate through desalination and food trade. To manage increasing water demand, Kuwait should scale up its reuse of water in the oil sector, and implement tighter domestic water, energy and food consumption measures.

[88] Thair Shaikh, 'Kuwait swelters in 54C heat – what could be the highest temperature ever recorded on earth', *The Independent*, 23 July 2016. Available at https://www.independent.co.uk/news/world/middle-east/kuwait-swelters-record-breaking-54c-heatwave-weather-7152911.html (accessed 23 November 2019); 'WMO examines reported record temperature of 54 °C in Kuwait', *World Meteorological Organization*, 26 July 2016. Available at https://public.wmo.int/en/media/news/wmo-examines-reported-record-temperature-of-54%C2%B0c-kuwait (accessed 20 November 2019); Ruth Michaelson, 'Kuwait's inferno: how will the world's hottest city survive climate change?', *The Guardian*, 18 August 2017. Available at https://www.theguardian.com/cities/2017/aug/18/kuwait-city-hottest-place-earth-climate-change-gulf-oil-temperatures (accessed 24 November 2019).

[89] 'Renewable Energy Market Analysis: GCC 2019', *International Renewable Energy Agency IRENA* (2019), p. 153.

At the **international scale**, exports and imports highlight more significant nexus trade-offs. Whilst its high oil export revenues shield Kuwait from the immediate impacts of higher prices, they do not fully buffer exposure to sudden export restrictions in exporting countries. Further analysis of the extent to which Kuwait and the GCC are exposed to water scarcity and food production risks in other countries, taking into account the increased likelihood of extreme events in a changing climate, is strongly recommended.

At the **global scale**, uncertainty remains about future international climate policy and its implications for oil and gas revenues in Kuwait. Our exploratory analysis suggests that implementation of measures to account for the social cost of carbon would significantly impact export revenues. However, if a cap on total global emissions were introduced, taking a more constructive stance in global climate negotiations (rather than blocking initiatives such as the endorsement of the IPPC's scientific '1.5 degrees Celsius' report during COP24 in 2018) might actually benefit Kuwait; with its low production costs and existing infrastructure, its oil and gas could form an important part in any agreement on economically efficient use of the remaining carbon budget, while ruling out less economic reserves elsewhere. This might give the country more time to adapt its economic and governance models to a low carbon future. This would entail massive progress in climate negotiations and international policy; however, if this were achieved it might also prevent serious impacts in the regions where Kuwait's food imports are sourced.

A better understanding of nexus trade-offs across these scales – both for Kuwait and the wider GCC – is essential to support strategic planning for water, energy and food security and economic diversification in today's changing, highly interconnected, but potentially more protectionist world.

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