UNIVERSITÀ DEGLI STUDI DI TORINO

Department of Economics and Statistics "Cognetti De Martiis"
Ph.D. in Economics "Vilfredo Pareto"
XXXII Cycle

WATER AND FOOD SECURITY ISSUES IN THE MENA REGION:

Limits and Opportunities for Socio-Economic Development

Ph.D. Candidate: Annamaria Mazzoni Reg. Number: 750869
Supervisors: Prof. Silvana Dalmazzone, Prof. Marco Bagliani
Ph.D. Program Director: Prof. Fabio Cesare Bagliano
Academic Coordinator: Prof. Andrea Gallice
Academic Discipline: SECS-P/06 – Applied Economics

Academic Years: 2016-2019

Examination Committee: Prof. Alessandro Barattieri, Prof. Alessandro Corsi, Prof. Luca Ridolfi.

Correspondence to: annamaria.mazzoni@unito.it

Turin, 25th March 2020

Per Aspera ad Astra

SUMMARY

Ensuring water and food security is one of the main challenges of the upcoming decades. Climate change, economic development, and population growth are among the major drivers affecting water reliability and availability at the global level. The Middle East and North Africa (MENA) is the world region facing the most severe water scarcity issues and is still affected by a lack of proper water resources management that can exacerbate the situation and pose severe threats in the food security realm and consequently affect future socio-economic development.

The main objective of this dissertation is to provide a synthesis of existing knowledge on some of the main environmental and socio-economic aspects of water resource domain in the MENA region, to outline current and future challenges, and to perform analyses that can serve policymakers and stakeholders to make informed decisions when dealing with water scarcity issues. Furthermore, I combine both economic and technical investigations to provide quantitative results instrumental to tackle water security issues by accounting simultaneously for environmental and societal constraints towards the realization of sustainable management of water resources.

The first paper in this thesis quantifies the magnitude of the water scarcity in the MENA region in terms of the water budget and fossil groundwater depletion for the upcoming decades. The geographic area of study comprises eleven MENA countries sharing the major fossil aquifer systems in the region. The model is defined as a regional hydro-economic model as it integrates both the physical and socio-economic aspects of water supply and demand, which are calculated per each economic sector. Besides, climate change scenarios and their impacts on water availability are also simulated. The results show that if the water deficit is going to significantly worsen for all countries analyzed, the fossil groundwater sources will reach alarming rates of depletion, with potential complete exhaustion before 2050. The paper concludes by discussing the linkages between the projected water stress and food security for the most vulnerable countries under the study. The results show that the water deficit is considerable for all the countries analyzed, but it is the fossil groundwater the natural resource at major risk by mid-century.

The second paper further explores the links between water and food security, focusing on the blockade imposed on Qatar by a Saudi Arabia-led coalition of countries since June 2017 as a case study. In particular, I quantify the economic impacts of the blockade in terms of trade losses using the difference-in-difference methodology in a gravity framework. Then, I investigate the sustainability in terms of water resources of the new local food production strategies promoted by the Qatari government in the aftermath of the blockade, making use of the Water Footprint indicator. My results show that in addition to causing economic losses in the short term, especially on the import side of the trade, the blockade also generated environmental losses in terms of increased water abstraction for the domestic food production realized

under the Qatari government's new food security strategic plans for 2023. The analysis confirms that governmental plans are not sustainable from a water resource perspective and in the long term such plans should be revised or should employ different water sources.

In my third paper, I address the water pricing issue for the agricultural water sector in the area under study. In the MENA region overall, despite the lack of water and average low quality of arable land, the agricultural sector is highly developed, and it accounts for about 80 percent of freshwater withdrawals. Still, water charges for irrigation are among the lowest in the world. To investigate the magnitude of the discrepancy between current water tariffs for agriculture (where existing) and the water price levels that would potentially encourage cost recovery and efficient water use, I calculate the shadow price for irrigation water for 19 countries in the MENA region and 12 different crop categories. The paper contributes to the existing literature by providing the most updated dataset on water prices for irrigation in the MENA region, and by expanding the coverage of previous studies and provide with a first-order assessment of potential introduction or increase in water tariffs for the area under study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

WATER AND FOOD SECURITY ISSUES IN THE MIDDLE EAST AND NORTH AFRICA REGION

In the Global Risks Report 2019 (World Economic Forum 2019) water crises are listed among the top 10 risks in terms of likelihood, in the 9th position. The numerous episodes of extreme events, which are happening more and more often on a global scale, such as floods and droughts, together with lack of water availability for drinking and sanitation, human and ecosystems' health are all linked to water management issues. Beyond their environmental impacts, these phenomena have major effects also on societies and economies. Annual global freshwater withdrawal has grown from 3,790 km^3 in 1995 to 4,430 km^3 in 2000 (Shiklomanov 1998) and is projected to increase by 20%-30% per year by 2050 (Burek et al. 2016).

Currently, over 2 billion people live in high water-stressed areas (WWAP 2019) and about 4 billion people, i.e. two-thirds of the population, experience severe water scarcity at least one month a year (Mekonnen & Hoekstra 2016). In particular, groundwater resources are the most vulnerable to overexploitation (Wada, Wisser & Bierkens 2014; Wada 2016; Bierkens & Wada 2019).

Water security, regarded as *"the capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability"* (UN Water 2013, p. 1) is indeed one of the major challenges of the next decades. Furthermore, the projected demand for food will certainly increase the water used in agriculture, which is already the most water-intensive economic sector. Water for food (and the lack thereof) recalls the concept of food security, which *"exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life",* as defined during the World Food Summit in 1996[1]. While for some places in the world these challenges are less urgent, for the Middle East and North Africa (MENA) region,[2] ensuring water and food security is a top priority in the institutional agenda since the late 1970s (Allan 1998, 2002). The region spans from Morocco to Iran, comprising also the Arabian Peninsula, and exhibits very different physical and geographic characteristics, but also different

---

[1] See FAO website: http://www.fao.org/economic/ess/ess-fs/en

[2] For the purpose of this study I consider in the MENA Region all the countries listed in the World Bank Group classification i.e. Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates and Yemen except for Djibouti.

levels of socio-economic and institutional development. The countries of this region are mainly classified as middle-low-income, but the area also hosts oil-rich countries such as the Gulf monarchies and Libya. Table 1.1, adapted from Devlin (2010), shows some of the main traits and features characterizing the region captured from different perspectives. Still, limited water availability is a common feature among these countries. Water resources come mainly from precipitation in Algeria, Morocco, and Tunisia, from surface and groundwater sources in Egypt and entirely from groundwater in the Gulf Countries. North Africa countries have a mainly agricultural economy, thus water withdrawal from surface and groundwater sources serve primarily to irrigation and food production.

In 2018, the MENA region reached a population of about 447 million people,[3] which is projected to grow beyond 1 billion by 2100, with most of the increase foreseen in Egypt, Iran, and Iraq. In the area, less than 1% of freshwater reserves are renewable and recent climate change estimates predict a reduction of rainfall regimes up to 40% by the end of the century. Water availability per capita is less than 500 m^3/year (the threshold of absolute water scarcity) for Yemen, Jordan, Libya, and Palestine.

The demand for food is met through moderate to high food imports – a source of worry in terms of food security especially for key staple food products, which are influenced by volatile prices on the global food markets and are vulnerable to climatic or geopolitical disruptions. Food insecurity has been already a driver of conflicts in the region, as it was the case of the Arab Spring in 2011. Lastly, the rural exodus towards urban areas driven by low productivity of agricultural activities raises also water management issues – or threatens to worsen the existing ones.

The challenges imposed by water and food insecurity in the MENA region are generally recognized, but policy responses vary widely across countries and are determined by income, know-how and technological development. Among all water resources, groundwater is the most undervalued, mainly because actual estimation and monitoring of groundwater resources are poor and imprecise. Both in Gulf Countries and North Africa the knowledge of exploitable groundwater reserves and aquifer dynamics, such as the movement, runoff, and flow of groundwater, is still limited. Also, economic governance of water use is weak: the Middle East and North Africa apply the lowest tariff in the world to water abstraction for irrigation, provide subsidies to water consumption and maintain very low water productivity (World Bank 2018). In general, water resources are treated as common-pool resources, and existing regulations are inadequately implemented.

The above-mentioned challenges highlight the need for substantial further analyses, which are required to deepen our knowledge of the socio-economic and environmental dimensions of water resource

---

[3] United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition. Rev. 1

management in the Middle East and North Africa region and help the development of new approaches and perspectives.

Table 0.1. Socio-Economics and Political features of the Middle East and North Africa Countries

Economy	***Political Economy***	***Social***
World Bank (2003)	**Richards & Waterbury (2007)**	**Drysdale & Blake (1985)**
Resource-poor *Egypt, Jordan, Morocco, Tunisia, Lebanon, West Bank, and Gaza*	Agro poor *Yemen*	Linguistically diverse, religiously cohesive *Morocco, Algeria, Iran*
Resource-rich, labor abundant *Algeria, Iran, Iraq, Syria, Yemen*	Watchmakers[4] *Israel, Jordan, Tunisia, Syria*	Religiously diverse, linguistically cohesive *Egypt, Yemen, Kuwait, Oman UAE, Bahrain, Saudi Arabia, Syria, Lebanon (multiple division)*
Resource-rich, labor imported *Bahrain, Kuwait, Libya, Oman, Qatar, Saudi Arabia, United Arab Emirates*	NIC[5] *Egypt, Morocco* Oil industrializers[6] *Iran, Iraq, Algeria, Saudi Arabia, Qatar, UAE* Coupon clippers[7] *Bahrain, Kuwait, Libya, Oman, Qatar, UAE*	Religiously and linguistically diverse: *Iraq*

Part of the solutions to both water and food security problems also relies on current and future alternative approaches i.e. enhance the development of non-conventional water sources, such as desalination, wastewater reuse, rainwater harvesting or weather modification. Such techniques are already largely

---

[4] Countries whose limited resources require investment in human capital and the export of specialized products based on skilled labor.

[5] Newly Industrialized Country

[6] Countries whose population and other resources are sufficient to enable them to invest the oil revenues in productive enterprises

[7] Countries with oil resources and few of other endowments

employed in the region, but the goal for the future should be to develop a strategy that is feasible from a financial, social, political and environmental point of view.

1.1. Research Objectives

This dissertation considers several aspects of water resource management in the MENA region. It builds on the existing literature and aims to provide new perspectives and insights into the main research topic, as well as build a framework useful for policymakers in designing policies and regulations in the water resources realm. I first assess and quantify the current and future water deficit and groundwater exploitation for selected countries in the study area, to estimate the magnitude of the water stress and water depletion phenomenon. Secondly, I exploit an exogenous shock, i.e. the blockade imposed on Qatar in June 2017, to evaluate the economic and environmental sustainability of autarkic food provision policies for a water-scarce country. Lastly, starting from a thorough review of the literature, I estimate the shadow price of water for irrigation in all the MENA countries, for different crop categories, to investigate possible options for water conservation and cost recovery in the agricultural sector. More specifically, I try to achieve the following Research Objectives (RO):

RO1: Reduce uncertainties in the socio-hydrologic systems associated with the water budget in the MENA region and provide a framework for decision making.

RO2: Understand the economic and environmental implications of exogenous shocks on rentier states and evaluate the sustainability of their food security strategies in the context of water scarcity.

RO3: Explore the potential for tackling water resources overexploitation in the agricultural sector in the Middle East and North Africa through economic instruments.

1.2. Thesis Outline

In this dissertation, I aim to contribute to the existing debate by providing new evidence and new perspectives on water scarcity and food security issues in the MENA Region. To this end, the thesis is divided into three essays, each one with its structure and framework, which are integrated into a coherent work with a logical progression from one to another. In Chapter 2 I present a new hydro-economic model for forecasting water budget deficit and groundwater depletion in some selected countries of the MENA Region. This serves as a starting point for the rest of my research where I outline the current and future water scarcity issues in hyper-arid environments and provide their quantification for potential inference on policy options. The concept of *water budget* expresses the relationship between inflow and outflow of water sources within a specific territory. As the water availability depends on different factors such as the water cycle but also water uses, the knowledge of the water budget of an area becomes extremely relevant for water services planning and environmental conservation within a society. The developed water budget model places itself within the most recent literature on water budget modeling, which integrates both the physical and hydrological properties of water bodies with socio-economic factors affecting water demand and supply. Also, I take into account the future climate change impacts on water resources, as they represent a major source of uncertainty in model projections.

Chapter 3 presents an applied case study in which water scarcity and food security in a country can be put further at risk by exogenous shocks. In particular, I study both the economic and environmental effects of the blockade imposed on Qatar in June 2017, by quantifying not only the trade disruption but also the pressure on water resources originated by the new food-security strategies developed by Qatar in the aftermath of the blockade. I estimate a gravity model of trade and then develop a water demand scenario in the time horizon 2016-2030 which is used, in turn, to quantify the *Water Footprint* necessary to meet the requirements of the new food-security strategies. Lastly, I confront the projected water need for food with the projected water supply available for Qatar as calculated in Chapter 2. This comparison enables me to evaluate the feasibility of the current food-security strategies developed by the Qatar government and suggest corrections.

Chapter 4 covers another relevant issue in the water resources management realm: water pricing. In the MENA area, at the origin of the mismanagement of water resources for irrigation and of a very low water-productivity ratio, there are extremely low service tariffs and high subsidies to the agricultural sector. My study adds to the existing literature and can be helpful to stakeholders and policymakers to evaluate scenarios and tradeoffs between profitable crop production and conservation of water resources.

Finally, Chapter 5 summarizes and discusses the main results and findings of the research. It also outlines potential limitations and challenges as well as future research directions. Each chapter is based on its dataset and literature of reference. Still, together they represent a consistent analysis offering potential new insights and approaches in the study of water resources management in the MENA Region.

CHAPTER 2

FORECASTING WATER BUDGET DEFICITS AND GROUNDWATER DEPLETION IN THE MAIN FOSSIL AQUIFER SYSTEMS IN NORTH AFRICA AND THE ARABIAN PENINSULA

ABSTRACT. We develop a water budget model that quantifies and forecasts water deficits and groundwater depletion of the main exploitable fresh fossil aquifer systems in North Africa and the Arabian Peninsula under different climatic and socio-economic scenarios from 2016 until 2050. Our results suggest that in the upcoming few decades, under the most plausible climatic and socio-economic scenario (SSP2-AVG), within North Africa, only Egypt and Libya will experience severe water deficits with respectively ∼45% and ∼90% of their current water budget in 2050. For the Arabian Peninsula, all countries will undergo water deficits, ranging from ∼20% for Saudi Arabia to almost double the supply for Yemen (∼190%). Under these alarming deficits resulting from severe anthropogenic discharges, the majority of the small to mid-size exploitable fossil aquifer systems in the Arabian Peninsula could reach full depletion by 2050 and the total depletion of groundwater resources in all aquifer systems could be reached in ∼60-90 years. Over the same time span, North African fossil aquifers will lose 1-15% of their exploitable fresh water volume and may reach total depletion in ∼200-350 years with the projected increased extraction rates. We find that the major cause of the water budget deficit and groundwater depletion in the MENA area are anthropogenic drivers rather than climatic ones. Finally, we conclude that if current hydrologic, climatic and socio-economic drivers continue, the nations with the lowest gross domestic product per capita, like Egypt, Yemen and Libya, will undergo the highest water deficit per capita, leading to substantial rise in food prices, potentially resulting in higher socio-economic instabilities over the next three decades.

Keywords: Arid Environments; Water Deficit; Groundwater Budget; Climate Change; Water and Food Security; Projections

Already published as: Mazzoni, A., Heggy, E. and Scabbia, G., 2018. Forecasting water budget deficits and groundwater depletion in the main fossil aquifer systems in North Africa and the Arabian Peninsula. *Global Environmental Change, 53*, pp.157-173.

2.1. Introduction

Most areas of North Africa and the Arabian Peninsula are classified as hyper-arid environments, with an aridity index (i.e. the ratio between the mean annual precipitation and mean annual potential evapotranspiration) below 0.03 (Penman, 1948; UNESCO, 1979). The average water availability per capita in the countries located in these areas is ~1,100 m^3 per year (World Bank, 2007), which is below the water security threshold of 1,700 m^3 per year proposed by Falkenmark et al. (1989), defined as the measure of water availability per capita per year within the country or region. Luo et al., (2015), suggest that in 2040, 14 of the 33 most water-stressed countries will be in this area, including nine having a score of 5.0 out of 5.0 on the water stress index (defined as the ratio of water withdrawal to water availability).

North Africa and the Arabian Peninsula comprise several countries with a substantial diversity in natural resources availability and wealth, economic and governmental structures, and population growth rates. Despite these differences, they strongly depend on groundwater resources for their development. Some of the world largest fossil aquifer systems extend throughout this geographic area, serving as the only natural strategic freshwater reserve for the region. Within North Africa, the Nubian Sandstone Aquifer System (NSAS), the Murzuq Aquifer and the North Western Sahara Aquifer System (NWSAS) serve as the major groundwater supplies for Algeria, Tunisia, Libya, Egypt, Chad and Sudan; while for the Arabian Peninsula, numerous aquifers contribute to the water needs of the Gulf Cooperation Council (GCC) countries and Yemen (Figure 2.1).

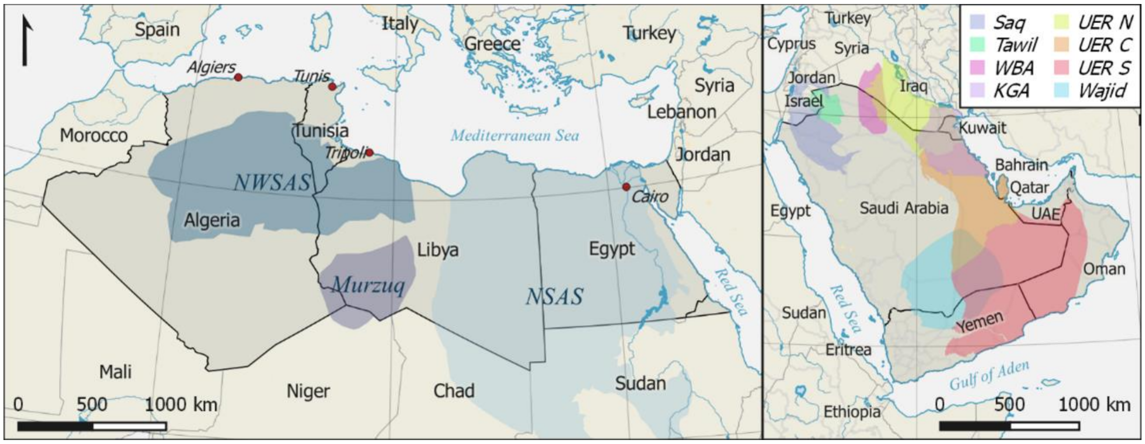

Figure 2.1 Map of the areas under study showing national boundaries and the extent of the regional fossil aquifer resources. Figure based on the 2015 IGRAC World Map of Transboundary Aquifers (IGRAC, 2015).

The challenges in the current water scarcity scenarios are accentuated by the forecasted increase in temperature and reduced precipitations, which will lower the volume of water recharge for renewable water resources (Sowers et al., 2011; Barros et al., 2014; Wodon et al., 2014). Population growth projections, combined with urbanization and economic development, will also increase the water demand, resulting in serious hazards for food security and issues with poverty reduction. Moreover, it is difficult to assess the aquifers' water budget, due to the large uncertainties in total groundwater storage (Richey et al., 2015).

Considering all of the above a thorough understanding of the dynamic of aquifer systems under climatic and socio-economic uncertainties is crucial to forecast water budgets, deficits and water demands. Early developments in water budget modeling by Korzoun et al., 1978; Gleick, 1989, Falkenmark et al., 1989, provide a first-order assessment of the evolution of the global water balance. These global water studies are further developed by integrating the potential impacts of climatic and socio-economic changes (e.g. Arnell, 1996; Shiklomanov, 1997; Alcamo et al., 1997; Vörösmarty et al., 1998; Arnell, 1999). Recent water budget models account for the variability of groundwater resources (e.g. Gleeson et al., 2012; Gleeson and Wada, 2013; Taylor et al., 2013; Döll et al., 2014; Wada et al., 2014) and consider time-variable increases in water demand (e.g. Rosegrant et al., 2002; Ercin and Hoekstra, 2014). Due to their global approach, many of the above-mentioned models successfully characterize the current hydrological conditions of global aquifer systems but cannot be applied to determining water deficits at the country-level for our study area, as they do not incorporate the local hydrological and climatic forecast complexities. In contrast, the existing regional water budget models are mainly focused on localized basins, catchments or groundwater systems, which do not account for the local water imbalances (e.g. Alsharhan et al., 2001; Voss et al., 2013; Ahmed et al., 2011, 2014) and their socio-economic impacts. The frequent instabilities in the Middle East and North Africa (MENA) area have caused an emerging interest in regional water budget models to integrate macroeconomic aggregate variables and thereby constrain the ambiguities of current water supply and demand projections (e.g. Immerzeel et al., 2011; Droogers et al., 2012). A coherent assessment of the intrinsic relationship between hydrologic and socio-economic factors, as well as their time scales and future projections, remains critical for these highly water-stressed countries. To address this uncertainty, we establish a water budget model that combines country-level demographic, macroeconomic, water supply and water demand data in order to quantify the water deficit volumes per country and the groundwater depletions rates, from 2016 to 2050, for the main aquifer systems in North Africa and the Arabian Peninsula. Finally, we discuss the implications of the projected deficits and their role in the socio-economic stability of these countries for the upcoming decades.

2.2. Methodology

We develop a water budget model that allows us to quantify the total simultaneous deficits and groundwater depletions, while accounting for climatic and macroeconomic drivers affecting the national and transboundary water resources in North Africa and the Arabian Peninsula. In particular, we calculate the time scale and volume depletion for each major exploitable fresh aquifer in this region under three climatic and five macroeconomic scenarios. The timespan of the simulation is set from 2016 to 2050 with a yearly time step. The year 2016 is considered the base year; for the period 2017-2050 we calculate the forecast related to water supply and demand. We chose this mid-range time frame for two main reasons: (1) to avoid large errors and uncertainties arising from long-term projections of input variables; and (2) to emphasize the critical changes in the water budget that will occur in the short- and mid-term.

Figure 2.2 shows the flow diagram of our water budget model. The model is organized in two main parts: water demand (in red) and water supply (in blue). The demand side includes all water requirements for each economic sector, i.e. agricultural, industrial and municipal requirements for each country. These, in turn, depend on macroeconomic factors such as population, gross domestic product (GDP), cropland cover and electricity production projections, which are based on different Shared Socio-economic Pathways (SSPs) scenarios described in detail in Section 3.1. For the supply side, we classify the water resources into two major groups: conventional sources, comprised of renewable (surface and renewable groundwater) and non-renewable water resources, and non-conventional supplies, including desalination and wastewater reuse. In each simulation cycle, the water budget model calculates how much water a given country will need to meet its annual consumption, i.e. the sum of its annual water demands per sector.

The climatic projections for the MENA area suggest with high confidence that average annual temperatures will continue to increase throughout the 21st century (Lelieveld et al., 2016), while the projections that show a reduction in precipitation exhibit higher local variability (Lionello and Giorgi, 2007; Kitoh et al., 2008; Evans, 2009; Christensen et al., 2013).

Hence, evaluating the impacts of such climatic variability on renewable and non-renewable groundwater resources generates additional challenges, due to the complexity of the hydrologic systems and the fact that measurable changes in aquifer storage are often visible only in the long term. In addition, forecasting groundwater recharge, which represents a key parameter for the aquifers' budget, often entails large uncertainties. Results from global hydrological models show that in the southern rim of the Mediterranean Sea there will be a decrease in recharge of more than 70% (Döll and Flörke, 2005). Several other studies, performed at catchment levels, highlight a similar negative trend (e.g. Kunstmann et al., 2007; Ludwig et al., 2012). However, in the MENA region's hyper-arid environments, groundwater recharge is mostly concentrated in periods of flash heavy rains and associated floods (Vogel and Van Urk, 1975; Al-Sefry et al., 2004). Moreover, recent studies have observed a potential increase in the focused recharge of some aquifer systems in the area during rare intensive rainfall events (Taylor et al., 2013; Hartmann et al., 2017). While there are several uncertainties in the groundwater recharge projections for arid environments, anthropogenic overexploitation is the most predominant factor impacting aquifer depletion rates (Wada, 2016; Rodell, 2018). The intensification of drought phenomena, coupled by population increase, urbanization and rapid economic development will further aggravate the present conditions.

Given the complexity of the above described phenomena, climate change impacts are reflected in our model as an alteration of both monthly temperatures and precipitation amounts. The temperature increase translates in higher evapotranspiration, which combined with rainfall variability directly affects our estimation of the agriculture water demand and the recharge of renewable water resources. A more detailed explanation on the impacts of climate change on water demand is outlined in Section 3, while Section 4 analyses the effects on the renewable water supply.

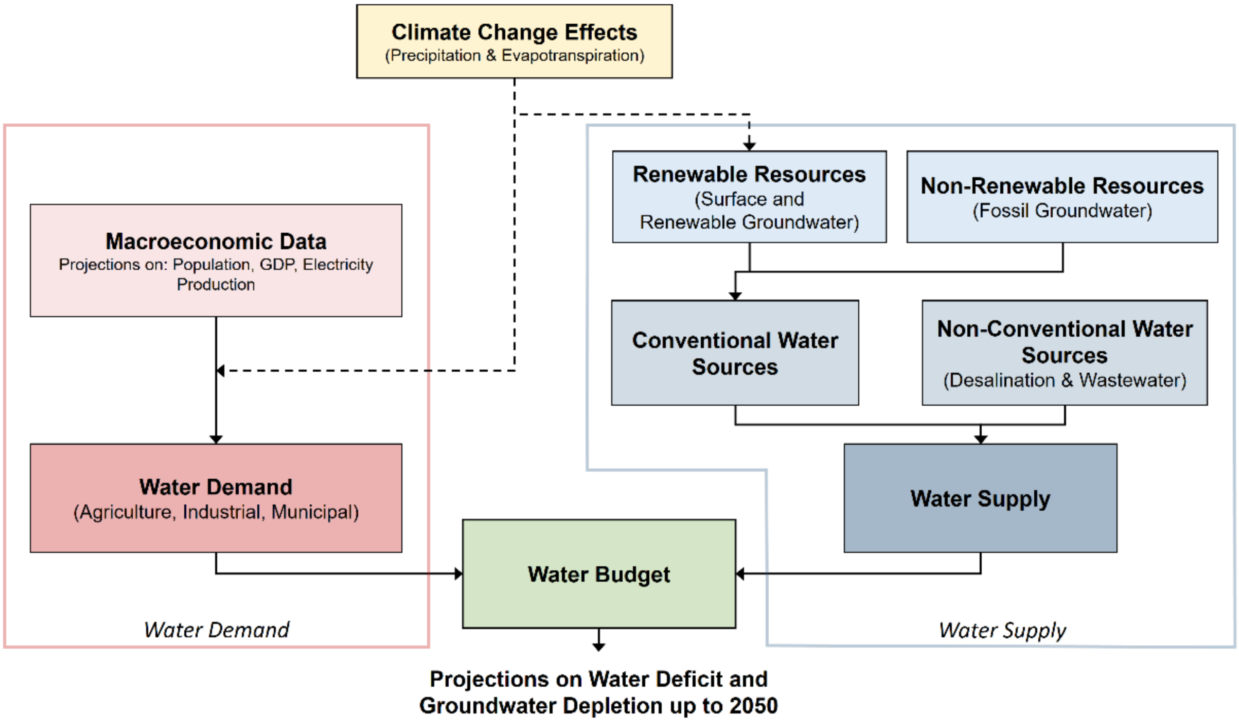

Figure 2.2. Flow diagram of the water balance model developed in this study. On the left side is the water demand per economic sector, while on the right side, the water supply combining conventional and non-conventional water resources. Results are presented as projections of water deficit and groundwater depletion volume (2016-2050).

As a first step in building our climatic projections, we retrieved the dataset of monthly average temperatures (accounting for daily mean, minimum and maximum temperature) and monthly average precipitations (in volume and in number of rainy days) from the historical Climatic Research Unit (CRU) (Harris et al., 2014); this data spans from 1901 to 2015 and is downscaled to the country-level. To forecast the future trends of temperature and precipitation variations from 2016 to 2050 we use the CRU data combined with the temperature and precipitation variations from Ruosteenoja et al. (2003) for the Sahara (SAH) region using the CSIRO, ECHAM4 and HADCM3 global circulation models and the A2, B2, A1FI, and B1 IPCC-AR4 emissions scenarios, combining them in a total of twelve monthly climatic projections. We only consider the CSIRO, ECHAM4 and HADCM3 circulation models, as they provide the most consistent precipitation forecasts for the MENA area. First, we calculate the overall country-based total annual reference evapotranspiration and precipitation for each year from 2016 to 2050. Then, we use the difference between these two variables to classify each of the twelve climatic projections in three marker scenarios: DRY, average (AVG) and WET. We consider as DRY the three climatic projections with the highest difference in precipitation and reference evapotranspiration, while the three with the lowest difference are assigned to the WET group. The remaining climatic projections are considered in the AVG group. In general, we observe that the twelve climatic projections produce highly heterogeneous forecasts for precipitation, while they concur on the steady increase of future mean temperatures, translating in a comparable slowly increasing trend of the reference evapotranspiration forecasts. Figure 2.3 provides an example of this classification for the case of Algeria, for which we highlighted the median values and the first and third quartiles for each of the three resulting marker scenarios.

In order to estimate the water deficit, we simulate the projected water gap for all the considered countries assuming that each nation does not increase its fossil groundwater extraction more than its present levels, which we define as “Business as Usual” (BAU). In order to estimate groundwater depletion, we perform the same simulation, but allowing countries to increase their groundwater withdrawals to compensate for the rising country water deficit, which we define as “Increased Groundwater Withdrawal” (IGW). With the simulation of this second case study we are able to calculate the water stress on each groundwater system in terms of aquifer volume depletion. After controlling for IGW, if a nation does not have any further available resource to compensate its annual water demand, it will generate a water deficit for the selected year. As most of these aquifers are transboundary, the effects of an increase in groundwater withdrawal can potentially affect the neighboring nations not only by lowering the total amount of available shared water, but also by modifying the groundwater flow patterns and piezometric heads, or by deteriorating the overall water quality of the aquifer. The objective of our model is limited to the estimate of the overall magnitude of the groundwater volume depletion and its timescale for each major transboundary aquifer as consequence of the simultaneous aggregate withdrawal of one or more riparian countries on a regional scale.

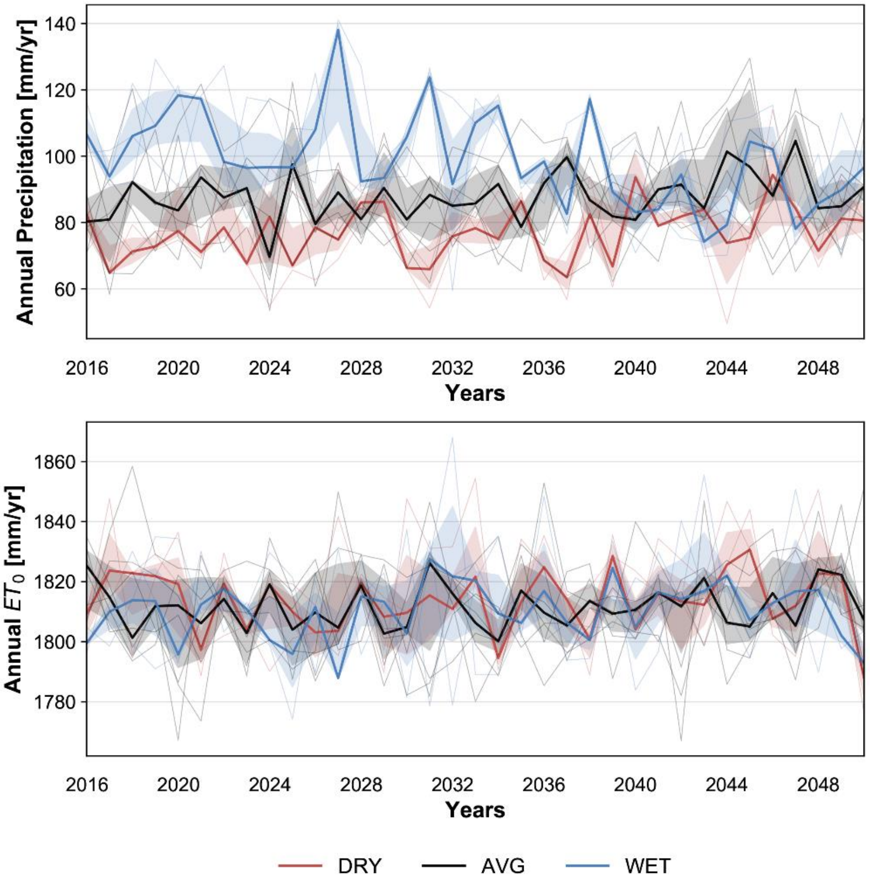

Figure 2.3. Total annual precipitation (upper plot) and total annual reference evapotranspiration $\boldsymbol{ET_0}$ (lower plot) trends from 2016 to 2050 for the twelve climatic projections for Algeria. Highlighted in red, black and blue bold lines are the median values for each of the three resulting marker scenarios, together with their respective first and third quartile represented as shaded areas.

2.2.1. Model Error Analysis

Water balance modelling is constrained by the uncertainties in the number of variables involved in the calculation and by the timeframe of the simulations. In this section, we address the potential limitations of our model and describe the error analysis that we have performed.

As outlined in the previous section, constraining the uncertainties on the projection of climatic variables is a key parameter for accurate water budget modeling. Unfortunately, these parameters present different ranges of confidence regarding their magnitude and temporal distribution. In particular, an important aspect is the prediction of future interannual variability in precipitation. Several studies have analyzed the region's historical precipitation trends suggesting that while the Arabian Peninsula shows a strong interannual precipitation variability without any specific temporal pattern, in North Africa changes in rainfall from one year to the other are much smaller (Zhang et al., 2005; Zittis, 2017). If future climatic changes will cause longer periods of drought, this will mostly affect countries, such as Algeria and Tunisia, that strongly depend on precipitation produced within their territory more than other countries in the MENA region. In order to lower the overall ambiguities in the climatic projections, we have combined the products of several GCMs and emission scenarios considered at a monthly-scale and then aggregated on an annual-scale. Further, the forecasts of the anthropogenic drivers used in our model contain estimation errors, especially in the long run. We therefore accounted for all the five available SSPs in our simulations, in order to capture a wider spectrum of variability.

The scarce availability of published data regarding the water resources of the area under study and their poor consistency across different sources can lead to large uncertainties in the development of a precise country water budget (UN-ESCWA and BGR, 2013). To constrain the ambiguities concerning this aspect, we have established a consistent dataset on the major characteristics of the considered aquifer systems as described in section 4.1.2 (see Table 2) with the most updated and reliable information publicly available. This, however, requires us to perform our simulations at the country level and on an annual-scale to maintain consistency between our entry data. Since this approximation can potentially lead to further inaccuracies in the estimation of variables that are function of climatic parameters, we have performed a comprehensive error analysis to assess the resulting uncertainty in model reliability. In particular, for each of the considered variables we calculated the average standard deviation error introduced by the spatial approximation to a single country-level average data. We then derived the resulting propagation error effect throughout the entire simulation by evaluating in every step the induced error for each dependent variable used in the model. Finally, we reported the error range for all the parameters presented in our results.

2.3. Modeling Water Demand

Water demand is defined as the quantity of water required by a country to meet its agricultural, industrial and municipal needs, and can be further categorized into water use and water consumption. Water use includes the amount of water withdrawn from different sources to fulfill demand, while water consumption is the portion of water use that is not returned in the water cycle and no longer available for reuse. In our model, we employ the water use approach to quantify the water demand as an input for our water budget calculation. This method allows us to directly link the dependency of demand to the water supply for each country.

Estimates of water demand per country and per sector are based on demographic and economic trends, described by population and GDP growth (Water, U.N., 2009). In the following subsections, we briefly describe each of the components that constitute the structure of our modeled water demand. First, we present the Shared Socio-economic Pathways (SSP) scenarios used in our projections analysis, and afterwards, we describe the method used to forecast water demand for each economic sector.

2.3.1. Shared Socio-Economic Pathways Scenarios

The first step in modeling water demand is the quantification of population and GDP trends, as well as the projection of land use (also referred to as cropland) and future electricity production over the selected time-horizon for the considered countries. In this study, we extrapolate data entries from the 2012-2016 SSPs database, which is an updated version of the Special Report on Emission Scenarios (SRES) by Nakicenovic et al. (2000). The SSPs represent a new set of classification scenarios produced by the climate change research community to be used for current and future studies on climatic impacts and the consequent evaluation of adaptation-mitigation policies (Riahi et al., 2017). The SSPs are based upon five storylines that are modified according to the required challenges for the adaptation and mitigation options; similar to the previous SRES families, they describe alternative socio-economic developments that range from a sustainable path to a fossil-fueled development economy. In particular, SSP1 describes a global shift towards a more sustainable path, with low challenges to mitigation and adaptation; SSP2 is the middle-of-the-road scenario, with medium challenges for both strategies; and SSP3 is outlined as the scenario with higher challenges towards mitigation and adaptation, with strong regional rivalry. In contrast, SSP4 and SSP5 present a world with asymmetric challenges for mitigation and adaptation policies: low challenges for mitigation and high for adaptation in the case of SSP4, and the opposite for scenario SSP5 (Riahi et al., 2017). The International Institute for Applied Systems Analysis (IIASA) has estimated population projections (Samir & Lutz, 2014), while the Organization for Economic Co-operation and Development (OECD) has produced long-term GDP and per capita income projections for each of the five SSP scenarios (Dellink et al., 2015). These data are used as input in our water demand model to calculate projections for population growth and GDP, for which we use World Bank statistics for 2016, hereafter referred to as base year, as initial conditions (World Bank, 2016a; World Bank, 2016b). In addition, we use Integrated Assessment Model (IAM) data that are centered on the baseline SSP scenarios to project each country's electricity production and cropland expansion for the MENA region (Riahi et al., 2016; Bauer et al., 2016). The base year values for electricity and cropland areas have been extrapolated from the OECD/IEA 2015 World Energy Outlook and the FAO AQUASTAT databases, respectively (OECD/IEA, 2015; FAO, 2016a). The resulting projections for aggregate population, aggregate GDP and aggregate electricity production under the five SSP scenarios are shown in Figure 2.4 for the two macro regions of North Africa and the Arabian Peninsula.

In North Africa, we observe that population projections for 2050 under the scenarios SSP1, SSP4 and SSP5 show the same trend, with an approximate total number of inhabitants that grows from 151 to 187 million. SSP2, in contrast, represents the intermediate path for population growth, while the highest aggregate population projection is given by the SSP3. SSP2 reaches 204 million in 2050, while SSP3 grows up to 228 million.

The Arabian Peninsula exhibits a different trend for each of the above mentioned SSP storylines. Its population starts at 81 million, and by 2050, it reaches a final aggregate population ranging between 131 and 161 million for SSP1 and SSP4, respectively. Although the North African countries have a higher number of inhabitants in absolute value, the population growth rate for the Arabian Peninsula almost doubles that of North Africa. Population projections from IIASA show that for all of the countries selected in this model, the maximum peak of population increase lies between the years 2050 and 2070, assuming a potential decline afterward. The GDP projections in our model show a rapid increase for both sub-regions, ranging between 1,770 and 3,250 billion USD from an initial value of ~600 billion USD for North Africa and between 3,630 and 5,800 billion USD, starting at 1,400 billion USD for the Arabian Peninsula. The lower bound is produced by the SSP3 and the upper bound by the SSP5. Within these limits, the storylines are arranged in ascending order as SSP4, SSP2 and SSP1 for North Africa, while this trend is reversed in the case of the Arabian Peninsula. Electricity production is projected to grow extensively, and especially for the SSP5, in which production is projected to increase up to five times the 2016 starting values after 2030. For the other SSP scenarios, electricity production is expected to increase by two to three times in both regions.

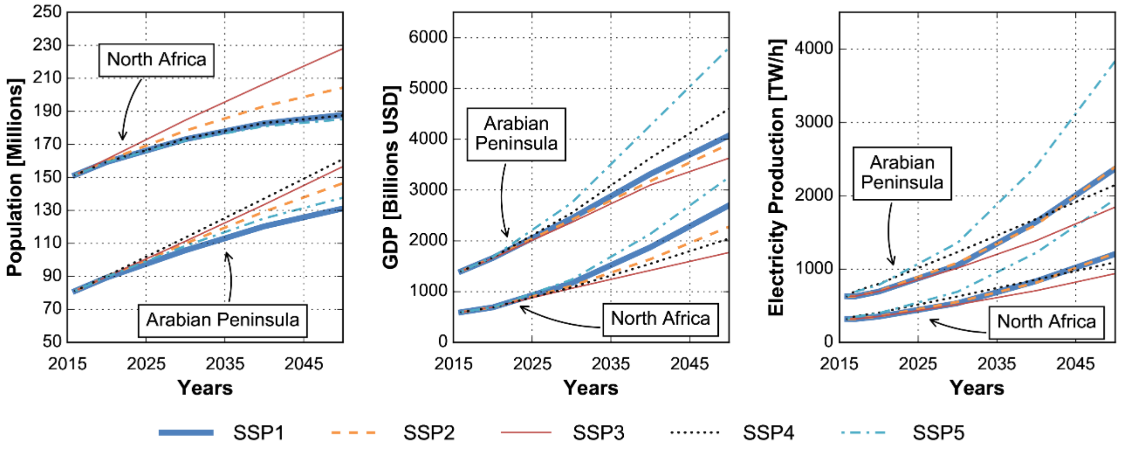

Figure 2.4. Trends of aggregate population, GDP and electricity production projections under the five SSP scenarios for North Africa and the Arabian Peninsula (2016-2050). Annual grow rates for population (Samir & Lutz, 2014), GDP (Dellink et al., 2015) and electricity production (Bauer et al., 2016) from the 2012-2016 SSP Database assuming base year data from the World Bank and OECD/IEA databases (World Bank, 2016a; World Bank, 2016b; OECD/IEA, 2015).

2.3.2. Agricultural, Industrial and Municipal Water Demand

The total annual water demand per country, as calculated in our model, is given by the sum of three major components: the agricultural, industrial and municipal water demand, as detailed below. We calculate the water demand per economic sector using data from the FAO AQUASTAT dataset in addition to other independent socio-demographic inputs to derive the model parameters of our water demand regression functions. The use of the FAO AQUASTAT entries for our water demand regression is justified by the need to maintain consistency in the comparison across the countries in our analysis. Different data sources use dissimilar methodologies or classifications methods for calculating and aggregating the final demand values, thus preventing us from reliably combine them together. Since the use of the FAO AQUASTAT data can lead to under- or over-estimate of the actual real values, we compare the resulting water demand estimates produced by our model with real data derived from governmental published reports. We obtain an average estimation error <5% for 2016, accounted singularly for each country. Therefore, for the purpose of this study, we consider the FAO AQUASTAT data as a reliable data-source, as also suggested by numerous authors, e.g. Alcamo et al., 2003; Immerzeel et al., 2011; Droogers et al., 2012.

Water utilization for agriculture accounts for different purposes: irrigation for crops production, livestock and aquaculture. Within these, irrigation requires the biggest share of the water supply, while livestock accounts only for the 0.54% in North Africa and the 0.3% in the Arabian Peninsula (calculated using livestock records from the FAO, 2016b and the drinking water requirements for livestock from Steinfeld et al., 2006) and negligible requirements for aquaculture as it is still currently underdeveloped in most of the MENA countries. The annual irrigation water demand for each country is calculated as the product between the country's estimated annual net irrigation water requirements (IWR_y) and the country-specific irrigation efficiency (IE_y) for the considered year y. This efficiency is defined as the ratio between the calculated IWR_y and the actual total agricultural water withdrawal obtained from the AQUASTAT database for each country at the specific year of the FAO survey (FAO, 2016a). To derive the annual net irrigation water requirements, we first retrieved the current crop-type production, crop calendar and cultivated area for each country from Frenken and Gillet, (2012). We then calculate the monthly potential evapotranspiration (ET_c) of each specific crop which is equal to the reference evapotranspiration (ET_0) of the considered area multiplied by a crop-specific coefficient (K_c), which in turn depends on the plant-type and its growing stage as retrieved from Frenken and Gillet, (2012). We estimated the monthly average reference evapotranspiration for each country using Hargreaves & Samani's equation, (1985) multiplied by the conversion factor 0.408 to obtain the equivalent evaporation in mm/day and by the number of days (N_d) of each specific month:

$$ET_0 = 0.0023 * R_a \sqrt{\Delta T}\,(T + 17.8) * 0.408 * N_d \qquad (2.1)$$

Using the CRU dataset by Harris et al., 2014, we retrieve T, the monthly average mean temperature, [C°] and ΔT defined as difference between the monthly average maximum and minimum temperatures [C°]. The extraterrestrial solar radiation R_a [MJm^{-2}day^{-1}] was instead calculated for each month of the year (we select the middle day of each month) using the equation from Allen et al., (1998). A portion of this water requirement is fulfilled by the plant-available precipitation which was derived using the historical monthly average precipitation and the number of wet days from the CRU dataset (Harris et al., 2014). The overall monthly difference of these two quantities is then combined with the crop calendar, the monthly cultivated land area and the crop intensity for each specific country, in order to derive the resulting annual net irrigation water requirement. Projecting the evolution of the IWR_y from 2016 to 2050 requires the forecast of the future temperature and precipitation variations in the region during this period. Future monthly mean, maximum and minimum temperatures have been estimated for each country combining historical data randomly selected between the values of the CRU dataset from 1961 to 1990 (Harris et al., 2014) and the projected variations of the specific months resulting from Ruosteenoja et al., 2003 for the Sahara (SAH) region. The interval 1961-1990 is selected in accordance to the climatological baseline period used by Ruosteenoja et al., 2003 in their study. Similarly, we use an analogous approach to estimate the countries' future monthly average precipitations combining historical data and future projections from the same sources described herein. As outlined in Section 2, this process produces twelve climatic projections, which are then classified for each country into DRY, AVG and WET scenarios. The forecast of cropland expansions is constrained by the choice of the specific SSP scenario selected for each simulation (cropland index of the SSP Database for the MENA region, Riahi et al., 2016) and estimated as projection of the current area under irrigation in each country (FAO, 2016a). Finally, given the expected development of more efficient irrigation systems in the area, we integrate into our agricultural water demand projections an analysis on the future trend of the country-specific irrigation efficiencies; such analysis, based on Alexandratos & Bruinsma, 2012, forecasts a 9% average increase of the agriculture water use efficiency ratio for the Near East/North Africa region from 2005/2007 to 2050 (equivalent to ~0.2% per year). This increase is applied on an annual basis to each country-specific efficiency and modulated depending on the SSP scenarios selected for the calculation. In addition, to further modulate the possible developments in modern irrigation systems, we assign an overall +50% to the FAO's forecasted average increase for SSP1 (13.5% in 2050); for SSP2 we keep the same value (9% in 2050); a -50% for SSP3 and SSP5 (4.5% in 2050), and for SSP4 a +50% (13.5%) for the high-income countries (GNI per capita > 12,475 USD, according to World Bank classification) and 9% increase for the others.

The water demand for the industrial water sector refers to the water used in the production processes, which is either self-supplied or provided by a public supplier. In our case, it includes water for thermoelectric and nuclear power plants cooling systems and it serves industries not connected to the public distribution network. With municipal water demand, instead, we consider the water supplied through the public distribution network serving households, residential areas, and the part of the industries and urban farms that are connected to the municipal network (FAO, 2016a). The major drivers for the increase of domestic and industrial water demand are GDP and population growth, which cause rapid urbanization and competition among users and economic sectors to meet the needs of a growing world (Oki and Kanae, 2006). We calculate the industrial and municipal water demands of each country as the product between their net water intensities, IWI [m^3/MWh] and MWI [m^3/person], a $ISWI = \frac{1}{\gamma_i(GDPP-GDPP_{min})} + ISWI_{min}$s defined by Alcamo et al. (2003), and the electricity production and population size, respectively. We first estimate the parameters of IWI and MWI, ISWI_{min}, MSWI_{min} and $\mathrm{MSWI}_{\mathrm{max}}$, combining the available AQUASTAT data on the historical industrial and municipal water demands (FAO, 2016a), the countries' electricity production (extracted from the World Energy Outlook and World Bank databases, OECD/IEA, 2015) and population size in the same year of the FAO survey. Similarly, historical data on population and GDP for all the selected countries were retrieved from the World Bank database (World Bank, 2016a; World Bank, 2016b), while γ_i and γ_d, the remaining constant dimensionless parameters of IWI and MWI, were estimated by iteration. To forecast the future variation trends of the two net water intensities we used GDP and population projections from the SSP database for the MENA region. Finally, similarly to the approach used for agriculture water demand, we match the technological change in industrial and domestic water efficiency to the specific SSP scenario selected in the simulation, using the same ranges of variation (+50% in SSP1 and SSP4 high-income countries; no increase for SSP2 and SSP4 low and middle-income countries; -50% in SSP3 and SSP5). Irrigation requirements for landscaping and recreational purposes, which are particularly substantial in the GGC countries (i.e. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates), are accounted either in the municipal demand, if the source is public, or are met by the use of wastewater reuse (FAO, 2016a).

Figure 2.5 shows the resulting projected aggregate water demand per economic sector from 2016 to 2050 for North Africa (2.5.a) and the Arabian Peninsula (2.5.b) in the case of the SSP2 and AVG climate change scenarios. The overall water requirements under these hypotheses will grow from 104 to 130 BCM (±3.69) for North Africa (+25%) and from 34.2 to 50 BCM (±1.07) in the Arabian Peninsula (+46%) by 2050. For both regions, the agricultural sector has the highest water needs, on average equal to 70-80% of the overall demand, growing at an almost constant pace of ~8% every decade. The industrial demand will instead grow at a much higher rate per decade: ~14% for North Africa and ~50% for the Arabian Peninsula, going from 5% to 17% of the total demand in 2050 for this latter region. The domestic water demand for the both regions will remain almost constant, averaging a ~15-18% of the overall demand, despite the projected increase in population size for some of the North African countries.

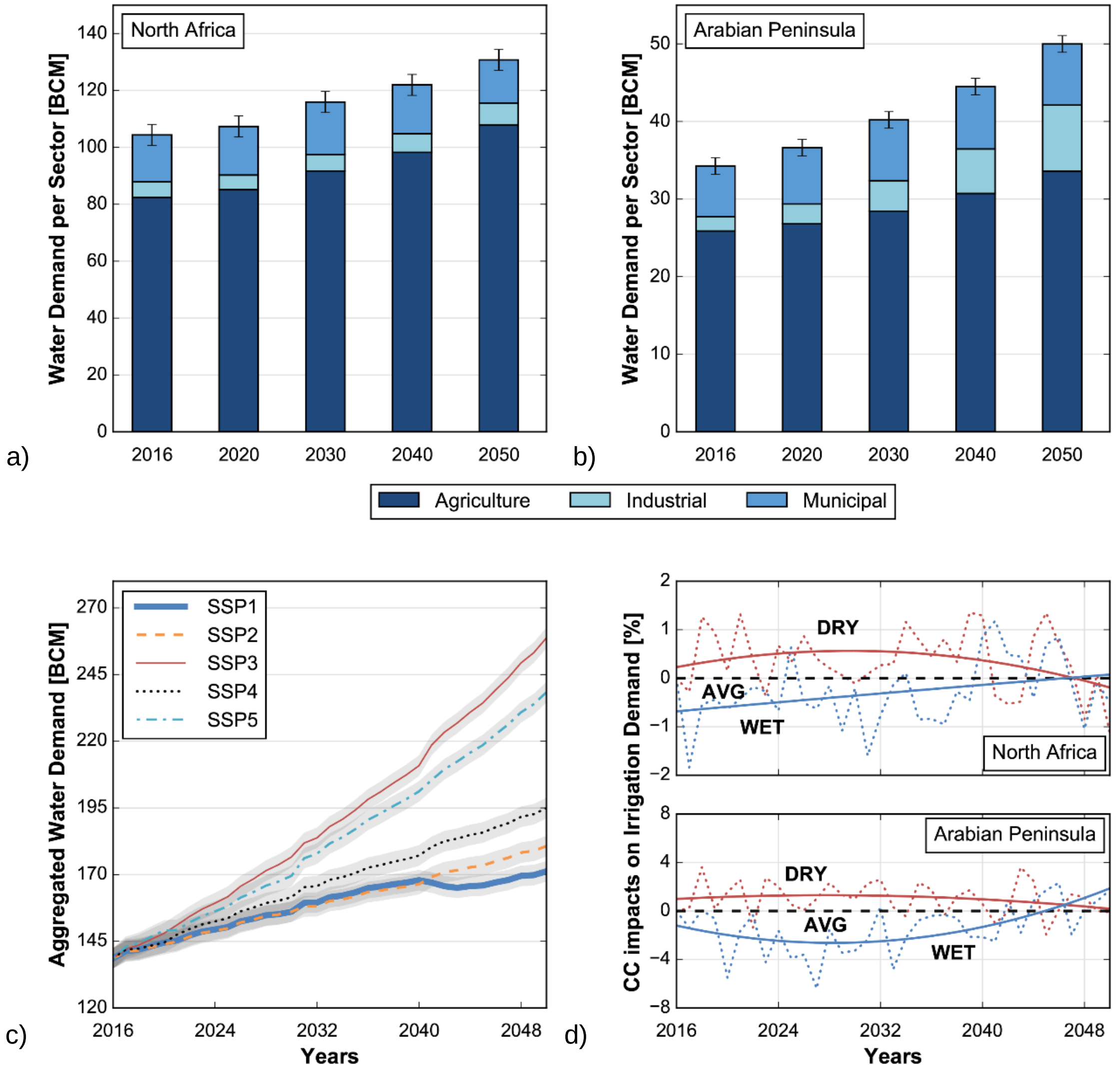

Figure 2.5. Water demand projections per economic sector for North Africa (2.5.a) and the Arabian Peninsula (2.5.b) for the SSP2 and AVG scenario. (2.5.c) Aggregated water demand up to 2050 for the different SSP scenarios with AVG climate change. (2.5.d) Climate Change effects of the DRY and WET scenarios compared to AVG on the irrigation demand for the SSP2 scenario. The shaded grey areas highlight the error ranges in our model.

Figure 2.5.c shows the forecasted aggregate water demand for each specific SSP scenario. SSP1 shows water requirements 5.2% lower than SSP2 in 2050, while SSP4, SSP5 and SSP3 present higher water demands of 8%, 32% and 43%, respectively when compared to SSP2. Finally, according to scenario SSP2, future climatic variability for the North African region will cause an annual fluctuation of water demand for irrigation by ±0.76% (about ±0.89 BCM/yr.), while for the Arabian Peninsula, it will have a similar fluctuation effect with a projected range of ±2.4% (about ±1 BCM/yr.) on average (see Figure 5.d).

2.4. Modeling Water Supply

From a hydrological perspective, conventional water resources can be classified into two main categories: surface runoffs collected in rivers, streams, lakes and catchments (perennial, seasonal or intermittent) and groundwater contained in renewable or fossil aquifers. These resources are all dependent on the natural processes of the water cycle and are strongly influenced by the variable evolution of regional climatic factors.

Harsh arid conditions, coupled by low precipitations and high levels of evaporation and evapotranspiration, make North Africa and the Arabian Peninsula region one of the driest and most water-scarce areas in the world. To compensate for the shortage of natural resources and the growing demand due to the increase of population, a few decades ago most of the MENA countries started to invest in non-conventional water resources, which offer a complementary supply of freshwater that can be used to partially alleviate their water scarcity.

In this section, we provide a brief description of the key characteristics of the main water supplies of North Africa and the Arabian Peninsula that we consider in our water budget model. We describe conventional sources differentiating between renewable and non-renewable. For non-conventional sources, we present the current status and the future projections on desalination capacity and wastewater reuse for each country.

2.4.1. Conventional Water Resources

Conventional water resources for Northern Africa and the Arabian Peninsula can be differentiated in renewable and non-renewable. The first ones are the total amount of a country’s net water supply (internal and external), both surface water and renewable groundwater, mostly shallow groundwater, generated through the water cycle. On the contrary, non-renewable water resources mainly comprise fossil groundwater bodies characterized by a negligible rate of recharge, several orders of magnitudes lower and slower when compared to renewable groundwater systems (McDonnell, 2017). For this reason, we account for climate change effects only on renewable water resources supply whether surface or groundwater. Fossil aquifers for the MENA region represent the dominant type of groundwater resources, while renewable aquifers constitute only a small fraction of the regional water budget.

Renewable Resources

The MENA countries considered in our model present different availability of renewable water supplies. For instance, Algeria's and Tunisia's streams originate mainly from precipitation, snowmelt and runoff from the mountains; Egypt possesses surface and shallow subsurface waters related to the Nile Basin, while Libya, the GCC countries and Yemen do not have any relevant renewable source of surface water, having to rely only on groundwater – both renewable and non-renewable –, and on desalination (FAO, 2016a).

We compile the data on the availability of renewable freshwater resources for each country from the FAO AQUASTAT database (FAO, 2016a) and we compare them with other publications and governmental reports. According to the FAO database, renewable freshwater availability is defined as the average annual flow of rivers and recharge of aquifers generated from precipitation. In hyper-arid environments, the annual changes in the renewable water supplies are influenced by the regional climatic variability. Hence, we modulate the changes in supply according to the percentage change of the difference between annual precipitation and evapotranspiration. As in the case of the agricultural water demand, the climate change projections are adjusted with the DRY, AVG and WET scenarios derived from the calculation outlined in section 2. A summary of the present total renewable water storages for each considered country is shown in Table 2.1.

Egypt, among the countries considered in this study, is the only one where renewable supply mostly originates outside of its territories. It is the last downstream riparian of the Nile river basin, which is shared with 10 other countries and composed by different sub-basins. The forecast of the Nile flow entering the Egyptian border is constrained by the interannual recharge variability and long-term climatic changes of the southern tropical region and the anthropogenic pressure caused by the upstream riparians.

The climate within this basin is extremely variable passing through very different climatic gradients, from humid equatorial in the south to semi-arid, arid and hyper-arid in the center/northern region. Precipitations have a significant interannual and decadal variability, with annual rainfall mostly concentrated in the upstream countries, such as the Rift Valley and the Ethiopian Highlands, while Egypt and Sudan exhibit very low amounts (Camberlin, 2009). The area of the basin that mostly contributes with significant volumes to the Nile flow is the Ethiopian Plateau, but it is however strongly affected by the seasonal rain patterns. The White Nile in the equatorial subsystem supplies a lower volume of water to the Nile, but it is characterized by a more stable rainfall availability. The Main Nile area, extended over the downstream countries, generates instead a negligible runoff and presents high evaporation resulting in an overall net loss. Studies on climate change effects on the Nile basin at regional scale observe that there is no unique and clear indication of the climate change effects on the Nile flow (Conway, 2005). Barnes, 2017, presents a thorough review of the latest climate change modeling studies for the Nile Basin and points out that the majority of the models agrees on the existence of an overall warming trend, while they present high degrees of uncertainty regarding the direction of changes in precipitation and streamflow.

Table 2.1. Total annual availability of renewable water in billions of cubic meters (BCM/year) for each considered country. Ref: [1] FAO, 2016a, [2] Hamiche et al., 2015, [3] Ansari, 2013 [4] Abdulrazzak, 1994, [5] Ismail, 2015, [6] Salem, 1992 [7] MRMWR, 2008, [8] Baalousha, 2016, [9], Abdulrazzak, 1995, [10] Shetty, 2004, [11] Ward, 2014.

Country	Renewable Surface Water	Renewable Groundwater	Overlap	Total Renewable Water Resources
Algeria	10.15 [1]	1.517 [1]	0 [1]	11.667 [1,2]
Bahrain	0.004 [1]	0.112 [1,3]	0 [1]	0.116 [1]
Egypt	56 [1]	2.3 [1]	0 [1]	58.3 [1]
Kuwait	0.001 [1,4]	0.02 [1,5]	0 [1]	0.02 [1]
Libya	0.2 [1,6]	0.6 [1,6]	0.1 [1]	0.7 [1,6]
Oman	1.05 [1,7]	1.3 [1,7]	0.95 [1]	1.4 [1]
Qatar	0 [1]	0.058 [1,8]	0 [1]	0.058 [1]
Saudi Arabia	2.2 [1,9]	2.2 [1]	2 [1]	2.4 [1]
Tunisia	3.42 [1]	1.595 [1]	0.4 [1]	4.615 [1,10]
U.A.E.	0.15 [1,10]	0.12 [1]	0.12 [1]	0.15 [1]
Yemen	2 [1]	1.5 [1,19]	1.4 [1]	2.1 [1, 11]

Furthermore, the current and projected population increase and consequent growth in water demand is spreading the tension in the hydro-politics of the region. The downstream riparians, namely Sudan and Egypt, signed an agreement in 1959 for the full utilization of the Nile waters. This treaty assigns 55.5 BCM/yr. to Egypt, 18.5 BCM/yr. to Sudan and 10 BCM/yr. accounted as annual evaporation at Lake Nasser/Nubia. In 2011, the unilateral announcement by Ethiopia of the construction of the Great Ethiopian Renaissance Dam (GERD) on the Blue Nile at the Ethiopian-Sudanese border and the independence of South Sudan from Sudan changed the hydro-political balance. Both these phenomena could additionally challenge the water management in the region adding uncertainty on the forecasts of the water availability in the downstream states. Given the above mentioned complexities, obtaining a reliable prediction of the effects of climate change and water management planning in the Nile Basin is challenging and would require a separate and more detailed analysis. Therefore, we assume in our model that the maximum withdrawal from the Nile for Egypt is fixed at 55.5 BCM/yr. and we discuss the potential effects induced by climatic changes and population increase within the basin on the Egyptian water deficit in Section 5.1.

Non-renewable water resources

Most of the groundwater in the MENA area is contained in fossil aquifer systems that are the remnant of wetter or more humid geological eras (Bourdon, 1977 and 1982). All the countries examined in the model present one or more fossil aquifer systems within their borders. The Northern African Sahara area includes: the North Western Sahara Aquifer System (NWSAS), the Murzuq Aquifer and the Nubian Sandstone Aquifer System (NSAS). The Arabian Peninsula has nearly 30 different shallow and deep water-bearing and transmitting formations (Alsharhan et al., 2001). In our model, we distinguish and characterize the following: Dibdibba-Kuwait Group, Neogene Eastern Saudi Arabia, Sand Dune-Liwa Aquifer; Western Gravel Aquifer, Ash Sharqiya Aquifer, Umm Er Radhuma (North, Center and South), Sakaka Aquifer, Wasia-Biyadh-Aruma Aquifer System, Tawil Aquifer, Minjur-Dhruma Aquifer, Saq-Ram Aquifer, Wajid Aquifer. A summary of the main hydrological characteristics for all the non-renewable aquifer systems in both Northern Africa and the Arabian Peninsula is presented in Table 2.2.

Table 2.2. Summary of the input data for the fossil aquifer systems in North Africa and the Arabia PeninsulaExploitable storage available in billions of cubic meters [BCM], present annual recharge in BCM/year, present annual extraction in BCM/year (for the considered nations), and list of the riparian countries for each transboundary aquifer. *Share of Egypt and Libya only. Ref.: [a] Values calculated in this study, [1] Foster and Loucks, 2006, [2] CEDARE, 2014, [3] Schmidt, 2008, [4] OSS, 2004, [5] Ibeda et al., 2013, [6] Maliva and Missimer, 2012, [7] UN-ESCWA and BGR, 2013, [8] Al-Rashed and Sherif, 2000, [9] MOP, 1985, [10] Brook et al., 2006, [11] Wagner, 2011, [12] MEW, 2010, [13] Al-Khamisi, 2011, [14] MRMWR, 2008.

Aquifer Systems	**Exploitable Volume**	**Recharge**	**Extraction**	**Riparian Countries**
NWSAS	1,280 [1]	1 [2,3]	2.851 [4,a]	Algeria, Libya, Tunisia
Murzuq Aquifer	70 [1]	0 [5]	1.75 [1,4]	Libya, Niger
NSAS	10,217* [1]	0.005 [6]	2.531 [4,a]	Chad, Egypt, Libya, Sudan
Dibdibba - Kuwait Group	11 [7,8]	0.059 [7]	0.092 [7]	Iraq, K.S.A., Kuwait
Neogene Eastern Saudi Arabia	5 [9]	0.28 [a]	0.55 [a]	K.S.A.
Sand Dune - Liwa Aquifer	101 [10]	0.072 [11]	2.189 [12]	U.A.E.
Western Gravel Aquifer	20.6 [a]	0.03 [7]	0.446 [7]	Oman, U.A.E.
Ash Sharqiya Aquifer	24 [13]	0.07 [14]	0.08 [14]	Oman
UER / Dammam (South)	112.89 [7]	0.012 [7]	0.053 [7]	K.S.A., Oman, U.A.E
UER / Dammam (Center)	57.51 [7]	0.922 [7]	1.242 [7]	Bahrain, K.S.A., Qatar
UER / Dammam (North)	42.6 [7]	0.173 [7]	0.12 [a]	Iraq, K.S.A., Kuwait
Sakaka Aquifer	100 [7]	0.242 [7]	0.3 [7]	Iraq, K.S.A.
Wasia-Biyadh-Aruma Aquifer System	500 [11]	0.045 [7]	0.09 [a]	Bahrain, K.S.A., Yemen
Tawil Aquifer	22 [7]	0.03 [7]	0.876 [a]	Jordan, K.S.A.
Minjur - Dhruma Aquifer	182 [8]	0.08 [8]	5.4 [8]	K.S.A.
Saq-Ram (Tabuk) Aquifer	665.37 [7]	0.35 [7]	6.565 [7]	Jordan, K.S.A.
Wajid Aquifer	39 [7]	0.104 [11]	2.358 [7]	K.S.A., Yemen

Since desalination is the primary source of freshwater for most of the GCC countries, in our simulation we modeled the projections of increase in desalinated water capacity planned for the immediate future for each country. For each state, we collect the number of desalination plants that are currently active, their capacity and the year they started operating (data are retrieved from local public utilities or water ministries annual statistic reports). Assuming an average plant lifespan of 25 years, we estimate a first order approximation of future desalination capacity, which also accounts for the desalination plants that are under construction or that have been already commissioned. Therefore, we produce a realistic estimate of future desalination capacity trends for each country, up to 2050 (see Figure 2.6.a). In our simulations, we hypothesize that once each country reaches its maximum desalination production capacity (highlighted in red in Figure 2.6.a), it will keep this value constant for the remaining years. This is a reasonable assumption that serves as lower bound for our simulations, since it is plausible to expect that a country that relies significantly on desalination will keep at least the same level of production of desalinated water in case of an increasing water demand. We assume that the country will replace each of its decommissioned desalination plants with a new one that has at least the same production capacity. Treated wastewater is instead mostly used for irrigation, in particular in North Africa. The high-income countries in the GCC use treated wastewater for agricultural and landscape irrigation. The efficiency of wastewater treatment in the MENA region is highly variable, due to the inability of accommodating the large volumes of wastewater resulting from increasing urban populations. Forecasting future wastewater reuse in the MENA region is challenging. Although wastewater reuse is expected to grow and develop in the next future, little if no data is publicly available for most of the countries under study. For this reason, from 2016 to 2050, we hypothesize a constant rate of investments in wastewater reuse for each country, calculated as percentage over each nation’s water demand. This assumption will give us as a lower bound for the forecasted water gap of each nation without affecting the accuracy of the predictions. Figure 2.6.b summarizes the overall water supply for the North Africa and the Arabian Peninsula.

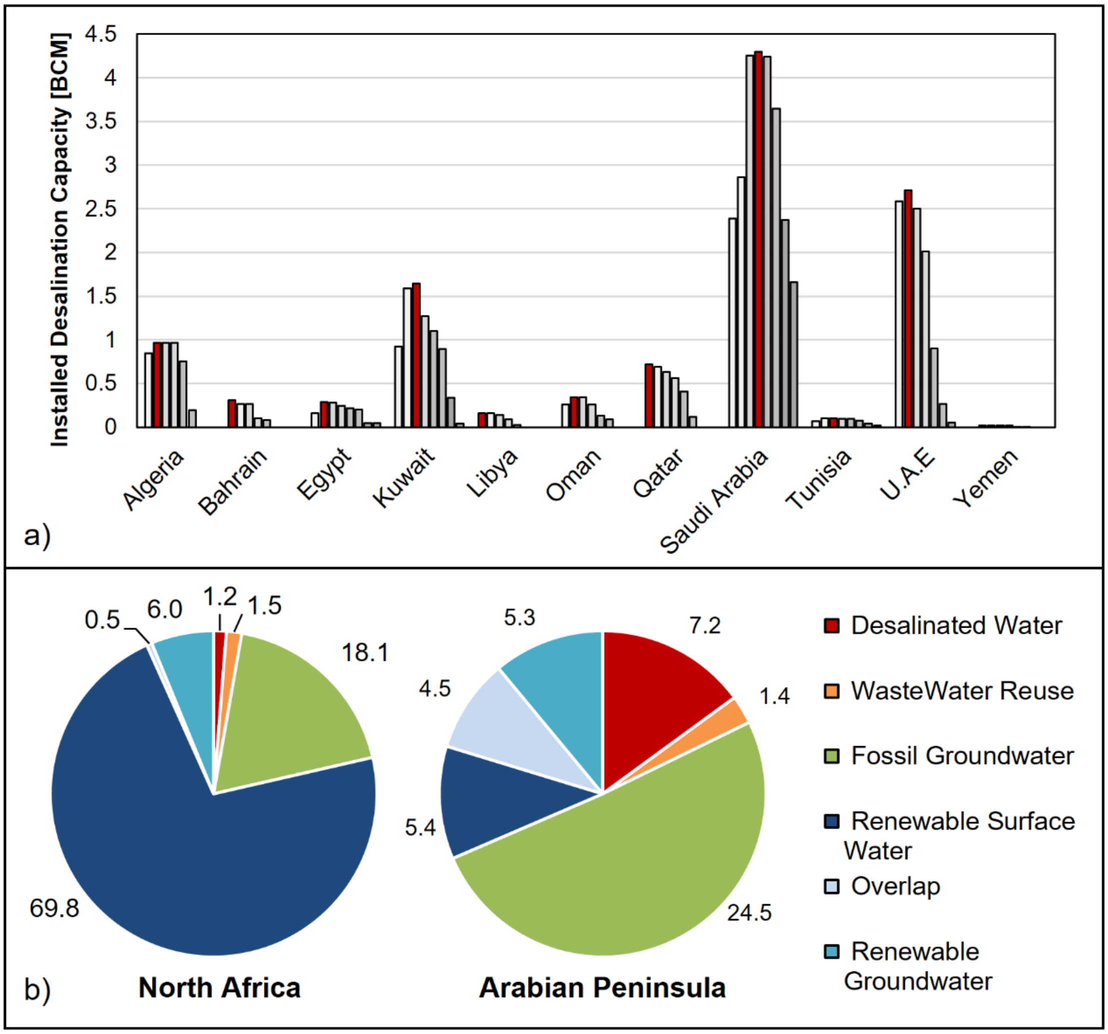

Figure 2.6. Projected desalination capacity in BCM/yr. from 2016 to 2050 (2.6.a, self-calculation) and summary of the present conventional and non-conventional water resources in BCM for North Africa and the Arabian Peninsula (2.6.b, self-calculation based on FAO, 2016a).

2.5. Simulations and Results

In this section we present the results of the calculated water budget under the different climatic and socio-economic scenarios considered for this study. The analysis has two major objectives:

1. Quantifying the projected water deficit per country, when holding constant the annual maximum fossil groundwater withdrawal to the present values of extraction (i.e. BAU study case). The goal is to measure and separate the effects of the projected raising water demands against the available conventional and non-conventional water supplies. In particular, our scope is to evaluate both how long the available renewable resources can sustain the increasing water requirements in the region and

if the current planned investments in non-conventional water resources can mitigate or withstand this growing need.

2. Understanding if groundwater can be used as a natural strategic source to fulfill the projected water demand of the region by assessing the consequential depletion of the aquifers' storages. We perform this analysis within our simulations, allowing for the countries to increase their annual fossil groundwater demand to meet their water requirements (i.e. IGW study case).

2.5.1. Projected Water Deficit

The first step consists in the simulation of the projected water deficit that the considered MENA countries may undergo from 2016 up to 2050 under all the different SSPs and climate change scenarios. In Figures 2.7.a and 2.7.b we present the resulting forecasted water gaps of the BAU study case under the SSP2-AVG scenario, selected herein as illustrative case for the countries in North Africa and in the Arabian Peninsula, respectively. We can first observe that in North Africa, Algeria and Tunisia are not likely to suffer from any significant water deficit within the simulated time frame. On the contrary, Libya and Egypt will suffer significant freshwater shortages. In particular, Egypt, which is already experiencing a substantial water gap of ∼11.40 BCM/yr. (±4.60), will further deteriorate its situation, reaching a deficit three times larger by 2050. This water gap corresponds to ∼15% in 2016 and ∼45% in 2050 of their freshwater supply. Even though Libya will face a smaller deficit in absolute value in 2050 (3.52 BCM/yr. (±1.17)), this amount is critical if compared to the available Libyan water supply (∼90%). For Egypt, these results can be altered by the possible natural and anthropogenic variabilities in streamflow of the Nile River, induced by changes in precipitations and development of infrastructures along the Basin (i.e. urban and agricultural expansion, and dams). Beyene at al., 2010 forecast an increase in annual average inflow of 11-14% during 2010-2039, but a decrease of 7-8% for the period 2040-2069, while Siam and Eltahir, 2017 suggest that the long-term mean and the standard deviation of the entire river flow could increase by 15% and 50%, respectively, compared to the twentieth century. On the demand side, the Nile Basin countries' total population is estimated to ∼500 million in 2016, of which ∼270 million live within the Nile Basin boundaries. Based on the SSPs projections considered in our study, the population growth for the riparian, excluding Egypt, is between 60% (SSP5) and 114% (SSP3) by 2050. This substantial increase will potentially affect the future water demand for the agricultural, industrial and municipal sectors. In particular, the current total withdrawn from the Nile to meet the irrigation water requirements is 82.2 BCM/yr., with Egypt, Sudan and Ethiopia accounting for 99% of the overall extraction (80%, 17% and 2%, respectively, Akol et al., 2016). Any further expansion of the irrigated land in Sudan and Ethiopia, aggravated by the ongoing process of land transfer to foreign investors, could result in increased withdrawals from the River. Moreover, the construction of hydropower dams in the upper Nile Basin could potentially decrease the availability of streamflow at the High Aswan Dam (Zhang et al., 2015), like the GERD, which could induce 6-14% average flow reduction during the first 5 years of filling operations (Digna et al., 2018). In summary, the short-term climate change effects on the Nile Basin could balance temporarily the increased demand for water resources for the riparian countries, but in the long-term this might not apply any longer, consequently harshening the water deficit that Egypt will experience after ∼2030.

Among the countries of the Arabian Peninsula, Saudi Arabia and Yemen show the highest deficit level in 2050, ~4.26 BCM/yr., (±3.39 for Saudi Arabia and ±1.73 for Yemen), which account for the ~20% and ∼190% of their freshwater availability, respectively. Saudi Arabia's water gap, in particular, starts growing by ∼2 BCM per decade after 2040. Bahrain, Kuwait, Oman and Qatar share a similar forecasted deficit trend, which will reach ~0.74 BCM/yr. in 2050 on average (±0.007, ±0.07, ±0.79, and ±0.014, respectively). Although this volume seems low in absolute terms, if compared with the countries' supplies, it corresponds to ∼108%, ~83%, ~40%, and ~60%, respectively. Finally, the U.A.E. will linearly increase its deficit of ~0.36 BCM/yr. every ten years, reaching 1.88 BCM/yr. (±0.2) in 2050 (~34% of its future supply).

If we consider the aggregate water deficit in 2050, calculated for the two regions in the SSP2-AVG scenario, which equals to 36.8 BCM/yr. (±4.74) and 13.4 BCM/yr. (±3.68), the variation induced by the selection of an alternative scenario in the same climatic conditions produces smaller water gaps for the SSP1 (-17% in average) and much greater for the other case studies. SSP4 induces a ∼23% higher deficit, while SSP3 and SSP5 more than double the results of SSP2 (+139% and +114% in average, respectively; see Figure 2.7.c).

Ultimately, when accounting for the effect of climate change on the agricultural water demand and the renewable water supply, with respect to the average projection, we observe a water gap variation for the SSP2 scenario in North Africa between -2.7% and +2% in average (which translates in about -0.66 and +0.53 BCM/yr.). For the Arabian Peninsula, the overall effect will range between -19% and 20% on average, which equals to -0.91 and +1.36 BCM/yr. (see Figure 2.7.d). Among all the considered countries, Egypt and Yemen appear as the two most vulnerable countries to future climatic variability due to their strong dependency on renewable freshwater sources.

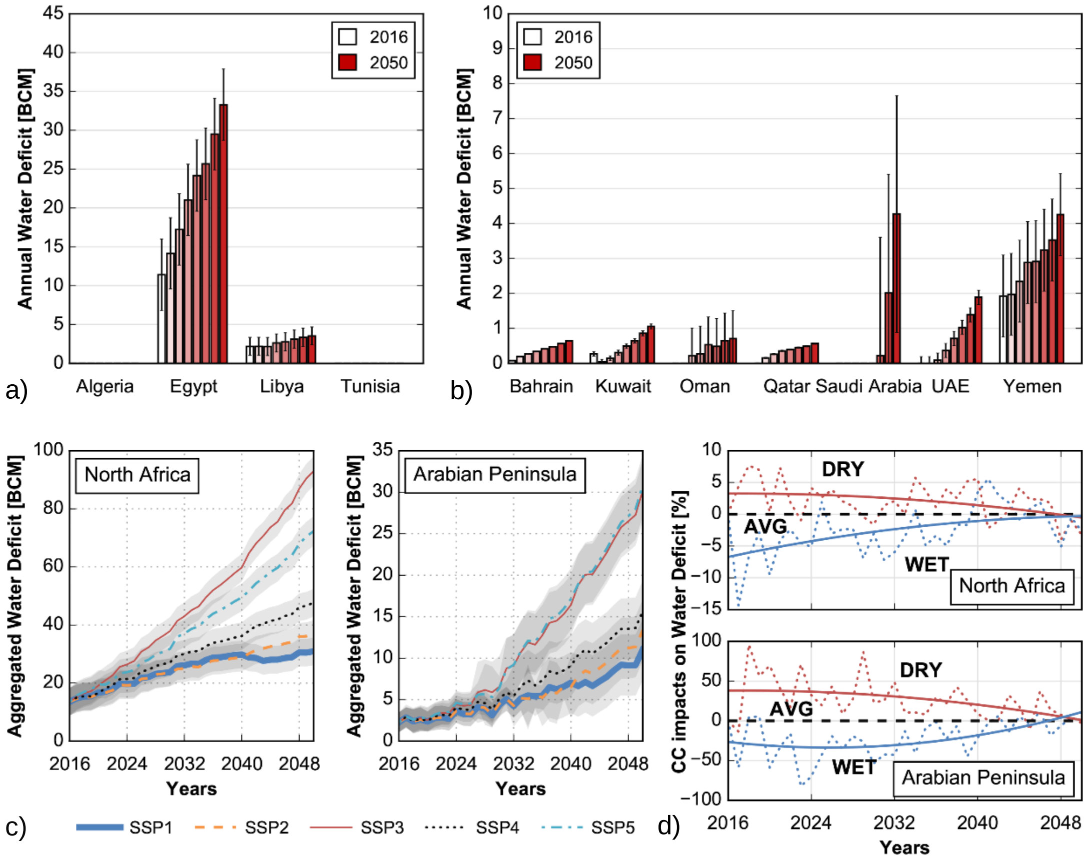

Figure 2.7. Histograms of the calculated annual water deficit from 2016 to 2050 for the SSP2-AVG scenario for each country of North Africa (7.a) and of the Arabian Peninsula (7.b). Figure 7.c presents the resulting aggregate water deficit for the two regions under the different SSP scenarios and the AVG climate. Figure 7.d shows the additional effects produced by climate variability respect the AVG scenario of drier or wetter future climatic conditions on the SSP2 aggregate regional water deficit. The shaded grey areas highlight the error ranges in our model.

Figure 2.8 instead, quantifies how much of the annual marginal increase in water deficit for every country is attributable to a decrease in their supply or increase in their water demand, averaged throughout the simulation and for each scenario (in % logarithmic scale). The colored bars display the deficit determinants for SSP2-AVG, while the error bars outline the range of variation when considering the effects of the other SSPs and climate change marker scenarios. We first observe that the main determinant for the marginal increase of the deficit is the demand variation, while changes in supply have a much lower significance on the overall result, corresponding to less than 5% for 2/3 of the countries in deficit. Oman, Saudi Arabia and Yemen, display a supply deficit dependence at ~31%, ~12% and ~14%, respectively, reflected by the erratic presence in their territories of limited amounts of renewable water sources, which are instead completely absent in Kuwait. If we consider the other SSPs and climatic marker scenarios, we find that for most of the considered countries, the upper bound of variation of the marginal deficit dependency from the supply is achieved under the SSP1-WET scenario, while the SSP3-DRY defines its lower limit. The SSP1 is characterized by a low population growth, which substantially decreases after 2050, and a high but sustainable and efficient economic development, which both contribute to decrease the overall water demand. The WET marker scenario contributes instead to increase the water supply availability, thus decreasing the dependency of the deficit on this variable. At the same time, however, a wetter climate lowers the water requirements for irrigation, decreasing the overall demand. The combination of these two effects results on an overall higher dependency of the marginal deficit on the supply side. Conversely, the SSP3-DRY scenario, which represent the lower bound for most of the considered countries, portrays a world with slow economic development and a very high population growth that create large water demand and high irrigation requirements. The impact of these phenomena, when combined with a scarcer supply, results in a higher dependency of the marginal deficit to the demand. Lastly, neither Algeria nor Tunisia experience any deficit under the SSP2-AVG along the considered time-span, but they display a measurable deficit only for the SSP3 and SSP5, which represent respectively the lower (SSP3-DRY) and upper (SSP5-WET) bounds for these two countries.

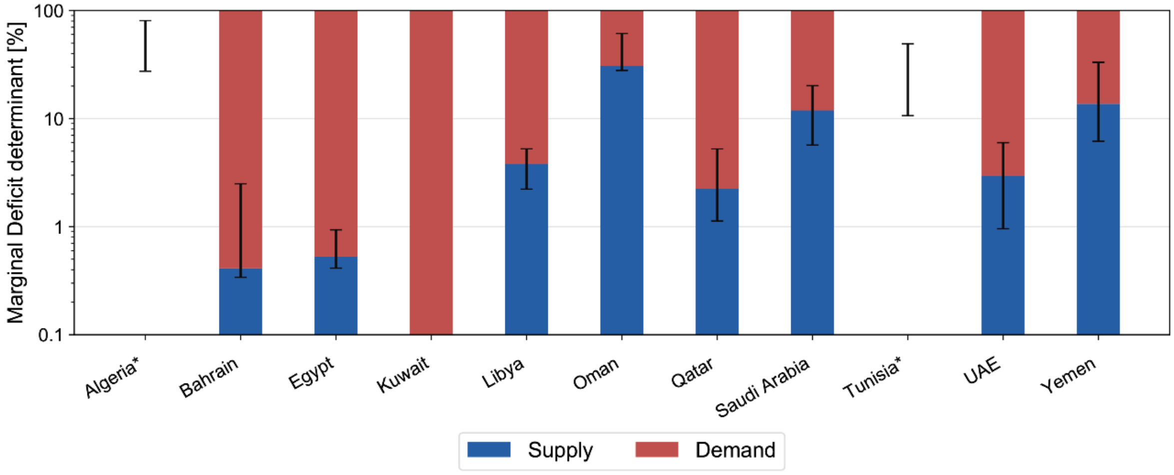

Figure 2.8. Attribution of the annual marginal increase in water deficit per country (in % logarithmic scale). The colored bars show the deficit determinants for the SSP2-AVG and the error bars delineate the range of variation considering the effects of the remaining SSPs and climate change marker scenarios (SSP1-WET upper bound and SSP3-DRY lower bound for all countries; *countries with SSP5-WET upper bound and SSP3-DRY lower bound).

2.5.2. Storage Depletion

After evaluating the projected water deficit for each considered country, we test if the fossil groundwater systems in North Africa and the Arabian Peninsula can be used as strategic reserves to mitigate the increasing water demand of the region. Our goal is to weigh the effects of a higher groundwater withdrawal on the aquifer storage levels compared to the present conditions of extraction, accounting for all the socio-economic and climatic hypotheses at the base of our study. We present the results of this analysis for all the considered aquifer systems of the MENA region in Figures 2.9, 2.10, 2.11 and 2.12. Every Figure shows in the left column, for each aquifer, the % volume depletion relative to the current exploitable storage (*Relative* $\Delta \boldsymbol{V}$) under the AVG climate change scenario and for the different socio-economic hypotheses analyzed in this study. In particular, the overall groundwater depletion estimates for the BAU case study (current extraction rates are kept constant up to 2050) are compared to the five SSP scenarios. On the right side of the Figure are outlined the changes in percentage of volume variation indirectly produced by the different climatic projections (DRY and WET) relatively to the average climatic conditions (AVG) are outlined. Although we clearly observe an alarming depletion trend for all the aquifer systems, some of these fossil resources are in danger of full exhaustion even at the present conditions of extraction.

North Africa's extensive groundwater reserves, such the NWSAS and the NSAS, are currently exploited by their riparian countries at a rate of 2.85 BCM/yr. and 2.53 BCM/yr., respectively, which will cause a loss of 5% and 0.87% of their initial volume by 2050 (Figure 2.9, BAU). The supplementary withdrawal from the NWSAS would result in an overall volume depletion between ~9% (±0.22%) for SSP1/SSP2, and ~11% (±3.58%) for SSP3. The NSAS' forecasted volume drop will reach levels more than ten times higher compared to the BAU scenario, ranging between ~8% (±0.26%) for SSP1/SSP2 and ~15% (±0.27%) in SSP3 (Figure 9). In contrast, the Murzuq aquifer is already heavily overexploited by Libya today; this might lead to its complete depletion by ~2037 (Figure 2.9, all scenarios). The effects produced by climatic variability will be limited to ±0.34%, ±0.16% and ±3.99%, for NWSAS, NSAS and Murzuq volume change, respectively (Figure 9). This variation will impact mostly the NSAS, with a resulting average annual variability in actual volumes of ±0.47 BCM/yr. From these results we can estimate that, while the Murzuq aquifer is already in extreme danger, the NSAS and NWSAS can sustain these increased extraction rates at maximum for 300 (±80) and 250 (±50) years after 2050, respectively.

In the Arabian Peninsula, almost one third of all the available groundwater systems are heavily overexploited and at risk of major depletion under the present conditions of withdrawal (BAU scenario). In particular, the Neogene aquifer of Eastern Saudi Arabia, the Tawil, the Wajid and the Minjur-Drhuma aquifers are expected to reach their complete exaustion between 2035 and 2045 (Figures 2.9, 2.10, and 2.12). The Liwa and the Western Gravel aquifers will see a drop of almost 70% of their present exploitable reserves (Figure 2.10), while the Dibdibba-Kuwait Group, the central part of the Umm Er Radhuma and the Saq-Ram aquifers are expected to lose between ∼34% and ∼46% of their current volume (Figure 2.9, 2.11 and 2.12). The remaining groundwater bodies will instead dysplay a decrease between ∼1.5% and ∼13% of their initial storage (Ash Sharqiya, UER-Dammam North and South, Sakaka and Wasia-Biyadh-Aruma; Figures 2.10, 2.11 and 2.12). The increased groundwater extraction needed to sustain higher demand of water will further deteriorate the already unsustainable situation of the region. The most impacted aquifer systems are the Dibdibba-Kuwait Group, which would reach full exaustion by 2050 for all the SSP scenarios (Figure 2.9), the Ash Sharqiya aquifer, with a relative volume drop between ∼32% (±11.53%) and ~64% (±11.92%) (SSP1 and SSP3, Figure 2.10), and the UER-Dammam North that would lose from ~23% (±1.39%) up to ~80% (±1.77%) of its starting exploitable volume for the SSP1 and SSP5 scenario, respectively (Figure 2.11). Similarly, the Liwa and the Western Gravel aquifers, which also reached a severe depletion in the BAU case study, could reach almost total depletion with higher extraction rates in all the SSP scenarios (Figure 2.10). A lower drop in storage is observed for the UER-Dammam South and the Wasia-Biyadh-Aruma aquifers, which would lose an additional ∼26% on average compared to their forcasted BAU depletion under the different SSP scenarios (Figures 2.11and 2.12). Finally, the Sakaka and the Saq-Ram aquifers will reach similar results to the BAU case study also under the different SSP scenarios (Figure 2.12). The impact of climatic variability on the Arabian Peninsula strongly differ from country to country and among different aquifers. The smallest variation in both percentage and absolute value of storage for the WET/DRY scenarios are observed for the Tawil and the Sakaka aquifers, with an average ±0.8% (0.5 BCM) on the resulting SSPs-AVG depletion simulations. On the contrary, the Ash Sharqiya and the Wasia-Biyadh-Aruma aquifers will face the largest uncertainty in terms of annual storage with -25/+12% (-6/+3 BCM) and ±4.5% (±22.5 BCM), respectively, relative to the average scenario results. For the remaining groundwater systems, the effects of climate variability are limited to a relative average storage variation of ±2% with respect to the average climate scenarios. The fossil aquifer resources of the Arabian Peninsula, which will not be fully depleted by 2050, sum up to ∼1,445 BCM in aggreagate and are currently exploited at a rate of ∼7.96 BCM/yr. Accounting for the present extraction (BAU), a first order approximation of the average lifespan for these groundwater resources would be ∼180 years. Instead, considering the higher projected extraction rates (IGW), this timeframe would shorten to 75 (±15) years.

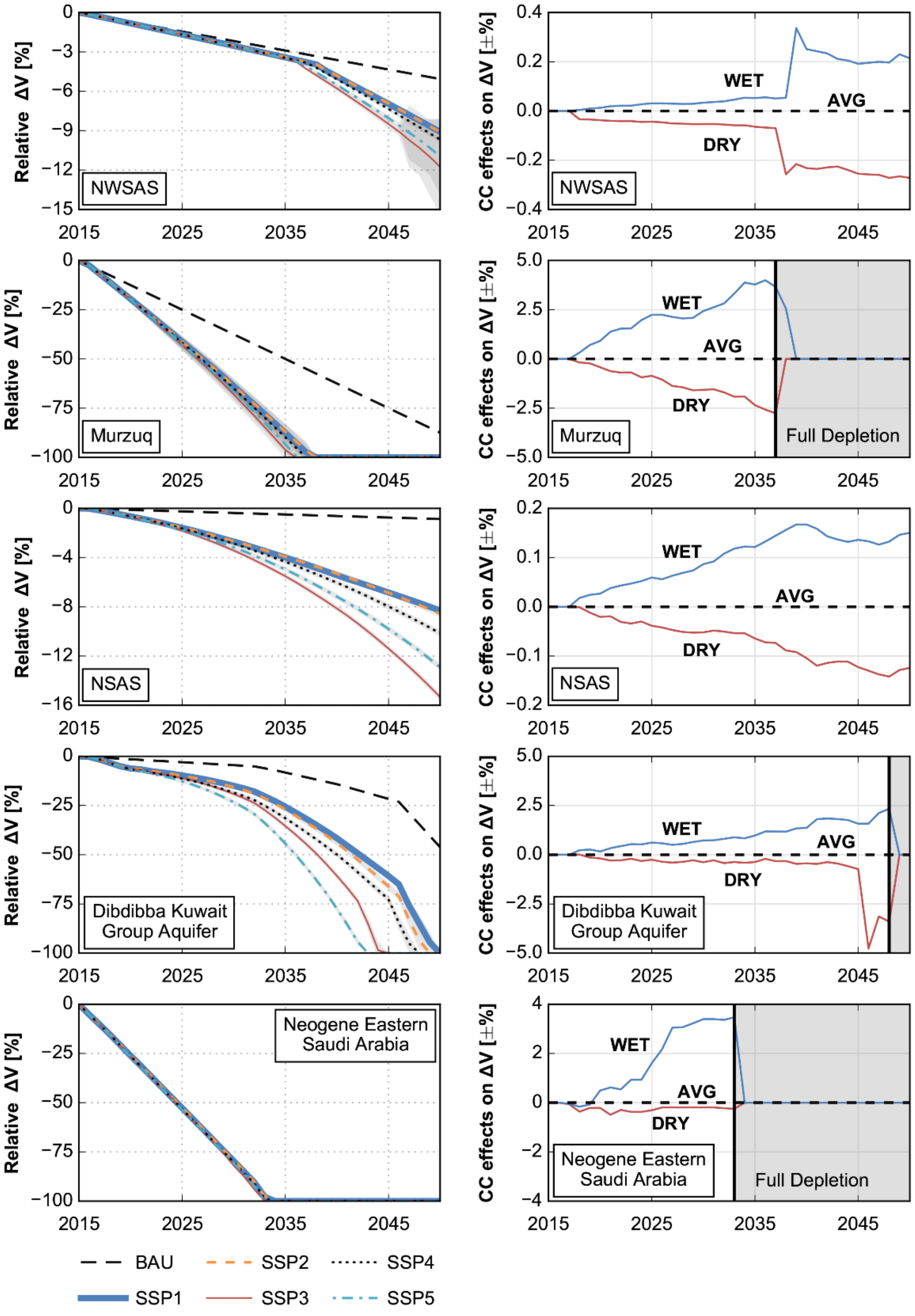

Figure 2.9. Left column: calculated groundwater storage depletion normalized respect to the current exploitable volumes under the average (AVG) climate scenario both for BAU and IGW. Right column: additional percentage volume (%) variation due to wetter (WET) or drier (DRY) climatic projections relative to AVG. The shaded grey areas highlight the error ranges.

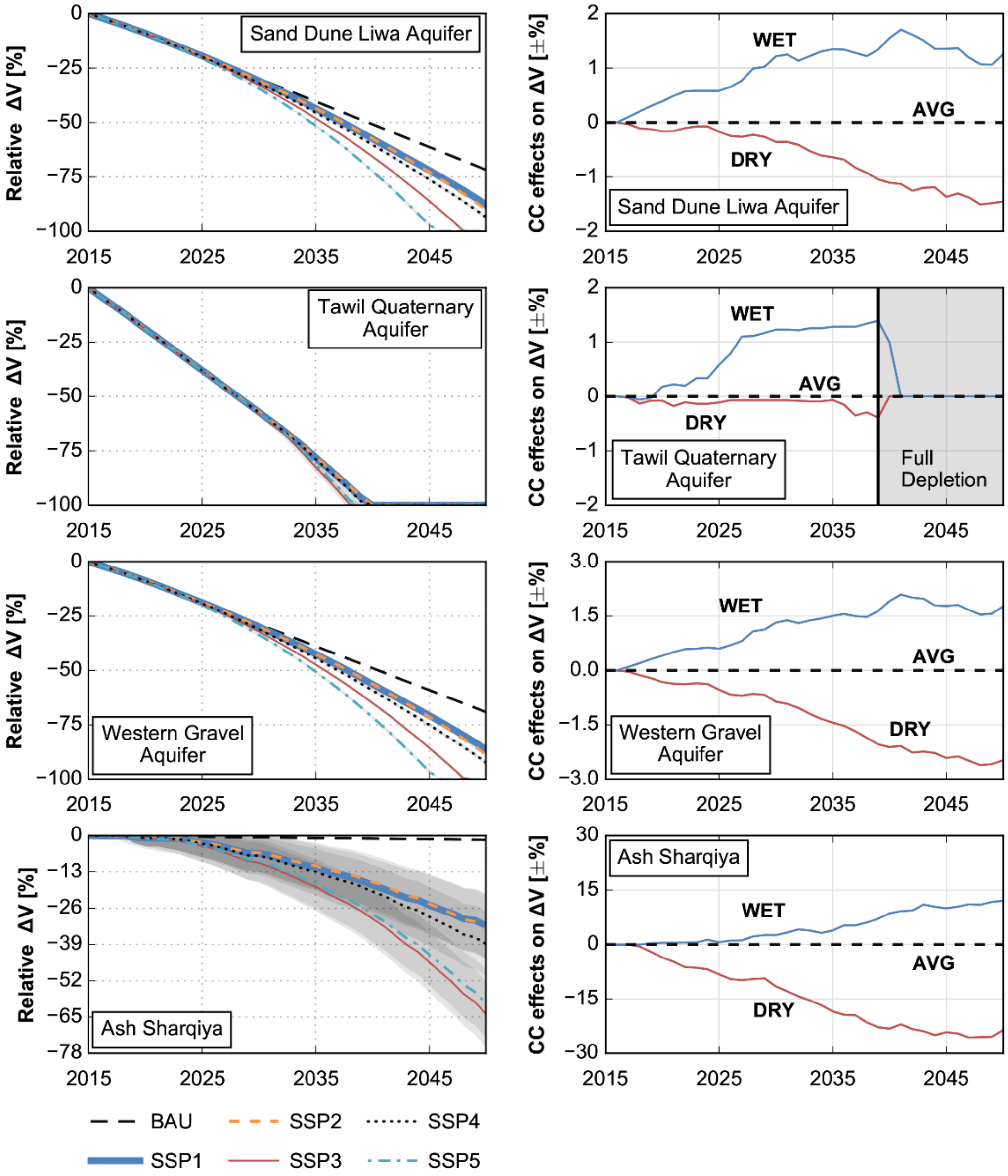

Figure 2.10. Left column: calculated groundwater storage depletion normalized respect to the current exploitable volumes under the average (AVG) climate scenario both for BAU and IGW. Right column: additional percentage volume (%) variation due to wetter (WET) or drier (DRY) climatic projections relative to AVG. The shaded grey areas highlight the error ranges.

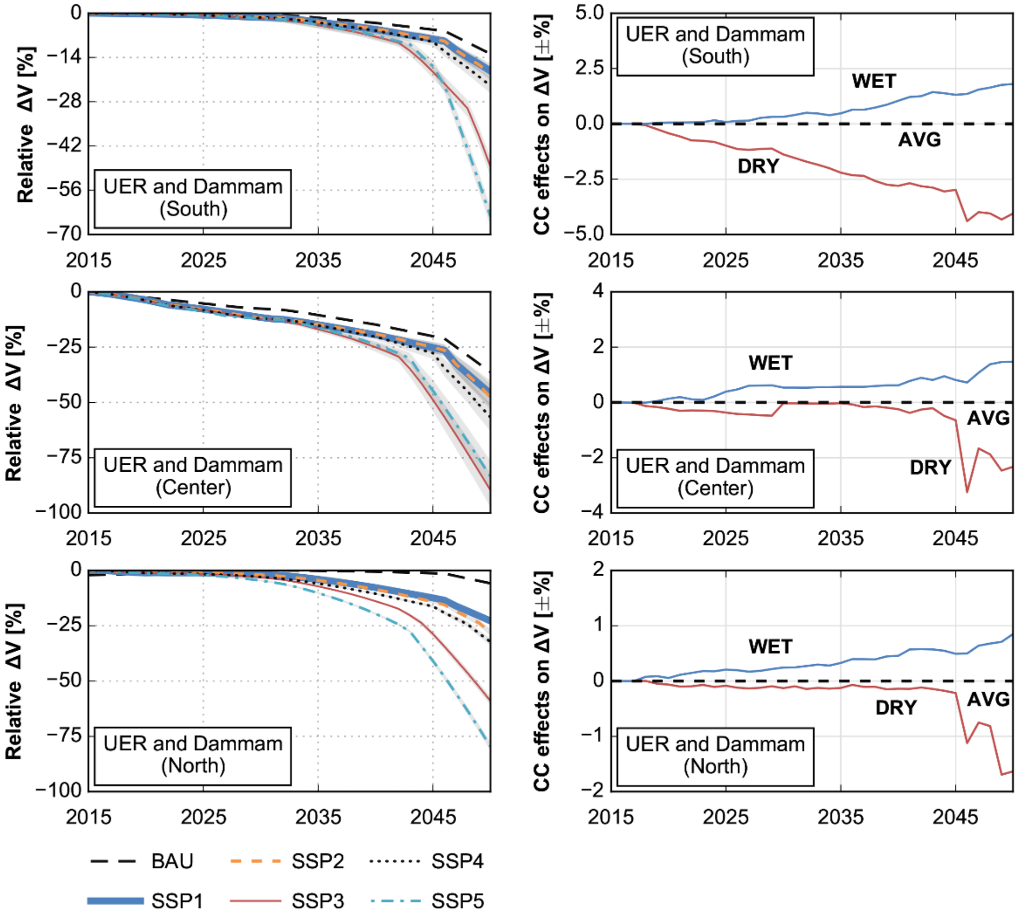

Figure 2.11. Left column: calculated groundwater storage depletion normalized respect to the current exploitable volumes under the average (AVG) climate scenario both for BAU and IGW. Right column: additional percentage volume (%) variation due to wetter (WET) or drier (DRY) climatic projections relative to AVG. The shaded grey areas highlight the error ranges.

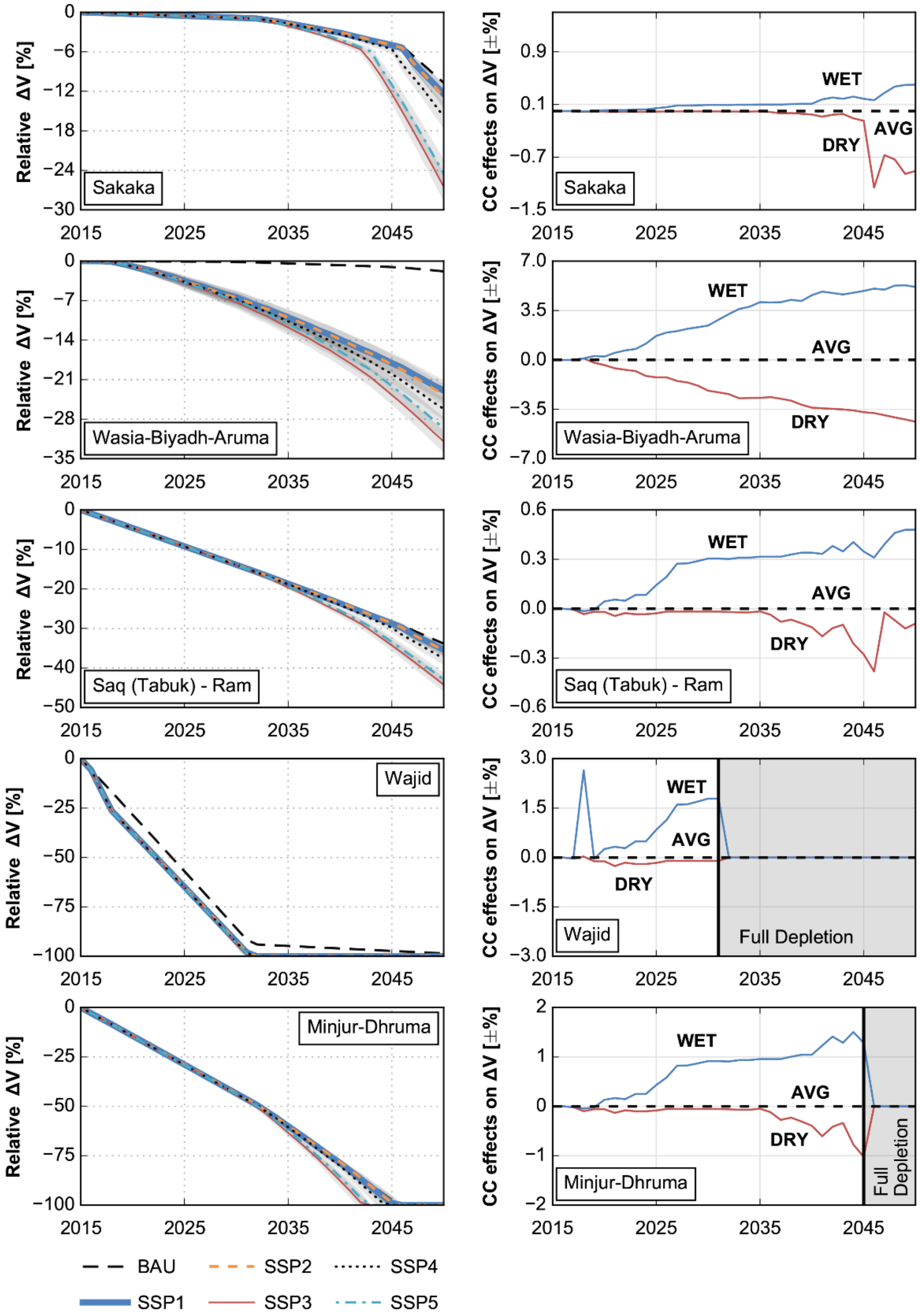

Figure 2.12. Left column: calculated groundwater storage depletion normalized respect to the current exploitable volumes under the average (AVG) climate scenario both for BAU and IGW. Right column: additional percentage volume (%) variation due to wetter (WET) or drier (DRY) climatic projections relative to AVG. The shaded grey areas highlight the error ranges.

2.6. Implications of Water Stress on Socio-Economic Stability in the MENA Region

The results of our water budget model quantify the severe water deficits and decrease in the exploitable fossil groundwater storage that the considered countries of the MENA region are likely to experience in the upcoming decades. The declines of groundwater levels are alarming also because exploitable aquifers serve as strategic reserves to mitigate periods of water shortages, driven by climatic variability and anthropogenic pressure (Tsur and Tomasi, 1991; Vouillamoz et al., 2015; Grönwall and Oduro-Kwarteng, 2018). Exploitable aquifers with relatively shallow fresh water differ from deeper ones with more saline and radioactive water that are more technically challenging and costlier to utilize as a water resource. Furthermore, as we approach the total volume depletion, water quality is more likely to rapidly degrade, further shortening the time scale of water availability to sustain the economic activities. As shown in our simulations, the present unsustainable use of these fossil resources, may lead to a rapid decrease in the water quality within the next two centuries. As highlighted also in our model, the agricultural sector is by far the largest user of water, mostly employing groundwater (Hötzl, 2008; Faysse et al., 2011; Shah, 2014); Egypt is the only country that relies almost entirely on surface water from the Nile Basin (Karajeh, et al., 2011). Therefore, the current and forecasted increasing water demand, aggravated by steady demographic growth and a dietary transition development (ElObeid and Hassan, 2014; Seyfert et al., 2014), directly correlate to the ongoing depletion of water resources, which in turn can cause serious threats to food production in the area. Additionally, the high dependency of the North African and Arabian Peninsula countries on food imports contributes to further deteriorating the food security for these nations. These countries are indeed much more susceptible to fluctuations of global food prices and stocks availability (Breisinger et al., 2010; Khouri and Byringyro, 2014), as it has been observed in 1973, and more recently in 2007-2008 and in 2011 (Eckstein and Heien, 1978; Holt-Giménez and Peabody, 2008; Larson et al., 2013). The connection between water stress and food security is illustrated in Figure 2.13, where countries' water deficit per capita in 2016 and 2050 and GDPP (red dotted line) are plotted. Two main groups are identifiable in Figure 2.13: (1) High and (2) Mid-Low Vulnerability in Food Security. For the first group, comprising Yemen, Egypt and Libya, domestic agriculture is an important source of food supply and employment for a substantial share of the population. For instance, Egypt produces ∼60% of its food supply (Sarant, 2017), while Libya and Yemen ∼20% (WFP, 2011; FAO-GIEWS, 2017); the agricultural sector accounts for ∼27% of the total employment for the three countries (World Bank, 2016c). Moreover, the above-mentioned countries exhibit high water deficits per capita and low GDPP. The second group, Mid-Low Vulnerability in Food Security, includes the GCC countries, which, unlike the first group discussed above, are heavily dependent on food imports. For instance, agriculture represents ∼2% of value added to GDP of Saudi Arabia and Oman, while agricultural revenue in Kuwait, Bahrain, Qatar and the UAE is negligible (World Bank, 2016c). The countries in this second group also suffer from high water deficits, but in contrast to the previous group, they are characterized by some of the highest GDPPs in the world (World Bank, 2016d), which could allow them to plan strategies to mitigate food security threats. The GCC countries, thus have already secured their food supplies from foreign markets, and are also expanding their domestic food storage capacity (UNDP, 2013). Finally, other countries such as Algeria and Tunisia (not shown in Figure 2.13), will not be affected by water deficits within the time-scale of our model, although they could exhibit scattered water deficits starting in 2045 and only under the SSP3 and SSP5 scenarios. The differences and discrepancies among the countries and within the two groups will definitely dictate the available responses to food and water issues. Finally, our results conclude that the exploitable part of some of most used fossil aquifers, especially in the Arabian Peninsula, will completely exhaust even before this mid-century. Response time on new water management plans will therefore be a key parameter in elaborating effective mitigation and adaptation options.

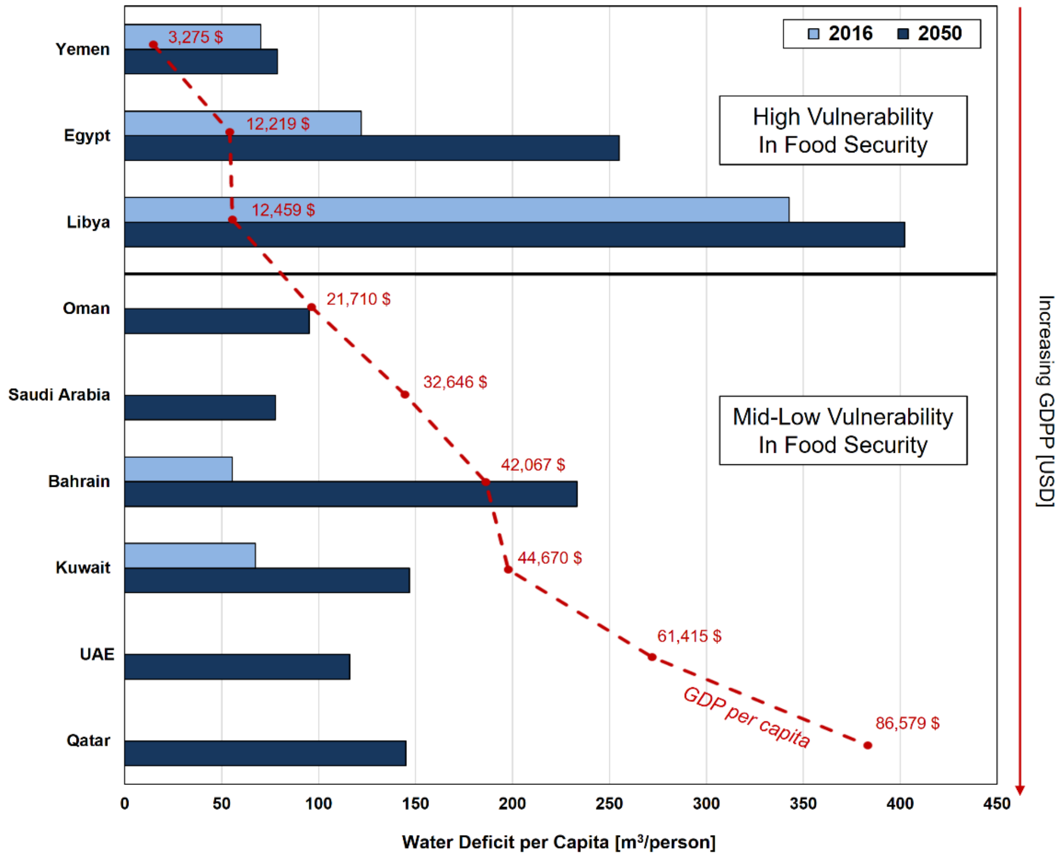

Figure 2.13. Comparison for scenario SSP2-AVG of countries' water deficit per capita in 2016 (real) and 2050 (projected).The country listed from top to bottom according to its forecasted GDPP level for 2050.

2.7. Conclusions

The countries analyzed in our model already display diminishing water storage availability due to the increase in water demand of the last decades, as observed by Rodell et al., 2018. Our study confirms that also future projections of water budget deficit and groundwater depletion will be mostly attributable to anthropogenic drivers rather than climatic ones. In North Africa, Egypt and Libya will further aggravate their respective national water shortages by ∼192% (+21.88 BCM/yr.) and ∼62% (1.35 BCM/yr.) due to their increasing population size and agricultural development in the upcoming decades (2016-2050) under the SSP2-AVG scenario. Algeria and Tunisia may experience small deficits starting in 2045, but only under the SSP3- and SSP5-AVG climatic scenarios, ranging between 1.08 and 1.26 BCM/yr. (±0.85). In the Arabian Peninsula, our model forecasts substantial water deficits for all the GCC countries with different temporal scales and magnitude. For instance, Bahrain, Kuwait, Oman, Qatar, and the UAE are either already suffering water shortages or will start to face water deficits between 2020-2025, with values between 0.56 and 1.88 BCM/yr. (±0.165) by 2050, respectively. Saudi Arabia will reach a negative water balance of 0.21 BCM/yr. in 2040 and is projected to grow up to 4.05 BCM/yr. (±3.39) in the successive decade. For Yemen, the results are similar to the North African countries: the scarcity of renewable water, coupled with a lack of investments in alternative water supply technologies, will linearly increase Yemen's present water deficit in the next decades by as much as ∼121% (2.33 BCM/yr. (±1.73)). Conversely, in the GCC, the absence of surface water resources is balanced by the fast development of alternative sources of water (e.g. desalination and wastewater reuse), but their mitigation efforts may still not be able to fully meet increasing water demands, if consumption rates continue to rise and if the degradation of seawater quality persists, due to increased salinity and pollution.

When considering the pressure on fossil groundwater resources, we find that the Murzuq aquifer in North Africa and most of the small to mid-size fossil aquifers in the Arabian Peninsula could reach full depletion by 2050. The NWSAS and the NSAS in North Africa could sustain higher exploitation rates for ∼200-350, while the exploitable part of the remaining water bodies in the Arabian Peninsula could be depleted within ∼60-90 years. Our uncertainty analysis suggests that the mean error in these water deficit forecasts is smaller than ∼12% and within ±3% for the storage depletion. Finally, our projected water deficit and groundwater depletion (i.e. water stress) could induce a substantial rise in domestic food production costs that could in turn increase local food prices and/or the countries' dependency on foreign markets. The implication of these effects will induce additional socio-economic uncertainties to the highly vulnerable low-income countries, which are unable to mitigate market price fluctuations. In contrast, the GCC countries have the economic potential to address these food price increases, although they will have to consider that these impacts will unevenly affect households with different income levels.

CHAPTER 3

ECONOMIC AND ENVIRONMENTAL SUSTAINABILITY OF AUTARKIC FOOD PROVISION POLICIES IN CASE OF SHOCKS: THE CASE OF QATAR’S BLOCKADE

ABSTRACT. In this study, I explore how countries’ food security can be impacted upon by an exogenous trade shock, and how autarkic food supply strategies can, in turn, impact on water resources supply. On June 5th, 2017 Bahrain, Egypt, Saudi Arabia, and the United Arab Emirates imposed a blockade on Qatar, cutting their diplomatic ties, closing their land and sea borders, and preventing Qatar to fly over their air-space. Qatar, whose imports made up to 90% of its food supply, 60% of which through the Saudi border and 20% from the other blockading countries, had to rapidly adjust to ensure both economic stability and food security. This paper evaluates the impact of the blockade on the trade relations between Qatar and its trading partners using a gravity model framework. The results of my difference-in-differences estimations show that the average trade disruption with the boycotting countries resulted in a decrease in imports of 98% and exports of 87% during the period 2016-2018. The analysis of the blockade effect by product category and for selected groups of countries suggests that the agricultural, dairy and animal products are the most affected by the blockade with a decrease in imports of 88%, 91%, and 86% respectively. Further analysis allows me to observe the new trade patterns originated by this event, with the opening of new routes through Iran and Turkey, towards both Europe and Asia that further changed the trade and geopolitical relations in the region. A secondary response of Qatar to the blockade was the launch of several programs for intensifying local food production, to improve national food security and decrease the country’s dependence from imports. Therefore, I investigate the environmental and natural resource impact of the new food security strategy and alternative food production scenarios in terms of *Water Footprint* and evaluate their medium to long-term sustainability by comparing them with the projected water availability in Qatar up to 2030.

JEL Classification: F14 F51 F63 Q18 Q56

Keywords: Embargo, International Trade, Water and Food Security, Sustainable Development

3.1. Introduction

Trade sanctions constitute one of the most used instruments to try and force other countries into determined foreign policy decisions, whose practice has grown during the 20th century (Barber 1979; Baldwin & Pape 1998; Hufbauer, G.C. et al. 2007; Oechslin 2014). In general, they are identified as a method other than military coercion to induce one or more countries to adopt certain behavior or to refrain from given undesired conduct. Such measures can be unilateral or bi/multilateral and exist in different forms, such as tariffs, quotas, restrictions, or actions to limit financial transactions. Trade embargoes are considered a special case of economic sanctions and by definition imply more severe actions, up to the imposition of a complete blockade. Noteworthy examples are the commercial embargo imposed by the United States against Cuba since 1960 (Askari 2003; Yang et al. 2004; Borer & Bowen 2007; Gordon 2016) and against Iran since 1979 (Fayazmanesh 2003; Rasoulinezhad 2017; Rasoulinezhad & Popova 2017), both still active. More recently, European and OECD countries imposed an embargo on Russian trade flows in 2014 (Crozet & Hinz 2016).

One of the crucial aspects of these actions is the debatable effectiveness of the sanctions (Kaempfer & Lowenberg 1988; Bergeijk Van 1989; Afesorgbor 2019), which strongly depends on the intensity, on the specific sender and target countries, on the number of participants, the actual political power and leverage of the parties. After sanctions are implemented, a certain degree of uncertainty exists about the target country's capacity to stand the economic losses associated with sanctions. Time is, therefore, a crucial variable in revealing the real strategy of the target and sender and their resolution decision. Occasionally, the situation created by the embargo can become the new status quo. From a trade disruption perspective, at least in the short run, economic sanctions create a disturbance on the target country's trade, consequently generating true or perceived economic instability, which in turn can cause internal political instability. Still, in an interconnected and interdependent world, a country can generally redirect its imports and/or exports to minimize economic impacts. Also, sender countries often experience economic losses due to the trade gains they surrender.

The empirical literature on the efficacy of trade policies and their impacts on the economy is quite extensive and it includes studies on sanctions (Eaton & Engers 1992, 1999), embargoes (Irwin 2005; Coulibaly 2009) and boycotts (Friedman 1985; Chavis & Leslie 2006; Ashenfelter, Ciccarella & Shatz 2007; Hong et al. 2011; Heilmann 2016), showing, however, heterogeneous outcomes. From a methodological perspective gravity models have been largely used to study the effects of different policy decisions on trade. The gravity model of trade, in its original form (Tinbergen 1962), explains trade flows between country pairs as being proportional to countries' national income and inversely proportional to their distance, in a fashion similar to the Newtonian law of gravity. In other words, the magnitude of trade flows between two countries is larger, the bigger are their respective GDPs. From an initial empirical foundation, this methodology became a work-horse of international trade analysis. Subsequently, a first attempt to provide a theoretical groundwork was made by Anderson (1979), who employed the concepts of constant elasticity of substitution (CES) and the Armington assumption. Krugman (1980) and Bergstrand (1985), among others, provided further theoretical studies, but it is the the work of Andreson and van Wincoop (2003) that is considered so far the most important contrinbution to this international trade topic. In particular, their contribution entails the inclusion into the theoretical model of the multilateral trade resistance (MTRs) that capture relative trade costs between countries. Afterwards, thanks to its flexibility, this model has been widely employed to study different aspects of international trade and its determinants, such as migration, remittances, foreign direct investments (FDIs) and as mentioned above, economic sanctions. Contemporarily, also the gap between empirical and theoretical foundations has been bridged, allowing for a sistematization of its estimation techniques (Baldwin & Taglioni 2006, Baier et al. 2008, among others), leading to a solid framework for understanding and interpreting international trade patterns and trade policy decisions.

This paper aims to evaluate the effectiveness of the blockade imposed on Qatar, to quantify its direct impact and – here lies the main novelty of my analysis – to understand what is the environmental impact induced by Qatar’s strategic response to the trade shock. The trade disruption can sometimes have consequences beyond the direct economic effects, especially if the countermeasures are taken by the target country to overcome the hurdle of the trade restrictions have secondary implications on the economic, social or environmental system.

Despite its economic wealth, Qatar is a quite vulnerable country due to its physical geography and climatic characteristics. The disruption of trade caused by the blockade prompted the country to actively search for alternative trade routes, replenish its food stocks, and augment its storage capacity. At the same time, the Qatari government decided to launch a new National Food-Security Strategy Plan, which aims to increase food self-sufficiency and lower its dependency on imports, to prepare for potential further developments of the crisis. Because of its lack of natural resources such as land and water, the consequent rapid and extensive increment of domestic agricultural production could potentially be detrimental for the already fragile local environment.

To quantify the economic effects of the blockade, I proceed with a difference-in-difference estimation within a gravity framework, whereas to analyze the potential environmental impact of the autarkic response I evaluate the new food security strategy and other alternative food production scenarios in terms of *Water Footprint*, comparing these results with the projected water availability for Qatar up to 2050 (Mazzoni et al. 2018). Lastly, I observe whether, to some extent, the economic and environmental negative outcomes are balanced by positive impacts in terms of visibility and reputation at the regional and international levels.

This study thus contributes to previous literature in many respects. The blockade imposed on Qatar represents a form of economic sanction which is truly exogenous and unexpected and thus unrelated to other unobserved confounding effects. For this analysis, I use monthly-level data for the import and export flow values, provided at product detail, which allows me to disentangle the blockade effect, given the short time-frame of study – which would have been impossible with quarterly or yearly data that instead is the frequency most commonly used in the literature. Furthermore, the product-level detail allows me to truly separate the analysis for each macro-category of products, showing what are the goods most affected by the blockade. Moreover, I compare the economic impacts of trade losses expressed in monetary terms with the potential impacts of the blockade on the natural resources of Qatar, originated by the requirement of increasing the domestic food production. To the best of my knowledge, most of the existing studies on economic sanctions evaluate their effects, besides on trade, on human health (Garfield & Santana 1997; Gibbons & Garfield 1999) and human rights (Moret 2015; Kokabisaghi 2018), but only two (not peer-reviewed) studies attempt to explore the potential links between economic losses and environmental impacts (Carucci 2000; Soroush, N. & Madani K. 2014). In fact, in the realm of international trade and economic sanctions, environmental matters are still mostly addressed from a legal perspective, i.e. resolution of WTO of GATT disputes in which environmental externalities are evaluated (Beyers, 1992). Alternatively, some literature covers the efficacy of economic sanctions in inducing cooperative (or non-cooperative behavior) into environmental policy matters, such as global environmental agreements (Barret 1997, Cirone & Urpelainen 2013). Still, no literature so far has covered the potential of economic sanctions as a catalyst for environmental issues.

Lastly, I argue that the impacts of the blockade are negative in the short term from an economic perspective and potentially even more harmful in the long term from an environmental one, from a geopolitical perspective instead, the blockade has had a positive impact on Qatar’s reputation both at the regional and international levels and boosted its confidence in pursuing a strong and independent foreign policy.

The results show the expected negative effects on imports and identify the categories of products, especially dairy and livestock, as the most impacted by the blockade. The effects of the blockade on exports turn out to be not as strong. This is mostly due to the export structure of Qatar, which is specialized in trading mainly in Liquefied Natural Gas (LNG) and oil products. From a food and water security perspective, the results of this paper show that the food strategies selected by the government are extremely water-intensive. If the majority of production is obtained making use of the available groundwater, which as of now is the most used water source for agricultural and food production in the country, the depletion of the aquifer system will be very rapid. The paper, hence, analyses the current food security strategy in terms of total feasible output, available water inputs, and alternatives import sources and suggests that these food-security strategies should be potentially revised.

The remainder of the paper is organized as follows: Section 3.2 outlines the economic and political background of the blockade on Qatar. Section 3.3 presents the methodology employed in the analysis, while Section 3.4 describes the data using descriptive and test statistics. Section 3.5 presents the results of the economic evaluation, while Section 3.6 develops the environmental analysis. Section 3.7 contributes to the discussion on the effectiveness and impacts of the blockade looking at the socio-political aspects of the phenomenon, and Section 3.8 concludes.

3.2. Qatar's Blockade

In this section, I outline the contextual information regarding Qatar's economy and trade, the blockade, and its historical and political background. The blockade is currently ongoing and there are no signs of any potential resolution from the parties. Therefore, I assume the current situation as the status quo of the dispute. On June 5, 2017, a coalition of states formed by Bahrain, Egypt, United Arab Emirates (UAE) and Saudi Arabia, led by the latter, declared a blockade against Qatar. These countries cut their diplomatic ties with their previous ally and subsequently closed their air-space and sea and land routes, isolating Qatar, whose only physical border is the one with Saudi Arabia.[8] Figure 3.1 shows the relative positions of the main countries involved in the blockade. Besides, Qatari nationals living in Bahrain, Saudi Arabia, and UAE were given two weeks to leave the boycotting countries, which also ordered the return home to their ~11,300 citizens present on Qatari soil in the same time-frame. A few other countries immediately joined the boycotting coalition, namely Comoros, Mauritania, Maldives, Senegal, Yemen and the Haftar's government in Libya, whereas a group of other nations including the two Gulf Cooperation Council (GCC)[9] countries, Kuwait and Oman, together with Iran, Turkey, USA expressed their willingness to cooperate to resolve this dispute. In response to these events, Qatar immediately withdrew its ambassadors from the main sender countries. The main allegations against Qatar included the accusation of financial support to terrorism and close ties with Iran. Furthermore, the Saudi-led coalition gave Qatar ten days to comply with a list of thirteen demands to end the dispute, which comprised, among others, the shutdown of the Al Jazeera Network, the closure of the Turkey military base in Qatar, a downgrade of the ties with Iran, and the stop

---

[8] For more details of the unfold of the events see: https://www.aljazeera.com/news/2017/11/qatar-gulf-crisis-started-june-5-171122105507731.html

[9] The Gulf Cooperation Council (GCC) is a regional intergovernmental political and economic union consisting of all Arab states of the Persian Gulf except Iraq, namely: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates.

to funding “terroristic” organizations such as Muslim Brotherhood and Hezbollah[10]. Qatar rejected all the demands claiming that it constituted an attack on the country’s sovereignty.

The blockade has disrupted the trade of goods and the mobility of individuals from and to Qatar. In the aftermath of the embargo, Qatari residents rushed to stock up food supplies and to transfer their savings in foreign currencies. Cargo transport of various goods and food were blocked at the Saudi borders, at UAE ports and offshore. Within a few days, food stocks were replenished and Qatar started to create alternative routes for trade through Iran, Turkey, and Oman. As time passed, attempts of resolutions were unsuccessful. Currently, the dispute has not evolved and the blockade is becoming the status quo for the region with consequent permanent re-arrangement of trade flows from and to Qatar.

Figure 3.1. Map of the main countries involved in the diplomatic dispute.

Political Background

From a political perspective, tensions between Qatar and the boycotting countries dated much further back than 2017, but diplomatic relations had been kept under control and there appeared to be no anticipation of the blockade by the Qatari government. Furthermore, given the importance of the Gulf monarchies and

---

[10] For a complete list of the demands see: https://www.aljazeera.com/indepth/interactive/2018/05/understanding-blockade-qatar-180530122209237.html

Egypt in the geopolitical framework of the MENA region, the echo of the blockade went beyond the regional borders influencing and affecting also nations not directly involved in the events.

The roots of this dispute can be traced back to the objective of Qatar to pursue an independent foreign policy, which contradicts the aspiration of Saudi Arabia to be the major leader in the Gulf and the key player in the Middle East. A previous standoff between the GCC nations happened in March 2014, when Bahrain, Saudi Arabia, and UAE withdrew their ambassadors from Qatar, as a response to a Qatari policy that was judged incompatible with the GCC security agreement of 2013. In particular, Qatar was accused of politically supporting the Muslim Brotherhood and its activists in Egypt through its media outlets (e.g. al Jazeera) and for pursuing foreign policy relations with Iran, the Syrian regime and Hezbollah, in open contradiction with the rest of the GCC countries' position. After almost nine months, in November 2014 the three countries announced the return of their ambassadors to Doha, ending the diplomatic tension between the nations. Even if the crisis was resolved without Qatar abandoning the GCC and its allies, the country stressed its intentions to keep pursuing an independent foreign policy. Some of the tension and mistrust among the GCC members remained thus unresolved. During the visit of the American president, Donald Trump in Saudi Arabia for the GCC summit in May 2017, strong accusations directed to Qatar were raised by the other Gulf nations for not putting enough effort into combating terrorism. Still, the escalation that led to the blockade was not foreseen.

In addition to the disruption of trade, which is the main object of this study and is introduced in the next sub-section, it is worth mentioning that the blockade has also had other impacts on the welfare of both Qatari nationals and the country's foreign residents. Qatar shares strong cultural and family ties with Bahrain, Saudi Arabia, and UAE: among the Qatari population, which represents only 10% of the total population of the country, it is estimated that about 20,000 citizens are Saudi and about 15,000 are from the Emirates and Bahrain. A study conducted by the Doha International Family Institute, which assessed the impact of the blockade on families in Qatar, shows that families, and especially mixed families (Qatari married with a citizen coming from another GCC country), were negatively affected by the physical separation and logistic problems in terms of students abroad, documents renewal, job security and financial investments (Abdelmoneium et al. 2018). While for the part of the Qatari national these issues were ruled out by the International Court of Justice (ICJ) decision on July 23rd, 2018, foreign workers in Qatar, who make up for about 80%[11] of the workforce in the country, were still affected by the blockade: many lost their jobs, especially in the manufacturing and construction sectors and in the small to medium businesses and enterprises.

---

[11] http://priyadsouza.com/population-of-qatar-by-nationality-in-2017/

Economic Background

Qatar's economy and wealth are driven by the exploitation of natural gas and oil derivative products. The country is one of the biggest exporters of LNG in the world and is endowed with the world's third-largest reserve of natural gas buried in the massive offshore North Field shared with Iran. Estimates attest to an available supply that could last for the next 140 years (Spencer 2019). Qatar Petroleum (QP) confirms a current annual production capacity of 77 million tons and the plans are to reach up to 126 million tons per annum (mtpa) by 2027, which corresponds to an increase of 64% of overall production.[12] The major export partners are in Europe and Asia, namely Italy, Spain, United Kingdom, China, India, Japan, South Korea, but Qatar has recently opened up to the new emerging markets of Bangladesh, Kuwait, Pakistan, Poland, and Thailand. Overall, exports comprise of petroleum gas, crude oil and refined petroleum products, nitrogenous fertilizers, hydrogen, polymers, iron, steel, and raw aluminum. The country is one of the major players in the energy markets, and the hydrocarbon sector accounts for about 46% of GDP in 2018 (Ministry of Development Planning and Statistics, 2016). Until the blockade, despite a few past diplomatic skirmishes Qatar's social and economic integration with the neighboring countries was highly developed, especially with Saudi Arabia and UAE. Together with Oman, Kuwait, and Bahrain, Qatar is part of the GCC. Even with its flourishing performance, Qatar's economy is challenged mainly by the volatility of oil prices and the relatively low level of economic diversification, which represents a serious risk in the case of exogenous shocks. This is particularly notable in the food sector. Before the blockade, the domestic food production was very low and 90% of the food required to meet the domestic demand was imported. In 2016 about 60% of the food entered into Qatar across the land border with Saudi Arabia or through shipping routes running through the Emirates. Furthermore, food products from the boycotting countries (in particular fresh products such as meat, vegetables, dairies, livestock, and beverages) represented about 20% of the total food consumed within the country.

Figure 3.2 shows the top-20 major trading partners of Qatar before and after the blockade, measured in traded values. Imports from both UAE, Saudi Arabia and Bahrain, which were at the third, seventh and nineteenth place respectively, disappear from the chart in the aftermath of the embargo. At the same time, India, Turkey, and Oman almost doubled their exports to Qatar after the blockade. Sweden, Kuwait, and Iran appear as new entrants in Qatari's trade landscape. The situation of Qatar's exports is quite similar. Exports towards the blockading countries were interrupted after the embargo, except for UAE, whose imports from Qatar only halved. The reason resides in the fact that even under the blockade, exports of

---

[12] Qatar Petroleum News Archive https://qp.com.qa/en/MediaCentre/Pages/ViewNews.aspx?NType=News (25/11/2019)

LNG through the Dolphin pipeline from Qatar to UAE, which constitutes around 30% of the energy supply for the Emirates, was not stopped. India, China, Singapore, and Turkey increased also their imports from Qatar, whereas Poland, the Netherlands, and Oman have become new top trading partners for Qatar. These new trade patterns are also contributing to create new geopolitical equilibria at the regional and international levels.

Lastly, as a response to the embargo, Qatar's incremented its internal investments in some key economic sectors, such as agriculture, intending to achieve higher food security. Some of the actions undertaken go in the direction of full autarky. The main objective of this paper is then to investigate the environmental impact and sustainability of the National Food-Security Strategy Plan adopted by Qatar in response to the trade sanctions.

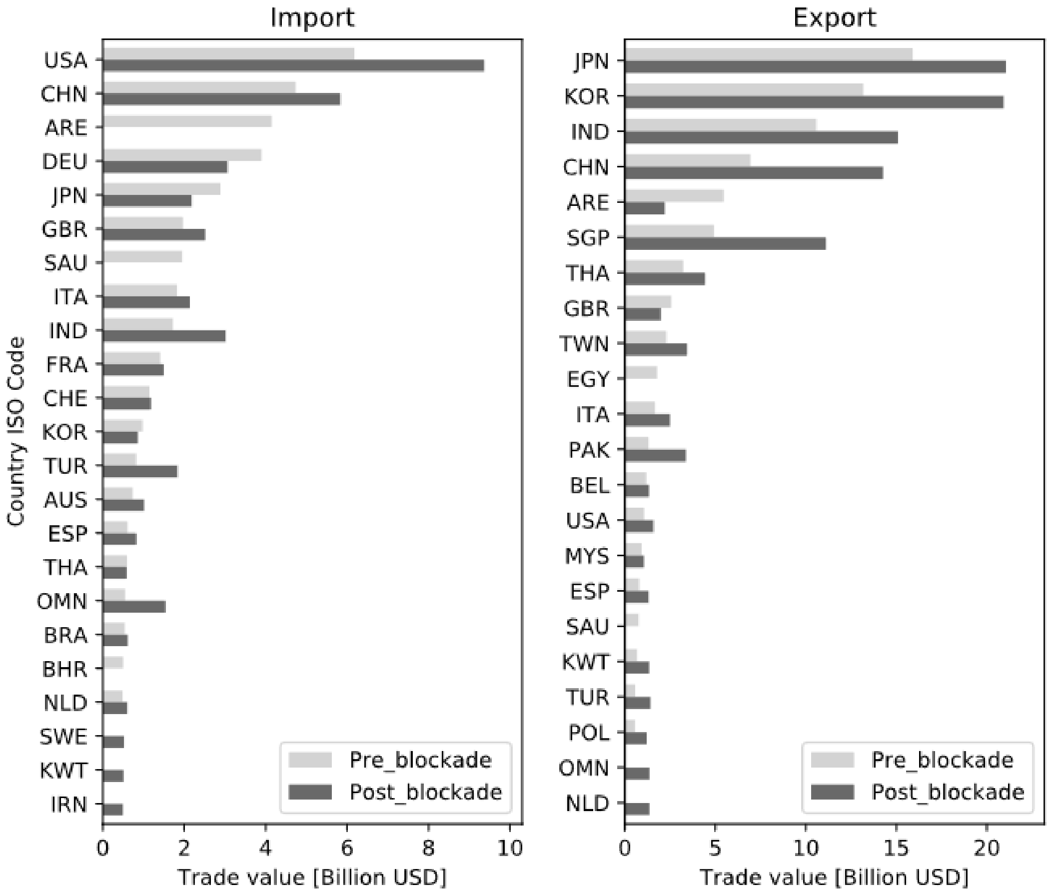

Figure 3.2. Qatar's top-20 major trading partners before and after the embargo.

3.3. Methodology

To evaluate the impact of the blockade on Qatar's trade flows, I estimate a difference-in-difference regression model of the logged exports and imports trade flows (separately) between Qatar and its commercial partners, at a monthly frequency. My identification strategy relies on the assumption that the blockade represented indeed an exogenous shock to the country's trade, triggered by the support of President Trump to the blockading countries during the Riyadh Summit and the fake news that started to circulate on May 23, 2017.[13] The plausibility of this assumption is based upon the fact that there were no signs of decrease in trade with the blockading countries in the months before the embargo, nor any change in the relationship among the countries. The relevance of this assumption lies in the fact that to be sure that my estimations are picking up solely the effect of the blockade, no other shocks need to happen in the same time-frame of my analysis, otherwise biasing my results

The treatment group in which I observe the main effects of the blockade is further separated into three sub-groups. The first sub-group is formed by the main sender countries that imposed the blockade on Qatar, the second comprises the countries that cut their diplomatic ties in the aftermath of the embargo declaration, and the third includes the countries that downgraded their diplomatic relations with Qatar to support the blockading countries. While for the initial sender countries the blockade started on the 5th of June 2017 and is still ongoing, some of the other countries joined one of the sub-groups or decided to leave it at different times. All these differences are taken into account in the construction of each sub-group. This further identification within the treatment group allows me to investigate the effect on trade between Qatar and the sender countries, as well as to ascertain whether the political declarations in support of the blockading countries by several other nations did translate into concrete actions and had an additional impact on Qatar's international trade flows. Furthermore, I try to identify the substitution effect, i.e. if Qatar has compensated for the loss in import and export by increasing trade with other partners or by opening new trade routes for new commercial relations. To do so, I have created a test group including all countries that in the days after the start of the embargo publicly declared their support to Qatar and were actively involved in the tentative negotiations to solve the dispute. Some of these countries, such as Iran, Oman, and Turkey, even sent food stocks and allowed Qatar to use their air, ports or sea space. A detailed list of the countries tested for treatment and substitution effects is found in Table A1 in Appendix A. To construct the different groups of countries I have used declarations of support to the sender or target side retrieved from online news and media. Lastly, all the remaining, non-embargoing countries are considered as the control group, whose effects are absorbed within the constant intercept of the regression.

---

[13] https://www.aljazeera.com/news/2017/05/qatar-prosecute-perpetrators-qna-hacking-170524145444746.html

The estimations stem from a standard gravity equation where I consider the common gravity repressors, GDP and distance, and control for time and country fixed effects. Following Anderson & van Wincoop (2003) and Feyrer (2009), the gravity relationship is defined as:

$$Trade_{ijt} = \frac{Y_{it}Y_{jt}}{Y_{\omega t}}\left(\frac{\tau_{ijt}}{P_{it}\Pi_{jt}}\right)^{1-\sigma} \tag{3.1}$$

where $Trade_{ij}$ is the bilateral trade between the country-pair *i* and *j* at time *t*; Y_{it}, Y_{jt} and $Y_{\omega t}$ indicate the "economic masses" i.e. income of the importer, of the exporter and the world at time *t*. τ_{ijt} includes the bilateral resistance terms, which are all the trade costs between the two countries such as distance, common language or borders; P_{it} and Π_{jt} denote instead the country-specific multilateral trade resistances (MTRs) at time *t*, which are structural terms indicating the general equilibrium effect associated with the barriers to trade that each country faces with all its trading partners. In other words, the two terms represent the barriers that each of i and j face in their trade will *all* their trading partners, including domestic or internal trade. Equation (3.1), log-linearized and expanded with an additive error term, can be re-written as:

$$\ln Trade_{ij} = \ln Y_{it} + \ln Y_{jt} - \ln Y_{\omega t} + (1-\sigma)\left(\ln \tau_{ijt} - \ln P_{it} - \ln \Pi_{jt}\right) + \varepsilon_{ijt} \tag{3.2}$$

In my case study, Qatar is the only trading partner (*i*) and the blockade is considered as bilateral friction, similarly to a trade cost (τ_{ijt}) like distance. I thus adjust Equation (3.2) accordingly, to obtain my final estimation equation (3.3). To account for MTRs (P_{it}, Π_{jt}), world income ($Y_{\omega t}$) and time-specific effects in a panel data framework, I include the country and time fixed effects (FE) (Glick & Rose 2002). The final regression equation takes the following form:

$$\begin{aligned} lnT_{jt} = {} & \beta_0 + \beta_1 Block\_Country_j + \beta_2 Block\_Time_t + \beta_3 Blockade_{j,t} + \beta_4 Cut\_DT_{jt} \\ & + \beta_5 Downgrade\_DT_{jt} + \beta_6 Support\_Resolution_{jt} + \beta_7 lnGDP_{jt} \\ & + \beta_8 lnDistance_j + \gamma_t + \gamma_j + \varepsilon_{jt}. \end{aligned} \tag{3.3}$$

The model describes Qatar's trade Y_{jt} for imports and exports separately, while dummies are used to identify the treatment variables. In particular: $Block\_Country_j$ takes value 1 if the country engages in the blockade, 0 otherwise; $Block\_Time_t$ equals 1 for all months since June 2017, which is the start date of the embargo. The coefficient β_1 measures trade for the treatment group, while β_2 shows how much change in trade occurred after the blockade. $Blockade_{jt}$ is my main variable of interest, i.e. the treatment effect, and is constructed as $Block\_Country_j \times Block\_Time_t,$ assuming value 1 if both the trading partner country and time equal 1, which is true only for the sender countries after the blockade started (time is equal to 1 after June 2017, before it is equal to 0). The expected sign of the coefficient β_3 is negative, since it should show the decrease in the trade flows from and to Qatar with the boycotting countries. Also, I anticipate this effect to be more prominent in the imports than in the exports, given the market structure and characteristics proper of Qatar's economy.

Cut_DT_{jt} and $Downgrade\_DT_{jt}$ are the other treatment effect dummies, which equals 1 if the country belongs to the group that cut or downgraded its relationships with Qatar after the original senders announced the blockade. Likewise, I expect the sign of the coefficient β_4 and β_5 to be negative, since I am expecting a measurable reduction of trade as a result of the announcements of siding with the blockading countries. The magnitude of the actual effect may, however, be quite low if *ex-ante* trade flows with these countries were not significant or if the announcement of supporting the embargo to Qatar was not followed by practical actions. $Support\_Resolution_{jt}$ aims to measure the substitution effect on a subset of the control group, testing whether Qatar has increased commercial exchanges with the countries that openly supported it in the aftermath of the blockade. This dummy variable equals 1 if the partner country has effectively supported Qatar after the start of the blockade. The coefficient of the substitution test set should have a positive sign since I expect a rise in trade with Qatar's supporters. Again, this variable is likely to be more relevant for imports than for exports because, as described in Section 3.2, the main exports of Qatar are natural gas and oil products towards very heterogeneous markets and these supply contracts have usually durations of multiple years.

$lnGDP_{tj}$ indicates the economic "mass" of the country and following the gravity theory is expected to positively relate to trade. $lnDistance_j$ specifies the simple mean geographical distance between the most populated cities of the country-pair, in kilometers. It is usually presented as a proxy for transportation costs, and should, therefore, have a negative sign since trade costs are expected to increase with distance. Finally, γ_t and γ_j account for the time period (month) and country FE. More specifically, the first controls for all the time-specific effects (common shocks, general trends) and the second covers all unobservable factors related to trade resistance[14].

The estimation of the gravity model presents a few econometric challenges, which I tried to correct for in my estimation. One major issue related to the ordinary least square (OLS) approach is that the log-linearization makes it impossible to account for zero trade flows and this information is directly dropped out of the sample after the variable is transformed. If zeros are not handled correctly, they can cause a selection bias (Heckman 1979). To overcome this limitation, as proposed by Santos Silva & Tenreyro

---

[14] Due to the presence of the partner countries fixed effects the identification of the distance coefficient in the OLS estimation is not possible (omitted). Therefore, such parameter will not be included in my results. Similarly, also in the PPML estimation, the identification of the distance parameter is possible solely because of the non-linearity of the model and therefore it will not be shown in the final results.

(2006, 2010), I run the regressions also with a Poisson Pseudo-Maximum Likelihood method (PPML), that performs effectively also in case of a large number of zero trade flows. Furthermore, I test the PPML with FE as suggested by Fally (2015), to solve the estimation issue raised by Anderson & van Wincoop (2003), since the estimated FE are consistent with the MTRs. The use of the PPML approach corrects also for the potential heteroscedasticity of trade data, which implies that the variance and the expected value of the error term are not constant and the latter is also a function of the regressors. Furthermore, the PPML estimates are robust to heteroscedasticity because the second or higher moment conditions are absent from the estimation procedure (Westerlund & Wilhelmsson 2011).

One of the other challenges in obtaining reliable estimates of the effects of the trade policies with the gravity approach is the potential endogeneity of trade variables. In my case study, the use of the difference-in-difference methodology based on the identification strategy that the blockade on Qatar is purely exogenous should correct the potential reverse causality arising in trade policy estimation. Also, the use of country FE should account for this issue (Baier & Bergstrand 2007). Lastly, to avoid understating the standard errors, as per common practice in gravity with panel data, I cluster the error term at the country level, which is the level at which most of the errors are potentially correlated.

3.4. Data and Descriptive Statistics

To estimate the regression presented in Section 3.3, I use data from several sources. The data on Qatar's imports and exports are obtained from the Foreign Trade System (FTS) database provided by the Planning and Statistic Authority (PSA)[15] of the State of Qatar. The database includes all the commodity flows as import, export, and re-export[16] from all the trading partners of Qatar at a monthly frequency. The source of the export data is generated by a direct survey of the exporting companies and is accounted at free on board (f.o.b.), while imports are valued at cost, insurance and freight (c.i.f.). Traded items are classified accordingly to the Unified Customs Tariff Code for the GCC countries (GCC Tariff), which is an adapted version of the International Harmonized System (HS). In my analysis, I consider the HS-4 level for exports (the most detailed level available) and the HS-6 level for imports. The HS level of detail allows me to run my regression not only at the aggregate level but also to assess the treatment effects by product type, to understand whether some product categories were more affected than others by the blockade. In particular,

---

[15] https://www.psa.gov.qa/en/statistics1/pages/topicslisting.aspx?parent=Economic&child=ForeignTrade

[16] For the purpose of my analysis I consider the definition given by the FTS database, i.e. total exports, which are the total physical movement of merchandise out of Qatar to foreign countries, including both exports of goods of domestic origin and re-exports. The latter are goods originally imported, cleared through customs formalities, and then re-exported without undergoing any transformation leading to change in shape or value, so that they cannot be considered as Qatari production or manufacture.

we have identified five macro-categories: “Animals”, “Crops”, “Dairy”, “Minerals” and “Others” – this latter including all remaining products not belonging to a specific group. The majority of products are concentrated in the latter category, but the previous four are the ones where I expect most of the effect to be visible, especially in the case of imports. These results are expected as the majority of the dairy, animals, and crop products were imported from the boycotting countries or transported through their borders. These categories are created aggregating the products at the HS-2 digit level for both exports and imports.

The results of the regressions at the product level are discussed in Section 3.5. Export data reported in foreign currencies are converted in the FTS dataset in Qatari Rials (QR) using the official exchange rate of 3.64 QR = 1 USD, which is fixed and pegged to the US dollar. I use the same exchange rate to transform both import and export values in US dollars. More detailed information about the economic zones and the product-level classification can be found in Appendix A (Tables A2 and A3, respectively). The regressions cover the period from January 2016 to December 2018, extremes included, with the embargo set to start at the beginning of June 2017. Since the time-period is not long, using monthly level data allows me to identify the phenomenon under study and isolate it from other potential events. The values of the distance between Qatar and its commercial partners are taken from the Centre d’Etudes Prospectives et d’Informations Internationales (CEPII) Gravity database. I selected the dyadic distance *“dist”*, which measures the overall average simple distance between the most populated cities, in km, provided by their GEODIST database. Data on GDP of the trading partners are taken from the World Economic Outlook (WEO) of the International Monetary Fund (IMF) database and are expressed in US dollars. GDP values are taken in nominal terms, as suggested by the gravity methodology (Baldwin & Taglioni 2006).

The final panel dataset contains Qatar’s import and export trade flows, by country, by product and by the month of transaction. The sanctioning countries, i.e. the treatment group, are from the GCC, from Africa, and other Arab Countries, whereas the countries of the substitution groups are from various regions, although mainly from Europe and Asia. Table 3.1 shows the descriptive statistics of the dataset for import and export respectively, with mean and standard deviation in parenthesis.

For this research, following the most recent literature on panel data estimation, I also conducted stationarity tests, and the respective results are reported in Appendix A Tables A.4 – A.9. In the same section, I also provide a brief background on the importance of stationarity tests for trade data and different estimation techniques.

Table 3.1: Summary Statistics. In parentheses are the values of standard deviation.

Panel A: Imports

Study Variables (logs)	All Countries	Blockading	Cut Diplomatic Ties	Downgrade Diplomatic Ties	Support Resolution	Others
GDP	25.539 (1.843)	26.206 (1.084)	23.450 (0.776)	24.074 (0.469)	27.019 (1.894)	25.362 (1.768)
Import	14.116 (2.920)	16.180 (2.667)	10.108 (2.307)	14.012 (3.000)	16.667 (2.468)	13.775 (2.774)
Distance	8.523 (0.841)	6.117 (0.986)	8.255 (0.603)	7.902 (0.554)	8.234 (0.751)	8.622 (0.745)
Number of Countries	184	4	6	5	25	145
Observations	6984	144	96	95	475	6174

Panel B: Exports

Study variables (logs)	All Countries	Blockading	Cut Diplomatic Ties	Downgrade Diplomatic Ties	Support Resolution	Others
GDP	25.283 (2.030)	26.225 (0.998)	22.332 (1.302)	23.007 (1.256)	26.912 (1.981)	25.150 (1.923)
Export	13.810 (3.281)	17.281 (2.563)	12.691 (1.380)	12.749 (3.095)	16.208 (2.747)	13.457 (3.204)
Distance	8.506 (0.838)	6.117 (0.986)	8.2554 (0.603)	7.902 (0.554)	8.234 (0.751)	8.606 (0.741)
Number of Countries	184	4	6	5	25	145
Observations	6624	144	96	95	475	5814

3.5. Results

In this section, I present the results of the gravity analysis for imports and exports at both aggregated and product-level. The main treatment effect under study is the blockade, but also two additional secondary treatment effects are tested - the cut or downgrade of diplomatic ties with Qatar by countries other than the original senders. Lastly, I check for the presence of a substitution effect with the countries that have shown support to Qatar in the aftermath of the blockade. As outlined in Section 3.4, the blockade was unanticipated by Qatar and by several countries comprised of the circumstance, thus the shock is considered a truly exogenous event. Besides, I can claim that no other shock happened at the same time as the blockade targeting the same set of countries, and therefore my estimates should solely reflect the effect of the blockade. Figure 3.3 shows the short- and medium-term impacts of the blockade on Qatar's imports and exports, respectively. As my timeline covers relatively a short time frame, by short-term effects I mean the ones observed in the first 5 months after the blockade, while the medium-term runs from the end of Q3 2017 to December 2018. The impacts on imports are confirmed larger than the one on exports and the majority of the effects are visible in the short-term. As anticipated above, this is likely determined by the market structure of Qatar's exports, almost entirely linked to LNG, oil and other refining products, whose sales remained solid even after the blockade since the majority of the contracts include countries not involved in the embargo.

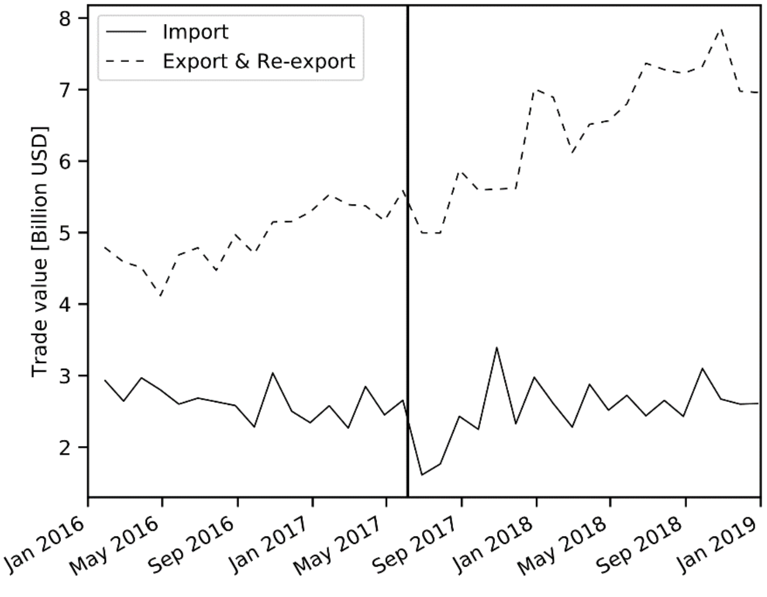

Figure 3.3. Blockade Effects on Imports and Exports

3.5.1. Imports

Table 3.2 summarizes the results of my estimation for the imports. I provide both OLS (columns 1-3) and PPML estimations (columns 4-6), with different sets of fixed effects along with different treatment dummy variables of interest. The reference group for all the estimations consists of all the countries that are not involved in the blockade (at any level) and that did not show open support to Qatar after the blockade. The elasticities concerning GDP present the expected positive sign and amplitude for all the specifications other than for (2) and (3), where they lose significance and switch to negative. This is possible since adding the country FE in my OLS specification the elasticities absorb the GDP dependency. The variables of interest present the same sign across all model specifications, consistently with my hypotheses. The only exception is the variable *Downgrade_DT,* whose sign is negative but not statistically significant for the OLS, while it is positive and statistically significant at .01 level for the PPML. This is possibly due to the fact that, at least for imports, there is not a homogeneous behavior among the countries that downgraded their diplomatic relations with Qatar. The magnitude of the treatment effects instead strongly varies across our specification, with a lower value for the PPML estimations, which is consistent with the results of Santos Silva & Tenreyro (2006) who observe that OLS in gravity equations tends to overestimate the coefficient. The results tell us that the blockade imposed on Qatar had a significant negative impact on the trade with the sender countries, which were among the major trading partners and were also indirectly involved in the trade logistics to and from Qatar. In particular, the average decrease in the import flow with the sender countries ranges from -98% (i.e. $e^{-4.006} - 1$) for specification (1) to -87% for specification (6). The losses, computed with reference to the import values recorded during the month before the blockade, would amount to values between 400 and 450 million USD per month. As for imports from countries that cut their diplomatic ties with Qatar, data are available only for Yemen; in that case, the trade decreased by 51% (1) up to 90% (6), which translates into a loss between 80,000 and 139,000 USD per month. Observing instead the substitution effect, imports from countries that supported Qatar during the blockade increased by 39% (6), an increase in value terms equivalent to approximately 600 million USD in the post blockade period.

Table 3.2. Qatar Blockade Imports Results

Dependent Variable	Logs of Imports			Levels of Imports		
	OLS			PPML		
	(1)	(2)	(3)	(4)	(5)	(6)
Blockade	-4.006*** *(0.60)*	-4.155*** *(0.54)*	-4.119*** *(0.54)*	-2.292*** *(0.29)*	-2.291*** *(0.29)*	-2.058*** *(0.29)*
Cut_DT			-0.716*** *(0.19)*			-2.343*** *(0.34)*
Downgrade_DT			-0.217 *(0.14)*			1.606*** *(0.29)*
Support_Resolution			0.211 *(0.14)*			0.326** *(0.16)*
Block_Country	2.322*** *(0.57)*	8.870*** *(2.63)*	8.834*** *(2.61)*	1.542*** *(0.43)*	1.530*** *(0.46)*	1.539*** *(0.45)*
Block_Time	0.046 *(0.09)*	0.364*** *(0.09)*	0.328*** *(0.10)*	0.031 *(0.07)*	0.031 *(0.07)*	-0.199** *(0.10)*
LnGDP	1.261*** *(0.06)*	-0.200 *(0.73)*	-0.197 *(0.72)*	0.971*** *(0.05)*	0.972*** *(0.05)*	0.936*** *(0.06)*
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	No	Yes	Yes	No	Yes	Yes
Observations	4043	4043	4043	4044	4044	4044
R^2	0.681	0.907	0.908	0.772	0.776	0.781
Adjusted R^2	0.680	0.904	0.904	0.771	0.775	0.780

Standard errors in parentheses (clustered at country level).
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This is also confirmed visually by Figure 3.4: in the first months after the blockade, Qatar registered a big drop in its imports from both blockading and supporting countries. Still, the data confirms that such a negative effect was offset within 6 months, by an increase in trade with the supporting countries and with several new commercial partners. If one looks at the imports with non-blockading countries, the average trade value before the blockade is lower than the average value of imports calculated after the blockade. This difference matches exactly the decrease in import value, also calculated as an average, of Qatar’s trade with blockade countries, confirming the fact that the country was able to re-direct its trade flows and recover within medium-term.

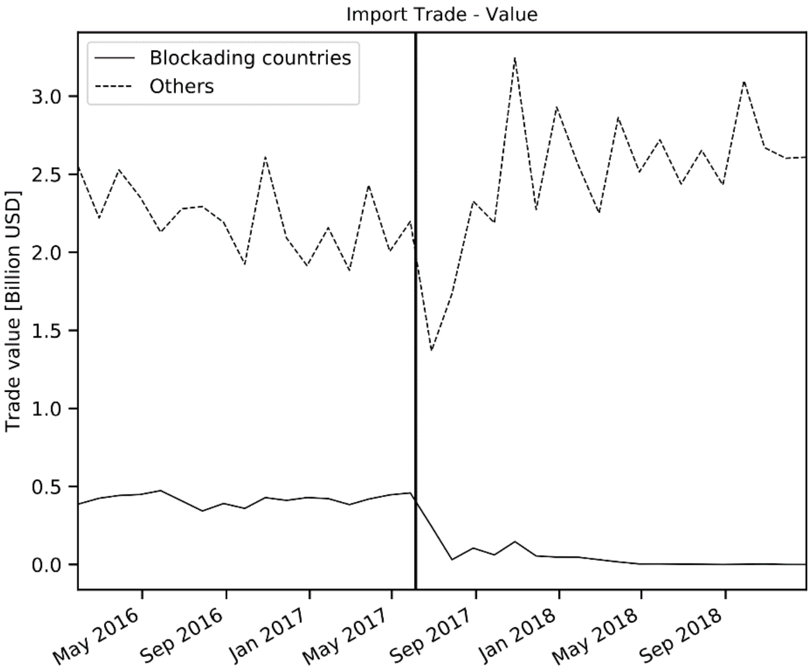

Figure 3.4. Qatar Blockade Effects on Imports: Sender – Support

3.5.2. Exports

As mentioned before, the export trade flows are less impacted by the blockade, and despite UAE being one of the major senders, Qatar did not interrupt the LNG provisions to the emirates through the Dolphin pipeline, which also provides energy to Oman. The results of these estimations are presented in Table 3.3. As in the case of imports, both GDP and distance have the expected positive and negative signs, respectively, and again the distance elasticity is significant, but very small, which confirms that these variables do not matter for the trade routes and commercial agreements of Qatar. The main treatment effect, i.e. the blockade, has a negative sign for all the specifications, and its magnitude is much higher in the case of OLS (1-3). The significance of the other two treatment effects is more difficult to disentangle, since in the case of *Cut_DT* the OLS specification appears positive and statistically significant at level 0.5, while it was expected to be negative. Conversely, it is negative, but not significant, in the PPML estimation (6), Likewise, *Downgrade_DT* is negative in both specifications, but not statistically significant. These results can be related to the fact that exports to the countries supporting the blockade were strategic for energy security and, as it happened with UAE, the trade-in those commodities were not interrupted despite the blockade. Also, the countries in these groups have small leverage compared to the original sender and it is plausible that in the case of exports the announcements "against" Qatar was not followed by concrete actions. For what concerns the exports, also the substitution effects do not have the expected sign and significance for both the specifications (1 and 6). Still, the negative sign and the significance at 0.1 level in the case of the PPML could be attributable to the fact that during the time-frame of the blockade an LNG plurennial contract of Qatar with one of the supporting countries expired.

These results are confirmed also by Figure 3.5, which highlights that since the majority of the exports are directed to non-sanctioning countries, the effects of the blockade on exports are in general more moderate than on imports. Still, the blockade impacted the exports flows of Qatar by causing a decrease in its trade values in ranges from -87% (1) to -78% (6), which is equivalent to 480 to 540 million USD per month compared to the average export levels of the month before the blockade.

Table 3.3: Qatar Blockade Exports Results

Dependent Variable	Logs of Exports			Levels of Exports		
	OLS			PPML		
	(1)	(2)	(3)	(4)	(5)	(6)
Blockade	-2.052** *(0.82)*	-2.974** *(1.16)*	-2.893** *(1.16)*	-0.870*** *(0.25)*	-0.850*** *(0.28)*	-1.547*** *(0.38)*
Cut_DT			0.690** *(0.33)*			-1.352 *(0,96)*
Downgrade_DT			-0.030 *(0.55)*			-0.072 *(0.48)*
Support_Resolution			0.198 *(0.13)*			-1.361*** *(0.42)*
Block_Country	2.911*** *(0.57)*	5.310*** *(1.91)*	4.805** *(1.89)*	0.795 *(0.64)*	0.788 *(0.65)*	1.539*** *(0.70)*
Block_Time	0.119 *(0.08)*	0.158** *(0.07)*	0.077 *(0.09)*	0.277*** *(0.06)*	0.277*** *(0.06)*	1.015*** *(0.18)*
LnGDP	1.045*** *(0.09)*	0.125 *(0.52)*	0.261 *(0.52)*	0.897*** *(0.10)*	0.829*** *(0.11)*	1.027*** *(0.11)*
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	No	Yes	Yes	No	Yes	Yes
Observations	4234	4234	4234	4235	4235	4235
R^2	0.463	0.830	0.830	0.251	0.244	0.344
Adjusted R^2	0.461	0.823	0.823	0.249	0.243	0.342

Standard errors in parentheses. Clustered at country level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

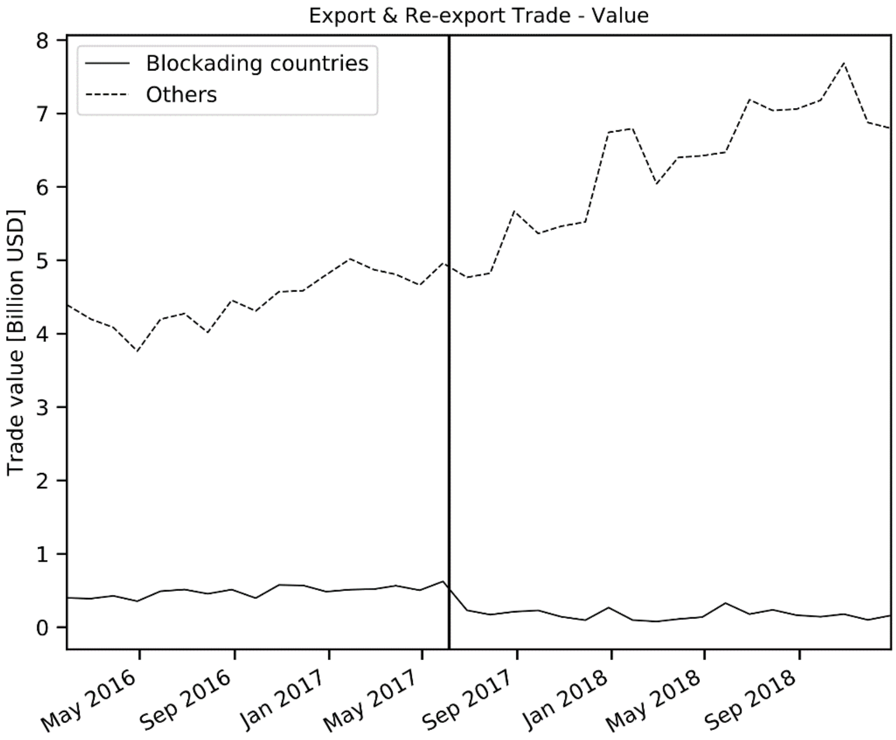

Figure 3.5. Qatar Blockade Effects on Exports: Sender – Support

3.5.3. Product-Level Results

In this paragraph I present the results of the impacts of the blockade on Qatar's imports and exports analyzed at product-level. To derive the considered five product categories I aggregated at level 2 the HS-4 and HS-6 digit codes of the exports and imports products, respectively. The five groups are then identified as follows: "minerals", which includes oil, gas and mineral products, "animal", including both livestock and animal products, "crops", dairy products", and "others", which accounts for most of the remaining observations. The results of my estimation for the latter category are quite similar to the overall results both for imports and exports. Furthermore, the majority of Qatar's export products fall under the category "minerals", thus I focus my analysis on this specific group.

Table 3.4 reports my estimation results. For the product-level category analysis, I use the PPML estimation as my benchmark estimation (column (6)) of Tables 3.2 and 3.3. As in the previous cases, both GDP and distance have the expected signs. Again, the magnitude of the distance coefficient is very low, and this confirms that Qatar's market is very open and its commercial relations span throughout the globe regardless of the actual distance with the partner countries. The main effect, the blockade, is significant at level .01 for imports of animals and at level .0.5 for crops and dairy products. When we observe the same effect on the import and export of minerals (LNG and oil products) and on imports of intermediate goods required in oil production and refinery, the coefficient is negative but not statistically significant. When observing the secondary treatment effects, *Cut_DT,* the sign is negative as expected and significant at .01 and 0.5 for all the product categories. What is worth noting, in this case, is the magnitude of the effect, more pronounced than for trade in aggregate. This result is likely an artifact produced by the fact that when considering the specific categories selected here, very few not-null observations are left for evaluating the regression coefficient of this variable. The other secondary treatment effect, *Downgrade_DT* does not exhibit the expected sign, other than for the case of the minerals import and exports, even if the latter is not significant. Conversely, all the other three import product categories have positive signs and significance at the 0.1 level. This could be explained by the fact that, for these products, the governments of countries that downgraded their relations with Qatar did not interrupt – and actually intensified – their trade with it.

As for the substitution effects, there are no homogeneous results and only the product category "crop" has the expected sign and is statistically significant. The product analysis shows that trade with the sender countries was indeed halted by the embargo for all the product categories taken into consideration. The drop in trade amounts to -86% for animals, -88% for crops, -91% for dairy products in the imports and -52% for minerals in the exports. Given the fact that Saudi Arabia was the only land-crossing border for Qatar, and also that a lot of goods were also shipped through the port hubs in UAE, these results account not only for the products embargoed by the sender countries but also for the supplies that were passing through the blockading countries. Furthermore, before the blockade, Saudi Arabia was the main exporter of dairy products in Qatar. The results of the other treatment and substitution effects for the product heterogeneity are not in line with the ones of the overall aggregate analysis, probably because there are not enough observations to obtain reliable outcomes. Lastly, if one looks closer to the category "others", which is here represented only for the import case, the results are quite similar to the main results of Table 3.4. This is due to the fact that in this category are comprised the majority of the products.

Table 3.4: Product Heterogeneity

PPML						
Dependent Variable	Levels of Import					Level of Export
	Animal	Crop	Dairy	Minerals	Others	Minerals
Blockade	-2.031***	-2.136**	-2.465**	-0.803	-2.022***	-0.745
	(0.38)	*(0.21)*	*(0.048)*	*(0.72)*	*(0.39)*	*(0.76)*
Cut_DT	-1.823**	-1.862***	-2.985**	-9.580***	-4.521***	-6.728***
	(0.90)	*(0.32)*	*(0.42)*	*(0.96)*	*(0.49)*	*(0.82)*
Downgrade_DT	1.279***	1.781***	0.863**	-3.533***	1.507***	-0.964
	(0.48)	*(0.24)*	*(0.38)*	*(0.54)*	*(0.27)*	*(0.61)*
Support_Resolution	-0.143	0.656***	-0.030	0.719	0.281*	-1.289***
	(0.48)	*(0.23)*	*(0.56)*	*(0.64)*	*(0.15)*	*(0.40)*
Block_Country	1.997***	1.358***	2.235***	1.347**	1.349***	-0.196
	(0.61)	*(0.49)*	*(0.47)*	*(0.66)*	*(0.47)*	*(0.77)*
Block_Time	0.222	-0.107	0.598**	0.210	-0.246**	0.820***
	(0.18)	*(0.14)*	*(0.27)*	*(0.34)*	*(0.10)*	*(0.17)*
LnGDP	0.387***	0.559***	0.427***	0.077	1.019***	0.720***
	(0.13)	*(0.11)*	*(0.13)*	*(0.18)*	*(0.05)*	*(0.12)*
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2166	3532	1767	1530	3784	1075
R^2	0.202	0.494	0.639	0.263	0.792	0.316
Adjusted R^2	0.199	0.492	0.637	0.258	0.791	0.310

Standard errors in parentheses. Clustered at country level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.5.4. Placebo Effect

The outcome of both the estimates is similar in terms of significance and magnitude, which contributes to the robustness of the results. Still, an additional concern is the potential presence of pre-existing trends in the result of interest that might be correlated with trade policy changes and can cause the effect under study. Therefore, for further validation, I conduct a placebo test to check the validity of the assumptions. This test aims to provide evidence in support of the validity of my identification strategy, i.e. the exogeneity of the blockade and that its effect is the sole emerging from the estimation without the interference of other shocks or processes on the same sample. The placebo effect is tested as follows. First, I select a different time sample, which covers the period spanning from January 2013 to December 2015 and I then set a false blockade event in May 2014. I then estimate the OLS with tune and time and country FE using the new counterfactual time, with the treatment and control groups remaining the same. Since the main variable of interest is the blockade, I test the placebo effect for this variable only. The results of this exercise are reported in Table 3.5. The first thing to notice is that for both imports and exports the treatment variable is not statistically significant, while in both cases, in my original estimation, it was at .01 significance level. Furthermore, for three specifications it is positive, while the expected sign on the parameter estimates of the coefficient of the *Blockade* variable should be negative. Lastly, the value of the false treatment is close to zero for all cases and in general is very different in magnitude compared to my model reported in the results (columns (1-3)) paragraphs 3.5.1 and 3.5.2. This confirms that no other shocks affected Qatar imports and exports before the blockade of 2017 and therefore the drop in the trade flows of Qatar is truly attributable to the imposition of trade sanctions.

Table 3.5. Placebo Effect

Imports			Exports		
Variables of Interest	(1)	(2)	Variables of Interest	(1)	(2)
Blockade	-0.058	0.121	Blockade	0.601	0.455
	(0.07)	*(0.121)*		*(0.41)*	*(0.42)*
Block_Time	0.419***	0.159***	Block_Time	-0.260***	-0.127
	(0.08)	*(0.05)*		*(0.10)*	*(0.10)*
Log of importers' GDP	1.274***	-0.413	Log of exporters' GDP	1.086***	1.097**
	(0.08)	*(0.26)*		*(0.10)*	*(0.46)*
Time FE	Yes	Yes	Time FE	Yes	Yes
Country FE	No	Yes	Country FE	No	Yes
Observations	4155	4155	Observations	4183	4183
R^2	0.666	0.933	R^2	0.466	0.828
Adjusted R^2	0.665	0.930	Adjusted R^2	0.464	0.821

Standard errors in parentheses (clustered at country level)
$^{*} p < 0.10$, $^{**} p < 0.05$, $^{***} p < 0.01$

3.6. The Environmental Sustainability of Qatar's National Food-Security Strategy Plan

The impact of the embargo on Qatar's trade flows have not only affected the economic balance of Qatar, but it has also highlighted a food-insecurity issue. The risks stem from the geographic and climatic conditions of the country, which lacks surface freshwater resources and presents a harsh climate and a desert environment that prevent the development of standard intensive agricultural practices. Therefore, the expansion of the food chain has always heavily relied on imports from foreign markets (before the blockade, about 90% of the local food demand was met by imported products), which highlights the exposure of the country's supply and demand to sudden disruptions generated by external factors. Producing food requires a large amount of water resources, whereas importing food puts pressure on the water resources of the exporting country.

The linkages between international trade and water-intensive commodities are well known. Especially in the current and future context of climate change, population growth and consequent dramatically increasing pressure on global water resources, the use of local water resources as well as the global allocation of virtual water and its international trade flows should be carefully investigated and reconsidered. The expression of 'virtual water' was coined in the late 90s by Allan (1998) to indicate the total volume of water used in the production of a product. Particularly for hyper-arid environments such as Qatar, imports of virtual water can be an effective way to preserve domestic water resources (to the expenses of the exporting countries, which cannot use that water amount for internal consumption). From the concept of virtual water, many studies had then originated to effectively measure the water endowments of specific consumption or production processes and products i.e. the so-called Water Footprint, which I am using in this paper (Mekonnen and Hoekstra 2010a, b, c, 2011a, b; Antonelli, Laio & Tamea 2017; D'Odorico et al. 2014, 2019).

Most of Qatar's food imports and consequently virtual water imports came traditionally from the chokepoints of the Strait of Hormuz between Iran, Oman and UAE and the Bab al Mandab across the Saudi Arabian border. The global food crisis of 2008, which caused a spike in food prices, together with the war in Syria in 2011, which deprived the Gulf of one of the key suppliers of fresh fruit and vegetables, had tangible effects on Qatar. As a response to those events, in 2008, the government decided to launch the first National Food Security Program (QNFSP). This program aimed to reduce Qatar's reliance on food imports through the development of several initiatives oriented towards self-sufficiency, to achieve 40% of food supplied domestically by 2030. The plan included the expansion of the agricultural sector and its endowment with the latest technologies. Furthermore, in 2016, the country started planning the construction of a new port, to turn the country into a regional trade hub, and to secure a reliable food stock for the domestic demand[17]. Besides, through its fully-owned subsidiary, Hassad Food, the national Qatar Investment Authority started to purchase and fund farms in Sudan, Australia, Kenya, Brazil, Vietnam, and the Philippines, with plans of expansion in North and South America. Such a self-sufficiency plan incurred several constraints that limited its feasibility. Qatar's agriculture is severely constrained by water scarcity, poor groundwater quality, lack of a proper water network in many of the rural area and infertile soils. The financial and environmental costs associated with the implementation of those plans appeared to outweigh the cost of relying on importing foreign food supplies. Despite a few examples of successful implementation of the QNFSP strategies, Qatar continued to depend on imports for a very significant portion of its food needs

The blockade starting in June 2017, however, exposed the country to an unprecedented level of food insecurity. This trade disruption hit the country directly. The panic effect caused by the blockade in the first few months forced Qatar's Ministry of Economy and Commerce to react by establishing fixed prices for most consumer goods and food products. The waters of the gulf surrounding the Peninsula cannot host large cargo vessels because the seafloor is too shallow. These vessels used to stop in UAE where the goods were then relocated to smaller cargo-ships destined to Qatar. To overcome this issue, Oman offered his hub in the Sohar port as a backup solution, allowing Qatar to re-establish at least some of its foreign commercial routes, together with the opening of new trade routes and trade agreements that were signed with Iran, Turkey, and India. Two years after the beginning of the blockade, a new Strategic Food Security Project for 2019-2023 was introduced by the Food Security Department of the Ministry of Municipality and Environment (MME). Differently from the first plan of 2008, the current plan is better organized from a logistics perspective and the food security targets are well outlined. The strategy is based on four main pillars: (1) boosting local production; (2) increasing the strategic storage that aims to provide non-produced goods in the country for covering its needs for up to six months; (3) keeping international trade as a cornerstone; (4) starting local market studies. The new plan has a much shorter time horizon, with objectives to be achieved as early as 2023, and very ambitious autarkic aims. These new strategies were disclosed only in March 2019, although the preparation of these plans started immediately after the blockade. The action plan was rapidly implemented, and local production started to increase, providing again the local market with livestock and vegetables, fruit and dairy products – this time, produced domestically.

The question I am addressing in this Section is whether the food-security strategies motivated by the blockade and by the necessity of reassuring the population, are effectively sustainable for the country from an environmental and natural resources management perspective.

---

[17] Hamad Port construction development has been performed by Mwani Qatar https://www.mwani.com.qa/English/Ports/Pages/HamadPort.aspx

In working towards this objective, I have developed a trade-off analysis of the allocation of natural resources. This analysis follows a scenario-based approach and aims to explicitly quantify the connections between water and food demand in Qatar to evaluate the feasibility of the food-strategies promoted by the MME in terms of water needed to realize them. The ultimate goal is to understand whether the economic diversification indirectly induced by the blockade could exacerbate the pressure on the already scarce environmental resources in the country. To evaluate the environmental implications of the new, readjusted trade patterns, I compare the total water demand required to fulfill the food-security scenarios with the projected availability of water supply for Qatar, retrieved from the results presented in Chapter 2 of this dissertation.

To reach my goal, the first step is to quantify the current and future domestic food demand for Qatar, i.e. the difference between the sum of imports (I) and local food production (P) levels and the sum of exports (E) and re-exports (rE) of primary and secondary food supplies: $(I + P) - (E + rE)$. For doing so, I retrieve estimates on the local food production from the Ministry of Municipalities and Environment and I combine these with historical data on population size from UNDESA to derive the food demand per-capita for Qatar from 2007 to 2017. Also, I create ten macro-categories of food products based on the HS system at 2-digit level, to correctly identify the water endowments corresponding to each food product. Each category and its characteristics are better described in Table A10 in Appendix A. To forecast the future food demand, I build a linear regression model for each of the 10 highlighted food categories using historical population data and past food demand for each category as the independent and dependent variable, respectively. To validate this approach, since I only have annual estimates for each category (2007-2017 annual data), I use a Leave-One-Out (LOO) cross-validation technique. With this approach, I can derive the accuracy of the linear regression model. This technique, given N-pairs of dependent and independent observations, consists of using N-1 observations to train the regression model and the remaining one for testing the residual error of the estimate. This process is repeated changing all the time the pair I am using for testing without repeating it. In the end, I average the N estimated absolute residual errors and I derive the percentage absolute error by dividing its average by the mean value of the dependent variable. This technique is applied to all 10 categories identified and I obtain an average error of 9.8% across categories. The errors for each category are reported in Table 3.6 below. While the average total error is acceptable given the type of estimate and the small number of observation available, I find that the category *"Others"* has a % error double than the average one, but this category includes items that are not primary food products, such as tea, coffee, spices and similar, which probably have much lower correlation with population growth than other food categories reported in the study.

Table 3.6. Percentage Absolute Error for each Food Category

Food Categories	Error (%)
Animal Products	8.5
Cereals and derivatives	10.5
Dairy and Eggs	6.4
Fish	7.7
Green Fodders	10.0
Livestock	11.7
Oil crops and oils	10.4
Others	18.6
Processed Food	5.8
Vegetables Fruit Legumes and derivatives	8.6

To forecast the future food demand up to 2030 I use the linear model in combination with the population projections from IIASA for 2016-2030 under the five different SSP scenarios (already discussed in Chapter 2, Riahi et al., 2017). This methodology assumes, as a first-order approximation, that future food demand will be only a function of the population size. Although this hypothesis is quite stringent and should also account for possible future changes in the dietary habits, I believe that, given the socio-economic characteristics of the society in Qatar, there should not be any major change in the country's diet in the medium-term. Since the diet is mainly based on wealth and income, I do not expect major changes in income redistribution in Qatar for the next 20 years.

After forecasting the future food demand in tons per year, I create four different scenarios to differentiate the strategies able to provide the food supply needed in Qatar: 1) baseline scenario, which maintains the same proportions between import and local production of 2016 (base year); 2) a scenario based on the MME Strategic Food Security Projects, which follows the paths of local production expansion for 2023 drawn by the ministry and maintains the same proportions afterward; 3) a full-autarky scenario, in which all the food needed in Qatar is produced domestically (full self-sufficiency) by 2030, and 4) a full-import scenario, which is based on the reliance on 100% imports for food demand up to 2030. All these scenarios account for different proportions between import and local production for each single food category, depending on the specific conditions. In particular, the full-autarky and full-import scenarios represents my upper and lower bound in terms of country's self-sufficiency, while the MME Strategic Food Security Projects 2019-2023 represents the intended food production plans, which are the core of the analysis and are outlined in Figure 3.6. It is important to notice that while I consider a total of ten different food categories, the strategies of the MME only cover some specific items that are included in our categories. Since these items are the main of their corresponding category, I apply the percentage of the MME strategy to the whole macro-category. The categories that instead are not reflected in the MME strategic plans, maintain the same proportion between import and local production as the baseline scenario.

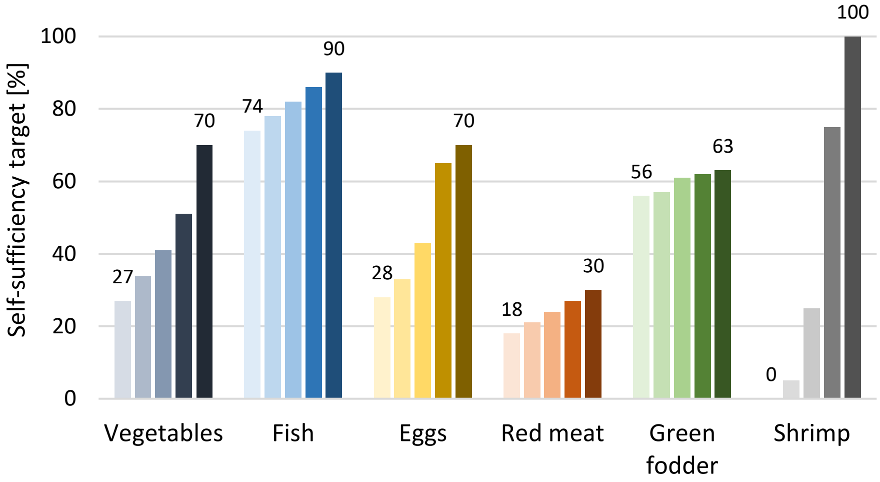

Figure 3.6. Strategic Food Security Projects by the Ministry of Municipality and Environment (MME) of Qatar

Finally, for evaluating the pressure of food production on Qatar's water resources, I use the water footprint database produced by Mekonnen & Hoekstra (2010a, 2010b, 2010c, 2011a, 2011b) for transforming all the food products in their respective water endowment needed for their production, depending on the origin of their production. I first translate the historical food imports data in water amounts (m^3/year) by multiplying all the imported values in Kg with each country's specific water footprint and then aggregating at the category level. If a country is exporting to Qatar products for which Mekonnen & Hoekstra's database does not provide its water footprint index, I use the world average of that specific product for the calculation of the water footprint. I apply the same in case Qatar's exports have missing information. For the re-export, since the FTS dataset provided by the MME does not give information on the country from which the products originated, I consider the world average water footprint for each specific food item, also because I cannot consider these re-exports as products produced in Qatar. Finally, I derive the category-specific mean water footprint and I use it to estimate the total annual water needs to satisfy the local food demand up to 2030, according to the different population projections. One could argue that with this approach I do not fully account for the portion of the water used for Qatar's food products that then are exported outside the country. However, the main objective of this study is to quantify the water footprint of achieving national food security, which means only fulfilling local food demand that is only a part of the food production system of a country. Furthermore, Qatar's food exports represent only a small percentage of its food production system and the plan of MME does not outline any export plan soon. A more detailed analysis would require modeling also future export projections.

Figure 3.7 displays the results of this analysis for the different SSPs scenarios under the baseline scenario analysis, showing a forecasted demand ranging between 5.3 and 5.8 BCM/year by 2030, starting from a present water footprint of 4.5 BCM/year. This would increase to 18 and 29% of the water footprint demand by Qatar under the forecasted conditions.

I then apply the four different strategy scenarios to quantify how much of this water demand will come from foreign sources (virtual water - imports) or the local supply. Figure 3.8 presents the results of this analysis for the SSP2 scenario, which is considered the most plausible one in terms of population growth. The shaded area depicts instead the 95% confidence interval for each analyzed scenario. Since the baseline scenario refers to the period before the blockade, where most of the food supply originated from imports, if we keep such trend until 2030, the resulting future internal water footprint of Qatar will not rise considerably, 20% (± 3%) on average, in the next 15 years, depending from the SSP scenario. On the contrary, following the strategies laid down by the government, Qatar will require to increase its water use for food production of almost 3 times by 2023 (compared to 2016 levels), with a further 10% increase to maintain the same strategy up to 2030. Unsustainable levels would be required by a hypothetical full-autarchic food strategy, with water use needs exceeding 5.5 BCM/year, almost ten times the current supply. For completeness, following a strategy based on the full import of the food stocks would benefit the scarce local water resources at the expense of the national food-resiliency of the country.

In 2016, Qatar has extracted 228 MCM from its aquifers, and it produced 721 MCM of desalinated water and 118 MCM of recycled water. By adding 58 MCM of annual runoff, the total water supply for the nation amounts to ~0.95 BCM. This means that, given the present conditions, any strategy that will require additional water compared to the baseline, will involve major investments in new water production infrastructures. Treating and reusing wastewater would be likely the most suitable and sustainable solution to avoid further exploitation of the already scarce fossil aquifers and to prevent further production of CO_2 from thermal desalination.

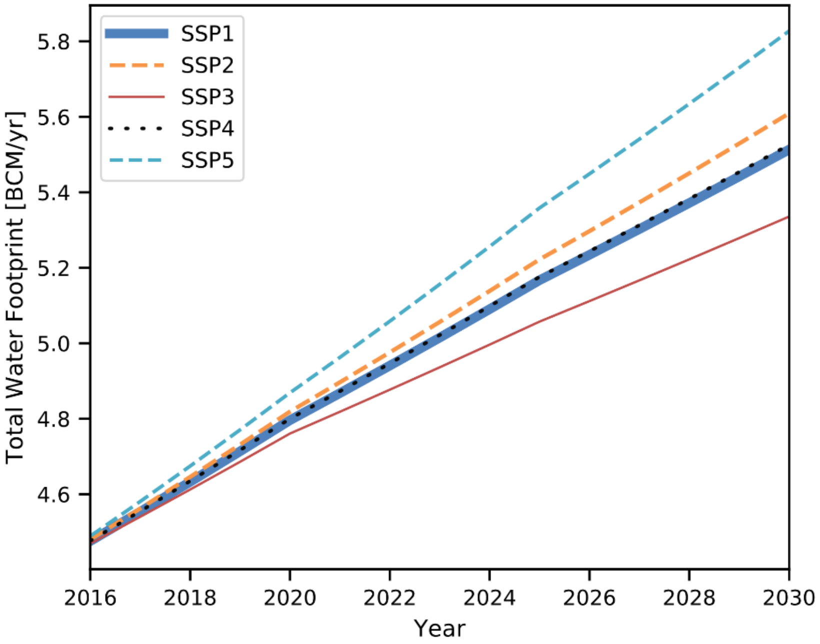

Figure 3.7. Total Water Footprint

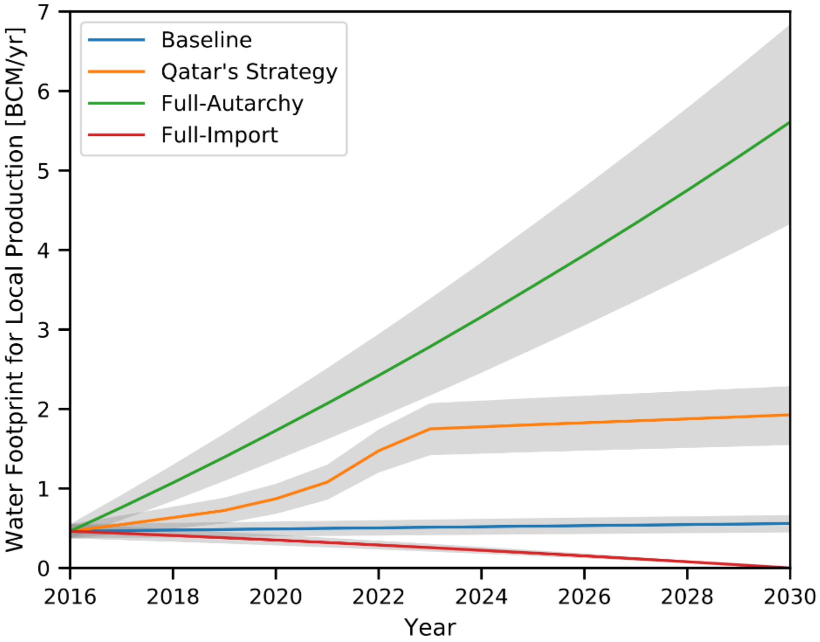

Figure 3.8. Water Footprint for Local Production

3.7. The blockade as a Catalyst for Institutional Change?

After analyzing the economic and environmental impacts caused by the blockade on Qatar’s economy and its water management and food security strategies, I will conclude with a few observations on the nuances of the blockade from a socio-political and geopolitical perspective. When the blockade started, the sender countries were quite confident of a fast surrender on the part of Qatar, given its physical and geographical traits and the strong economic and cultural bonds shared by the sender and the receiving side of the embargo. The actual evolution of events has shown that such bet was misplaced. The position of neutrality chosen by Oman and Kuwait, which offered harbors and support in the diplomatic resolution of the dispute, contributed to weakening the efficacy of the blockade. Furthermore, the contribution of Turkey and Iran in easing the economic grievance of the blockade, especially in the short term, opening their airspaces and providing immediately food stock, strongly reinforced Qatar’s position, also lowering the potential for further military escalation of the dispute. At the same time, their gains in the international arena, or at least in the regional one, were worth the help. This was particularly true for Iran, which has a history of strategic rivalry with Saudi Arabia for the regional dominance, and is much closer to Qatar, with which it shares the South Pars/North Dome Gas-Condensate field. In the aftermath of the blockade, Qatar was also very active in securing and attracting political support from Europe and Asia, which were already gravitating in the Qatari sphere thanks to the investments of the Qatar Investment Authority in cooperation with European countries and the major LNG contracts with the Asian market. To some extent, the capability of rapidly attracting support and enhance domestic security can be seen as a result of the soft power of Qatar (Nye 1990). Clearly, in the case of the Gulf monarchy, this capacity is based more on the wealth provided by the hydrocarbon sector, rather than on cultural and political values. Nonetheless, conversely to its other neighbors, Qatar is strongly pushing for promoting a new state brand, especially considering all the investments made in the last decades for promoting its role for sports events in Asia, ultimately achieved by securing the FIFA 2022 World Cup. This and many other choices contribute also to better secure Qatar’s economy through diversification. Indeed, in 2017, the share of non-hydrocarbon sectors, such as constructions, manufacturing, and real estate has witnessed an increase of 15%, 8.7%, and 7.1%, respectively, compared to their values in the previous years[18]. Still, in the short term, the effects of the blockade were strong not only on the economy and the financial capital but also shook Qataris and foreign residents, which constitute the majority of the population and have not the same rights as Qatari citizens. In addition to the economic issues, the realization of being landlocked and closed was palpable. Therefore,

---

[18] https://www.psa.gov.qa/en/statistics/Statistical%20Releases/Economic/NationalAccounts/NationalAccounts/2018/National_Accounts_MDPS_Bu_AE_2018.pdf.pdf

to reassure the local and foreign citizens living in the Peninsula, the government started to promulgate laws and policies which were promoting openness and helped to boost again the tourism and consequently the revenues of Qatar Airways, the national flag carriers, which observed major losses in the first months of the blockade[19] . In August 2017, Qatar ended visa requirements for over 80 nations, which are now able to obtain a visa waiver after arriving in Qatar of those states, 33 can stay in Qatar without a visa for up to 90 days, while the remaining 47 for up to 30. In connection to this, in May 2019, Qatar National Tourism Council (QNTC) announced visa-free entry for the entire summer of 2019 starting from June 4th to August 16th, regardless of the country of origin of the visitor. Another relevant law issued in 2018 is the Amir Law No. 13 of 2018, amending certain provisions of Law No. 21 of 2015, and granting the possibility to the expatriate worker to temporarily exit the country, or for good, at any time during his/her employment contract without an exit permit. There are of course conditions applicable, but it represents a big step forward for Qatar. The other two laws regard instead of the economic landscape of Qatar. First, in 2018, a new Qatar Free Zone Authority has been established net to the Hamad Port, and it adds up to the Ras Abufontas free zone, located next to the Hamad international airport, and the Qatar Science and Technology Park (QSTP), located inside the Education City Campus and mostly focusing in start-up funding, technology and innovation. Also, in early 2019 the Foreign Direct Investment Law came into force, enabling 100% foreign ownership in most sectors of the Qatar economy, excluding only the banking and insurance services. This law will also put foreign companies on the same legal footing as domestic firms, allowing them to bid on government contracts while strengthening investor rights and legal standing of overseas companies. This also represents a big step forward, since before the foreign ownership could be only up to 49%. Overall, while the economic and potential environmental losses are undoubted, Qatar's strategy to move away from these burdens pushed towards major openness and changes that were not anticipated before the blockade. Whether this is only a tactic, and it will not bring any other major change in the future, it helped the country to rule out the blockade and gain a higher reputation and support beyond its physical borders.

---

[19] https://www.aljazeera.com/news/2018/09/qatar-airways-reports-69m-loss-gulf-blockade-180919053048255.html

3.8. Conclusions

In this paper, I provide a detailed analysis of different aspects of the blockade imposed on Qatar since June 2017. Through the construction of an ad hoc dataset and its econometric analysis, I quantify the impact of the embargo in terms of changes in volumes of trade with old and new partners, as well as the economic losses generated by the trade disruption. I then quantify the secondary effects on the country's water resources induced by the response policies oriented to higher food self-sufficiency. Lastly, I briefly outline the socio-political effects of this blockade in the context of the regional and international arena.

To analyze the trade disruption, I employ a difference-in-difference methodology in a gravity framework to disentangle the main treatment effect, i.e. the blockade's impact in terms of loss of trade with the original sender countries, and two sub-treatment effects (changes in trade with the countries that sided with the original senders and cut or downgraded their diplomatic relations with Qatar). I also observe the substitution effects, which is represented by the potential gains in trade with nations that openly supported Qatar. I exploit the characteristic of my dataset to check the effects of the blockade on five major product categories. The results show that the impacts of the blockade have been stronger for imports than for exports, as expected, given the export market of Qatar mainly based on LNG traded with countries not involved in the blockade. Still, the loss of trade with the blockading countries summed up to ~400-450 million USD per month for imports and ~480-540 USD[20] per month for exports. The products most impacted by the blockade turn out to be the dairy, agricultural and animal products. The trade disruption with the countries which cut or downgraded their diplomatic relations is not as sharp as the blockade. This is probably due to the specificity of the countries in those groups, whose markets are very different, and smaller, compared to the Qatari ones. At the same time, Qatar managed to engage with its other commercial partners, which granted a monthly gain in trade compared to the levels before the blockade of ~600 million USD for the imports, which allow Qatar to offset the losses in the relatively short term. Nonetheless, the blockade is still ongoing and the new situation seems to have become the status quo. For this reason, Qatar's government has announced the implementation of new food-security strategies for the time horizon 2019-2023. Given the intrinsic water scarcity of the region, I have also tried to quantify the potential effects on the water resources of the countries of these plans. My water-food security model indeed confirms the unsustainability of that response strategy, at least with the projected water endowment for Qatar.

---

[20] Values in USD are higher for exports than for imports because the export market of Qatar is mostly in LNG and oil products, which are more expensive compare to the products of the import category. Still, in terms of elasticities, the drop in the imports is much higher in term of magnitude.

These findings point to the need for resetting such strategies, based on a comprehensive assessment of potential alternative water resources, such as desalination or treated sewage water. While the blockade is shown to have had negative economic effects mainly in the short term for the receiving country, in the medium to long term the harmful effects appear to be linked more to the deterioration of the natural water resources endowment induced by the autarkic food security strategy adopted in response by the country.

On the contrary, from a reputation and visibility perspective, it looks like that the decisions taken by Qatar in terms of foreign and domestic policy during the blockade, helped the state to rule out the blockade and secure the needed support at regional and international level.

CHAPTER 4

WATER PRICING FOR AGRICULTURE IN THE MIDDLE EAST AND NORTH AFRICA REGION

ABSTRACT. Global water resources are currently over-exploited at an unprecedented rate. This phenomenon is ongoing for few decades in the Middle East and North Africa region, where water resources are already scarce and their use is disputed among countries, as the majority of those are transboundary, and there is also competition between different economic sectors within the same country. Agricultural activities are the one with the highest water requirements and irrigation demands are growing, as in the last decades increasing food self-sufficiency is one of the top priorities for these countries. Besides, water use for agriculture is heavily subsidized both for farmers and consumers. Still, sustainable water management is far behind and policies and instruments promoting efficiency in water use are not particularly effective in promoting water conservancy. For example, water tariffs for irrigation are the lowest in the world and the majority of the MENA countries' introduction of water pricing reforms encounters a lot of resistance. In this paper, I provide a thorough review of the existing water tariff for irrigation for all countries in the MENA region. Being charges very low, I then estimate the shadow price for water in the agricultural sector, for a total of 19 countries and 12 different crop categories through marginal value product (MVP) obtained from a Cobb-Douglas production function for the period 1991-2016. Finally, I compare the results with the current prices. The results show that on average, for the period 2011-2016, the shadow prices on average, are higher than the existing tariffs and that there is quite a lot of heterogeneity among countries and crops. This confirms that exists a fair margin for improvement in water management. Therefore, this study can be helpful to evaluate scenarios and tradeoffs between profitable crop production and sustainable water use in the agricultural sector.

JEL Classification: O53, Q11, Q15, Q18, Q25

Keywords: Water Pricing, Irrigation, Shadow Price, Agriculture, Middle East, and North Africa

4.1. Introduction

On the global scale, water use in the agricultural sector is the key concern of any food-security oriented policy, particularly now that several natural and anthropogenic drivers such as global warming and population growth are escalating the pressure on global water resources both in terms of quantity and quality. Overall, agriculture accounts for about 70% of global water withdrawals, the vast majority of which is used for irrigation. Future agricultural water consumption, both rain-fed and irrigated, is attested to increase by about 19% to 8,515 km^3 per year by 2050 (Molden 2007). The order of magnitude of the irrigation demand is quite uncertain, mainly because of the nature of the practice itself, which is very heterogeneous across countries. Furthermore, irrigation water requirements vary with crop type and growing season, cropping practices, climate conditions, the efficiency of the irrigation techniques and the changes in the land area used for irrigation. Therefore, studies on this are particularly challenging also for the number of variables that need to be collected to represent the agro-hydrological systems.

The overexploitation of water resources is extremely obvious in the Middle East and North Africa region, where water is scarce and the need for increased food production intensifies the competition for water use among the other economic sectors. In this area, irrigation water use is met both by surface and groundwater resources, the latter often been non-renewable, and currently depleting at very alarming rates (Haddeland et al. 2014; Wada, et al., 2014; Mazzoni, et al., 2018; Odhiambo 2017; De Graaf et al. 2017; Bierkens & Wada 2019). The majority of the issues in agricultural water management in the Arab region are certainly determined by the chronic water scarcity, but there are additional factors such as the lack of proper efficiency in water use, the predominance of outdated irrigation methods, the unrestricted use of both surface and groundwater, the presence of low or absent water tariff for agriculture and the cultivation of water-intensive crops that strongly contribute to making water resources even more vulnerable.

Potential policies and investment strategies' developments in the agricultural sector require changes in water management schemes. Inter-sectoral water re-allocation could be useful to better assess the water needs in the economy and reduce water waste in the irrigation. Moreover, the increase in water use efficiency for irrigation, calls for an intra-sectoral shift towards less water-intensive crop varieties. Furthermore, water can also virtually move from water-poor to water abundant countries. All these changes, generally require advancements in water management planning and there are several methods to intervene to manage scarce goods and promote more sustainable practices. As per the Fourth Principle of 1992 Dublin Statements (WMO 2007), water is recognized as an economic good and therefore it has to be used efficiently and equitably. This definition is complemented by the First Principle of 1992 Rio Statements, which advises considering water as a social good. As such, there exist several instruments that can help policymakers and governmental institutions to drive water allocation decisions among the different sectors and agents. Between those, water pricing is recognized as a policy intervention that can be used as a starting point to mitigate both quantity and quality dimensions of water scarcity and ensure its efficient use (Grimble 1999; Renzetti 2002; Ward & Michelsen 2002; Young 2005; Al-Rubaye 2019). Still, there are many ways to define both efficiency and equity in water allocations and also different methodologies to set the optimal price. The criteria for which to assign the price often depends on the policy goal, whether is it for cost-recovery of the agency investment in the operation and maintenance (O&M), for signaling the scarcity value of a resource and identify its opportunity cost to guide allocation decisions both within and across water subsectors or finally, for accounting for the environmental externalities (Dinar 2000; Johansson 2002; Tsur et al. 2004; Molle & Berkoff 2007). Furthermore, setting up the water price for irrigation depends on a variety of determinants such as physical conditions, institutional, legal and cultural aspects of water allocation regulations, which differ worldwide.

In the MENA region, water tariffs for irrigation have been proven to be the lowest in the world and are 10 times lower than those for municipal or industrial sectors, a situation that highly contributes to the overexploitation of the resources. Water pricing in the Middle East is not a new topic and the literature on this topic dates back to the late early 2000s (Ahmad 2000; Tsur et al. 2004; Laoubi & Yamao 2011). There are therefore several ways to calculate the “optimal” water price, but since water is not quoted in a well-established market, its price can be primarily identified as the shadow price, which is the theoretical price that would be obtained were all market imperfections removed. Without water markets, such it is the case in the MENA region, shadow prices will, as a rule, differ across different economic activities and different locations.

There exist different valuation techniques used to estimate the shadow price for water, well summarized in Young (1996). As an example, Ziolkowska (2015) employs the residual valuation method applied to the High Plains in the US, He et al. (2006) employ partial equilibrium agricultural sector model for allocating scarce water to agricultural production both in Egypt and Morocco; other studies use instead Computable General Equilibrium (CGE) models for Morocco, Tunisia and the Netherlands (Diao, Roe & Doukkali 2005; Thabet, Mahé & Surry 2005; Chemingui & Thabet 2016; Koopman et al. 2017). Jaghdani, Brümmer & Barkmann (2012) calculate the willingness to pay for water for agriculture with three different methods: contingent valuation, marginal value product (MVP) and residual imputation methods. Lastly, other studies both in the Arab region and other areas estimate the economic value of the water also as marginal value product (MVP) of irrigation water in crop production, which is known as economic returns to water (Madariaga & McConnell 1984; De Lange & Mahumani 2012; Frija et al. 2014; Gezahegn & Zhu 2015; Sun, Huang & Wang 2017; Williams et al. 2017; Bierkens et al. 2019). Following this stream of literature, in this study, the shadow price of water for irrigation is calculated through MVP, because it reflects how much value a unit of water adds to crop revenue. This also implies that low shadow prices express low revenue per cubic meter of water consumed and for an arid environment where water is already scarce, this corresponds to the wasteful use of a natural resource. In my study, I do not account for intertemporal efficiency and future water use rather, I focus on efficient allocation of irrigation water among crops given the current abstraction. The possibility to compare shadow prices between the main crop-categories produced by a country and between countries allows to infer about the possibility to reduce water consumption for irrigation and to change the crop-production portfolio towards less water-intensive crop varieties, or eventually to the so-called cash-crops, which are the one generating higher revenues on the market.

If the main goal is not to increase the ratio of the crop-water revenue, but instead to secure cost-recovery for water provider agency and promote water conservancy, an increase in water tariff closer to the shadow price, could allow the water providers to raise their recovery costs and/or reduce the subsidies in the agricultural sector. Alternatively, the revenues from higher prices can be used to stimulate irrigation efficiency investing in new technologies and more modern agricultural practices.

In this paper, I determine the shadow price of water for irrigation for all the countries in the MENA region and 12 crop categories. I first estimate the elasticity of water for irrigation using a Cobb-Douglas production function, then I calculate the marginal value product of the water for irrigation and employ both to generate the shadow price of water per country and per crop category for the period 1991-2016. Lastly, I confront my results with the existing water prices and infer about potential improvements to be realized in the agricultural water sector.

This paper contributes to the topic in several ways. First of all, there are no studies until now that collect and combine information to cover together at the same time all the countries in the MENA region (19) and for such crop varieties (12). The majority of the literature focuses on some selected countries or crops only. Further, to evaluate the discrepancy between the estimated shadow prices with the current water tariff in place, I proceed in an extensive literature review to reconcile the most updated possible data on existent water prices per country, which is also an effort that has not been done before in such systematic way. The obtained results show that all the prices for crops and countries are, on average, much higher than the existing water tariff. This indicates that there is a margin of improvement for the implementation of adjusted pricing reforms, especially in the countries where no charges are applied, and in those with the financial capability to sustain fewer subsidies to the agricultural sector, such as the GCC countries.

Water pricing reforms are not the only viable instruments and potentially they can be implemented in combination with other methods, such quotas or water markets to become even more effective.

The remainder of the paper is organized as follow: Section 4.2 briefly presents the status of the agricultural development in the MENA region and its irrigation practices, together with the summary of water tariff for the irrigation sector. Section 4.3 outlines the theoretical framework employed to calculate the shadow prices for water for agriculture. In Section 4.4 the data and descriptive statistics are presented, while in Section 4.5 one finds the main results. Finally, in Section 4.6 I discuss the results and explain the limitations and uncertainties of the study.

4.2. Agricultural Development and Irrigation Water Use in the MENA Region

The Middle East and North Africa region spans from the Atlantic Ocean to Central Asia. For this study, I consider the countries that are most commonly included in the list. To delineate the regional agricultural development and status, it is easier to group them into five major sub-regions based primarily on geographic, physical, but also economic and institutional conditions. These sub-groups are Maghreb (Algeria, Libya, Morocco, and Tunisia), North-Eastern Africa (Egypt), Arabian Peninsula (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, and Yemen), Middle East (Iraq, Israel, Jordan, Lebanon, Palestine, Syria), and Central Asia (Iran), for a total of 19 countries.

The climate and physical patterns of these areas vary quite significantly, but overall they are considered arid to hyper-arid environments, characterized by very low precipitation rates throughout the year. For this reason, irrigation plays a big role in enabling greater agricultural production than the one achieved with rain-fed crops. In particular, since these countries are already highly dependent on food imports, mainly for staple food products, irrigated agriculture allows them to attain a higher level of food security increasing their food self-sufficiency (i.e. the demand is met with higher domestic production) and overall contributes to enhancing the sense of national security as a response to a potential exogenous shock, whether natural, geopolitical or market-related. Still, given the climatic challenges and the rapid socio-economic development and population growth, self-sufficiency policies the high allocation of water resources to the agricultural sector happens at the expense of the industrial and municipal development. Furthermore, it contributes to an alarming surface and groundwater overexploitation. Figure 4.1 shows the percentage of water for irrigation on the total amount of water available for each MENA country of this study, compared to the % of the water used by the other economic sectors. Counting for the region all-together, 85% of the water withdrawals effectively are employed in the agricultural sector.

Furthermore, food production is extremely vulnerable to climate events, and harvest cannot be granted at the same level in every season, therefore the agricultural performance and its contribution to GDP remain quite low, for all the countries, as it is shown in Figure 4.2.

In addition to water scarcity, another severe constraint of the MENA region is the land constraint. Less than 5% of the land is arable for 2/3 of the countries in this area, and many of those have large amounts of desert pastures for livestock grazing (FAO & OECD 2018). The soil is also severely degraded because of the natural agents but also poor irrigation practices. Lastly, two additional obstacles in the agricultural sector are limited investments and limited improvements in the use of new and more efficient technologies, especially for irrigation techniques.

Horticultural crops and cereal production have expanded through the years and consequently also the land area. Still, efficient decisions in this sector, especially when dealing with natural resources constraints, should also be made in terms of choosing which kind of crop to cultivate. Land area in the region is mainly assigned to cereals, which together with cotton and sugarcanes require a huge amount of water, but at the same time, their market value is quite low. On the other hand, vegetables and fruits have potentially higher payoffs.

The agricultural sector is dominated by Egypt and Iran, which together harvest half of the total value of agricultural production, followed by Morocco and Algeria. Since it is impossible to rely mainly on precipitation for irrigation requirements, the countries in the MENA region heavily depend on freshwater resources. Surface water is the main source of water, but to meet the demand, groundwater resources both renewable and non-renewable are also highly employed in this sector. Their distribution and abundance vary, but the withdrawal of renewable freshwater is overall higher than its renewability for the majority of the countries in the region. Furthermore, for many of these countries, the source of water originates outside of their border, which generates further challenges for the appropriation rights and water uses sustainably. Egypt and Syria depend on almost 90% of their water sources from the Nile and the Euphrates, originating in Ethiopia and Sudan, and Turkey, respectively. The case is similar in Bahrain, Kuwait, and Qatar which fossil groundwater derives from Saudi Arabia.

Looking at the irrigation techniques, standard surface irrigation is the most employed technique for the full or partial control irrigation areas in the region. Conversely, pressurized irrigation techniques are mostly practiced in the Gulf, Libya, where sprinklers and localized irrigation are applied over half of the area. From this brief overview of the agricultural sector in the MENA region, it is particularly evident that natural drivers and management planning inefficiency continue to generate a lot of water waste. While most countries acknowledge the problem and tried to make considerable technical, political and institutional progress in the water sector, there is still a lot that can be achieved for water resources regulation and conservancy.

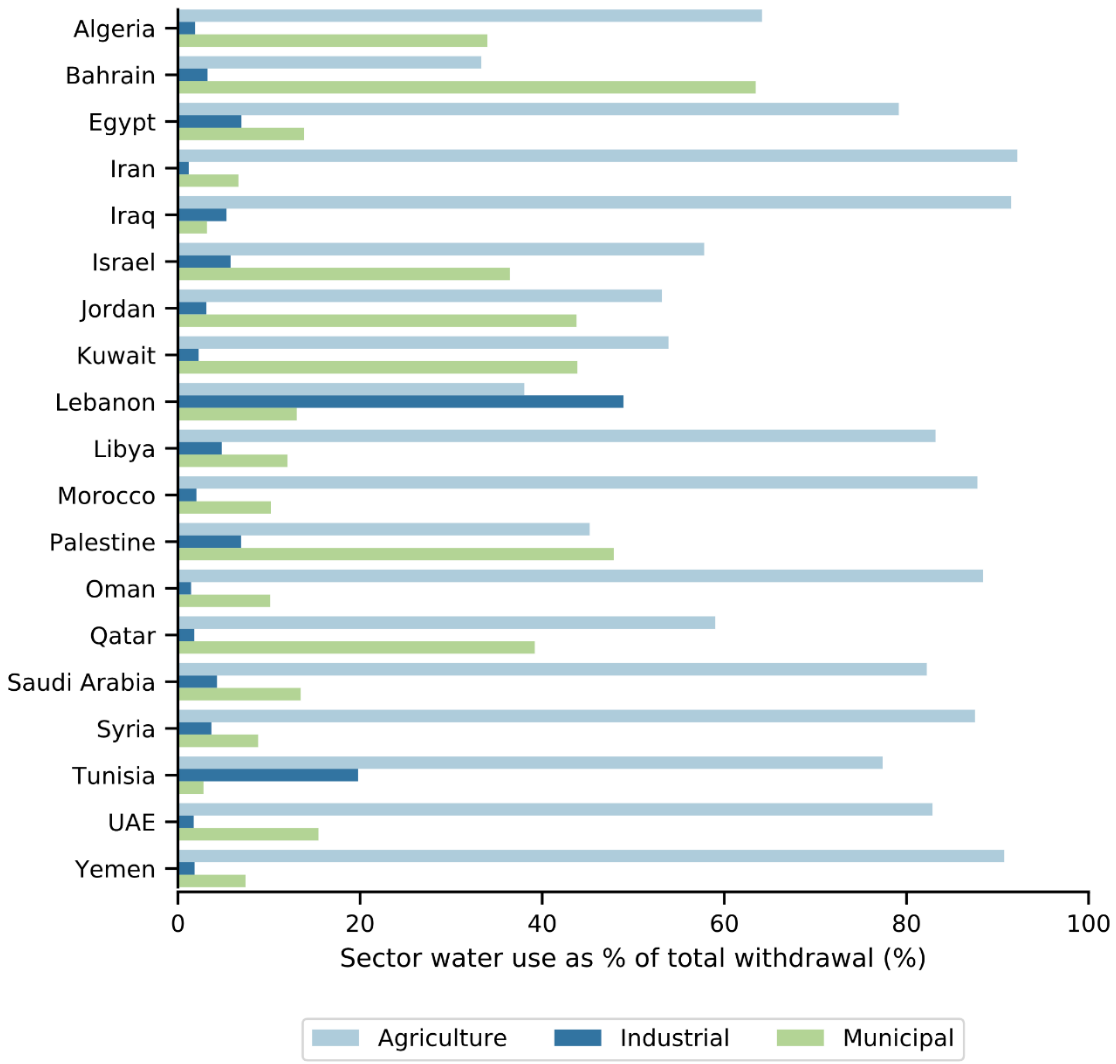

Figure 4.1. Water withdrawal per sector in the MENA region

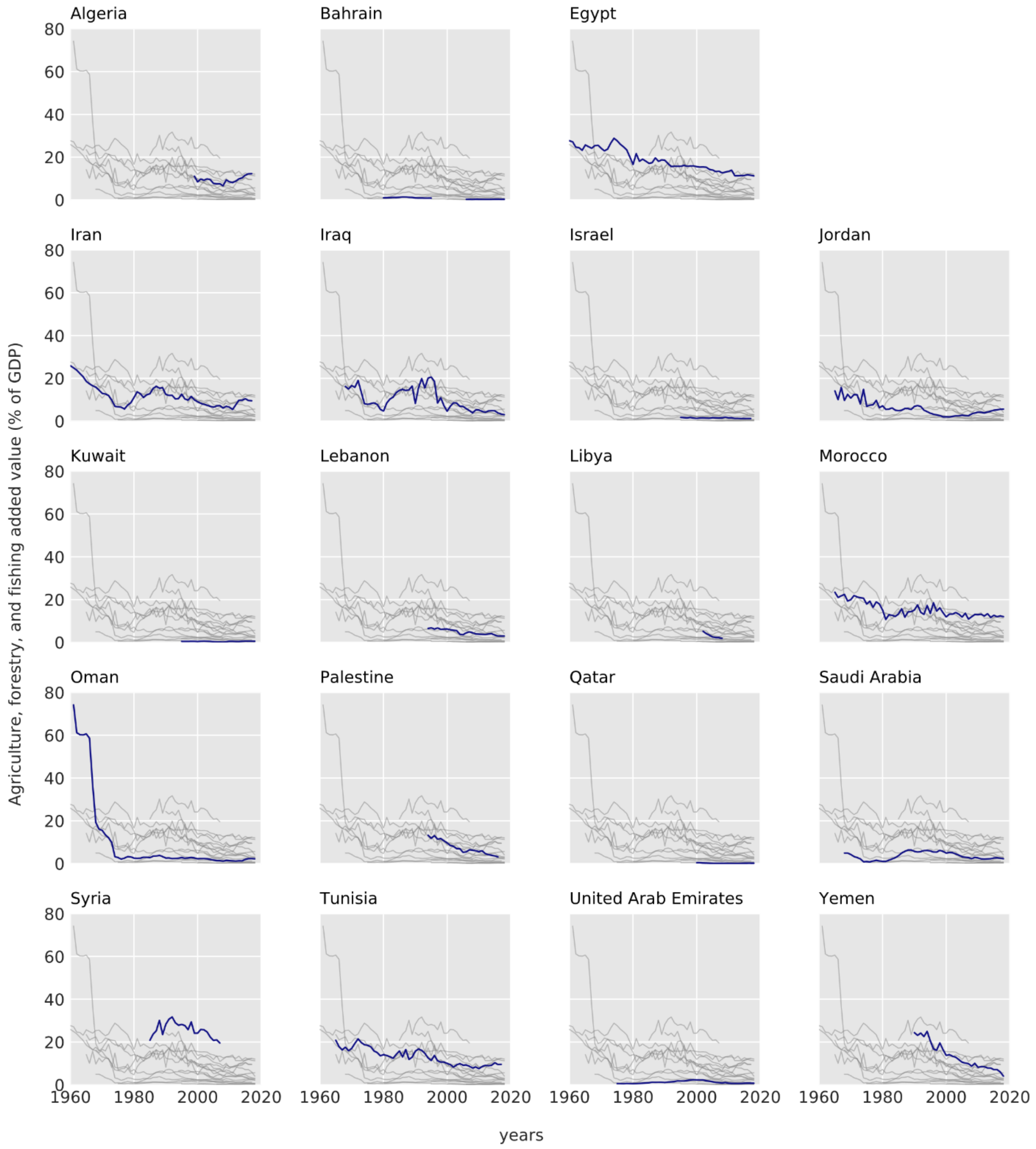

Figure 4.2. Added Value to GDP by Agriculture in the MENA region

4.2.1. Water Tariff for Irrigation in the MENA Region

Despite the vulnerability of water resources and unsustainable abstraction, many governments in the area support and incentivize agricultural production at the expense of efficient water resources management. Still, there are a lot of economic instruments that can be used to incentive water conservation-oriented policies, water allocation efficiency and ecosystem protection (Panayotou 1994) and the most common are (1) water rights, (2) market creation, (3) fiscal instruments, (4) charge systems and (5) financial instruments. These can be employed alone or combined depending on the final policy objective. The timing, implementation, monitoring, and information awareness requirements differ among the instruments and their effectiveness strongly depends on these variables too.

For this paper, I want to analyze water tariff systems throughout the MENA. The region has the lowest water tariffs in the world, subsidizes water consumption (about 2% of GDP) and has total water productivity of only half the world average (World Bank 2018). Supports for wheat production is considerable in Egypt or Morocco. Also, many governments maintain consumer prices for selected food products at artificially low levels, subsidizing consumers. All these different mechanisms, contribute to raising the need for water in agriculture. The public water providers are not the only one supplying water in the region, in many cases, farmers have their facilities to abstract water from surface and groundwater resources. In these cases, not only the monitoring appears difficult, but also the charging mechanisms are challenging and ineffective.

In general, the main difficulties in the water sector in this region exist because of the difference between the private and social price of water. In the first case, water is considered a free commodity, which leads to weak cost recovery and high subsidizes, in the second case, the social price should reflect the opportunity cost for using the water resources for the best alternative, and the price of water coincides with its marginal value. The social price is never charged fully and for the case of water, no water markets exist other than few cases such as Mexico, Pakistan or California. Except for a few countries, the region is not extremely receptive and proactive in policy implementation reducing the gap between these two prices. The tariff regimes of water for irrigation differ between and within sectors, and most of the time there is a fixed and a variable component. The price is usually measured in cubic meters and expressed in local currency. The countries in the Maghreb are the most responsive in terms of policy implementation for water efficiency. In Algeria, since its independence, there have been cyclic policy reforms to address the challenges of water scarcity in the agricultural sector. They have developed in 3 stages: 1962—1980, 1980-1999 and 2000-today, and it is possible to see the progress incurred both at institutional, management and water-pricing levels (Laoubi & Yamao 2011). The current water tariffs for agriculture are stipulated by Law No. 05-12 of August 2005 and are based on the type of user, tariff zone, the volume of water provided and the nature and quality of the water (Kelkouli et al. 2011). Morocco and Tunisia are also quite advanced and a lot of efforts are being made to bring tariffs into line with European values. Still, government support is quite strong in both cases and tariff recovery is not uniform across the country. This shows that water pricing reforms alone are less effective than combined with other instruments and developments to be done at the institutional level. The other two countries in North Africa, Egypt, and Libya do not apply any charge to water for irrigation, even if in the first case, agriculture is the most developed activity, while in the second case, the lack of surface water resources forces the use of renewable and non-renewable groundwater to meet the agricultural water requirements, causing overexploitation.

In the Middle East area, all the countries impose water charges, but except for Lebanon and Israel, they are very low, which is quite a problem for Iran that exploits a lot of its transboundary water resources for food production. Lastly, in the countries of the GCC water regulations for the agricultural sector are far behind. This is mainly because such a sector is less developed, and there is a lack of suitable land and an extremely harsh climate. Nonetheless, domestic food production has grown in the past decades answering for the quest for food self-sufficiency and the over-abstraction of groundwater for agriculture has reached unprecedented levels. The emblematic case is Saudi Arabia, which expanded its agricultural development between the 1980s and the 1990s at the detriment of its groundwater resources and even the new agricultural policy introduced in 2008, despite the reduction in water use for irrigation, does not support the sustainable utilization of groundwater resources (Ouda 2014). Still, Bahrain, Saudi Arabia, and Oman do not apply any form of charge for water used in irrigation. Qatar and Kuwait have instead water tariff imposed by their Water Agencies and Ministries, while in UAE, the farmers pay for the boreholes drilling and groundwater pumping. In Yemen, the groundwater depletion is reaching alarming rates and water charges are indeed very low for encouraging proper water management. Table 4.1 provides water prices employed for irrigation in agriculture for each of the country comprised in this study with the most updated data as possible. The range of prices is quite broad, spanning from countries providing water for free, to countries open to pricing reforms and re-align the prices for irrigation. The conversion rates correspond to the conversion rates of the price-year.

Table 4.1. Water price

Country	**Price USD/m^3 or USD/ha**			**Year**	**Notes**	**Source**
	Area	Volumetric (USD/m^3)	Fixed (USD/s/ha)			
Algeria	Sig	0.02	3.47	2005		(Kelkouli et al. 2011)
	Habra	0.02	3.47			
	Mined	0.01	3.47			
	Low Chelif	0.01	3.47			
	Chelif Medium	0.013	3.47			
	High Celif	0.021	5.56			
	Western Mitidja	0.01	5.56			
	Hamiz	0.021	5.56			
	Saf Saf	0.01	5.56			
	Bou Namoussa	0.02	5.56			
	Other areas	0.01	3.47			
Bahrain	No charges			1990	An incremental tariff structure for charging for groundwater use in agricultural, industrial, and tourism sectors has also been proposed but is yet to be implemented Privately-owned water use rights Scattered policies, not integrated	(Al-Noaimi 2005; FAO-AQUASTAT 2008a)
Egypt	No charges			1996		(Perry 1996)
Iran	Rates vary per ha, crop type and irrigation method. Overall, they range from 0.068 USD/ha for the date with the traditional irrigation system to the 660 USD/ha for sweet melons with a modern irrigation system.			2019	Irrigation water is charged per ha, per type of irrigation system and type of product. In the case of a different product being irrigated in the land, the following rule is applied: - Total water rate = 3% of the total	(BSRW 2019; IRCSA 2019; KBRW 2019; QZRW 2019)

<table>
<tr><td></td><td colspan="3"></td><td></td><td>product (for modern irrigation systems)
- Total water rate = 2% of the total product (for semi-modern irrigation systems)
- Total water rate = 1% of the total product (for traditional irrigation systems)
The rates of the products are set by the government</td><td></td></tr>
<tr><td>Iraq</td><td colspan="3">0.08 USD/m^3 (average)</td><td>2018</td><td>Irrigation water pricing varies accordingly to irrigation methods and O&M.</td><td>(Al-Rubaye 2019)</td></tr>
<tr><td>Israel</td><td colspan="3">0.79 USD/m^3</td><td>2016</td><td>- No different quantities, without VAT;
- Potable water for agriculture only</td><td>(Water Authority 2019)</td></tr>
<tr><td rowspan="5">Jordan</td><td>Segment</td><td>2011</td><td>2017</td><td rowspan="5">2017</td><td rowspan="5">Jordan Valley Authority started to increase the prices progressively since 2014</td><td rowspan="5">(Van den Berg et al. 2016; The Jordan Times 2014)</td></tr>
<tr><td><2500 m^3/month</td><td>0.02</td><td>0.10</td></tr>
<tr><td>2,500-3,500 m^3/month</td><td>0.04</td><td>0.13</td></tr>
<tr><td>3,500-4,500 m^3/month</td><td>0.05</td><td>0.14</td></tr>
<tr><td>>4,500 m^3/month</td><td>0.09</td><td>0.17</td></tr>
<tr><td>Kuwait</td><td colspan="3">8.22 USD/1,000 imperial gallons (4.54m^3)</td><td>2017</td><td>Ministry of Water and Electricity Law No. 20/2016, enter into force 22 May 2017</td><td>(Arab Times Kuwait 2016; Kuwait up to Date 2016)</td></tr>
<tr><td rowspan="2">Lebanon</td><td>Volumetric Charges</td><td colspan="2">Area Charges</td><td rowspan="2">2010</td><td rowspan="2">Law No. 221/2000</td><td rowspan="2">(Ministry of Energy and Water 2010)</td></tr>
<tr><td>0.10-0.15 USD/m^3 used in case of pressurized networks, where hydrants are equipped with water meters</td><td colspan="2">140 – 650 USD/ha/yr. based on area irrigated</td></tr>
<tr><td>Libya</td><td colspan="3">No charges</td><td>2014</td><td>At present, farmers are only charged the cost of energy used</td><td>(CEDARE 2014)</td></tr>
</table>

				for the production of water, and that energy is also subsidized. Private uses for all purposes from wells are not subject to tariffs.	
Morocco	0.20 USD/m^3 in Meknes to 0.44 in El Jadid on average for the big perimeters.		2002	Cost recovery not always efficient.	(Tenneson & Rojate 2003)
Oman	No charges for water use. Water lease prices observed in the aflaj vary considerably. On average the water price varies from 0.02-0.142 USD/m^3		2009	Most of the groundwater is used for agriculture and although water is considered to be national wealth, farmers do not pay any fee or rent for the water they use. They do pay for the electricity for pumping; to which most farmers now have access. The average cost of pumping from a 21m deep well is US$0.05/CM.	(FAO 2009)
Palestine	Jordan Valley	0.03-0.19 USD/m^3	2006		(Abu-Madi 2009)
	Jenin	0.15-0.21 USD/m^3			
	Tulkarm	0.25-0.34 USD/m^3			
	Gaza Strip	0.12-0.14 USD/m^3			
Qatar	1.43 USD/m^3 for productive farms		2019	Subsidies by the government both for water and electricity in the agricultural sector: seeds, fertilizers, and fodder bought from the Ministry of Agriculture have a 25% discount and water and electricity at a 50% discount. Subsides also include consultation, pest	(Kahramaa Qatar General Electricity and Water Corporation 2019)

			treatment and access to markets.	
Saudi Arabia	No charges	2000		(Ahmad 2000)
Syria	- Fixed at 70 USD/ha irrespective of the crop type; - Variable from 40 USD/ha - 140 USD/ha/yr for beneficiaries of public irrigation systems - A flat fee of O&M 70 USD/ha for permanent irrigation and 12 USD/ha winter irrigation	2008	Fees determined by Decision no. 5 of 21/11/199	(FAO-AQUASTAT 2008b)
Tunisia	0.05 USD/m^3 for public irrigation	2015	Since introduction of the structural adjustment program (SAP) in 1986.	(Chemingui & Thabet 2016)
UAE	No charges	2008	There are no irrigation water charges levied by the government, but the farmers pay for the drilling of boreholes on their farms and the pumping of groundwater.	(FAO-AQUASTAT 2008c)
Yemen	0.02-1.45 USD/m^3	1998	Price in water markets	(Ahmad 1998, 2000)

4.3. Theoretical Framework

As outlined in previous sections, water behaves differently from other resource commodities, which makes it difficult to implement efficient water management policies. Water is also fluid by its nature making it difficult to estimate its quantity and to calculate future projections on its availability. Furthermore, water does not follow political borders, which adds further challenges in the inter/intra-sectoral allocation, especially in the case of a basin shared by several countries as in the MENA region. Water is often defined as a high exclusion cost resource since its property rights are complex to define if nonexistent at all. Water used for agriculture and industrial or municipal services also tend to be rival. The fact that water is considered as an economic good is mostly due to the recognition of its scarcity, which would then require the compromise of its optimal allocation. If water is scarce, its shadow price corresponds to the amount by which one additional unit of water (e.g. 1 cubic meter) will increase its economic value as a natural resource.

Governmental policies for water management that use economic instruments such as water pricing have mainly two scopes, in particular in the agricultural sector: cost recovery by the provider or water conservation to avoid over-abstraction (or better to encourage more efficient use of the resource). The effectiveness of these instruments depends on many factors, among which the on-farm profitability and profit are determined, for the major part, by the crop-water production function. In this section, I describe how to derive the shadow price for irrigation water by studying its marginal contribution to the national agricultural production function in the MENA region.

Shadow prices are primarily theoretical values, estimation of which can be useful when market prices do not exist or do not reflect the true value of the products. There are several approaches for identifying and estimating measures related to shadow prices in the productivity literature. These approaches differ in their objective functions, nature of inputs and outputs, and methods of identification. Economic analysis of the crop-estimated relationships has been developed since the 1970s and regression analysis is used to estimate the coefficient of the variables of the production functions, which are then used in the calculation of the shadow price. Production (in weight) is estimated as a function of water used for irrigation and a set of non-water inputs. The Marginal Value Product (MVP) of water is determined by estimating the production function and taking the partial derivative concerning the irrigation water use. Subsequently, the shadow price is calculated by multiplying the MVP by the crop output price. In this paper, I use a Cobb-Douglas production function approach to determine the marginal value of all the production input of the food-chain system.

The general production function used to model crop production is a function of agricultural land, marketable inputs, such as labor, capital and materials, and water input, as:

$$Y = f(A, L, X, W, e) \tag{1}$$

Where:

Y = Crop Production (kg)
A = Agricultural Land (ha)
L = Labor (employment in the agricultural sector – thousand)
X = vector of marketable inputs: Capital (USD) and Fertilizer (kg)
W = Water used for Irrigation (m^3)
e = stochastic disturbance

The description of the data source and elaboration is reported more in detail in Section 4.4. The resulting Cobb-Douglas production function can be summarized with the following equation:

$$Y = \beta_0 \, A^{\beta_1} L^{\beta_2} C^{\beta_3} F^{\beta_4} W^{\beta_5} e \tag{2}$$

The Cobb-Douglas production function assumes that all inputs are substitutes and that the elasticity of substitution between inputs equals one. The major advantage of the Cobb-Douglas is that although the function is nonlinear, it can be easily transformed into a linear function by taking the logarithm of both sides of the equation. The unknown coefficients (β) of the function can be estimated by OLS regression. In the logarithmic form, the function results as:

$$lnY = \ln \beta_0 + \beta_1 \ln A + \beta_2 \ln L + \beta_3 \ln C + \beta_4 \ln F + \beta_5 \ln W + e \tag{3}$$

The marginal value product of water for irrigation is then derived by taking the partial derivative of the crop production with respect to water input for irrigation:

$$MVP_W = \frac{\partial Y}{\partial W} = \beta_5 \frac{Y}{W} \tag{4}$$

Finally, the MVP_W is multiplied by the crop output price to get the shadow price:

$$P_{shadow=} MVP_W \times P_{output\ crop} \tag{5}$$

The shadow price depends on the marginal productivity of the water and in the perfect case, the price for water for irrigation paid by the farmers should be equal to the shadow price. If farmers face prices lower than the shadow price, they are not paying the fair price and eventually using water in a non-efficient manner.

4.4. Data and Descriptive Statistics

To estimate the regression outlined in Section 4.5, I use data from several sources. The data are retrieved from the FAOSTAT database (FAO 2019), which provides data on crop production and harvested area for every single crop, while data on labor, capital and fertilizer are provided in aggregate. I identify 13 major crop-categories: of which the ten are defined by FAOSTAT, in addition to three more that I have created for this purpose: ‘Coffee and Tea’, ‘Other Crops’ and ‘Spices’ (more details on the different crop and related categories are reported in Table B.1 of Appendix B). The countries selected for this study are 19, all part of the MENA region, namely: Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Tunisia, United Araba Emirates, and Yemen. The regression covers the period 1991-2016, which is the longest time time-horizon for which there are observations for every country and variable. Lastly, to calculate the shadow price, I need the information on the crop price for each crop type. For the countries, such as UAE, where I do not have complete information on the prices of each product, to fill in the gaps, I use the average annual price calculated across the MENA region for that specific crop. Given this, if I would compute the annual price of each category for each country as the average of the crops' price within the category, I could risk underestimating the value of some of the important crops. For example, while the price of fruit in general across the MENA region is quite low, dates, which are the most produced fruit crop for many of the gulf countries can reach very high values. By calculating the average across the whole category I would underestimate the added value that dates bring to these countries. To overcome this issue, I instead retrieve the overall value of production for each crop, country and year, by multiplying the production quantities for their respective price. I then aggregate the variables (both the value and the production) by crop category and I then finally compute a more reliable value per quantity (i.e. price) for each category.

The most challenging variable to retrieve is the irrigation water requirements, which depend on many variables, such as crop calendar, evapotranspiration, precipitation, and other physical variables. For its calculation, I estimate the historical annual water requirement for each country and crop category as the supplementary amount of water that the farmer needs to provide to their crops during the year to offset the residual water requirements that the precipitation alone cannot fulfill. I first start computing the overall annual water requirement to grow all the different crops of a country. The overall amount of water that a plant needs during its development is proportional to the value of reference evapotranspiration (ET_0), specific of the considered location and time of the year, by a factor that depends on the type of crop and its growth stage. I use the historical Climatic Research Unit (CRU) (Harris et al., 2014) data of the average daily reference evapotranspiration measured from 1901 to 2015 and downscaled to the country-level for each month of the year, as a starting point. I then calculate the overall monthly total evapotranspiration, by multiplying the monthly average ET_0 for the number of days of each month. I then need to know what crops each country is producing each month of the year and how much-irrigated land is used with these plants. The FAO AQUASTAT database provides for each country the most updated crop calendar including information on physical irrigation areas, harvested irrigated crop areas as well as the percentage of the irrigated area occupied by crop each month (Frenken & Gillet 2012). Unfortunately, these crop calendars are prepared for a specific year for which data are available and do not cover all the actual crops that a country produces or that may have produced during a specific past period. For this reason, I use data on the annual crop production and the annual harvested land from FAOSTAT to draw a more complete picture of the farmed land proportion across the different crop categories for each country for all the different years. Furthermore, I use the data on land area equipped for irrigation (AEI) (originally from FAOSTAT, but retrieved from the UNdata (UNdata 2019) as a proxy of the variable "land area equipped for irrigation actually irrigated" (AAI). I use the very few observations from AQUASTAT to calculate the ratio between AAI and AEI, and I assume that this proportion is kept almost constant for the years for which AAI is missing. This procedure allows me to obtain a reliable approximation on the amount of AAI that each country uses in the period 1990-2016, and a better estimate of how the annual national calendar is organized for each crop category. I thus obtain a complete information for all the considered countries on how much irrigated land is used with a particular crop category for each month and each year of my simulation space. Furthermore, the calendar gives me information on the specific growing phase that each crop undergoes, at which I link the corresponding crop-specific coefficient (K_c), retrieved from Frenken and Gillet, (2012). The calculated category-specific coefficient is calculated as the average K_c of the single crops belonging to the same category. By combining this information, with the data on historical monthly average precipitation from the CRU dataset, I can then calculate the monthly additional water requirement to grow each type of crop over its corresponding irrigated area, for each country and year. The final step is to aggregate together this information at a yearly level, thus obtaining the annual water requirement for all the countries of the MENA region in the period 1990-2016. To validate this result, I compare it with the few observations (one for each of the MENA countries) from the AQUASTAT database on the irrigation water requirements. This variable estimates the quantity of water exclusive of precipitation and soil moisture required for normal crop production. Although this variable differs in its estimation approach and definition, it should still provide a good degree of analogy, at least for comparing its order of magnitude with my estimation. The final results validated against the water requirements for irrigation as calculated by the FAO AQUASTAT database are shown in Figure 4.3. The value of R^2 at 86% indicates that this process has provided a fair approximation of the unknown variables. The resulting panel dataset (production, area, labor, capital, fertilizers, and water for irrigation), per year, country and type of crop will provide the parameters to calculate the shadow price per crop-category and per country. Table 4.2 below provides the descriptive statistics of my final dataset.

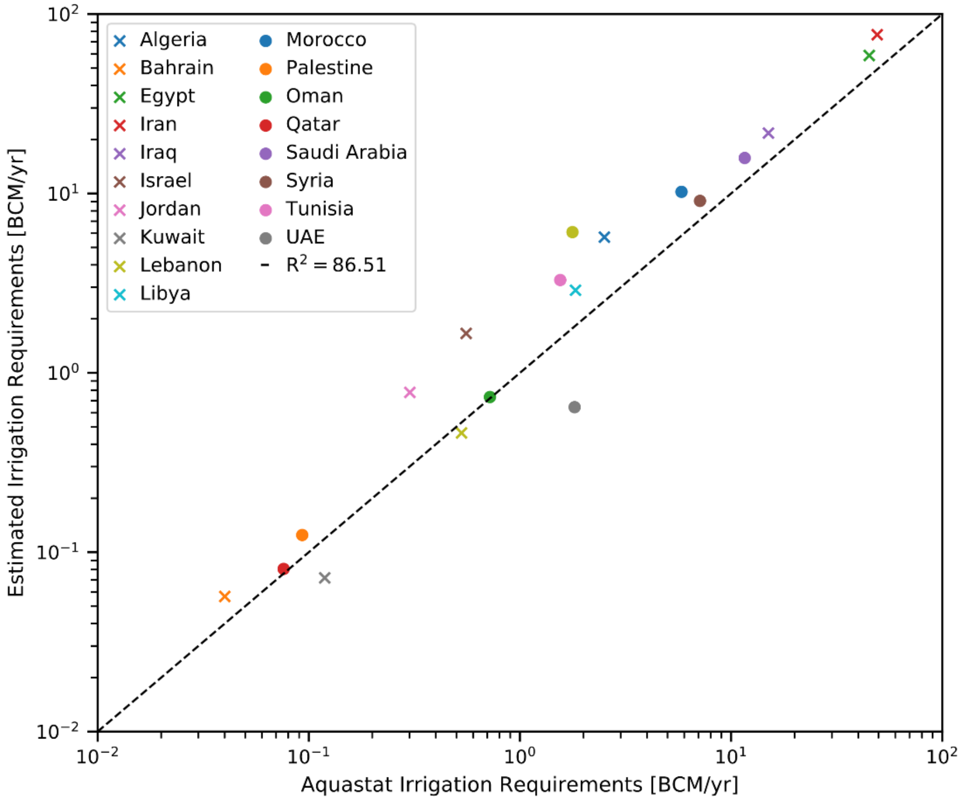

Figure 4.3. Validation Exercise

Table 4.2. Summary Statistics

Variables	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
Year	4831			1991	2017
Production (kg)	4,831	1.19e+09	3.17e+09	1000	2.79e+10
Area (ha)	4,831	2.47e+09	8.78e+09	0	9.81e+10
Labor (agriculture)	4,831	1353768	1773693	3000	7116000
Capital (USD)	3,963	5.76e+08	7.68e+08	3791259	4.83e+09
Fertilizer (kg)	4,584	5.59e+08	1.13e+09	0	7.30e+09
Irrigation Water (m^3)	4,387	1.25e+09	5.79e+09	0	7.07e+10

4.5. Results

The data presented in Section 4.4 are used to estimate the parameters of the production function as per Equation (3). The final panel dataset covers 19 countries and 12 crop-categories for the period 1991-2016. Even if the category "spices" was initially included in the dataset, there are no water irrigation data available for this specific crop type, therefore it was discarded from the final estimation. The resulting panel data is not balanced, since the input data are not available for all years, but the number of observations is still reasonably high to allow a consistent estimate of my parameters.

The final production function from which we derive our elasticities takes then the following form:

$$lnY_{it} = \beta_0 + \beta_1 \ln A_{it} + \beta_2 \ln L_{it} + \beta_3 \ln C_{it} + \beta_4 \ln F_{it} + \beta_5 \ln W_{it} + e \tag{6}$$

Where:

i = 1,…, 19 is the country index and t = 1,…, 25 is the specific annual step (1991-2016)

Y_{it} = Agricultural Production (kg)

A_{it} = Agricultural Land (ha)

L_{it} = Labor

C_{it} = Capital (USD)

F_{it} = Fertilizer (kg)

W_{it} = Water for Irrigation m^3

I first test for the simple OLS estimation, for which the results are presented in Table 4.3. Still, given the fact that I have differences that are correlated to the specific crop type and country, I use the fixed-effect estimation, which can account for country-variations. The results of this approach are presented in Table 4.4 where the estimated values of all the elasticities are higher and more variables result statistically significant. The country-fixed effects can be interpreted as the production differences between countries that are attributable to factors not included in the production function, such as the GDP of the different countries, their development in terms of agricultural techniques and efficiency or potential investments in the agricultural sector. The parameter estimates for the OLS with FE exhibit statistical significance for the following category: 'Cereals', 'Fruit Primary', 'Other Crops', 'Roots and Tubers' and 'Vegetable Primary'. For the other crop types, elasticities are positive, but not statistically significant except for 'Fibre Crops', which has a negative coefficient. The negative coefficient would lead to a negative shadow price, which would imply that for each additional m^3 of water used for irrigation, the added production would decrease. This means that the current production of this crop would seem to be un-optimal and that farmers increase their profit by using less water. This result is derived more likely by an erroneous estimation of the model for the fiber crops, which are quite high-water demanding crops. Therefore, for this category, I have not calculated its shadow price. In general, all the water inputs are relatively inelastic (their absolute values are lower than 1), which should imply that the production is not very sensitive to changes in the water input. Still, this verifies also for categories that are quite high in water consumption, such as ‘Coffee and Tea’, ‘Fruit’ and ‘Sugarcrops’. It is plausible that these relatively low values strongly depend on the combination of relatively low observations and on the method of the calculation of the water requirement for irrigation, which is not derived through the use of a physical model. Based on the parameter estimates, the shadow price is then calculated for each crop type and country for the period 1991-2016, combining the elasticities from Equation (6) following the formula in Equation (5).

Table 4.5 shows the shadow prices per country and crop type on average for the period 2011-2016. Countries in North Africa, namely Algeria, Egypt, Libya, Morocco, and Tunisia, which are also the more developed in the agricultural sector, exhibit comparable water prices for the majority of their crops, but especially for cereals, oil crops, other crops, pulses, and tree nuts. Sugar crops are produced only in Morocco and Tunisia and their price is comparable. The highest shadow prices are observed for the fruit category and ranges from 0.8 in Egypt USD/m^3 to over 6 USD/m^3 in Morocco. Egypt is also the country that exhibits less variability among prices. Looking at the GCC countries and Yemen, the shadow prices of water for irrigation are more consistent and have lesser variability, other than for the fruit category. In the Gulf, the portfolio of crop production is much low than in North Africa, given the harsh climate and land constraints. Lastly, in the Middle East and Iran, the prices are quite homogeneous other than for fruit crops, roots and tubers, and tree nuts.

Table 4.3. OLS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Dep Variable Crop Prod. (kg)	*Cereals*	*Citrus Fruit*	*Coffee Tea*	*Fibre Crops*	*Fruit*	*Oilcrops*	*Other Crops*	*Pulses*	*Roots Tubers*	*Sugarcrops*	*Treenuts*	*Vegetables*
Agri Land (ha)	0.556***	1.071***	1.755*	1.292***	0.611***	0.667***	0.920***	0.583***	0.876***	1.071***	0.728***	0.948***
	(0.09)	*(0.09)*	*(0.22)*	*(0.04)*	*(0.10)*	*(0.14)*	*(0.14)*	*(0.08)*	*(0.03)*	*(0.03)*	*(0.10)*	*(0.09)*
Labor	0.144	-0.076	0.194	-0.360***	0.090	-0.013	0.270*	0.178**	-0.156***	-0.463	-0.188*	-0.163**
	(0.09)	*(0.12)*	*(0.35)*	*(0.03)*	(0.09)	*(0.09)*	*(0.15)*	*(0.08)*	*(0.03)*	*(0.30)*	*(0.10)*	*(0.06)*
Capital (USD)	0.106*	0.148*	-0.267	-0.058	0.056	0.028	0.021	0.100**	0.038	0.173*	-0.005	0.114**
	(0.06)	*(0.08)*	*(0.27)*	*(0.06)*	*(0.06)*	*(0.08)*	*(0.16)*	*(0.04)*	*(0.03)*	*(0.08)*	*(0.08)*	*(0.05)*
Fertilizer (kg)	0.129	0.023	0.516	0.054	0.119**	0.140**	-0.185**	-0.011	0.014	-0.052	0.355***	0.086*
	(0.09)	*(0.06)*	*(0.16)*	*(0.06)*	*(0.05)*	*(0.05)*	*(0.08)*	*(0.04)*	*(0.03)*	*(0.08)*	*(0.10)*	*(0.05)*
Water Irr (m^3)	0.145	-0.088	0.956**	0.027	0.119	0.327**	-0.236	0.092*	0.280***	0.200	0.036	0.019
	(0.11)	*(0.09)*	*(0.07)*	*(0.02)*	*(0.08)*	*(0.15)*	*(0.18)*	*(0.05)*	*(0.05)*	*(0.18)*	*(0.11)*	*(0.07)*
Observations	365	385	44	190	387	297	274	300	386	152	280	387
R^2	0.966	0.963	0.938	0.989	0.961	0.969	0.894	0.923	0.994	0.981	0.934	0.955
Adjusted R^2	0.966	0.963	0.929	0.988	0.961	0.968	0.892	0.922	0.994	0.980	0.933	0.954

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4.4. OLS FE

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Dep Variable Agri Prod. (kg)	*Cereals*	*Citrus Fruit*	*Coffee Tea*	*Fibre Crops*	*Fruit*	*Oilcrops*	*Other Crops*	*Pulses*	*Roots Tubers*	*Sugarcrops*	*Treenuts*	*Vegetables*
Agri Land (ha)	0.907***	0.912***	1.052	0.897***	0.401**	0.864***	0.881***	0.674***	0.900***	0.989***	0.497***	1.041***
	(0.07)	*(0.08)*	*(0.73)*	*(0.05)*	*(0.14)*	*(0.10)*	*(0.06)*	*(0.12)*	*(0.05)*	*(0.04)*	*(0.14)*	*(0.17)*
Labor	0.200**	-0.319**	-1.059	0.072	0.013	0.235	-0.043	-0.405	0.021	-0.314	0.193	-0.017
	(0.08)	*(0.14)*	*(0.50)*	*(0.22)*	*(0.06)*	*(0.21)*	*(0.07)*	*(0.64)*	*(0.06)*	*(0.19)*	*(0.23)*	*(0.09)*
Capital (USD)	0.155***	-0.111	-0.370	-0.073	-0.004	0.081	0.029	0.073	0.063*	-0.088*	0.077	0.058*
	(0.05)	*(0.08)*	*(0.43)*	*(0.08)*	*(0.05)*	*(0.05)*	*(0.05)*	*(0.09)*	*(0.03)*	*(0.05)*	*(0.07)*	*(0.03)*
Fertilizer (kg)	0.004	0.055	0.161	-0.113*	0.044*	0.061	0.072	-0.018	0.018	-0.009	0.040	0.043**
	(0.02)	*(0.04)*	*(0.09)*	*(0.05)*	*(0.02)*	*(0.04)*	*(0.06)*	*(0.03)*	*(0.01)*	*(0.04)*	*(0.05)*	*(0.02)*
Water Irr (m^3)	0.266**	0.102	0.607	-0.061	0.802**	0.226	0.210*	0.415	0.305**	0.588	0.085	0.226***
	(0.09)	*(0.09)*	*(0.29)*	*(0.04)*	*(0.31)*	*(0.27)*	*(0.10)*	*(0.40)*	*(0.11)*	*(0.35)*	*(0.06)*	*(0.07)*
Observations	365	385	44	190	387	297	274	300	386	152	280	387
R^2	0.992	0.993	0.975	0.995	0.990	0.990	0.991	0.936	0.998	0.997	0.987	0.992
Adjusted R^2	0.992	0.992	0.971	0.995	0.989	0.990	0.991	0.932	0.998	0.997	0.986	0.992

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4.5. Shadow Prices

Country	*Cereals*	*Citrus Fruit*	*Coffee and Tea*	*Fruit Primary*	*Oilcrops*	*Other crops*	*Pulses*	*Roots and Tubers*	*Sugarcrops*	*Treenuts*	*Vegetables*
Algeria	0.060	0.859		2.963	0.140	0.513	0.279	1.550		0.434	1.375
Bahrain		0.079		0.546			0.569	0.126		0.130	0.290
Egypt	0.047	0.313		0.806	0.054		0.062	0.330	0.291	0.621	0.134
Iran	0.032	0.456	0.167	1.757	0.147	0.152	0.057	0.506	0.302	0.435	0.942
Iraq	0.039	0.112		1.927	0.099	0.034	0.041	1.151	0.225	0.287	0.383
Israel	0.069	0.394		5.071	0.321	0.001	0.276	2.402		7.168	1.237
Jordan	0.042	1.147		2.053	0.097	0.001	0.004	1.180		1.401	0.562
Kuwait	0.400	0.267		5.866	0.089			0.352			0.534
Lebanon	0.103	5.945		3.092	0.267	0.877	0.151	1.518	0.378		1.356
Libya	0.028	0.787		1.981	0.074	0.513	0.058	1.181		0.129	0.464
Morocco	0.070	1.642		6.418	0.151	0.157	0.243	1.480	2.809	0.499	1.608
Oman	0.031	0.047		0.873		0.287		0.189	0.631		0.122
Palestine	0.192	0.901		6.505	0.448	0.766	0.227	4.318		4.037	4.775
Qatar	0.012	0.015		3.009				0.047			0.083
Saudi Arabia	0.011	0.158		1.195	0.145		0.273	1.805			0.480
Syria	0.063	2.804		2.226	0.280	0.346	0.319	2.322	2.529	5.171	2.752
Tunisia	0.095	3.232		4.715	0.058	0.117	0.547	2.325	2.206	0.105	1.535
UAE	0.080	0.085		1.522		0.358		0.258		0.194	0.149
Yemen	0.027	1.986	0.843	4.200	0.255	0.298	0.244	1.784		0.177	0.591

Comparison between all the countries can be made by looking at Figure 4.4, where water shadow prices are presented as an average for the period 2011-2016 for all the considered countries accordingly to the crop variety. Cereals have the lowest water prices even if they are the category that requires the highest water requirements, followed by pulses and oil crops. Conversely, the “Coffee and Tea” category has the highest water prices, similar to fruit, vegetables and tree nuts, which are considered cash crops i.e. have a higher market value.

Figure 4.5 presents the shadow prices per country, averaged per all the crop types produced in every country considered. The black dot represents the average of the effective water tariff, while the grey area represents the range of water tariffs as reported in Table 4.1 in Section 4.2.1. On the horizontal axes are reported all the MENA countries (19). The countries with a star (*) sign are the ones for which no water tariffs are currently implemented, namely Bahrain, Egypt, Libya, Saudi Arabia, United Arab Emirates. The countries marked with the dot sign (°) instead have current water charges expressed in USD per area, so cannot be used for comparison purposes as I had calculated the shadow prices as volumetric charge (USD/m^3). From these results, it appears Palestine, Lebanon, Morocco, Tunisia, Algeria, Jordan, Iraq, and Oman have current water tariffs which are below the average of the shadow price of water, even if in some cases, current charges are at least in the ranges of the modeled prices. Differently, Israel, Yemen Kuwait, and Qatar have current water tariffs above average shadow prices. Still, while this can be true for Israel, for what concern Yemen, water tariff data are very old (1998), and the current political situation and war have certainly worsened the water management. If we consider instead Kuwait and Qatar, such high water tariffs, in reality, are often waived or levied through subsidies to farmers and therefore not applied.

Overall, despite the difficulties in comparing different crops and different countries, my preliminary results indicate that there exists a margin of improvement in water management issues through the use of rates.

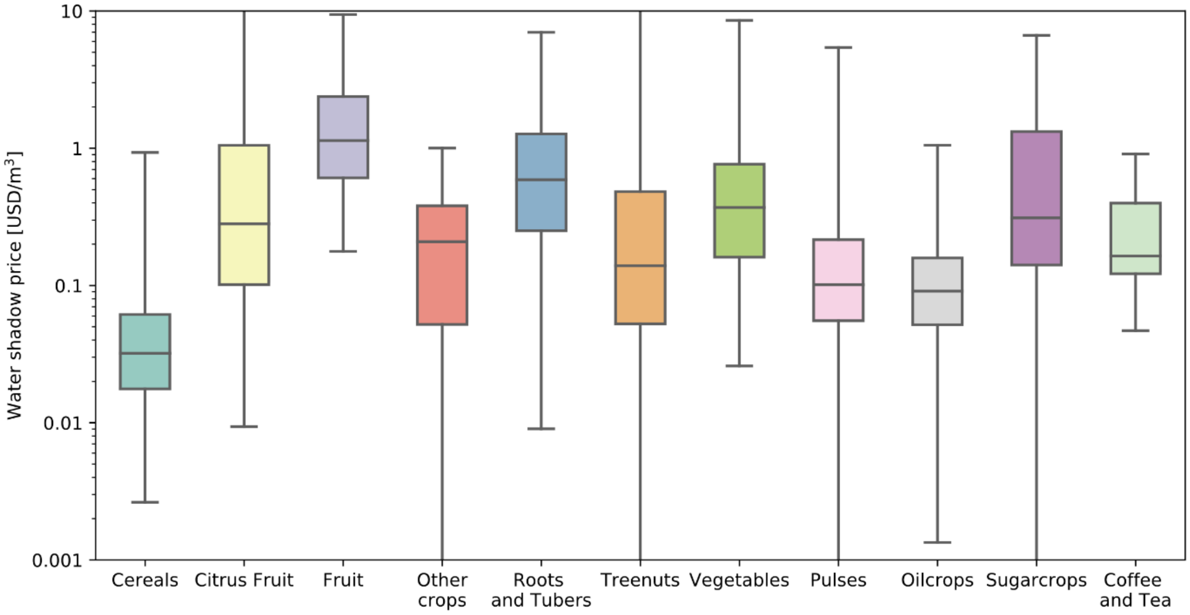

Figure 4.4. Water Shadow Price per Category, calculated as an average of the different countries.

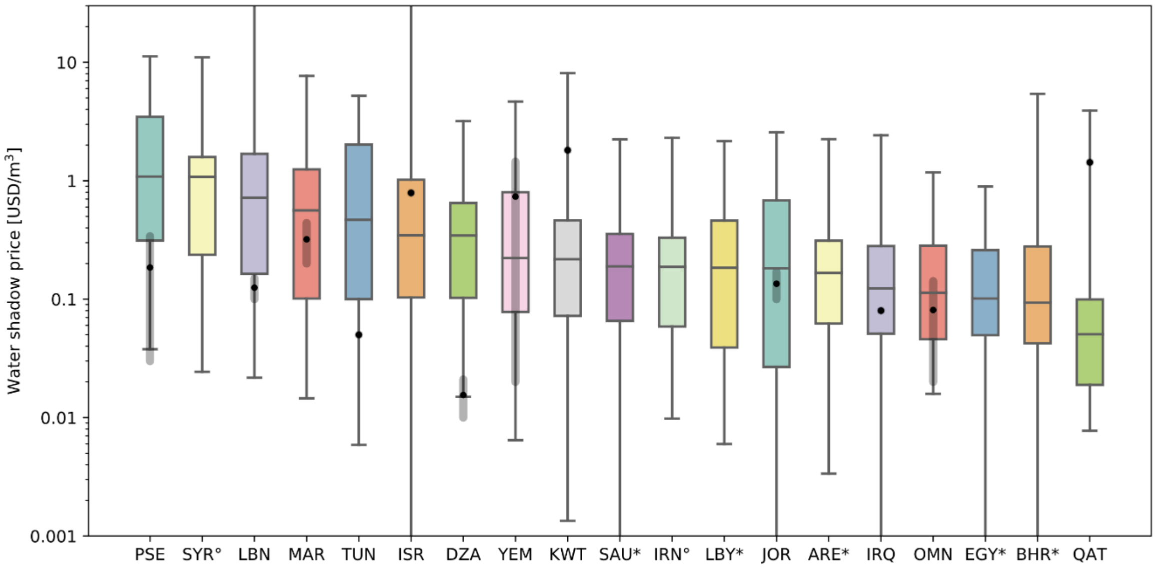

Figure 4.5. Water Shadow Price for Country, calculated as the average of different crops. Black dots indicate average current water tariffs, and grey area the entire range from min to max. *: no charges applied; ° indicates that area charges are applied.

4.6. Discussions and Conclusions

In this study, I estimate the shadow prices for irrigation water requirements for 12 crop categories in the 19 main countries of the MENA region. The shadow price in this paper is calculated as the marginal value product created by the water used for irrigation. As such, it becomes an indicator of the efficient use of irrigation water and allows for countries and crop comparison. My results exhibit a lot of heterogeneity both in terms of crop types and countries, confirming the fact that exists a lot of margin of improvements for water allocation efficiency in all of the countries in the MENA region. Furthermore, the estimated shadow prices are much higher if compared to the existing water tariffs, confirming the fact that such charges are extremely low and contribute to the current depletion of their scarce water resource. In my analysis, to calculate the water requirement for each crop category, I have employed a model based loosely on the FAO AQUASTAT methodology, which still provides a reasonably close estimation if validated against the estimated water withdrawal provided by AQUASTAT.

The estimation of the marginal product value is based on a Cobb-Douglas production function, which is one of the main approaches used in the literature. Still, when considering improvements and extension of my approach, multiple options are available. First, the possibility of using data for the water requirement using a physical model, would probably further improve my estimation. Furthermore, it would probably allow for differentiating the water resources employ in for irrigation by their sources i.e. surface, groundwater, and non-renewable groundwater, to provide results by which infer even more on water allocation efficiency between sector. A physical model would also be able to better take into account the crop-related characteristic, potentially generate estimates much closer to the actual behavior of crops.

Besides, more tests such as stationarity and co-integration should be run for the panel dataset, to verify its strength for the OLS estimations. Lastly, expanding the framework of analysis I could also add consideration on intertemporal efficiency or scenario analyses, which results could provide further guidelines in terms of the actual water price to set up and the potential water savings induced by its introduction.

Despite the need for further improvements, this study represents an addition to the existing literature for two main reasons: first, it provides a very comprehensive review of all the existing water tariffs in the MENA region, as updated as possible. This is extremely useful when elaborating policy-oriented studies, which need to be based on actual information, and inference on outdated information is then not reliable and credible. Second, it is the first study that estimates the economic value of water resources for all the countries in the MENA region and such a variety of crops. Such coverage is extremely helpful if one wants to add further consideration on water allocation efficiency between riparian countries and potentially introduce the evaluation of virtual water markets.

CHAPTER 5

CONCLUSIONS

The main objective of this dissertation was to provide a comprehensive analysis of water and food security issues in the Middle East and North Africa region, evaluating several aspects of this subject to provide new perspectives and insights on water resources management and food security issues, which take into account of the current and future climatic, anthropogenic and geopolitical challenges of the area. To achieve the above-mentioned objective, I elaborated three sub-objectives, presented as follow:

RO1: Reduce uncertainties in the socio-hydrologic systems associated with the water budget in the MENA region and provide a framework for decision making.

RO2: Understand the economic and environmental implications of exogenous shocks on rentier states and evaluate the sustainability of their food security strategies in the context of water scarcity.

RO3: Explore the potential for tackling water resources overexploitation in the agricultural sector in the Middle East and North Africa through economic instruments.

In this last chapter, I briefly discuss the main results and contributions of this research and provide recommendations and outlook for further expansion of the study in the future. Since each chapter can be considered as an individual paper, I proceed to outline main contributions, results, and recommendations for each essay.

5.1. Main Contributions and Results

In the first paper, I wanted to quantify the current and future water depletion in the MENA region, considering not just the physical but also the socio-economic variables to better understand the magnitude of the phenomenon and provide the basis for policy analysis. In doing so, I have developed a water budget model, which combines country-level demographic, macroeconomic, water supply and demand data to quantify the water deficit volumes per each country and the groundwater depletion rates for the main aquifer system in North Africa and Arabian Peninsula form 2016 to 2050. My study confirms that future projections of the water budget and groundwater depletion will be mostly due to anthropogenic drivers rather than climate change. Water shortages in Egypt and Libya will reach 192% and 62%, respectively under the SSP2-AVG scenario, followed by the Arabian Peninsula, where all the countries will experience substantial water deficit within 2020-2025. Similarly, also the fossil groundwater resource will encounter major depletion: the Murzuq aquifer in North Africa and most of the mid-size fossil aquifers in the Arabian

Peninsula could reach full depletion by 2050. Lastly, I briefly summarize the potential implications of the water stress on socio-economic stability in the MENA region. In fact, it is plausible that such deficit both in renewable and non-renewable water resources could induce a substantial rise in domestic food production costs, consequently further increasing the dependency on foreign markets for food imports. If this will be the case, low-income countries such as Egypt, Yemen or Libya will have to face further pressure at the societal and institutional level, being unable to rapidly re-adjust to markets' price fluctuation. Conversely, GCC countries have the financial capability to address potential these food price increases, although they will have to consider that these impacts will unevenly affect households with different income levels.

In the second paper, I explore how the economic and the natural resources of a country are impacted by an exogenous shock. In doing so, I exploit the blockade imposed on Qatar on the 5th of June 2017. I first analyze the trade disruption employing a difference-in-difference methodology in a gravity framework, in order to disentangle the main treatment effect i.e. the blockade's impacts with the sender countries and two sub-treatment effects i.e. the potential trade disruption with the countries that sided with the original senders and cut or downgraded their diplomatic relations with Qatar. Furthermore, I also observe the substitution effects, which is represented by the potential gains in trade with nations that openly supported Qatar. In addition, I exploit the characteristic of my dataset to check the effects of the blockade on five major product categories. The main results show that the blockade effects were bigger for the imports than for the exports and the trade losses with the blockading countries attested to ~400-450 million USD per month in the case of the imports and ~480-540 USD per months in the case of the exports. Similarly, the products that were most impacted by the blockade were dairy, agricultural and animal products. In order to estimate the secondary effects of the blockade on the natural resources of Qatar, namely on its water resources, I elaborated on a water-food security scenario analysis that evaluates the feasibility and sustainability of the food-security strategies promoted by the government in the aftermath of the blockade for the period 2019-2023. My results confirm the unfeasibility of those strategies, which will end up overexploiting the water resources of Qatar. Lastly, I concisely evaluate the effects of the blockade from a reputation and visibility perspective and it looks like that conversely to the negative economic and environmental effects, the course of actions implemented by Qatar in terms of foreign and domestic policies during the blockade helped the state to secure the needed support at regional and international level.

In the last paper, I cover another important issue in water resources management: water pricing. In the MENA area, at the origin of the mismanagement of water resources for irrigation, there are low service tariffs and high subsidies to farmers and to the agricultural sector, which has also a very low water-productivity ratio. My study can complement the existing literature and can be helpful to stakeholders and policymakers to evaluate scenarios and tradeoffs between profitable crop production and conservation of water resources. I first perform a review of the existing water tariffs in 19 countries in the MENA region, secondly, I estimate the shadow price for water in the agricultural sector, for all the countries and 12 different crop categories through marginal value product (MVP) obtained from a Cobb-Douglas production function for the period 1991-2016. Finally, I compare the results with the current prices. The results show that on average, for the period 2011-2016, the shadow prices are higher than the existing tariffs and that there is quite a lot of heterogeneity among countries and among crops. This confirms that exists a considerable margin for improvements in the water management and agricultural sector.

5.2. Recommendations and Future Research Outlook

Given the variety of the topic covered, of the methodologies employed and the dataset construction, clearly, there is still room for improvements and future research outlooks for each paper.

In the first paper, I could extend my analysis to all the countries in the MENA region, covering additional transboundary water resources, both surface, and groundwater. Particularly interesting, could be a focus on the Nile Basin area and the Tigris and Euphrates rivers between Syria, Iran, and Turkey. Furthermore, I could strongly improve my hydro-economic model using more recent data and modeling water requirements per sector with more precise methodologies. Lastly, more inference could be conducted on the socio-economic implications of the water budget deficit and groundwater depletion, pushing further the scenario analysis to add more inputs in the picture.

In the second paper, the main efforts should be focused on refining the econometric estimation techniques, and to better characterize the trade disruption analysis at the product level. Looking at the environmental aspects of the blockade, having more recent data both on water footprint and current and future agricultural production in Qatar, would highly potentiate the water-food security model. In addition, a more comprehensive analysis of dietary requirements of the Qatari population would strongly reinforce the food projection estimation, adding details.

Lastly, for the third paper, few extensions and further analysis should be conducted. Definitely, the possibility of using data for the irrigation water requirements derived from a physical model would highly improve my estimation of such parameters. Furthermore, it would probably allow for differentiating the water resources employ in for irrigation by their sources i.e. surface, groundwater and non-renewable groundwater, in order to provide results by which infer even more on water allocation efficiency between sector. A physical model would also allow us to better take into account the crop-related characteristic, potentially generate estimates much closer to the actual behavior of crops. In addition, more tests such as stationarity and co-integration should be run for the panel dataset, to verify its strength for the OLS estimations. To conclude, expanding the framework of analysis I could also add considerations on intertemporal efficiency or scenario analyses, which results could provide further guidelines in terms of the actual water price to set up and the potential water savings induced by its introduction.

BIBLIOGRAPHY

Abdelmoneium, A., Al-Attiyah, A., Khalifa, B., Alobaid, N., Sultan, A. & Aref, A. 2018, The impact of the blockade on families in qatar, Research to Advance Family Policies. Doha Family Institute, Doha, Qatar.

Abdulrazzak, M.J., 1994. Review and assessment of water resources in Gulf Cooperation Council Countries. International Journal of Water Resources Development, 10(1), pp.23-37. https://doi.org/10.1080/07900629408722607

Abdulrazzak, M.J., 1995. Water supplies versus demand in countries of Arabian Peninsula. Journal of Water Resources Planning and Management, 121(3), pp.227-234. 10.1061/ (asce)0733- https://doi.org/10.1061/(ASCE)0733-9496(1995)121:3(227)

Abu-Madi, M., Al-Sa'ed, R., Braadbaart, O. & Alaerts, G. 2008, Viability of increasing the tariff of freshwater for irrigation as a tool to stimulate wastewater reuse in the MENA region, Water Science and Technology, vol. 57, no. 9, pp. 1475–81.

Abu-Madi, M.O. 2009, Farm-level perspectives regarding irrigation water prices in the Tulkarm district, Palestine, Agricultural Water Management, vol. 96, no. 9, pp. 1344–50.

Afesorgbor, S.K. 2019, The impact of economic sanctions on international trade: How do threatened sanctions compare with imposed sanctions?, European Journal of Political Economy, vol. 56, pp. 11–26, viewed 11 August 2019, <https://www.sciencedirect.com/science/article/pii/S017626801730616X>.

Ahmad, M. 1998, Sectoral and economy-wide policies and options: food security policies in Yemen.

Ahmad, M. 2000, Water pricing and markets in the Near East: policy issues and options, Water Policy, vol. 2, no. 3, pp. 229–42.

Ahmed, M., Sultan, M., Wahr, J. and Yan, E., 2014. The use of GRACE data to monitor natural and anthropogenic induced variations in water availability across Africa. Earth-Science Reviews, 136, pp.289-300. https://doi.org/10.1016/j.earscirev.2014.05.009

Ahmed, M., Sultan, M., Wahr, J., Yan, E., Milewski, A., Sauck, W., Becker, R. and Welton, B., 2011. Integration of GRACE (Gravity Recovery and Climate Experiment) data with traditional data sets for a better understanding of the time-dependent water partitioning in African watersheds. Geology, 39(5), pp.479-482. http://dx.doi.org/10.1130/G31812.1

Akol J. P., , Robert P. Z. Galla R. P. Z., , Mr. Sabuni Wanyonyi S., et al., 2016. Nile Basin water resources atlas. Nile Basin Initiative (NBI). ISBN: 978-9970-444-02-1

Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T. and Siebert, S., 2003. Development and testing of the WaterGAP 2 global model of water use and availability. Hydrological Sciences Journal, 48(3), pp.317-337. http://dx.doi.org/10.1623/hysj.48.3.317.45290

Alcamo, J., Döll, P., Kaspar, F. and Siebert, S., 1997. Global change and global scenarios of water use and availability: an application of WaterGAP 1.0. Center for Environmental Systems Research, University of Kassel, Kassel, Germany.

Alexandratos, N. and Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision (No. 12-03, p. 4). Rome, FAO: ESA Working paper.

Al-Khamisi, S.K.M., 2011. Optimal water resources management model for Ash Sharqiyah region domestic water supply, Oman (Doctoral dissertation, Heriot-Watt University). URL: http://hdl.handle.net/10399/2497

Allan, J.A. 1998, Virtual water: A strategic resource global solutions to regional deficits, Ground Water, vol. 36, no. 4, pp. 545–6.

Allan, J.A. 1998, Virtual water: a strategic resource global solutions to regional deficits, Ground Water, vol. 36, no. 4, pp. 545–6.

Allan, J.A. 2002, The Middle East Water Question: Hydropolitics and the Global Economy, I.B.Tauris.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and Drainage Paper 56. FAO, Rome, 300(9), p.D05109. ISBN: 92-5-104219-5

Al-Noaimi, M.. 2005, Water use and management in Bahrain: An overview.

Al-Rashed, M.F. and Sherif, M.M., 2000. Water resources in the GCC countries: an overview. Water Resources Management, 14(1), pp.59-75. https://doi.org/10.1023/A:1008127027743

Al-Rubaye, S. 2019, Agricultural irrigation pricing: review of theories and practices, Irrigation and Drainage, vol. 68, no. 2, pp. 129–39.

Al-Sefry, S., Şen, Z., Al-Ghamdi, S.A., Al-Ashi, W. and Al-Baradi, W., 2004. Strategic ground water storage of Wadi Fatimah—Makkah region Saudi Arabia. Saudi Geological Survey, Hydrogeology project team, final report.

Alsharhan, A.S., Rizk, Z.A., Nairn, A.E.M., Bakhit, D.W. and Alhajari, S.A. 2001. Hydrogeology of an Arid Region: The Arabian Gulf and Adjoining Areas. Elsevier. ISBN: 978-0-444-50225-4

Anderson, J.E. & van Wincoop, E. 2003, Gravity with gravitas: A solution to the border puzzle, American Economic Review, vol. 93, no. 1, pp. 170–92.

Anderson, J.E. 1979, A theoretical foundation for the gravity equation, The American Economic Review, vol. 69, no. 1, pp. 106–16.

Ansari, M.S.A., 2013. The water demand management in the Kingdom of Bahrain. International Journal of Engineering and Advanced Technology, 2(5), pp.544-554. ISSN: 2249 – 8958, Volume-2, Issue-5, June 2013

Antonelli, M., Laio, F. & Tamea, S. 2017, Water resources, food security and the role of virtual water trade in the mena region, Environmental Change and Human Security in Africa and the Middle East, Springer International Publishing, Cham, pp. 199–217.

Arab Times Kuwait 2016, MEW completes regulations concerning tariff hikes, 10 September.

Arnell, N., Bates, B., Lang, H., Magnuson, J.J. and Mulholland, P., 1996. Hydrology and Freshwater Ecology. Cambridge University Press, New York, NY (USA), pp.325-364. ISBN: 731946TL1775

Arnell, N.W., 1999. Climate change and global water resources. Global Environmental Change, 9, pp.S31-S49. https://doi.org/10.1016/S0959-3780 (99)00017-5

Ashenfelter, O., Ciccarella, S. & Shatz, H.J. 2007, French wine and the U.S. boycott of 2003: Does politics really affect commerce?, Journal of Wine Economics, vol. 2, no. 1, pp. 55–74.

Askari, H. et al. 2003, Case studies of US economic sanctions: The Chinese, Cuban, and Iranian experience, Praeger Publishing Group. ISBN: 1567205410

Baalousha, H.M., 2016. Using Monte Carlo simulation to estimate natural groundwater recharge in Qatar. Modeling Earth Systems and Environment, 2(2), p.87. https://doi.org/10.1007/s40808-016-0140-8

Bai, J. & Ng, S. 2001, A consistent test for conditional symmetry in time series models, Journal of Econometrics, vol. 103, no. 1–2, pp. 225–58.

Baier, S.L. & Bergstrand, J.H. 2007, Do free trade agreements actually increase members international trade?, Journal of International Economics, vol. 71, no. 1, pp. 72–95.

Baier, S.L., Bergstrand, J.H., Egger, P. & McLaughlin, P.A. 2008, Do economic integration agreements actually work? issues in understanding the causes and consequences of the growth of regionalism, The World Economy, vol. 31, no. 4, pp. 461–97.

Baldwin, D.A. & Pape, R.A. 1998, Evaluating economic sanctions, International Security, vol. 23, no. 2, pp. 189–98.

Baldwin, R. & Taglioni, D. 2006, Gravity for dummies and dummies for gravity equations, Cambridge, MA.

Baltagi, H.B. 1995, Econometric analysis of panel data, vol. 2 Wiley, New York.

Barber, J. 1979, Economic sanctions as a policy instrument, International Affairs, vol. 55, no. 3, pp. 367–84.

Barnes, J., 2017. The future of the Nile: climate change, land use, infrastructure management, and treaty negotiations in a transboundary river basin. Wiley Interdisciplinary Reviews: Climate Change, 8(2), p.e449. https://doi.org/10.1002/wcc.449

Barrett, S. 1997, The strategy of trade sanctions in international environmental agreements, Resource and Energy Economics, vol. 19, no. 4, pp. 345–61.

Barros, V.R., Field, C.B., Dokke, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C. and Girma, B., 2014. Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. ISBN: 9781107683860

Bauer, N., Calvin, K., Emmerling, J., Fricko, O., Fujimori, S., Hilaire, J., Eom, J., Krey, V., Kriegler, E., Mouratiadou, I. and de Boer, H.S., 2016. Shared socio-economic pathways of the energy sector–quantifying the narratives. Global Environmental Change. https://doi.org/10.1016/j.gloenvcha.2016.07.006

Bergeijk Van, P.A.G. 1989, Success and failure of economic sanctions, Kyklos, vol. 42, no. 3, pp. 385–404.

Bergstrand, J.H. 1985, The gravity equation in international trade: some microeconomic foundations and empirical evidence, The Review of Economics and Statistics, vol. 67, no. 3, p. 474.

Beyene, T., Lettenmaier, D.P. and Kabat, P., 2010. Hydrologic impacts of climate change on the Nile River Basin: implications of the 2007 IPCC scenarios. Climatic Change, 100(3-4), pp.433-461. https://doi.org/10.1007/s10584-009-9693-0

Beyers, C.J. 1992, The U . S ./ Mexico tuna embargo dispute : a case study of the gatt and environmental progress, Maryland Journal of International Law, vol. 16, no. 2, pp. 229–53.

Bierkens, M.F.P. & Wada, Y. 2019, Non-renewable groundwater use and groundwater depletion: a review, Environmental Research Letters, vol. 14, no. 6, p. 063002.

Bierkens, M.F.P. & Wada, Y. 2019, Non-renewable groundwater use and groundwater depletion: A review, Environmental Research Letters, vol. 14, no. 6, p. 063002.

Bierkens, M.F.P., Reinhard, S., Bruijn, J.A., Veninga, W. & Wada, Y. 2019, The shadow price of irrigation water in major groundwater-depleting countries, Water Resources Research, vol. 55, no. 5, pp. 4266–87.

Borer, D.A. & Bowen, J.D. 2007, Rethinking the Cuban embargo: an inductive analysis, Foreign Policy Analysis, vol. 3, no. 2, pp. 127–43.

Bourdon, D.J., 1977. Flow of fossil groundwater. Quarterly Journal of Engineering Geology and Hydrogeology, 10(2), pp.97-124. https://doi.org/10.1144/GSL.QJEG.1977.010.02.02

Bourdon, D.J., 1982. Environmental conditions favouring deposition of potential aquifers. In ACSAD workshop on regional correlation of geologic formations in the Hamad basin, Damascus.

Breisinger, C., Van Rheenen, T., Ringler, C., Pratt, A.N., Minot, N., Aragon, C., Yu, B., Ecker, O. and Zhu, T., 2010. Food security and economic development in the Middle East and North Africa. International Food Policy Research Institute, pp.1-52

Brook, M.C., Al Houqani, H., Darawsha, T. and Achary, M.A.A.S., 2006. Groundwater Resources: Development & Management in the Emirate of Abu Dhabi, United Arab Emirates. Arid Land Hydrogeology: In search of a Solution to a Threatened Resource. Taylor and Francis, Balkema, Netherlands, Ch. 1, pp.15-34. https://doi.org/10.1201/9781439833421

BSRW 2019, Regional Water Company of Bushehr.

Burek, P., Satoh, Y., Fischer, G., Kahil, M.T., Scherzer, A., Tramberend, S., Nava, L.F., Wada, Y., Eisner, S., Flörke, M., Hanasaki, N., Magnuszewski, P., Cosgrove, B. & Wiberg, D. 2016, Water Futures and Solution, Water Futures and Solution: Fast Track Initiative (Final Report). IIASA Working Paper. Laxenburg, Austria, International Institute for Applied Systems Analysis (IIASA).

Camberlin, P., 2009. Nile basin climates. In Dumont H, ed. The Nile: Origin, Environments, Limnology, and Human Use (pp. 307-333). Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-9726-3

Carucci, A. 2000, Environmental effects of economic sanctions : the Cuban experience, Colby College.

CEDARE 2014, Libya water sector m&e rapid assessment report, monitoring & evaluation for water in North Africa (MEWINA) Project, Water Resources Management Program.

CEDARE, 2014, North Western Sahara Aquifer System (NWSAS) M&E Rapid Assessment Report, Monitoring & Evaluation for Water In North Africa (MEWINA) Project, Water Resources Management Program, CEDARE.

Chavis, L. and Leslie, P., 2009. Consumer boycotts: the impact of the Iraq war on French wine sales in the US. Quantitative Marketing Economics, vol. 7(1), pp.37-67.

Chemingui, M.A. & Thabet, C. 2016, Economy-Wide analysis of alternative water management policies: a comparative analysis for Morocco and Tunisia, Water Economics and Policy, vol. 02, no. 04, p. 1650030.

Choi, I. 2001, Unit root tests for panel data, Journal of International Money and Finance, vol. 20, no. 2, pp. 249–72.

Christensen, J.H., K. Krishna Kumar, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie and T. Zhou, 2013. Climate Phenomena and their Relevance for Future Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://doi.org/10.1017/CBO9781107415324

Cirone, A.E. & Urpelainen, J. 2013, Trade sanctions in international environmental policy: Deterring or encouraging free riding?, Conflict Management and Peace Science, vol. 30, no. 4, pp. 309–34.

Conway, D., 2005. From headwater tributaries to international river: observing and adapting to climate variability and change in the Nile basin. Global Environmental Change, 15(2), pp.99-114. https://doi.org/10.1016/j.gloenvcha.2005.01.003

Coulibaly, B. 2009, Effects of financial autarky and integration: The case of the South Africa embargo, Journal of International Money and Finance, vol. 28, no. 3, pp. 454–78.

Crozet, M. & Hinz, J. 2016, Highlights Collateral Damage: The Impact of the Russia Sanctions on Sanctioning Countries' Exports Working Paper, viewed 11 August 2019, <www.cepii.fr>.

D'Odorico, P., Carr, J., Dalin, C., Dell'Angelo, J., Konar, M., Laio, F., Ridolfi, L., Rosa, L., Suweis, S., Tamea, S. & Tuninetti, M. 2019, Global virtual water trade and the hydrological cycle: Patterns, drivers, and socio-environmental impacts, Environmental Research Letters, vol. 14, no. 5.

D'Odorico, P., Carr, J.A., Laio, F., Ridolfi, L. & Vandoni, S. 2014, Earth's Future feeding humanity through global food trade, Earth's Future, vol. 2, pp. 458–69.

De Graaf, I.E.M., van Beek, R.L.P.H., Gleeson, T., Moosdorf, N., Schmitz, O., Sutanudjaja, E.H. & Bierkens, M.F.P. 2017, A global-scale two-layer transient groundwater model: Development and application to groundwater depletion, Advances in Water Resources, vol. 102, pp. 53–67.

De Hoyos, R.E. & Sarafidis, V. 2006, Testing for cross-sectional dependence in panel-data models, The Stata Journal: Promoting communications on statistics and Stata, vol. 6, no. 4, pp. 482–96.

De Lange, W.J. & Mahumani, B.K. 2012, The marginal product value of irrigation water for potato and vine cultivation in the Sandveld region, South Africa, Agrekon, vol. 51, no. 4, pp. 129–43.

Dellink, R., Chateau, J., Lanzi, E. and Magné, B., 2015. Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environmental Change. http://dx.doi.org/10.1016/j.gloenvcha.2015.06.004

Devlin, J.C. 2010, Challenges of Economic Development in the Middle East and North Africa Region, World Scientific Publishing Co Pte Ltd, Singapore.

Diao, X., Roe, T. & Doukkali, R. 2005, Economy-wide gains from decentralized water allocation in a spatially heterogenous agricultural economy, Environment and Development Economics, vol. 10, no. 3, pp. 249–69.

Digna, R.F., Mohamed, Y.A., van der Zaag, P., Uhlenbrook, S., van der Krogt, W. and Corzo, G., 2018. Impact of Water Resources Development on Water Availability for Hydropower Production and Irrigated Agriculture of the Eastern Nile Basin. Journal of Water Resources Planning and Management, 144(5), p.05018007. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000912

Dinar, A. 2000, The political economy of water pricing reforms, Oxford University Press.

Döll, P. and Flörke, M., 2005. Global-Scale estimation of diffuse groundwater recharge: model tuning to local data for semi-arid and arid regions and assessment of climate change impact. Frankfurt Hydrology Paper 03, Institute of Physical Geography, Frankfurt University, Frankfurt am Main, Germany.

Döll, P., Mueller Schmied, H., Schuh, C., Portmann, F.T. and Eicker, A., 2014. Global-scale assessment of groundwater depletion and related groundwater abstractions: Combining hydrological modeling with information from well observations and GRACE satellites. Water Resources Research, 50(7), pp.5698-5720. https://doi.org/10.1002/2014WR015595

Droogers, P., Immerzeel, W.W., Terink, W., Hoogeveen, J., Bierkens, M.F.P., Van Beek, L.P.H. and Debele, B., 2012. Water resources trends in Middle East and North Africa towards 2050. Hydrology and Earth System Sciences, 16, pp.3101-3114. https://doi.org/10.5194/hess-16-3101-2012

Drysdale, A. & Blake, G.H. 1985, The Middle East and North Africa: A Political Geography, Oxford University Press.

Eaton, J. & Engers, M. 1992, Sanctions, Journal of Political Economy, vol. 100, no. 5, pp. 899–928.

Eaton, J. & Engers, M. 1999, Sanctions: Some Simple Analytics, The American Economic Review, vol. 89, no. 2, pp. 409–14.

Eckstein, A. and Heien, D., 1978. The 1973 food price inflation. American Journal of Agricultural Economics, 60(2), pp.186-196. https://doi.org/10.2307/1240047

Egger, P. & Pfaffermayr, M. 2003, The proper panel econometric specification of the gravity equation: A three-way model with bilateral interaction effects, Empirical Economics, vol. 28, no. 3, pp. 571–80.

ElObeid, T., Hassan, A., 2014. The Nutrition Transition and Obesity in Qatar. Food Security in the Middle East. C Hurst & Co Publishers Ltd., http://doi.org/10.1093/acprof:oso/9780199361786.003.0008

Engle, R.F., Granger, C.W.J., Engle, B.Y.R.F. & Grangeri, C.W.J. 1987, Co-integration and error correction: Representation , estimation , and testing, Econometrica, vol. 55, no. 2, pp. 251–76.

Ercin, A.E. and Hoekstra, A.Y., 2014. Water footprint scenarios for 2050: A global analysis. Environment International, 64, pp.71-82. https://doi.org/10.1016/j.envint.2013.11.019

Evans, J.P., 2009. 21st century climate change in the Middle East. Climatic Change, 92(3-4), pp.417-432. https://doi.org/10.1007/s10584-008-9438-5

Falkenmark, M., Lundqvist, J. and Widstrand, C., 1989, November. Macro-scale water scarcity requires micro-scale approaches. In Natural Resources Forum (Vol. 13, No. 4, pp. 258-267). Blackwell Publishing Ltd. https://doi.org/10.1111/j.1477-8947.1989.tb00348.x

Fally, T. 2015, Structural gravity and fixed effects, Journal of International Economics, vol. 97, no. 1, pp. 76–85, viewed 30 August 2019, <https://www.sciencedirect.com/science/article/pii/S0022199615001026>.

FAO & OECD 2018, OECD - FAO Agricultural Outlook 2018 - 2027: Special Focus Middle East and North Africa, OECD/FAO, Paris, Rome.

FAO 2009, Groundwater Management in Oman-Draft Synthesis Report, Rome.

FAO 2019, FAOSTAT.

FAO, 2016a. AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). Website accessed on [2017/01/30]

FAO, 2016b. FAOSTAT Database, Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). Website accessed on [2017/01/30]

FAO-AQUASTAT 2008a, Irrigation in the Middle East region in figures – AQUASTAT Survey 2008 - Bahrain.

FAO-AQUASTAT 2008b, Irrigation in the Middle East region in figures – AQUASTAT Survey 2008 - Syrian Arab Republic.

FAO-AQUASTAT 2008c, Irrigation in the Middle East region in figures – AQUASTAT Survey 2008 - United Arab Emirates.

FAO-GIEWS, 2017. Country Briefs report on Yemen. Website accessed on [2017/04/12]

Faruquee, H. 2004, Measuring the Trade Effects of EMU, International Monetary Fund 04/154.

Fayazmanesh, S. 2003, The politics of the U.S. economic sanctions against Iran, Review of Radical Political Economics, vol. 35, no. 3, pp. 221–40.

Faysse, N., Hartani, T., Frija, A., Tazekrit, I., Zairi, C. and Challouf, A., 2011. Agricultural use of groundwater and management initiatives in the Maghreb: challenges and opportunities for sustainable aquifer exploitation. AFDB Economic Brief, pp.1-24

Feyrer, J. 2009, Distance, Trade, and Income - The 1967 to 1975 Closing of the Suez Canal as a Natural Experiment, No. w15557. National Bureau of Economic Research, Cambridge, MA.

Fidrmuc, J. 2009, Gravity models in integrated panels, Empirical Economics, vol. 37, no. 2, pp. 435–46.

Foster, S. and Loucks, D.P., 2006. Non-renewable groundwater resources. A guidebook on socially sustainable management for water policy makers. IHP Series on Groundwater, (10).

Frenken, K. & Gillet, V. 2012, Irrigation water requirement and water withdrawal by country, Food and Agriculture Organization of the United Nations, p. 264.

Frenken, K. and Gillet, V., 2012. Irrigation water requirement and water withdrawal by country. FAO, Rome, Italy.

Friedman, M. 1985, Consumer boycotts in the United States, 1970-1980: Contemporary events in historical perspective, Journal of Consumer Affairs, vol. 19, no. 1, pp. 96–117.

Frija, I., Frija, A., Chebil, A., Cheikh M'Hamed, H., Speelman, S. & Makhlouf, M. 2014, Marginal Water Productivity of Irrigated Durum Wheat in Semi-Arid Tunisia, Journal of Agricultural Science, vol. 6, no. 10, pp. 84–95.

Garfield, R. & Santana, S. 1997, The impact of the economic crisis and the US embargo on health in Cuba, American Journal of Public Health, vol. 87, no. 1, pp. 15–20.

Gezahegn, T.W. & Zhu, X. 2015, Marginal value of natural water in agriculture: a study in the suburbs of Mekelle City, Ethiopia, Water Policy, vol. 17, no. 2, pp. 316–31.

Gibbons, E. & Garfield, R. 1999, The impact of economic sanctions on health and human rights in Haiti, 1991-1994, American Journal of Public Health, vol. 89, no. 10, pp. 1499–504.

Gleeson, T. and Wada, Y., 2013. Assessing regional groundwater stress for nations using multiple data sources with the groundwater footprint. Environmental Research Letters, 8(4), p.044010. http://dx.doi.org/10.1088/1748-9326/8/4/044010

Gleeson, T., Wada, Y., Bierkens, M.F. and van Beek, L.P., 2012. Water balance of global aquifers revealed by groundwater footprint. Nature, 488(7410), pp.197-200. https://doi.org/10.1038/nature11295

Gleick, P.H., 1989. Climate change, hydrology, and water resources. Reviews of Geophysics, 27(3), pp.329-344. https://doi.org/10.1029/RG027i003p00329

Glick, R. & Rose, A.K. 2002, Does a currency union affect trade? The time-series evidence, European Economic Review, vol. 46, no. 6, pp. 1125–51.

Gordon, J. 2016, Economic Sanctions as "Negative Development": The Case of Cuba, Journal of International Development, vol. 28, no. 4, pp. 473–84.

Grimble, R.J. 1999, Economic instruments for improving water use efficiency: theory and practice, Agricultural Water Management, vol. 40, no. 1, pp. 77–82.

Grönwall, J. and Oduro-Kwarteng, S., 2018. Groundwater as a strategic resource for improved resilience: a case study from peri-urban Accra. Environmental Earth Sciences, 77(1), p.6. https://doi.org/10.1007/s12665-017-7181-9

Haddeland, I., Heinke, J., Biemans, H., Eisner, S., Flörke, M., Hanasaki, N., Konzmann, M., Ludwig, F., Masaki, Y., Schewe, J., Stacke, T., Tessler, Z.D., Wada, Y. & Wisser, D. 2014, Global water resources affected by human interventions and climate change, Proceedings of the National Academy of Sciences, vol. 111, no. 9, pp. 3251–6.

Hadri, K. 2000, Testing for stationarity in heterogeneous panel data, The Econometrics Journal, vol. 3, no. 2, pp. 148–61.

Hamiche, A.M., Stambouli, A.B. and Flazi, S., 2015. A review on the water and energy sectors in Algeria: Current forecasts, scenario and sustainability issues. Renewable and Sustainable Energy Reviews, 41, pp.261-276. https://doi.org/10.1016/j.rser.2014.08.024

Hargreaves, G.H. and Samani, Z.A., 1985. Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture, 1(2), pp.96-99. https://doi.org/10.13031/2013.26773

Harris, I.P.D.J., Jones, P.D., Osborn, T.J. and Lister, D.H., 2014. Updated high-resolution grids of monthly climatic observations–the CRU TS3. 10 Dataset. International Journal of Climatology, 34(3), pp.623-642. https://doi.org/10.1002/joc.3711

Hartmann, A., Gleeson, T., Wada, Y. and Wagener, T., 2017. Enhanced groundwater recharge rates and altered recharge sensitivity to climate variability through subsurface heterogeneity. Proceedings of the National Academy of Sciences, 114(11), pp.2842-2847. Vancouver. https://doi.org/10.1073/pnas.1614941114

Hayashi, F. 2000, Econometrics, Princeton University Press, vol. 1, pp. 60–9.

He, L., Tyner, W.E., Doukkali, R. & Siam, G. 2006, Policy options to improve water allocation efficiency: analysis on Egypt and Morocco, Water International, vol. 31, no. 3, pp. 320–37.

Heckman, J.J. 1979, Sample selection bias as a specification error, Econometrica, vol. 47, no. 1, pp. 153–61.

Heilmann, K. 2016, Does political conflict hurt trade? Evidence from consumer boycotts, Journal of International Economics, vol. 99, pp. 179–91.

Helmut, H. 2003, On the (nonlinear) relationship between exchange rate uncertainty and trade — An investigation of US trade figures in the group of seven, Review of World Economics, vol. 139, no. 4, pp. 650–82.

Hoechle, D. 2007, Robust standard errors for panel regressions with cross-sectional dependence, Stata Journal, vol. 7, no. 3, pp. 281–312.

Holt-Giménez, E. and Peabody, L., 2008. From Food Rebellions to Food Sovereignty: Urgent call to fix a broken food system. Food First Backgrounder, 14(1), pp.1-6

Hong, C., Hu, W.-M., Prieger, J.E. & Zhu, D. 2011, French automobiles and the Chinese boycotts of 2008: Politics really does affect commerce, The B.E. Journal of Economic Analysis & Policy, vol. 11, no. 1.

Hötzl, H. ed., 2008. Climatic changes and water resources in the Middle East and North Africa. Berlin: Springer. ISBN: 978-3-540-85046-5

Hufbauer, G.C. et al. 2007, Economic sanctions reconsidered, 3rd Edition, Peterson Institute for International Economics, Washington, DC.

Hurlin, C. and Mignon, V. 2007, Second generation panel unit root tests, halshs-00159842

Ibeda, A., Abosith, M.F., Alemad, A., Elkharrim, K. and Belghyti, D., 2013. Physicochemical Quality of Murzuq Groundwater Sabha, Libya. WIT Transactions on Ecology and the Environment, 178, pp. 225-239. https://doi.org/10.2495/WS130191

IGRAC (International Groundwater Resources Assessment Centre), UNESCO-IHP (UNESCO International Hydrological Programme), 2015. Transboundary Aquifers of the World [map]. Edition 2015. Scale 1: 50 000 000. Delft, Netherlands: IGRAC, 2015.

Im, K. S., Pesaran, M. H. and Smith, R. 1996, Dynamic linear models for heterogeneous panels, in P. eds. Matyas, L. and Sevestre (ed.),The Econometrics of Panel Data: A Handbook of the Theory with Applications, Kluwer Academic Publishers, Boston, MA, pp. 145–95.

Im, K.S., Pesaran, M.H. & Shin, Y. 2003, Testing for unit roots in heterogeneous panels, Journal of Econometrics, vol. 115, no. 1, pp. 53–74.

Immerzeel, W. W., Droogers, P., Terink, W., Hoogeveen, J., Hellegers, P. J. J. G., Bierkens, M., & van Beek, R. 2011. Middle-East and Northern Africa Water Outlook. Report FutureWater, 98.

IRCSA 2019, Iranian Rainwater Catchment Systems Association.

Irwin, D.A. 2005, The welfare cost of autarky: evidence from the Jeffersonian trade embargo, 1807-09, Review of International Economics, vol. 13, no. 4, pp. 631–45.

Ismail, H., 2015. Kuwait: Food and Water Security. Strategic Analysis Paper, Future Directions International.

Jaghdani, T.J., Brümmer, B. & Barkmann, J. 2012, Comparison of methods for the valuation of irrigation water: case study from Qazvin, Iran, Irrigation and Drainage, vol. 61, no. 3, pp. 375–85.

Johansson, R. 2002, Pricing irrigation water: a review of theory and practice, Water Policy, vol. 4, no. 2, pp. 173–99.

Joseph S . Nye, J. 1990, Soft Power, Foreign Policy, no. 80, pp. 153–71.

Kaempfer, W.H. & Lowenberg, A.D. 1988, The theory of international economic sanctions: A public choice approach, The American Economic Review, vol. 78, no. 4, pp. 786–93.

Kahramaa Qatar General Electricity and Water Corporation 2019, Water Tariff for Productive Farms, viewed <https://www.km.qa/CustomerService/Pages/Tariff.aspx>.

Kao, C. & Chiang, M. 2000, On the estimation and inference of a cointegrated regression in panel data, in R. (Ed. . Baltagi, B., Fomby, T. and Carter Hill (ed.),Nonstationary Panels, Panel Cointegration, and Dynamic Panels Advances in Econometrics, vol. 15, Emerald Group Publishing Limited, Bingley, pp. 179–222.

Karajeh, F., Oweis, T. and Swelam, A., 2011. Water and Agriculture in Egypt (No. 565-2016-38920).

KBRW 2019, Regional Water Company of Kohgiluyeh and Boyer-Ahmad.

Kelkouli, M., Ait Hammou, R., Zareb, D., Saidi, L., Kelkouli, O., Meouch, A., Karrou, M. & Qadir, M. 2011, Potential use of treated wastewater for supplemental irrigation of cereals Algeria, in M. Karrou, T. Oweis & A. Bahri (eds), Improving water and land productivities in rainfed systems. Community-Based Optimization of the Management of Scarce Water Resources in Agriculture in CWANA, ICARDA, Aleppo, Syria, pp. 119–30.

Khouri, N., & Byringyro, F. 2014. Developing food chains. In A. Sadik, M. El-Solh, & N. Saab (Eds.) Arab environment: Food security. Annual report of the Arab forum for environment and development, 2014 (pp. 102–129). Beirut: Technical Publications

Kitoh, A., Yatagai, A. and Alpert, P., 2008. First super-high-resolution model projection that the ancient "Fertile Crescent" will disappear in this century. Hydrological Research Letters, 2, pp.1-4. https://doi.org/10.3178/hrl.2.1

Kokabisaghi, F. 2018, Assessment of the effects of economic sanctions on Iranians' right to health by using human rights impact assessment tool: A systematic review, International Journal of Health Policy and Management, vol. 7, no. 5, pp. 374–93.

Koopman, J.F.L., Kuik, O., Tol, R.S.J. & Brouwer, R. 2017, The potential of water markets to allocate water between industry, agriculture, and public water utilities as an adaptation mechanism to climate change, Mitigation and Adaptation Strategies for Global Change, vol. 22, no. 2, pp. 325–47.

Korzoun, V.I., Sokolov, A.A., Budyko, M.I., Voskresensky, K.P., Kalinin, G.P., Konoplyantsev, A.A., Korotkevich, E.S. and L'vovich, M.I., 1978. Atlas of World Water Balance and Water Resources of the Earth. USSR Comm. for the Int. Hydrol. Decade, Leningrad. (English translation, UN Educ., Sci. and Cultural Org., Paris, 1978).

Krugman, B.P. 1980, Scale economies, product differentiation, and the pattern of trade, The American Economic Review, vol. 70, no. 5, pp. 950–9.

Kunstmann, H., Suppan, P., Heckl, A. and Rimmer, A., 2007. Regional climate change in the Middle East and impact on hydrology in the Upper Jordan catchment. IAHS Publication, 313, p.141.

Kuwait up to Date 2016, New electricity and water bills rates, 14 November.

Laoubi, K. & Yamao, M. 2011, Water policy reforms in Algeria’s agriculture: A review and prospects, WIT Transactions on Ecology and the Environment, vol. 153, no. March, pp. 435–46.

Larson, D.F., Lampietti, J., Gouel, C., Cafiero, C. and Roberts, J., 2013. Food security and storage in the Middle East and North Africa. The World Bank Economic Review, 28(1), pp.48-73. https://doi.org/10.1093/wber/lht015

Lelieveld, J., Proestos, Y., Hadjinicolaou, P., Tanarhte, M., Tyrlis, E. and Zittis, G., 2016. Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century. Climatic Change, 137(1-2), pp.245-260. https://doi.org/10.1007/s10584-016-1665-6

Levin, A., Lin, C.-F. & James Chu, C.-S. 2002, Unit root tests in panel data: asymptotic and finite-sample properties, Journal of Econometrics, vol. 108, no. 1, pp. 1–24.

Lionello, P. and Giorgi, F., 2007. Winter precipitation and cyclones in the Mediterranean region: future climate scenarios in a regional simulation. Advances in Geosciences, 12, pp.153-158. https://doi.org/10.5194/adgeo-12-153-2007

Ludwig, F., Kabat, P., van Schaik, H. and van der Valk, M. eds., 2012. Climate change adaptation in the water sector. Routledge. ISBN 9781844076529

Luo, T., Young, R. and Reig, P., 2015. Aqueduct projected water stress country rankings. Technical Note. Available online at: www.wri.org/publication/aqueduct-projected-water-stresscountry-rankings

Madariaga, B. & McConnell, K.E. 1984, Value of irrigation water in the Middle Atlantic States: An econometric approach, Journal of Agricultural and Applied Economics, vol. 16, no. 2, pp. 91–8.

Maddala, G.S. & Wu, S. 1999, A comparative study of unit root tests with panel data and a new simple test, Oxford Bulletin of Economics and Statistics, vol. 61, no. s1, pp. 631–52.

Maliva, R. and Missimer, T., 2012. Arid lands water evaluation and management. Springer Science & Business Media. http://dx.doi.org/10.1007%2F978-3-642-29104-3

Mazzoni, A., Heggy, E. & Scabbia, G. 2018, Forecasting water budget deficits and groundwater depletion in the main fossil aquifer systems in North Africa and the Arabian Peninsula, Global Environmental Change, vol. 53, pp. 157–73.

Mazzoni, A., Heggy, E. & Scabbia, G. 2018, Forecasting water budget deficits and groundwater depletion in the main fossil aquifer systems in North Africa and the Arabian Peninsula, Global Environmental Change, vol. 53, pp. 157–73.

McDonnell, J.J., 2017. Beyond the water balance. Nature Geoscience, 10(6), p.396. https://dx.doi.org/10.1038/ngeo2964

Mekonnen, M.M. & Hoekstra, A.Y. 2016, Four billion people facing severe water scarcity, *Science Advances*, vol. 2, no. 2, p. e1500323.

Mekonnen, M.M., Hoekstra, A.Y. 2010a, The green, blue and grey water footprint of crops and derived crop products - Volume 1, Main report, Value of Water Research Report Series, 47, Delft, The Netherlands.

Mekonnen, M.M., Hoekstra, A.Y. 2010b, The green, blue and grey water footprint of crops and derived crop products - Volume 2, Appendices, Value of Water Research Report Series, 47, Delft, The Netherlands.

Mekonnen, M.M., Hoekstra, A.Y. 2010c, The green, blue and grey water footprint of farm animals and animal products - Volume 1, Main Report, Value of Water Research Report Series, 48, Delft, The Netherlands.

Mekonnen, M.M., Hoekstra, A.Y. 2011a, National water footprint accounts: The green, blue and grey water footprint of production and consumption - Volume 1, Main report, Value of Water Research Report Series, 50, Delft, The Netherlands.

Mekonnen, M.M., Hoekstra, A.Y. 2011b, National water footprint accounts: The green, blue and grey water footprint of production and consumption - Volume 2, Appendices, Value of Water Research Report Series, 50, Delft, The Netherlands.

MEW (Ministry of Environment and Water), 2010. United Arab Emirates Water Conservation Strategy. Dubai, United Arab Emirates.

Ministry of Development Planning and Statistics 2016, Qatar Economic Outlook.

Ministry of Energy and Water 2010, National Water Sector Strategy - Sector Enabling Environment.

Molden, D. 2007, Water for food water for life a comprehensive assessment of water management in agriculture, Routledge, London.

Molle, F. & Berkoff, J. 2007, Irrigation water pricing: the gap between theory and practice, F. Molle & J. Berkoff (eds), CABI.

Moon, H.R. & Perron, B. 2004, Testing for a unit root in panels with dynamic factors, Journal of Econometrics, vol. 122, no. 1, pp. 81–126.

MOP (Ministry of Planning), 1985. Fourth Development Plan: 1985-1990. Riyadh, Saudi Arabia.

Moret, E.S. 2015, Humanitarian impacts of economic sanctions on Iran and Syria, European Security, vol. 24, no. 1, pp. 120–40.

MRMWR (Ministry of Regional Municipalities, & Water Resources), 2008. Water Resources in Oman, Ed. 2, MWR, Muscat, Sultanate of Oman.

Nakicenovic, N. and Swart, R., 2000. Special report on emissions scenarios. Special Report on Emissions Scenarios, Edited by Nebojsa Nakicenovic and Robert Swart, pp. 612. ISBN 0521804930. Cambridge, UK: Cambridge University Press, July 2000, 1.

Newey, W. K. and West, K. 1994, Automatic Lag Selection in Covariance Matrix Estimation, Review of Economic Studies, vol. 61, no. 4, pp. 631–53.

Odhiambo, G.O. 2017, Water scarcity in the Arabian Peninsula and socio-economic implications, Applied Water Science, vol. 7, no. 5, pp. 2479–92.

OECD/IEA, 2015. 2015 World Energy Outlook, IEA Publishing. Licence: www.iea.org/t&c

Oechslin, M. 2014, Targeting autocrats: Economic sanctions and regime change, European Journal of Political Economy, vol. 36, pp. 24–40, viewed 14 August 2019, <https://www.sciencedirect.com/science/article/pii/S0176268014000676>.

Oki, T. and Kanae, S., 2006. Global hydrological cycles and world water resources. Science, 313(5790), pp.1068-1072. http://dx.doi.org/10.1126/science.1128845

OSS, 2004. Water resources in the OSS (Observatory of the Sahara and the Sahel) countries, UNESCO-IHP Non Serial Publications in Hydrology.

Ouda, O.K.M. 2014, Impacts of agricultural policy on irrigation water demand: A case study of Saudi Arabia, International Journal of Water Resources Development, vol. 30, no. 2, pp. 282–92.

Panayotou, T. 1994, Economic instruments for environmental management and sustainable development, UNEP.

Pauwels, L.L., Chan, F. & Mancini Griffoli, T. 2012, Testing for structural change in heterogeneous panels with an application to the Euro’s trade effect, Journal of Time Series Econometrics, vol. 4, no. 2.

Pedroni, P. 1996, Fully modified OLS for heterogenous cointegrated panels and the case of purchasing power parity, Indiana University Working Papers in Economics, p. No. 96-020.

Pedroni, P. 2000, Fully modified OLS for heterogeneous cointegrated panels, in R. (Ed. . Baltagi, B., Fomby, T. and Carter Hill (ed.), Nonstationary Panels, Panel Cointegration, and Dynamic Panels (Advances in Econometrics), Emerald Group Publishing Limited, Bingley, pp. 93–130.

Pedroni, P. 2004, Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis, Econometric Theory, vol. 20, no. 03, pp. 597–625.

Penman, H.L., 1948, April. Natural evaporation from open water, bare soil and grass. In Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences (Vol. 193, No. 1032, pp. 120-145). The Royal Society. http://dx.doi.org/10.1098/rspa.1948.0037

Perry, C.J. 1996, Alternative approaches to cost sharing for water service to agriculture in Egypt, IWMI Research Report 2, pp. 1–21.

Pesaran, M.H. 2004, General diagnostic tests for cross section dependence in panels, CESifo Working Paper Series No. 1229; IZA Discussion Paper No. 1240. Available at SSRN: https://ssrn.com/abstract=572504

Pesaran, M.H. 2007, A simple panel unit root test in the presence of cross-section dependence, Journal of Applied Econometrics, vol. 22, no. 2, pp. 265–312.

Phillips, P.C.B. & Ouliaris, S. 1990, Asymptotic Properties of Residual Based Tests for Cointegration, Econometrica, vol. 58, no. 1, p. 165.

Phillips, P.C.B. & Sul, D. 2003, Dynamic panel estimation and homogeneity testing under cross section dependence, The Econometrics Journal, vol. 6, no. 1, pp. 217–59.

QZRW 2019, Regional Water Company of Qazvin.

Rasoulinezhad, E. & Popova, L. 2017, An estimation of the impact of economic sanctions and oil price shocks on Iran-Russian trade: Evidence from a gravity- VEC approach, Iranian Economic Review, vol. 21, no. 3, pp. 469–97.

Rasoulinezhad, E. 2017, Iran’s trade modification under sanctions: An evidence of trade divergence and trade convergence through the gravity model, Journal of Economic Cooperation and Development, vol. 38, no. 4, pp. 25–56.

Renzetti, S. 2002, The economics of water demands, the economics of water demands, Springer US, Boston, MA.

Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O’Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A. & Tavoni, M. 2017, The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview, Global Environmental Change, vol. 42, pp. 153–68.

Richards, A. & Waterbury, J. 2007, A Political Economy of the Middle East, Avalon Publishing.

Richey, A.S., Thomas, B.F., Lo, M.H., Famiglietti, J.S., Swenson, S. and Rodell, M., 2015. Uncertainty in global groundwater storage estimates in a total groundwater stress framework. Water Resources Research, 51(7), pp.5198-5216. Vancouver. https://doi:10.1002/2015WR017351

Rodell, M., Famiglietti, J.S., Wiese, D.N., Reager, J.T., Beaudoing, H.K., Landerer, F.W. and Lo, M.H., 2018. Emerging trends in global freshwater availability. Nature, p.1. https://doi.org/10.1038/s41586-018-0123-1

Rosegrant, M.W., Cai, X. and Cline, S.A. 2002 World water and food to 2025: dealing with scarcity. International Food Policy Research Institute. ISBN: 0896296466 / 9780896296466

Ruosteenoja, K., Carter, T.R., Jylhä, K. and Tuomenvirta, H., 2003. Future climate in world regions: An intercomparison of model-based projections for the new IPCC emissions scenarios. The Finnish Environment, 644, p.83. ISBN: 9521114649 / 9789521114649

Salem, O.M., 1992. The great manmade river project: A partial solution to Libya's future water supply. International Journal of Water Resources Development, 8(4), pp.270-278. https://doi.org/10.1080/07900629208722564

Samir, K.C. and Lutz, W., 2014. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change. https://dx.doi.org/10.1016/j.gloenvcha.2014.06.004

Santos Silva, J.M.C. & Tenreyro, S. 2010, On the existence of the maximum likelihood estimates in Poisson regression, Economics Letters, vol. 107, no. 2, pp. 310–2, viewed 30 August 2019, <https://www.sciencedirect.com/science/article/pii/S0165176510000832>.

Sarant, L., 2017. Egypt: Space to grow. Nature, 544(7651), pp.S14-S16. https://doi.org/10.1038/544S14a

Schmidt, O., 2008. The North-West Sahara Aquifer System, A case study for the research project “Transboundary groundwater management in Africa”, in: W. Scheumann and E. Herrfahrdt-Pähle (eds.), German Development Institute, Bonn, 231-274

Seyfert, K., Chaaban, J. and Ghattas, H., 2014. Food security and the supermarket transition in the Middle East, two case studies. Food Security in the Middle East. C Hurst & Co Publishers Ltd., https://doi.org/10.1093/acprof:oso/9780199361786.003.0008

Shah, T., 2014. Groundwater governance and irrigated agriculture. TEC Background Papers, (19), p.69.

Shetty, S., 2004. 15. Treated Wastewater Use in Tunisia: Lessons Learned and the Road Ahead. Wastewater Use in Irrigated Agriculture, p.163. https://doi.org/10.1079/9780851998237.0001

Shiklomanov, I. a. 1998, World Water Resources. A new appraisal and assessment for the 21st century, United Nations Educational, Scientific and Cultural Organization, p. 40.

Shiklomanov, I.A., 1997. Assessment of water resources and availability in the world. In Comprehensive assessment of the freshwater resources of the world. Stockholm, Stockholm Environment Institute. 88 pp.

Siam, M.S. and Eltahir, E.A., 2017. Climate change enhances interannual variability of the Nile river flow. Nature Climate Change, 7(5), p.350. https://doi.org/10.1038/nclimate3273

Silva, J.M.C.S. & Tenreyro, S. 2006, The log of gravity, Review of Economics and Statistics, vol. 88, no. 4, pp. 641–58.

Soroush, N. and Madani, K. 2014, Every breath you take: The environmental consequences of Iran sanctions, The Guardian.

Sowers, J., Vengosh, A. and Weinthal, E., 2011. Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. Climatic Change, 104(3), pp.599-627. https://doi.org/10.1007/s10584-010-9835-4

Spencer, D. 2019, BP statistical review of world energy statistical review of world, BP Statistical Review of World Energy.

Steinfeld, H., Gerber, P., Wassenaar, T. D., Castel, V., & de Haan, C. 2006. Livestock's long shadow: environmental issues and options. Food & Agriculture Organization, Ch. 4 pg. 129. ISBN: 9251055718 / 978-9251055717

Sun, T., Huang, Q. & Wang, J. 2017, Estimation of irrigation water demand and economic returns of water in Zhangye Basin, Water (Switzerland), vol. 10, no. 1, pp. 1–21.

Taylor, R.G., Scanlon, B., Döll, P., Rodell, M., Van Beek, R., Wada, Y., Longuevergne, L., Leblanc, M., Famiglietti, J.S., Edmunds, M. and Konikow, L., 2013. Ground water and climate change. Nature Climate Change, 3(4), pp.322-329. https://doi.org/10.1038/nclimate1744

Tenneson, M. & Rojate, D. 2003, La tarification de l’eau au Maroc: Comment servir diffrentes causes?, Afrique Contemporaine, vol. 205, no. 1, pp. 151–69.

Thabet, C., Mahé, L.-P. & Surry, Y. 2005, La tarification de l'eau d'irrigation en Tunisie : Une analyse en équilibre général, Économie rurale, no. 285, pp. 51–69.

The Jordan Times 2014, Gradual increase of irrigation water tariff begins next month.

Tinbergen, J. 1962, Shaping the world economy: Suggestions for an interational economic policy, New York: The Twentieth Century Fund.

Tsur, Y. and Graham-Tomasi, T., 1991. The buffer value of groundwater with stochastic surface water supplies. Journal of Environmental Economics and Management, 21(3), pp.201-224., https://doi.org/10.1016/0095-0696

Tsur, Y., Dinar, A., Doukkali, R. & Roe, T. 2004, Irrigation water pricing: Policy implications based on international comparison, Environment and Development Economics, vol. 9, no. 6, pp. 735–55.

UNdata 2019, Land area equipped for irrigation.

UNDP, 2013. Water Governance in the Arab Region, Managing Scarcity and Securing the Future. United Nations Publications Two UN Plaza DC2 - Room 853 New York, NY 10017 USA. ISBN: 978-92-1-126366-4

UNESCO, 1979. Map of the world distribution of arid regions: Map at scale 1:25,000,000 with explanatory note. MAB Technical Notes 7, UNESCO, Paris. ISBN: 9231015486

UN-ESCWA and BGR, 2013. Inventory of shared water resources in Western Asia. United Nations Economic and Social Commission for Western Asia. Federal Institute for Geosciences and Natural Resources, Beirut. ISBN: 978-92-1-128361-7

UN-Water 2013, Water Security & the Global Water Agenda, UNU-INWEH.

Van den Berg, C., Agha Al Nimer, S.K.H., Fileccia, T., Gonzalez, L.M. & Wahseh, S. 2016, The cost of irrigation water in the Jordan Valley.

Vogel, J.C. and Van Urk, H., 1975. Isotopic composition of groundwater in semi-arid regions of southern African Journal of Hydrology, 25(1-2), pp.23-36. https://doi.org/10.1016/0022-1694(75)90036-0

Vörösmarty, C.J., Federer, C.A. and Schloss, A.L., 1998. Potential evaporation functions compared on US watersheds: Possible implications for global-scale water balance and terrestrial ecosystem modeling. Journal of Hydrology, 207(3-4), pp.147-169. https://doi.org/10.1016/S0022-1694(98)00109-7

Voss, K.A., Famiglietti, J.S., Lo, M., Linage, C., Rodell, M. and Swenson, S.C., 2013. Groundwater depletion in the Middle East from GRACE with implications for transboundary water management in the Tigris-Euphrates-Western Iran region. Water Resources Research, 49(2), pp.904-914. https://doi.org/10.1002/wrcr.20078

Vouillamoz, J.M., Lawson, F.M.A., Yalo, N. and Descloitres, M., 2015. Groundwater in hard rocks of Benin: Regional storage and buffer capacity in the face of change. Journal of Hydrology, 520, pp.379-386. https://doi.org/10.1016/j.jhydrol.2014.11.024

Wada, Y. 2016, Modeling Groundwater Depletion at Regional and Global Scales: Present State and Future Prospects, Surveys in Geophysics, vol. 37, no. 2, pp. 419–51.

Wada, Y., 2016. Modeling groundwater depletion at regional and global scales: Present state and future prospects. Surveys in Geophysics, 37(2), pp.419-451. https://doi.org/10.1007/s10712-015-9347-x

Wada, Y., Gleeson, T. and Esnault, L., 2014. Wedge approach to water stress. Nature Geoscience, 7(9), pp.615-617. https://doi.org/10.1038/ngeo2241

Wada, Y., Wisser, D. & Bierkens, M.F.P. 2014, Global modeling of withdrawal, allocation and consumptive use of surface water and groundwater resources, Earth System Dynamics, vol. 5, no. 1, pp. 15–40.

Wada, Y., Wisser, D. & Bierkens, M.F.P. 2014, Global modeling of withdrawal, allocation and consumptive use of surface water and groundwater resources, Earth System Dynamics, vol. 5, no. 1, pp. 15–40.

Wagner, W., 2011. Groundwater in the Arab Middle East. Springer Science & Business Media. https://doi.org/10.1007/978-3-642-19351-4

Ward, C., 2014. The water crisis in Yemen: Managing extreme water scarcity in the Middle East (Vol. 21). IB Tauris. ISBN: 9781780769202

Ward, F. & Michelsen, A. 2002, The economic value of water in agriculture: Concepts and policy applications, Water Policy, vol. 4, no. 5, pp. 423–46.

Water Authority 2019, Water Tariffs.

Water, U.N., 2009. The United Nations World Water Development Report 3–Water in a Changing World. United Nations Educational Scientific and Cultural Organization, Paris. UNESCO ISBN: 978-9-23104-095-5

Westerlund, J. & Wilhelmsson, F. 2011, Estimating the gravity model without gravity using panel data, Applied Economics, vol. 43, no. 6, pp. 641–9.

Westerlund, J. 2007, Testing for error correction in panel data, Oxford Bulletin of Economics and Statistics, vol. 69, no. 6, pp. 709–48.

WFP, 2011. Food Security in Libya – An Overview. World Food Programme, Regional Bureau for the Middle East, ODC.

Williams, R.B., Al-Hmoud, R., Segarra, E. & Mitchell, D. 2017, An estimate of the shadow price of water in the Southern Ogallala aquifer, Journal of Water Resource and Protection, vol. 09, no. 03, pp. 289–304.

Wodon, Q., Liverani, A., Joseph, G. and Bougnoux, N. eds., 2014. Climate change and migration: evidence from the Middle East and North Africa. World Bank Publications. Washington, DC. World Bank Group. ISBN: 978-0-8213-9971-2

World Bank 2018, Beyond Scarcity: Water Security in the Middle East and North Africa, MENA Deveopment Report, The World Bank, Washington, DC.

World Bank 2018, Beyond scarcity: Water security in the Middle East and North Africa, MENA Deveopment Report, The World Bank, Washington, DC.

World Bank, 2007. Making the Most of Scarcity: Accountability for better Water Management Results in the Middle East and North Africa. Washington D.C. ISBN-13: 978-0-8213-6926-5; https://doi.org/10.1596/978-0-8213-6925-8

World Bank, 2016a. World Development Indicators, World Bank Group. Retrieved from: http://data.worldbank.org/indicator/SP.POP.TOTL

World Bank, 2016b. World Development Indicators, World Bank Group. Retrieved from: http://data.worldbank.org/indicator/NY.GDP.MKTP.CD

World Bank, 2016c. World Development Indicators, World Bank Group. Retrieved from: http://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=EG-XQ

World Bank, 2016d. World Development Indicators, World Bank Group. Retrieved from: http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

World Economic Forum 2019, Global risks 2019 Insight report.

World Meteorology Organization 2007, The Dublin statement on water and sustainable development.

WWAP, U. 2019, United Nation World Water Development Report 2019: Leaving No One Behind.

Yang, J., Askari, H., Forrer, J. & Teegen, H. 2004, U.S. Economic Sanctions: An Empirical Study, International Trade Journal, vol. 18, no. 1, pp. 23–62.

Young, Robert, A. 1996, Measuring economic benefits for water investments and policies. The World Bank.

Young, Robert, A. 2005, Determining the economic value of water: concepts and methods, Resources for Future.

Zhang, X., Aguilar, E., Sensoy, S., Melkonyan, H., Tagiyeva, U., Ahmed, N., Kutaladze, N., Rahimzadeh, F., Taghipour, A., Hantosh, T.H. and Albert, P., 2005. Trends in Middle East climate extreme indices from 1950 to 2003. Journal of Geophysical Research: Atmospheres, 110(D22). https://doi:10.1029/2005JD006181

Zhang, Y., Block, P., Hammond, M. and King, A., 2015. Ethiopia's Grand Renaissance Dam: Implications for downstream riparian countries. Journal of Water Resources Planning and Management, 141(9), p.05015002. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000520

Ziolkowska, J.R. 2015, Shadow price of water for irrigation—A case of the High Plains, Agricultural Water Management, vol. 153, pp. 20–31.

Zittis, G., 2017. Observed rainfall trends and precipitation uncertainty in the vicinity of the Mediterranean, Middle East and North Africa. Theoretical and Applied Climatology, pp.1-24. https://doi.org/10.1007/s00704-017-2333-0

Zwinkels, R.C.J. & Beugelsdijk, S. 2010, Gravity equations: Workhorse or Trojan horse in explaining trade and FDI patterns across time and space?, International Business Review, vol. 19, no. 1, pp. 102–15, viewed 31 August 2019, <https://www.sciencedirect.com/science/article/abs/pii/S0969593109001176>.

APPENDIX A

Table A.1. Treatment and Substitution Countries

	ISO Code	List of countries involved in the diplomatic dispute	Time	N	Ref.
Treatment Countries	Group I	**Blockade**		4	
	BHR	Bahrain	5 Jun. 2017 - Present		[1]
	EGY	Egypt	“		“
	SAU	Saudi Arabia	“		“
	ARE	United Arab Emirates	“		“
	Group II	**Cut diplomatic ties**		6	
	TCD	Chad	Sept. 2017 - Mar. 2018		[2]
	COM	Comoros	5 Jun. 2017 - Present		[3]
	MRT	Mauritania	5 Jun. 2017 - Present		[4]
	MDV	Maldives	5 Jun. 2017 - Dec. 2018		[5]
	SEN	Senegal	5 Jun. 2017 - Sept. 2018		[6]
	YEM	Yemen	5 Jun. 2017 - Present		[7]
	Group III	**Downgrade diplomatic ties/Statement of**		5	
	DJI	Djibuti	5 Jun. 2017 - Present		[8]
	ERI	Eritrea	“		[9]
	GAB	Gabon	“		[10]
	JOR	Jordan	“		[11]
	NER	Niger	“		[12]
		Support resolution of the dispute		25	
Substitution Countries	DZA	Algeria	5 Jun. 2017 - Present		[13]
	CAN	Canada	“		[14]
	CHN	China	“		[15]
	ETH	Ethiopia	“		[16]
	FRA	France	“		[17]
	DEU	Germany	“		[18]
	GIN	Guinea	“		[19]
	IND	India	“		[20]
	IDN	Indonesia	“		[21]
	IRN	Iran	“		[22]
	ITA	Italy	“		[23]
	KWT	Kuwait	“		[24]
	MYS	Malaysia	“		[25]
	MAR	Morocco	“		[26]
	OMN	Oman	“		[27]
	PAK	Pakistan	“		[28]
	RUS	Russia	“		[29]
	SOM	Somalia	“		[30]
	SDN	Sudan	“		[31]
	CHE	Switzerland	“		[32]
	TUN	Tunisia	“		[33]
	TUR	Turkey	“		[34]

GBR	United Kingdom	“	[35]
VEN	Venezuela	“	[36]
USA	United States of America	“	[37]

Ref.	Source
[1]	https://www.gco.gov.qa/en/focus/gcc-crisis/
[2]	https://www.aa.com.tr/en/africa/chad-severs-diplomatic-ties-with-qatar/892347
[3]	https://www.spa.gov.sa/viewstory.php?lang=en&newsid=1638089
[4]	https://www.reuters.com/article/gulf-qatar-mauritania/mauritania-breaks-diplomatic-ties-with-qatar-idUSL8N1J3646 https://www.middleeastmonitor.com/20170607-mauritania-breaks-diplomatic-ties-with-qatar/
[5]	http://english.alarabiya.net/en/News/gulf/2017/06/05/Maldives-severs-diplomatic-ties-with-Qatar.html#
[6]	https://www.fragomen.com/insights/alerts/comoros-djibouti-mauritius-and-senegal-sever-diplomatic-ties-qatar; http://english.alarabiya.net/en/News/world/2017/06/07/Mauritania-becomes-eighth-country-severing-ties-with-Qatar.html
[7]	https://sputniknews.com/middleeast/201706051054312446-yemen-severs-diplomatic-relations-qatar/
[8]	https://africatimes.com/2017/06/08/gulf-crisis-djibouti-chad-latest-african-nations-to-create-distance-from-qatar/
[9]	http://awate.com/eritrea-might-sever-diplomatic-ties-with-qatar/
[10]	https://www.reuters.com/article/us-gulf-qatar-mauritania/mauritania-breaks-diplomatic-ties-with-qatar-gabon-voices-condemnation-idUSKBN18X2ZH
[11]	https://thepeninsulaqatar.com/article/06/06/2017/Jordan-downgrades-diplomatic-relations-with-Qatar https://www.khaleejtimes.com/region/qatar/jordan-downgrades-diplomatic-relations-with-qatar
[12]	https://www.khaleejtimes.com/region/qatar-crisis/niger-recalls-ambassador-to-qatar
[13]	https://www.mofa.gov.qa/en/all-mofa-news/details/2017/07/25/qatar's-ambassador-praises-algeria's-position-towards-gulf-crisis-as-honourable https://www.aa.com.tr/en/africa/algeria-calls-for-dialogue-to-resolve-qatar-row/835502
[14]	https://www.theglobeandmail.com/report-on-business/international-business/amid-qatar-boycott-canadian-firms-urged-to-consider-alternative-plans/article35240109/
[15]	https://af.reuters.com/article/energyOilNews/idAFL3N1J221D https://www.thepeninsulaqatar.com/article/31/03/2019/Chinese-official-calls-for-end-to-GCC-crisis https://www.scmp.com/week-asia/geopolitics/article/2149915/china-pillar-strength-qatars-fightback-against-arab-blockade
[16]	https://web.archive.org/web/20170619215539/http://www.awrambatimes.com/?p=16412
[17]	https://sputniknews.com/politics/201707151055568500-french-minister-qatar-mediation/ https://www.alaraby.co.uk/english/news/2017/7/15/france-offers-assistance-in-resolving-concerning-qatar-blockade
[18]	https://www.reuters.com/article/us-gulf-qatar-germany/germany-urges-diplomatic-solution-to-qatar-crisis-idUSKBN19010W
[19]	https://www.reuters.com/article/us-gulf-qatar-guinea/guineas-president-offers-to-mediate-in-gulf-crisis-idUSKBN19214I https://www.gulf-times.com/story/575705/Qatar-expands-ties-with-Ivory-Coast-Guinea
[20]	https://timesofindia.indiatimes.com/india/qatar-crisis-india-favours-constructive-dialogue/articleshow/59084917.cms
[21]	https://en.antaranews.com/news/111240/indonesia-calls-for-dialogue-over-qatar-rift-with-arab-states

https://www.thepeninsulaqatar.com/article/11/12/2018/Qatar-Indonesia-ties-%E2%80%98at-an-all-time-high%E2%80%99

[22] https://www.reuters.com/article/gulf-qatar-iran-dispute/iran-calls-on-gulf-arab-neighbours-to-resolve-dispute-through-dialogue-tv-idUSL1N1J20A6
https://www.rt.com/news/393644-iran-qatar-food-supply-blockade/
https://www.reuters.com/article/us-gulf-qatar-iran/qatar-says-its-ambassador-to-return-to-iran-foreign-ministry-idUSKCN1B32J6

[23] https://www.nytimes.com/2017/08/02/world/middleeast/qatar-buys-italian-warships-as-persian-gulf-crisis-deepens.html
https://www.reuters.com/article/us-gulf-qatar-italy/qatar-seals-5-billion-euro-navy-vessels-deal-with-italy-idUSKBN1AI1VS
https://www.alaraby.co.uk/english/news/2018/11/20/italy-stresses-need-for-dialogue-to-end-gulf-crisis

[24] https://www.aljazeera.com/news/2017/06/kuwait-qatar-ready-heal-gulf-rift-170611104242520.html
https://www.gulf-times.com/story/578457/Gulf-crisis-UN-official-supports-Kuwaiti-mediation

[25] https://www.thestar.com.my/news/nation/2017/06/30/neutral-malaysia-hopes-to-mediate-qatar-crisis/

[26] https://www.aljazeera.com/news/2017/06/morocco-offers-mediate-qatar-gcc-crisis-170611190417048.html

[27] https://www.mei.edu/publications/kuwait-oman-and-qatar-crisis
https://www.aljazeera.com/news/2017/11/oman-stance-qatar-gulf-crisis-171125061013462.html
https://timesofoman.com/article/111419/Oman/Transport/More-Oman-Air-flights-to-Qatar

[28] https://www.dawn.com/news/1338258/middle-east-diplomatic-crisis-lawmakers-pass-resolution-in-na-urging-restraint

[29] https://www.aljazeera.com/indepth/opinion/2017/06/russia-gcc-crisis-170613073826800.html

[30] https://www.gulf-times.com/story/562101/Somalia-says-no-to-Saudi-offer-stands-by-Qatar
https://allafrica.com/stories/201706080163.html

[31] https://www.thepeninsulaqatar.com/article/08/06/2017/Sudan-hails-Qatar-s-positions-in-support-of-peace,-stability
https://m.news24.com/Africa/News/sudan-urges-reconciliation-to-end-gulf-row-with-qatar-20170606
https://www.middleeastmonitor.com/20170606-sudan-appeals-for-calm-between-qatar-and-gulf/

[32] https://www.thepeninsulaqatar.com/article/31/03/2018/Switzerland-backs-Kuwaiti-efforts-to-resolve-Gulf-crisis

[33] https://carnegieendowment.org/sada/67703

[34] https://www.reuters.com/article/us-gulf-qatar-turkey-idUSKBN18W19Z
https://www.reuters.com/article/us-gulf-qatar-turkey-saudi/turkey-sends-qatar-food-and-soldiers-discusses-gulf-tensions-with-saudi-idUSKBN19D0CX

[35] https://www.aljazeera.com/news/2017/07/uk-welcomes-qatar-call-gulf-crisis-talks-170723144805446.html

[36] https://www.gulf-times.com/story/622922/Venezuela-rejects-unjust-blockade-against-Qatar

[37] https://www.cnbc.com/2017/06/05/tillerson-says-break-with-qatar-by-saudi-arabia-others-wont-affect-counter-terrorism.html
https://www.reuters.com/article/us-gulf-qatar-usa-pentagon-idUSKBN18X2G2
https://edition.cnn.com/2017/06/07/politics/trump-qatar-call/index.html
https://www.reuters.com/article/us-gulf-qatar-usa/trump-offers-to-mediate-talks-on-qatar-crisis-idUSKCN1BI2SG

Table A.2. Trade Economic Zones

Economic Zones	List of Countries	N
Gulf Cooperation Council	Qatar, Kingdom of Saudi Arabia, United Arab Emirates, Oman, Bahrain and Kuwait.	6
Other Arab Countries	Iraq, Syria, Lebanon, Jordan, Palestine, Yemen, Egypt, Libya, Tunisia, Algeria, Morocco, Mauritania, Sudan, Somalia, Comoro Islands and Djibouti.	16
Asia	Japan, South Korea, Democratic Republic of Korea, China, Taiwan, Hong Kong, Vietnam, Thailand, Cambodia, Philippines, Singapore, Malaysia, Maldives, Indonesia, Bangladesh, India, Sri Lanka, Pakistan, Azerbaijan, Kazakhstan, Armenia, Tajikistan, Turkmenistan, Afghanistan, Uzbekistan, Iran, Myanmar, Nepal, Laos, Bhutan, New Guinea, Brunei Darussalam, Georgia, Macau, Turkey and Kyrgyzstan.	35
European Union	Austria, Belgium, Bulgaria, Cyprus, Czech, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Gibraltar, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and United Kingdom.	28
Other European Countries	Albania, Belarus, Bosnia and Herzegovina, Croatia, Iceland, Liechtenstein, Macedonia, Moldova, Norway, Russia, Switzerland, and Ukraine.	12
United States of America	United States of America	1
Other American Countries	Canada, Mexico, Panama, Cuba, Guatemala, Costa Rica, Honduras, Salvador, Ecuador, Bolivia, Venezuela, Brazil, Uruguay, Paraguay, Peru, Chile, Argentina, Dominican, Colombia, Trinidad and Tobago, Aruba, Antilles Islands, Jamaica, Puerto Rico, Antigua and Barbuda.	25
Africa except Arab Countries	Mali, Ivory Coast, Ghana, Nigeria, Cameroon, Gabon, Sierra Leone, Zambia, Democratic Republic of Congo, Lesotho, Zimbabwe, Madagascar, Botswana, Swaziland, Malawi, Tanzania, Kenya, Ethiopia, Uganda, Liberia, Namibia, South Africa, Niger, Angola, Mauritius, Senegal, Mozambique, Eritrea, Togo, Burundi, Guinea, Guinea Bissau, Cape Verde, Republic of Chad and Zaire.	35
Oceania	Australia, Tonga, Fiji, New Zealand, Seychelles, New Caledonia and Nauru.	7
Total		165

Table A.3. Product - Level Classification

Imports/Exports		
Macro-Category	HS2	Product Description
Animal	01, 02, 03, 16, 05	Live animals and animal products other than dairy (edible)
Crop	06, 07,08 ,09, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24	Vegetable products and crop derivatives (edible)
Dairy	04	Birds' eggs, natural honey, edible products of animal origin
Mineral	25, 26, 27	Salt, Sulphur, earth, stone, plastering materials, lime and cement, ores, slag and ash, mineral fuels, oils and products of their distillation, bituminous substances, mineral waxes
Others	28-97	Chemicals and allied industries, plastics/rubbers, raw hides, skins, leather and furs, wood and wood products, textiles, footwear, stone/glass, metals, machinery/electrical, transportation, miscellaneous.

Stationarity Test

The most recent developments in trade policy analysis strongly encourage the use of panel data, when available. In general, panel data improve the estimation efficiency and enable the use of fixed effects (country-pair and time), which in turn solve some of the challenges of the estimation, as described in Section 3.3. At the same time, panel data, similarly to time-series, are not exempt from the econometric issues related to the non-stationarity of the variables that compose the set of data (Baltagi 1995; Engle & Granger 1987; Hayashi 2000). Non-stationary data present mean, variance and covariance that change over time and thus the regression results obtained from the use of time series can be spurious and may falsely indicate the existence of a relationship between two variables. Typical non-stationary data are asset prices, exchange rates, GDPs or trade values. Since the latter are usually the main regressors used in the gravity model estimation, ignoring this issue may lead to inconsistent results and interpretation of the trade policy (Baldwin & Taglioni 2006; Egger & Pfaffermayr 2003; Faruquee 2004; Fidrmuc 2009; Helmut 2003; Pauwels, Chan & Mancini Griffoli 2012; Zwinkels & Beugelsdijk 2010). It is also worth noticing that, as demonstrated by Fidrmuc (2009), the simple fixed-effect model performs relatively well in comparison with panel co-integration techniques, as fully modified OLS suggested by Pedroni (1996, 2000) or dynamic OLS proposed by Kao & Chiang (2000). Therefore, I expect that the potential bias due to non-stationarity should be reasonably small. Furthermore, as confirmed also by Zwinkels & Beugelsdijk (2010) macroeconomic variables like GDP and trade present very slow time-trends. Consequently, the problem of non-stationarity is less of an issue when using a short time series, such as in this case study. This notwithstanding, in order to align this work with the most recent econometric literature on panel data and gravity I run all the tests required for testing the stationarity on my variables' regressions.

In order to identify the appropriate panel unit root tests is necessary to verify some characteristics of the variables of interest (Hurlin & Mignon 2007). This initial step is based on checking if the assumption of cross-sectional independence holds, i.e. if the observations across individuals are independent, as in the case of the first generation of panel unit root tests (Im, K. S., Pesaran, M. H. and Smith 1996; Maddala & Wu 1999; Hadri 2000; Choi 2001; Levin, Lin & James Chu 2002; Im, Pesaran & Shin 2003). More recently, the literature on non-stationary panels observed that such assumption is unlikely to hold for many datasets (De Hoyos & Sarafidis 2006; Phillips & Sul 2003) and moved towards the elaboration of a new set of tests that allow for cross-sectional dependence, or better, that relax the assumption on cross-sectional independence (Bai & Ng 2001; Moon & Perron 2004; Pesaran 2007).

Therefore, I first perform the Pesaran (2004) Cross-section Dependence (CD) test on my variables of interest. This test considers panel data with both large and small T, as well as balanced or unbalanced panels. Furthermore, it is robust to structural breaks in the slope coefficients and in the error variances of the individual regressions. The results of the test are reported in Table A.4 for imports and Table A.5 for exports. In both cases, I can strongly reject the null hypothesis of cross-sectional independence for the panel and observe the presence of cross-sectional dependence among the variables.

Table A.4: Pre-estimation Test on Cross-section Correlation - Imports

Variables (in logs)	CD Test	p-value	Average correlation coefficient	Absolute correlation coefficient
GDP	210.138	0.000	0.35	0.54
Imports	130.435	0.000	0.21	0.26

Note: I report the average and absolute correlation coefficient across N × (N-1) pairs of correlation. CD returns the Pesaran (2004) cross-section dependence statistic, distributed as a normal function (CD ~N (0, 1), and tests the null hypothesis of cross-section independence. I use the STATA routine xtcfd.

Table A.5: Pre-estimation Test on Cross-section Correlation – Exports

Variables (in logs)	CD Test	p-value	Average correlation coefficient	Absolute correlation coefficient
GDP	109.757	0.000	0.31	0.51
Export	24.574	0.000	0.07	0.18

Note: I report the average and absolute correlation coefficient across N × (N-1) pairs of correlation. CD returns the Pesaran (2004) cross-section dependence statistic, distributed as a normal function (CD ~N (0, 1), and tests the null hypothesis of cross-section independence. I use the STATA routine xtcfd.

When a series is stationary, it is also said to be integrated of order 0, which corresponds to the minimum number of differences needed to get a stationary series. Panel unit root tests are the tools employed to verify for stationarity, and if the presence of a unit root is identified, then the series is defined to be non-stationary. However, even if a series is confirmed to be non-stationary, it is still possible to run the regression consistently if a linear combination with another of the regressors is stationary, i.e. the series is co-integrated, and therefore a long-run equilibrium between the economic series exists. This last step is tested through different co-integration tests, which are based on the residuals and consider either the no co-integration option as its null hypothesis (Engle et al. 1987; Phillips & Ouliaris 1990; Pedroni 2004) or are based on error correction models (Westerlund 2007). Given the results of the CD test, which also determines the choice of the panel unit root tests to be used, I can apply the Pesaran (2007) test. This test is based on the mean of individual ADF t-statistics of each unit in the panel. It eliminates cross-sectional dependence by augmenting the ADF regression with the lagged cross-sectional mean and its first differences of the individual series (CADF statistics) to capture CD by a single factor model. Following Hoechle (2007), I select the ideal lag length using (Newey & West 1994) plug-in procedure with the resulting optimal lag-length equal to $4 * (T/100)^{2/9} \approx 3$, which indicates a lag bandwidth of [0, 4]. The results of the Pesaran (2007) test are presented in Table A.6 and Table A.7 for imports and exports respectively. For GDP, the null hypothesis about the existence of unit root in levels cannot be rejected. After the variable is differentiated, it becomes stationary, i.e. I can reject the null hypothesis about the unit root and the obtained result is statistically significant. Conversely, the results on the import and export values reject the null hypothesis of unit root already in levels.

Table A.6: Pesaran (2007) Panel Unit Root Test GDP- Imports

	Levels				First Differences			
	Without Trend		With Trend		without trend		With trend	
	Z[t-bar]	p-value	Z[t-bar]	p-value	Z[t-bar]	p-value	Z[t-bar]	p-value
LnGDP								
Lag 0	4.479	1.000	3.152	0.999	-44.050	0.000	-44.142	0.000
Lag 1	4.252	1.000	3.181	0.999	-43.944	0.000	-44.021	0.000
Lag 2	3.984	1.000	3.202	0.999	-40.162	0.000	-39.192	0.000
Lag 3	3.663	1.000	3.210	0.999	-32.690	0.000	-31.287	0.000
Lag 4	3.273	0.999	3.197	0.999	-27.585	0.000	-26.198	0.000
LnImport								
Lag 0	-39.818	0.000	-40.454	0.000				
Lag 1	-29.885	0.000	-31.817	0.000				
Lag 2	-20.870	0.000	-22.090	0.000				
Lag 3	-16.351	0.000	-17.295	0.000				
Lag 4	-12.364	0.000	-13.472	0.000				

Note: The null hypothesis is that the variable is I(1). I use the standard STATA routine pescadf with and without trend.

Table A.7: Pesaran (2007) Panel Unit Root Test GDP- Exports

	Levels				First Differences			
	Without Trend		With Trend		Without Trend		With Trend	
	Z[t-bar]	p-value	Z[t-bar]	p-value	Z[t-bar]	p-value	Z[t-bar]	p-value
LnGDP								
Lag 0	3.738	1.000	1.602	0.945	-33.846	0.000	-34.241	0.000
Lag 1	3.579	1.000	1.638	0.949	-33.705	0.000	-34.066	0.000
Lag 2	3.390	1.000	1.677	0.953	-30.630	0.000	-29.588	0.000
Lag 3	3.165	0.999	1.716	0.957	-24.933	0.000	-23.404	0.000
Lag 4	2.892	0.998	1.753	0.960	-21.070	0.000	-19.382	0.000
LnExport								
Lag 0	-28.935	0.000	-31.147	0.000				
Lag 1	-20.010	0.000	-23.497	0.000				
Lag 2	-12.910	0.000	-15.671	0.000				
Lag 3	-9.928	0.000	-12.324	0.000				
Lag 4	-6.929	0.000	-8.944	0.000				

Note: The null hypothesis is that the variable is I(1). I use the standard STATA routine pescadf with and without trend.

After finding that GDP is a non-stationary variable, while both trade variables are stationary, I can still conduct the panel co-integration test to check whether there is a linear combination between our variables of interests, i.e. whether they are co-integrated. I use the Pedroni (2004) co-integration test, which allows testing for co-integration with one or more non-stationary variables. Furthermore, the combination I(0) and I(1), accordingly to Engle & Granger (1987) is a special case of co-integration that can be consistently tested. Table A.8 and Table A.9 report the results of these tests for both imports and exports, with the null hypothesis stating that co-integration is not present. For all combinations between GDP and imports and exports, I find that the null hypothesis is rejected at the .01 significance level, which suggests that co-integration is present in our data. Given this result, a long-run relationship between the variables in the model holds and thus I can proceed with my estimations.

Table A.8: Pedroni Panel Co-integration Test: GDP-Imports

Statistics	Trend	No Trend	
	Panel Co-integration Statistics		p-value
Panel v	20.49	30.07	0.000
Panel rho	-104.2	-105.7	0.000
Panel PP	-66.21	-52.72	0.000
Panel ADF	-47.55	-32.21	0.000
	Group Mean Co-integration Statistics		p-value
Panel rho	-94.78	-108.9	0.000
Panel PP (t)	-72.24	-63.46	0.000
Panel ADF	-48.14	-35.26	0.000

Table A.9: Pedroni Panel Co-integration Test: GDP-Exports

Statistics	Trend	No trend	
	Panel Co-integration Statistics		p-value
Panel v	15.92	25.68	0.000
Panel rho	-81.33	-89.18	0.000
Panel PP	-49.66	-42.46	0.000
Panel ADF	-30.38	-22.97	0.000
	Group Mean Co-integration Statistics		p-value
Panel rho	-71.32	-84.96	0.000
Panel PP	-52.54	-49.16	0.000
Panel ADF	-28.79	-24.51	0.000

Table A.10. Water Footprint Categories

HS-4	Description	Cat.	Category Name
0101	Horses, asses, mules and hinnies; live	1	Livestock
0102	Bovine animals; live	1	Livestock
0103	Swine; live	1	Livestock
0104	Sheep and goats; live	1	Livestock
0105	Poultry; live, fowls of the species Gallus domesticus, ducks, geese, turkeys and guinea fowls	1	Livestock
0106	Animals; live, n.e.c. in chapter 01	1	Livestock
0201	Meat of bovine animals; fresh or chilled	2	Animal Products
0202	Meat of bovine animals; frozen	2	Animal Products
0203	Meat of swine; fresh, chilled or frozen	2	Animal Products
0204	Meat of sheep or goats; fresh, chilled or frozen	2	Animal Products
0205	Meat; of horses, asses, mules or hinnies, fresh, chilled or frozen	2	Animal Products
0206	Edible offal of bovine animals, swine, sheep, goats, horses, asses, mules or hinnies; fresh, chilled or frozen	2	Animal Products
0207	Meat and edible offal of poultry; of the poultry of heading no. 0105, (i.e. fowls of the species Gallus domesticus), fresh, chilled or frozen	2	Animal Products
0208	Meat and edible meat offal, n.e.c. in chapter 2; fresh, chilled or frozen	2	Animal Products
0209	Pig fat, free of lean meat, and poultry fat, not rendered or otherwise extracted, fresh, chilled, frozen, salted, in brine, dried or smoked	2	Animal Products
0210	Meat and edible meat offal; salted, in brine, dried or smoked; edible flours and meals of meat or meat offal	2	Animal Products
0301	Fish; live	3	Fish
0302	Fish; fresh or chilled, excluding fish fillets and other fish meat of heading 0304	3	Fish
0303	Fish; frozen, excluding fish fillets and other fish meat of heading 0304	3	Fish
0304	Fish fillets and other fish meat (whether or not minced); fresh, chilled or frozen	3	Fish
0305	Fish, dried, salted or in brine; smoked fish, whether or not cooked before or during the smoking process; flours, meals and pellets of fish, fit for human consumption	3	Fish
0306	Crustaceans; in shell or not, live, fresh, chilled, frozen, dried, salted or in brine; smoked, cooked or not before or during smoking; in shell, steamed or boiled, whether or not chilled, frozen, dried, salted or in brine; edible flours, meals, pellets	3	Fish
0307	Molluscs; whether in shell or not, live, fresh, chilled, frozen, dried, salted or in brine; smoked molluscs, whether in shell or not, cooked or not before or during the smoking process; flours, meals and pellets of molluscs, fit for human consumption	3	Fish
0308	Aquatic invertebrates, other than crustaceans and molluscs; live, fresh, chilled, frozen, dried, salted or in brine, smoked, whether or not cooked before or during the smoking process; flours, meals, and pellets, fit for human consumption	3	Fish

0401	Milk and cream; not concentrated, not containing added sugar or other sweetening matter	4	Dairy and Eggs
0402	Milk and cream; concentrated or containing added sugar or other sweetening matter	4	Dairy and Eggs
0403	Buttermilk, curdled milk and cream, yoghurt, kephir, fermented or acidified milk or cream, whether or not concentrated, containing added sugar, sweetening matter, flavoured or added fruit or cocoa	4	Dairy and Eggs
0404	Whey and products consisting of natural milk constituents; whether or not containing added sugar or other sweetening matter, not elsewhere specified or included	4	Dairy and Eggs
0405	Butter and other fats and oils derived from milk; dairy spreads	4	Dairy and Eggs
0406	Cheese and curd	4	Dairy and Eggs
0407	Birds' eggs, in shell; fresh, preserved or cooked	4	Dairy and Eggs
0408	Birds' eggs, not in shell; egg yolks, fresh, dried, cooked by steaming or boiling in water, moulded, frozen or otherwise preserved, whether or not containing added sugar or other sweetening matter	4	Dairy and Eggs
0409	Honey; natural	2	Animal Products
0410	Edible products of animal origin; not elsewhere specified or included	2	Animal Products
0701	Potatoes; fresh or chilled	5	Vegetables Fruit Legumes and derivatives
0702	Tomatoes; fresh or chilled	5	Vegetables Fruit Legumes and derivatives
0703	Onions, shallots, garlic, leeks and other alliaceous vegetables; fresh or chilled	5	Vegetables Fruit Legumes and derivatives
0704	Cabbages, cauliflowers, kohlrabi, kale and similar edible brassicas; fresh or chilled	5	Vegetables Fruit Legumes and derivatives
0705	Lettuce (lactuca sativa) and chicory (cichorium spp.) fresh or chilled	5	Vegetables Fruit Legumes and derivatives
0706	Carrots, turnips, salad beetroot, salsify, celeriac, radishes and similar edible roots; fresh or chilled	5	Vegetables Fruit Legumes and derivatives
0707	Cucumbers and gherkins; fresh or chilled	5	Vegetables Fruit Legumes and derivatives
0708	Leguminous vegetables; shelled or unshelled, fresh or chilled	5	Vegetables Fruit Legumes and derivatives
0709	Vegetables; n.e.c. in chapter 07, fresh or chilled	5	Vegetables Fruit Legumes and derivatives

0710	Vegetables (uncooked or cooked by steaming or boiling in water); frozen	5	Vegetables Fruit Legumes and derivatives
0711	Vegetables provisionally preserved; (e.g. by sulphur dioxide gas, in brine, in sulphur water or in other preservative solutions), but unsuitable in that state for immediate consumption	5	Vegetables Fruit Legumes and derivatives
0712	Vegetables, dried; whole, cut, sliced, broken or in powder, but not further prepared	5	Vegetables Fruit Legumes and derivatives
0713	Vegetables, leguminous; shelled, whether or not skinned or split, dried	5	Vegetables Fruit Legumes and derivatives
0714	Manioc, arrowroot, salep, Jerusalem artichokes, sweet potatoes and similar roots and tubers with high starch or inulin content; fresh, chilled, frozen or dried, whether or not sliced or in the form of pellets; sago pith	5	Vegetables Fruit Legumes and derivatives
0801	Nuts, edible; coconuts, Brazil nuts and cashew nuts, fresh or dried, whether or not shelled or peeled	5	Vegetables Fruit Legumes and derivatives
0802	Nuts (excluding coconuts, Brazils and cashew nuts); fresh or dried, whether or not shelled or peeled	5	Vegetables Fruit Legumes and derivatives
0803	Bananas, including plantains; fresh or dried	5	Vegetables Fruit Legumes and derivatives
0804	Dates, figs, pineapples, avocados, guavas, mangoes and mangosteens; fresh or dried	5	Vegetables Fruit Legumes and derivatives
0805	Citrus fruit; fresh or dried	5	Vegetables Fruit Legumes and derivatives
0806	Grapes; fresh or dried	5	Vegetables Fruit Legumes and derivatives
0807	Melons (including watermelons) and papaws (papayas); fresh	5	Vegetables Fruit Legumes and derivatives
0808	Apples, pears and quinces; fresh	5	Vegetables Fruit Legumes and derivatives
0809	Apricots, cherries, peaches (including nectarines), plums and sloes, fresh	5	Vegetables Fruit Legumes and derivatives
0810	Fruit, fresh; n.e.c. in chapter 08	5	Vegetables Fruit Legumes and derivatives

0811	Fruit and nuts; uncooked or cooked by steaming or boiling in water, frozen, whether or not containing added sugar or other sweetening matter	5	Vegetables Fruit Legumes and derivatives
0812	Fruit and nuts provisionally preserved; e.g. by sulphur dioxide gas, brine, in sulphur water or in other preservative solutions, but unsuitable in that state for immediate consumption	5	Vegetables Fruit Legumes and derivatives
0813	Fruit, dried, other than that of heading no. 0801 to 0806; mixtures of nuts or dried fruits of this chapter	5	Vegetables Fruit Legumes and derivatives
0814	Peel of citrus fruit or melons (including watermelons); fresh, frozen dried or provisionally preserved in brine, in sulphur water or in other preservative solutions	5	Vegetables Fruit Legumes and derivatives
0901	Coffee, whether or not roasted or decaffeinated; husks and skins; coffee substitutes containing coffee in any proportion	9	Others
0902	Tea	9	Others
0903	Mate	9	Others
0904	Pepper of the genus piper; dried or crushed or ground fruits of the genus capsicum or of the genus pimenta	9	Others
0905	Vanilla	9	Others
0906	Cinnamon and cinnamon-tree flowers	9	Others
0907	Cloves (whole fruit, cloves and stems)	9	Others
0908	Nutmeg, mace and cardamoms	9	Others
0909	Seeds of anise, badian, fennel, coriander, cumin, caraway or juniper	9	Others
0910	Ginger, saffron, tumeric (curcuma), thyme, bay leaves, curry and other spices	9	Others
1001	Wheat and meslin	6	Cereals and derivatives
1002	Rye	6	Cereals and derivatives
1003	Barley	6	Cereals and derivatives
1004	Oats	6	Cereals and derivatives
1005	Maize (corn)	6	Cereals and derivatives
1006	Rice	6	Cereals and derivatives
1007	Grain sorghum	6	Cereals and derivatives
1008	Buckwheat, millet and canary seeds; other cereals	6	Cereals and derivatives
1101	Wheat or meslin flour	6	Cereals and derivatives
1102	Cereal flours; other than of wheat or meslin	6	Cereals and derivatives

1103	Cereal groats; meal and pellets	6	Cereals and derivatives
1104	Cereal grains otherwise worked (e.g. hulled, rolled, flaked, pearled, sliced or kibbled) except rice of heading no. 1006; germ of cereals whole, rolled, flaked or ground	6	Cereals and derivatives
1105	Flour, meal, powder, flakes, granules and pellets of potatoes	6	Cereals and derivatives
1106	Flour, meal and powder; of the dried leguminous vegetables of heading no. 0713, of sago or of roots or tubers of heading no. 0714 or of the products of chapter 8	6	Cereals and derivatives
1107	Malt; whether or not roasted	6	Cereals and derivatives
1108	Starches; inulin	6	Cereals and derivatives
1109	Wheat gluten; whether or not dried	6	Cereals and derivatives
1201	Soya beans, whether or not broken	5	Vegetables Fruit Legumes and derivatives
1202	Ground-nuts; not roasted or otherwise cooked, whether or not shelled or broken	5	Vegetables Fruit Legumes and derivatives
1203	Copra	7	Oilcrops and oils
1204	Oil seeds; linseed, whether or not broken	7	Oilcrops and oils
1205	Rape or colza seeds; whether or not broken	7	Oilcrops and oils
1206	Sunflower seeds; whether or not broken	7	Oilcrops and oils
1207	Oil seeds and oleaginous fruits, n.e.c. in chapter 12; whether or not broken	7	Oilcrops and oils
1208	Flours and meals of oil seeds or oleaginous fruits; other than those of mustard	7	Oilcrops and oils
1209	Seeds, fruit and spores; of a kind used for sowing	7	Oilcrops and oils
1210	Hop cones, fresh or dried, whether or not ground, powdered or in the form of pellets; lupulin	7	Oilcrops and oils
1212	Locust beans, seaweeds and other algae, sugar beet, sugar cane, fresh, chilled, frozen or dried, whether or not ground; fruit stones, kernels and other vegetable products (including unroasted chicory roots) used primarily for human consumption, n.e.c.	5	Vegetables Fruit Legumes and derivatives
1213	Cereal straw and husks, unprepared; whether or not chopped, ground, pressed or in the form of pellets	8	Green Fodders
1214	Swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets	8	Green Fodders
1301	Lac; natural gums, resins, gum-resins and oleoresins (for example, balsams)	5	Vegetables Fruit Legumes and derivatives

1302	Vegetable saps and extracts; pectic substances, pectinates and pectates; agar-agar and other mucilages and thickeners, whether or not modified, derived from vegetable products	5	Vegetables Fruit Legumes and derivatives
1501	Pig fat (including lard) and poultry fat, other than that of heading 0209 or 1503	2	Animal Products
1502	Fats of bovine animals, sheep or goats, other than those of heading 1503	2	Animal Products
1503	Lard stearin, lard oil, oleostearin, oleo-oil and tallow oil; not emulsified or mixed or otherwise prepared	2	Animal Products
1504	Fats and oils and their fractions of fish or marine mammals; whether or not refined, but not chemically modified	2	Animal Products
1505	Wool grease and fatty substances derived therefrom (including lanolin)	2	Animal Products
1506	Animal fats and oils and their fractions; whether or not refined, but not chemically modified, n.e.c. in chapter 15	2	Animal Products
1507	Soya-bean oil and its fractions; whether or not refined, but not chemically modified	7	Oilcrops and oils
1508	Ground nut oil and its fractions; whether or not refined, but not chemically modified	7	Oilcrops and oils
1509	Olive oil and its fractions; whether or not refined, but not chemically modified	7	Oilcrops and oils
1510	Oils and their fractions n.e.c. in chapter 15, obtained solely from olives, whether or not refined, but not chemically modified, including blends of these oils or fractions with oils or fractions of heading no. 1509	7	Oilcrops and oils
1511	Palm oil and its fractions; whether or not refined, but not chemically modified	7	Oilcrops and oils
1512	Sun-flower seed, safflower or cotton-seed oil and their fractions; whether or not refined, but not chemically modified	7	Oilcrops and oils
1513	Coconut (copra), palm kernel or babassu oil and their fractions; whether or not refined but not chemically modified	7	Oilcrops and oils
1514	Rape, colza or mustard oil and their fractions; whether or not refined, but not chemically modified	7	Oilcrops and oils
1515	Fixed vegetable fats and oils (including jojoba oil) and their fractions, whether or not refined; but not chemically modified	7	Oilcrops and oils
1516	Animal or vegetable fats and oils and their fractions; partly or wholly hydrogenated, inter-esterified, re-esterified or elaidinised, whether or not refined, but not further prepared	7	Oilcrops and oils
1517	Margarine; edible mixtures or preparations of animal or vegetable fats or oils or of fractions of different fats or oils of this chapter, other than edible fats or oils of heading no. 1516	7	Oilcrops and oils
1518	Animal or vegetable fats, oils, fractions, modified in any way, excluding heading no. 1516; inedible versions of animal or vegetable fats, oils or fractions of this chapter, n.e.c. or included	7	Oilcrops and oils
1601	Sausages and similar products of meat, meat offal or blood; food preparations based on these products	2	Animal Products
1602	Prepared or preserved meat, meat offal or blood	2	Animal Products
1603	Extracts and juices of meat, fish or crustaceans, molluscs or other aquatic invertebrates	3	Fish

1604	Prepared or preserved fish; caviar and caviar substitutes prepared from fish eggs	3	Fish
1605	Crustaceans, molluscs and other aquatic invertebrates, prepared or preserved	3	Fish
1701	Cane or beet sugar and chemically pure sucrose, in solid form	5	Vegetables Fruit Legumes and derivatives
1702	Sugars, including lactose, maltose, glucose or fructose in solid form; sugar syrups without added flavouring or colouring matter; artificial honey, whether or not mixed with natural honey; caramel	5	Vegetables Fruit Legumes and derivatives
1703	Molasses; resulting from the extraction or refining of sugar	5	Vegetables Fruit Legumes and derivatives
1704	Sugar confectionery (including white chocolate), not containing cocoa	5	Vegetables Fruit Legumes and derivatives
1801	Cocoa beans; whole or broken, raw or roasted	5	Vegetables Fruit Legumes and derivatives
1802	Cocoa; shells, husks, skins and other cocoa waste	5	Vegetables Fruit Legumes and derivatives
1803	Cocoa; paste; whether defatted	5	Vegetables Fruit Legumes and derivatives
1804	Cocoa; butter, fat and oil	5	Vegetables Fruit Legumes and derivatives
1805	Cocoa; powder, not containing added sugar or other sweetening matter	5	Vegetables Fruit Legumes and derivatives
1806	Chocolate and other food preparations containing cocoa	5	Vegetables Fruit Legumes and derivatives
1901	Malt extract; flour/groats/meal/starch/malt extract products, no cocoa (or less than 40% by weight) and food preparations of goods of headings 04.01 to 04.04, no cocoa (or less than 5% by weight), weights calculated on a totally defatted basis, n.e.c.	10	Processed Food
1902	Pasta; whether cooked or stuffed with meat or other substance, or otherwise prepared, egg spaghetti, macaroni, noodles, lasagne, gnocchi, ravioli, cannelloni; couscous, whether or not prepared	10	Processed Food
1903	Tapioca and substitutes therefor prepared from starch; in the form of flakes, grains, pearls, siftings or similar forms	10	Processed Food
1904	Prepared foods obtained by swelling or roasting cereals or cereal products (e.g. corn flakes); cereals (other than maize (corn)) in grain form or in the form of flakes or other worked grains (not flour and meal), pre-cooked or otherwise prepared, n.e.c.	10	Processed Food

1905	Bread, pastry, cakes, biscuits, other bakers' wares, whether or not containing cocoa; communion wafers, empty cachets suitable for pharmaceutical use, sealing wafers, rice paper and similar products	10	Processed Food
2001	Vegetables, fruit, nuts and other edible parts of plants; prepared or preserved by vinegar or acetic acid	10	Processed Food
2002	Tomatoes; prepared or preserved otherwise than by vinegar or acetic acid	10	Processed Food
2003	Mushrooms and truffles, prepared or preserved other than by vinegar or acetic acid	10	Processed Food
2004	Vegetables preparations n.e.c.; prepared or preserved otherwise than by vinegar or acetic acid, frozen, other than products of heading no. 2006	10	Processed Food
2005	Vegetables preparations n.e.c.; prepared or preserved otherwise than by vinegar or acetic acid, not frozen, other than products of heading no. 2006	10	Processed Food
2006	Vegetables, fruit, nuts, fruit-peel and other parts of plants, preserved by sugar (drained, glace or crystallised)	10	Processed Food
2007	Jams, fruit jellies, marmalades, fruit or nut puree and fruit or nut pastes, being cooked preparations; whether or not containing added sugar or other sweetening matter	10	Processed Food
2008	Fruit, nuts and other edible parts of plants; prepared or preserved in ways n.e.c., whether containing added sugar or other sweetening matter or spirit, not elsewhere specified or included	10	Processed Food
2009	Fruit juices (including grape must) and vegetable juices, unfermented, not containing added spirit; whether containing added sugar or other sweetening matter	5	Vegetables Fruit Legumes and derivatives
2101	Extracts, essences, concentrates of coffee, tea or mate; preparations with a basis of these products or with a basis of coffee, tea or mate; roasted chicory and other roasted coffee substitutes and extracts, essences and concentrates thereof	9	Others
2102	Yeasts (active or inactive); other single-cell micro-organisms, dead (but not including vaccines of heading no. 3002); prepared baking powders	9	Others
2103	Sauces and preparations therefor; mixed condiments and mixed seasonings, mustard flour and meal and prepared mustard	10	Processed Food
2104	Soups and broths and preparations therefor; homogenised composite food preparations	10	Processed Food
2105	Ice cream and other edible ice; whether containing cocoa	10	Processed Food
2106	Food preparations not elsewhere specified or included	10	Processed Food
2201	Waters, including natural or artificial mineral waters and aerated waters, not containing added sugar or other sweetening matter nor flavoured; ice and snow	9	Others
2202	Waters, including mineral and aerated waters, containing added sugar or sweetening matter, flavoured; other non-alcoholic beverages, not including fruit or vegetable juices of heading no. 2009	9	Others
2203	Beer made from malt	9	Others

2204	Wine of fresh grapes, including fortified wines; grape must other than that of heading no. 2009	9	Others
2205	Vermouth and other wine of fresh grapes, flavoured with plants or aromatic substances	9	Others
2206	Fermented beverages, n.e.c. in chapter 22; (e.g. cider, perry, mead, sake)	9	Others
2207	Ethyl alcohol, undenatured; of an alcoholic strength by volume of 80% vol. or higher; ethyl alcohol and other spirits, denatured, of any strength	9	Others
2208	Ethyl alcohol, undenatured; of an alcoholic strength by volume of less than 80% volume; spirits, liqueurs and other spirituous beverages	9	Others
2209	Vinegar and substitutes for vinegar obtained from acetic acid	9	Others

APPENDIX B

Table B.1. Crop Categories with Corresponding FAOSTAT Codes

Item Group	Item Code	Item
Cereals	44	Barley
	89	Buckwheat
	101	Canary seed
	108	Cereals nes
	94	Fonio
	103	Grain mixed
	56	Maize
	79	Millet
	75	Oats
	92	Quinoa
	27	Rice paddy
	71	Rye
	83	Sorghum
	97	Triticale
	15	Wheat
Citrus Fruit	512	Fruit citrus nes
	507	Grapefruit (inc. pomelos)
	497	Lemons and limes
	490	Oranges
	495	Tangerines mandarins clementines satsumas
Coffee and Tea	656	Coffee Green
	667	Tea
Fibre Crops Primary	800	Agave fibres nes
	782	Bastfibres other
	767	Cotton lint
	821	Fibre crops nes
	773	Flax fibre and tow
	777	Hemp tow waste
	780	Jute
	310	Kapok fruit
	809	Manila fibre (abaca)
	788	Ramie
	789	Sisal
	328	Seed Cotton
Fruit Primary	515	Apples
	526	Apricots

	572	Avocados
	486	Bananas
	558	Berries nes
	552	Blueberries
	461	Carobs
	591	Cashewapple
	531	Cherries
	530	Cherries sour
	554	Cranberries
	550	Currants
	577	Dates
	569	Figs
	619	Fruit fresh nes
	542	Fruit pome nes
	541	Fruit stone nes
	603	Fruit tropical fresh nes
	549	Gooseberries
	560	Grapes
	592	Kiwi fruit
	571	Mangoes mangosteens guavas
	568	Melons other (inc.cantaloupes)
	600	Papayas
	534	Peaches and nectarines
	521	Pears
	587	Persimmons
	574	Pineapples
	489	Plantains and others
	536	Plums and sloes
	523	Quinces
	547	Raspberries
	544	Strawberries
	567	Watermelons
Oilcrops	249	Coconuts
	329	Cottonseed
	242	Groundnuts with shell
	336	Hempseed
	277	Jojoba seed
	263	Karite nuts (sheanuts)
	333	Linseed
	299	Melonseed
	292	Mustard seed
	257	Oil palm
	339	Oilseeds nes

	260	Olives
	256	Palm kernels
	296	Poppy seed
	270	Rapeseed
	280	Safflower seed
	289	Sesame seed
	236	Soybeans
	267	Sunflower seed
	305	Tallowtree seed
	275	Tung nuts
	265	Castor beans
Other crops	754	Pyrethrum, dried flowers
	826	Tobacco leaves
Pulses	203	Bambara beans
	176	Beans dry
	181	Broad beans horse beans dry
	191	Chick peas
	195	Cow peas dry
	201	Lentils
	210	Lupins
	187	Peas dry
	197	Pigeon peas
	211	Pulses nes
	205	Vetches
Roots and Tubers	125	Cassava
	116	Potatoes
	149	Roots and tubers nes
	122	Sweet potatoes
	136	Taro (cocoyam)
	137	Yams
	135	Yautia (cocoyam)
	459	Chicory roots
Spices	711	Anise, badian, fennel
	689	Pimento
	748	Peppermint, spearmint
	723	Spices nes
Sugarcrops	157	Sugar beet
	156	Sugar cane
Treenuts	221	Almonds with shell
	216	Brazil nuts with shell
	217	Cashew nuts with shell
	220	Chestnut

	225	Hazelnuts with shell
	234	Nuts nes
	223	Pistachios
	222	Walnuts with shell
Vegetables Primary	366	Artichokes
	367	Asparagus
	414	Beans green
	358	Cabbages and other brassicas
	426	Carrots and turnips
	378	Cassava leaves
	393	Cauliflowers and broccoli
	401	Chillies and peppers green
	397	Cucumbers and gherkins
	399	Eggplants (aubergines)
	406	Garlic
	407	Leeks other alliaceous vegetables
	372	Lettuce and chicory
	446	Maize green
	449	Mushrooms and truffles
	430	Okra
	403	Onions dry
	402	Onions shallots green
	417	Peas green
	394	Pumpkins squash and gourds
	373	Spinach
	423	String beans
	388	Tomatoes
	463	Vegetables fresh nes
	420	Vegetables leguminous nes

ACKNOWLEDGMENTS

Despite there is only my name on the cover of this thesis, my research was not a solitary exercise. In the past years I had the pleasure to work and share my time with truly amazing people who made this PhD adventure a great and enriching learning experience. I will now switch to Italian to be able to truly express my gratitude with (I hope) my best words.

Un sentito ringraziamento va ai membri della commissione d’esame, Alessando Barattieri, Alessandro Corsi e Luca Ridolfi, i quali hanno letto con sincero interesse ed entusiasmo la mia tesi e mi hanno offerto correzioni, commenti e spunti di riflessione estremamente insteressanti per gli sviluppi futuri del mio elaborato.

Vorrei poi ringraziare i miei supervisors, Silvana Dalmazzone e Marco Bagliani , che ho il privilegio di considerare tali dalla stesura della tesi di laurea magistrale (lontano 2013). Raramente capita di essere accompagnati nella propria crescita professionale e individuale da persone così entusiaste e ottimiste per il lavoro svolto assieme. Mi auguro che questo sodalizio continui e produca risultati ancora migliori e di grandissima soddisfazione.

Allo stesso modo, il mio PhD non sarebbe stato possibile senza il supporto di Andrea Gallice, che sin dalla prima email post colloquio di selezione mi ha aiutato affinchè questo percorso, non facile da remoto, funzionasse perfettamente. Davvero, molte scelte, molti accadimenti, non sarebbero stati possibili senza il tuo aiuto. Un grande ringraziamento va anche ad Alberto Galvan, per avermi aiutato ad accorciare le distanze tra Doha e Torino.

Senza dubbio, questo percorso non sarebbe stato lo stesso senza i miei amati colleghi, che ora ho il privilegio di chiamare amici, Sarah, Lorien, Alessandra e Salvatore, che dopo un attimo di smarrimento per la mia ansia diffusa (e il mio iniziale sconcerto per gli esami del primo anno), mi hanno supportato e sopportato facendomi amare ogni singolo momento trascorso assieme. Non potevo essere più fortunata di così.

Credo poi che la mia vita torinese (e non) non sarebbe stata la stessa senza la mia adorata Lorena, con la quale ho la fortuna di condividere gioie e dolori, momenti di pazzia e studio disperatissimo dal primo giorno di laurea magistrale. Dopo anni a distanza, il dottorato ci ha nuovamente permesso di stare assieme e vederci più spesso, per scoprire, in fondo, che non ci sono distanze reali che possono limitare la nostra amicizia.

Allo stesso modo, il mio percorso universitario iniziato a Bologna 13 anni fa, ha fatto si che ancora oggi io possa contare ciecamente sulla presenza di Petra, Arianna, Giulia, Ivo, Elisabetta, Monica, Elisa e Frank. Credo non ci sia stata alcuna scelta, alcuna avventura, della mia vita di cui tutti voi non siate stati partecipi. In particolare, con quattro di voi ho condiviso anche il PhD e il vostro sostegno non è mai venuto meno. Questo traguardo lo devo anche a tutti voi. Non vedo l'ora di festeggiare i nostri prossimi.

Il dottorato per me è iniziato a Doha e per quanto sia stato difficile abituarsi a vivere qui, ci sono un po' di persone che vorrei ringraziare per avermi fatto sentire a casa. In particolare, grazie al mio coinquilino Alessandro, che è tutt'ora il mio coinquilino nonostante il dottorato e che ha saputo neutralizzare le mie ansie sdrammatizzandole in maniera magistrale. Un grazie speciale anche a Margherita ed Emanuele, che contribuiscono a rendere la mia vita a Doha davvero migliore e che sono stati super entusiasti per questo mio traguardo. Also, I truly consider a fundamental part of my Doha family Ben and Carly, who really supported me, not just for my PhD, but for what I like and enjoy the most in Doha. Thank you for the great moments together, I hope there will be many more.

Un grande ringraziamento va ai miei amici di sempre. Con voi ho la fortuna di condividere le mie avventure da oltre 15 anni e nonostante la distanza, mi dimostrate ogni giorno l'importanza che date alla nostra amicizia. In particolare, grazie dal più profondo del mio cuore ad Annu, Dani, Guida e Lucia, per esserci e per sostenermi sempre, aiutandomi a credere ancora di più nelle mie capacità. La vostra stima e il vostro incoraggiamento sono stati e sono ogni giorno, fondamentali.

Ovviamente, questo traguardo non sarebbe mai stato possibile senza la mia famiglia. Grazie a mia sorella Elena, che ha sempre creduto in me più di quanto l'abbia mai fatto io e con la quale ho avuto il piacere di condividere sedute di studio. Grazie perchè la tua motivazione e dedizione è stata un grande esempio nei momenti più difficili. Mamma e Papà grazie infinite per avermi aiutato a diventare la persona che sono oggi, grazie per aver sopportato la distanza e per avermi incoraggiato a viaggiare e aspirare a fare sempre meglio, nonostante questo ci portasse lontani. Non vedo l'ora di festeggiare questo traguardo assieme.

Infine, grazie a Giovanni, che nel frattempo (e durante il dottorato) ha anche scelto di diventare mio marito. Non so più immaginare la vita senza te. Grazie per il supporto anche durante questo percorso e per la tua fiducia incondizionata nelle mie capacità. Per davvero, ogni cosa è per me possibile se ci crediamo assieme.