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ORIGINAL ARTICLE

# Development, water and energy in the context of climate change in North Africa

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**Abstract** This article adopts a holistic approach to explore and quantify interactions between water and energy in the context of climate change in North Africa. We bring together results from different research areas to describe the physical interactions and to shortly discuss governance issues in the sectors of water and energy. We highlight the fact that water demand management options combined with a sustainable energy model is a priority action to answer the challenge of climate change adaptation in North African countries. We use the IPAT formula approach to compute scenarios for quantifying the magnitudes of advantages to expect from water demand side management actions coupled with energy efficiency options. According to our results, water demand management is a very appropriate adaptation option with significant benefits in terms of water saving, energy use and energy bill. Overall, in 2050, the water saved thanks to demand management actions could be around 68 billion of cubic meters, which is the magnitude of the total water demand of Egypt in 2005. Depending on the scenario and assumptions, the expected cumulated benefit in terms of energy bill over the period 2005–2025 could range between 30 and 48 billion US Dollar, which is comparable to the GDP of Tunisia in 2011 (46 billion US Dollar). Nevertheless, up to 2050, regardless the scenario, additional options will be needed to cover the water deficit of the region. This leads us to consider virtual water as an additional option to reduce the local water demand. Finally, we discuss the political implications and the reforms to be implemented for integrating water and energy demand side policies in North Africa.

**Keywords** Climate change · Energy · Water · Adaptation · Governance · North Africa

## Introduction

North Africa's climate will continuously become warmer and dryer in the course of the twenty-first century (IPCC 2007; Touret 2008; Van der Linden and Mitchell 2009; García-Ruiz et al. 2011; Ludwig et al. 2011; Lelieveld et al. 2012; IPCC 2013). A rise of temperature from 4 to 6 °C, together with longer periods of drought, is expected at the end of the twenty-first century (2080–2099) compared to the end of the twentieth century (1980–1999) (under IPCC 2007 A1B scenario) (Lelieveld et al. 2012). The frequency and intensity of extreme rainfall events should increase,

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whereas, in average, a decline of rainfall, in a range of −15 to −30 %, is anticipated up to 2040–2070 (García-Ruiz et al. 2011). The combination of these climatic factors already severely impacts water resources, both in quantity and in quality (Gleick 2003a, b; Benoit and Comeau 2005; Tourre 2008; Ludwig et al. 2011). Water availability could decrease by 22 % for a 2 to 3 °C increase in average temperature in North Africa (Warren et al. 2006; Stern 2007), which, according to Milly et al. (2005) could happen by 2050 (under IPCC 2007 scenarios B1 and B2).

The negative effect on food production due to lower yields[1] caused by reduced rainfall, desertification and extreme events is a particularly serious issue (Hanjra and Qureshi 2010). North Africa is one of the areas where the increase of irrigation needed to maintain the same yields is the highest (Döll 2002). In addition to population and economic development, climate change is therefore a potential driver of the future water demand, mainly through additional needs for irrigation.

Furthermore, because of the water scarcity and the increase of water demand, the climate challenge for the energy sector in North Africa is not only the reduction of green house gas emissions (GHG). Climate change puts the electricity sector under pressure by increasing the energy demand and simultaneously reducing production capacities (Mideksa and Kallbekken 2010; Ebinger and Ebinger 2011).

On the one hand, additional electricity needs are expected, first due to the increasing use of air-conditioning systems (Giannakopoulos et al. 2009) and second to compensate for water scarcity. Installed desalination capacity could be multiplied by five or six by 2030 (Boyer 2008), which will require considerable amount of electricity to operate the desalination plants. On the other hand, climate change could significantly reduce hydropower generation capacities in Egypt, Tunisia and Morocco (Hamududu and Killingtveit 2012).

The water scarcity issue could lead to very critical, unstable situations and conflicts within and between countries (Gleick 1996; Yoffe et al. 2004; PNUD 2006; Barrios et al. 2007; Brown 2008; Santi et al. 2012). The increasing dependency of water supply to energy and the challenge of water/energy/food security in the context of climate change are therefore a matter of increasing concern (WEF 2011; Bazilian et al. 2011; OECD 2009; Glassman and Wucker 2011; FAO 2011; Sathaye 2011), and it can be seen as one of the biggest challenges of the twenty-first century for North African countries.

In this context, how are North African countries going to secure water supply? Many options are identified in the literature, but, in North Africa, the scarcity of water and the low level of water and energy efficiency call, in priority, for adaptation measures in the demand side. The issue is not only about water resource scarcity but also about the current level of energy and water efficiency and about the governance of water and energy.

The objective of this paper was to better understand the water energy challenge in North Africa and to provide an order of magnitude of the benefits to expect from a demand side action. In "Climate, water and energy challenges," section we provide an overview of the current water and energy situation and we look both at the history of the governance and reorientation to be taken toward demand management. In "Projection of future water demand and energy for water," section we present a scenario simulating synergistic effects of sustainable energy with water demand management options to estimate potential gains in terms of resources and energy bill. In "Consideration on water deficit and virtual water" and "Discussions and conclusion," sections we discuss how to cover remaining water deficit and what governance reforms are needed.

## Climate, water and energy challenges

### Water and energy: current situation

The water exploitation index provides information about the pressure on the water resources. All of the five North African countries register a ratio above 40 %, indicating a critical water stress situation (see Table 1). The main water user in North Africa is agriculture. This sector accounts for 90 % of the total water withdrawal. The demand side is also characterized by important losses and wastages. In North Africa, water losses in the irrigation systems (collection, transport end use) account for more than half of the withdrawals (UNESCO 2009; Blinda 2009). The poor state of equipments, the outdated irrigation methods and the poor practices are the causes of these major losses. Losses during the transport and the use of drinking water are between 30 and 50 % (Lalhou 2006). The degree of wastage at the level of end users would be about 20 % of the water used in a typical Moroccan household (Oubalkace 2007).

This relatively low water efficiency situation is comparable to what is observed in the energy sector. Energy efficiency, measured as GDP per unit of energy used, is significantly below the EU average (nine USD per kg of TOE), and except in Tunisia, little progress has been made since the last 10 years. It is estimated that, in North Africa, from 20 to 50 % of energy is wasted, depending on countries and sectors (OME 2011). The energy system is qualified as nonsustainable, also because the electricity production is almost fully based on fossil fuels (even in

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[1] See online Resource 1 for a selection of impact studies results.

**Table 1** Water, energy and agriculture: key figures

| Year | Indicator | Algeria | Egypt | Morocco | Libya | Tunisia |
|---|---|---|---|---|---|---|
| 2008 | GDP per capita (constant 2000 US Dollar) | 2,174 | 1,859 | 1,734 | 7,865 | 2,747 |
| 2005–2007 | Water withdrawal for agriculture (% of total withdrawals) | 62.8 | 83.5 | 89.3 | 83.1 | 78.1 |
| 2005–2007 | Water withdrawal for households (% of total withdrawals) | 21.2 | 6.8 | 9.0 | 14.1 | 16.5 |
| 2005–2007 | Water withdrawal for industry (% of total withdrawals) | 15.9 | 9.8 | 1.7 | 2.8 | 5.4 |
| 2005 | Exploitation index (withdrawal as % of renewable freshwater resources) | 38 | 98 | 45 | 83 | 41 |
| 2008 | Water stress index (renewable water resources per inhabitant $m^3$/capita/year) | 230 | 610 | 633 | 101 | 356 |
| 2008 | Water productivity (USD GDP per $m^3$ of water used) | 9 | 1.5 | 2.9 | 8 | 7.4 |
| 2008 | Alternative and nuclear energy (in % of energy use) | 0 | 2 | 1 | 0 | 0 |
| 2008 | Production hydroelectricity (as % of the electricity production) | 1 | 11 | 4 | 0 | 0 |
| 2008 | Production of electricity from fossil fuels (as % of the electricity production) | 99 | 88 | 94 | 100 | 99 |
| 2008 | Energy imports (% of energy used) | −337 | −24 | 96 | −469 | 18 |
| 2008 | GDP per unit of energy use (constant 2005 PPP US Dollar per kg of oil equivalent) | 7 | 6 |  | 5 | 8 |
| 2008 | Agricultural value added (% of GDP) | 7 | 13 | 15 | 2 | 10 |
| 2008 | Employment in agriculture (% of total employment) | 18.1 | 32 | 41 | : | 18.7 |
| 2008 | Irrigated area (% of agricultural land) | 2 | : | 4 | : | 4 |

*Sources*: GDP, water productivity, GDP per unit of energy use: World Bank (WDI). Water data: UN Statistical Division, Food an Agriculture Organisation (FAO)/Aquastat, Eurostat/Medstat, UNEP/MAP/Plan Bleu (2009). Energy data: International Energy Agency (IEA) and World Bank (WDI). Agricultural data: World Bank (WDI), Eurostat/Medstat

Morocco and Egypt where hydroelectricity is significant). In the region, solar and wind energy potentials are poorly exploited.

Another striking fact in North Africa is that the share of energy spent for water is very significant and is growing fast. 8–13 % of electricity was used for water in North Africa in 2005 to pump, desalinate and treat water (Boyer 2008). In the larger region of North Africa and Gulf countries, at least from 4 to 12 % or more of the total electricity consumption may be from desalination alone (Siddiqi and Anadon 2011).

All these trends, associated with climate pressures, tend to increase the cost of mobilizing additional water. The costs of investment and maintenance to produce additional conventional water are expected to increase because (1) almost all sites offering an easy and cheap access for the dams have been operated, (2) energy needs to mobilize deeper groundwater vary more than proportionately to the depth of pumping, (3) evaporation and (4) generalized siltation of reservoirs reduce the production of electricity initially planned. On top of that, uncertainties about future climatic and hydrologic conditions may seriously affect cost-effectiveness of infrastructures during their life span (Sophocleous 2004; Kundzewicz 2007; World Bank 2007; Magnan et al. 2009). Although investment costs for nonconventional water (e.g., desalination) are expected to decrease, the energy required contributes to drive up the cost of producing water this way. This is one of the reasons why, the production costs of nonconventional water are currently high compared to conventional water mobilization: from 0.6 euros to 0.7 euros per cubic meter (Zhou and Tol 2005; Boyer 2008) against 0.4 euros (Benoit and Comeau 2005). Finally, one can also mention that existing irrigation systems are already underused due to lack of water resources, creating economic turmoil for irrigated agriculture and reducing investment returns (World Bank 2007). Whatever the technological choice, higher costs to mobilize and produce fresh water are therefore expected.

How the situation could have turned so critical? Explanations may be found in the history of governance of water and energy.

## Governance aspects: toward demand management

As many other countries in the world, North African countries followed the conventional approach to the energy and water paradigm: A permanent increase in supply must meet a growing demand at the lowest possible cost. No limit to demand or to supply growth is considered (Benoit and Comeau 2005). In the past 40 years, governments opted for highly centralized energy systems based on proven low-cost technologies (Trieb et al. 2008). Planners have responded to a growing demand by massively investing to mobilize additional water and energy resources: Infrastructures necessary for the exploitation of fossil energy resources, for electrification, for mobilization of groundwater, for water storage (dams) and for irrigation (Margat 2008). In a context of fast growing needs for development, decisions were made without considering the long-term effect on the environment. It may be either because of ignorance, because the time of political action is much shorter than the time of environmental changes or because increasing supply was the easiest political way to solve conflicts between users. This lack of consideration for long-term environmental issues is also explained by the fact that priorities of economic players are, in general, mainly focused on the short-term and on private interests (World Bank 2007). Sustainable resources management, the rational use of water and energy, environmental impacts and alternative technologies were more or less ignored, and even discredited by big companies operating in the construction of infrastructures.

Until the late twentieth century, no serious consideration was given to the issues of energy efficiency and renewable energy. Despite large potential and greater political attention in recent years, energy efficiency and renewable energy continue to face many institutional, regulatory and economic barriers. Subsidies to fossil energy constitute one of the most important (OME 2011). Access to energy is currently not generalized in poor and isolated rural areas, and the current energy system shows strong limits such as: (1) Exhaustion of fossil resources (Egypt, Tunisia) and increased energy dependency (Morocco, Tunisia, Egypt), (2) uncontrolled energy bill and subsidy expenditures, (3) increasing impact of air pollutants emissions on health in cities, (4) carbon-intensive economy and (5) increasing vulnerability to climate change of the electricity sector (increased demand, declining production, risk for infrastructures) (Quéfélec 2008).

From the water side, similar governance leads to a comparable critical situation (Brooks and Rached 2010). However, there are important differences between water and energy (Bouhia 2001). Unlike energy, water is an essential resource for life and for a wide variety of ecological services and, if energy is considered mainly as a paying resource, it is not the case for water. If fresh water is theoretically a public good in developed countries because water utilities are designed to be accessible to all users at a price allowing not to exclude anyone (Bontems and Rotillon 2007), in North Africa, the direct intake in the resource by private users (groundwater pumping) and the absence of water pricing is a usual practice, turning water into a common good. Authorities' controls are very lax, and the measurement of water used is not effective, especially because of the absence of water meters for businesses, farms or households. People having access to groundwater are encouraged to make maximum use of the water resource before its depletion, which leads to the "tragedy of the commons: The inefficient, intense and uncontrollable use of a renewable resource leads to its overexploitation, degradation or depletion (Hardin's 1968)."

Since the last 10 years, this system seems to reach its limits faster than expected, demonstrating that a change of water and energy paradigm is needed. From the water side, a consensus has been reached: An effective management should consider water as both an economic and social asset and the water needed for ecosystems should be considered. The right trade-off between efficiency (value added by quantity of resource) and equity criteria (between sectors and individuals) (Beaumont 2002) needs to be found. The decision on allocation of water needs to consider, for instance, that water for agricultural is crucial not only for food production, but also for social reasons since the income of rural people depends on irrigated crops. But, the final decision should not ignore that the value added in agriculture is often much lower than in other sectors (e.g., tourism).

The previous comments are relevant to North African countries adaptation to climate change. Increasing efforts and investment to mobilize additional amount of water are still possible, but, it will inevitably be more costly, as explained before, and it will be made more difficult due to uncertainties related to climate change. In North Africa, it seems therefore quite obvious that managing better the demand side is a valuable "no regret" adaptation option. Water demand management, which finds its roots in the energy demand management concept, can be defined, as all actions able to: (1) Reduce the quantity or quality of water needed to accomplish a particular task, (2) modify processes to accomplish the same production with less water, (3) reduce losses and the decrease of quality at all production and use stages, (4) smooth the consumption peaks by promoting a better distribution of consumption over time and (5) improve water distribution system to provide water in times of water shortage (Brooks 2006, 2007).

The same type of consensus is reached from the energy side. A sustainable energy management needs to put the emphasis on the improvement of the energy efficiency and on developing renewable solar and wind energies (Allal and Quéfélec 2008; Quéfélec 2006, 2008; Quéfélec et al. 2008). In both water and energy, investing in various efficient technologies is needed: small-scale dams, individual rain water tanks, precision irrigation, reduced leakages, reduced grid losses, energy efficient products, water treatment/recycling systems, energy efficient building, renewable energy technologies, etc. Nevertheless, the equation also includes societal variables like behavior, habits and cultural changes to avoid individual negligent use of water (water sobriety). The challenge is to move from a centralized supply and old technology-based system, to a system placing users and new technologies at the center of decisions. This means moving to a system able to identify acceptable trade-offs, involving local actors, citizens, companies and integrating a number of actions, not only in the water and energy sectors themselves, but also in all other sectors (agriculture, industry, transport, real estate, etc.).

Given that the current water system wastes around half of the water withdrawal (Benoit and Comeau 2005) and that the energy system is strongly unsustainable (Trieb et al. 2008), rooms for improvement do exist. To go further into our analysis of water demand management—sustainable energy nexus, we introduce in the following a simulation exercise to estimate what is the order of magnitude of expectable benefits if such adaptation options are massively implemented.

## Projection of future water demand and energy for water

To foresee the magnitude of benefits from such options, we proceed by successive steps: socio-economic and climate assumptions (main drivers), water demand scenario calculation up to 2050, computation of energy needs for each scenario, conversion of energy needs to energy bills according to different assumptions on energy prices up to 2025 (see diagram of steps and causal loop relationship in the online resource 2).

### Methodology

#### *Main drivers*

Demography, economic development and climate change are crucial drivers of the present and future water demand.

In North Africa, the intermediate population scenario published by the United Nations World Population Prospect, 2008 revision, expects an additional 100 million persons by 2050 as compared to 2005 (see Fig. 1). The population would then account for almost 250 millions of inhabitants in 2050. It constitutes a major pressure on water resources, especially if countries wish to maintain a stable level of food dependence.

Economic development, here represented by the growth of the gross domestic product (GDP) per capita, significantly impacts household and industrial water consumption. We assume that GDP per capita of North African countries will converge in 2050 toward a GDP level close to the one currently observed in Eastern European countries (between 18,000 and 20,000 US Dollar per capita) (see Fig. 1), which is the level observed in South European countries (Portugal, Spain and Greece) in the 80s. The GDP is expressed in USD 2005 purchasing power parity (PPP) as published in the World Bank WDI database.

The third driver is the magnitude of climate change and its effects on both water resources and irrigation demand. We base ourselves on the results given by the literature on the impact of climate change to select consistent and credible assumptions. We assume that (1) renewable resources will be in 2050, 22 % lower than in 2005, for a temperature rise of about 2–3 °C (Warren et al. (2006) and that (2) water demand for agriculture will be 15 % higher in 2050 as compared to a situation without climate change (order of magnitude given by Bouazza et al. (2002) for Morocco and from Rodríguez Díaz et al. (2007) for 2–3 °C increase in temperature).

#### *Water demand*

We use a simple equation to compute water demand in the five North African states (Morocco, Algeria, Tunisia, Libya and Egypt). Our approach rests on the general IPAT formula introduced by Ehrlich and Holdren (1971) which allows to quantify an impact according to assumptions about variables considered as the driving forces (in our case, population, GDP and climate). This type of approach can be used for quantifying future freshwater demand at country, regional or global level (See various approaches for instance in: Duarte et al. 2011; Rosegrant et al. 2002; Alcamo et al. 2000, 2003a, 2003b; Oki et al. 2003b; Seckler et al. 1998; Raskin et al. 1997; Shiklomanov 2003; Gleick and Lundqvist 1997; El-Fadel and Bou-Zeid 2001; Trieb et al. 2008). The general form of IPAT model is as follows:

$$\text{Envir}I = I = \text{P.A.T} \tag{1}$$

The pressure on the environment by human activity ($I$) is the product of three factors: Population ($P$), output per

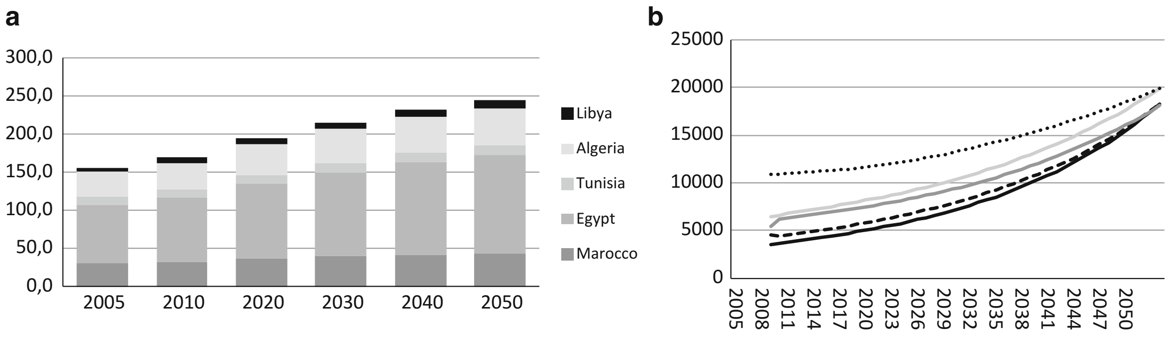

**Fig. 1** Population and GDP in the countries of North Africa. *Sources*: Population: United Nations, World Population Prospect (medium variant scenario 2008). GDP (expressed in constant 2005 PPP USD): World Bank WDI data and projections by authors. **a** Population in the North African countries (in millions), medium variant scenario. **b** Projection of the GDP level per capita in USD

capita ($A$) and technology ($T$) which determines the amount of resources used per unit of consumption. In our case, $I$ is the water demand which represents a pressure on the environment through the withdrawal of fresh water. $T$ is the water intensity of the economy. $T$ includes all the technologies and behaviors influencing the amount of water needed to produce the same amount of goods. $T$ evolves, for instance, when reducing leakages in the distribution network. Less water withdrawal from the environment is then necessary to provide the same amount of water to the final user. If the final user, in addition, adopts a water-friendly technology (e.g., precision irrigation), the efficiency of water use is then improved again and the water used in % of water withdrawal increase.

We use the following equation, adapted from Trieb et al. (2008), to compute the total water demand ($I = \omega(t)$ in m$^3$):

$$\omega(t) = \omega(t-1) \cdot \left[(1+\gamma(t)) \cdot \frac{\eta(t-1)}{\eta(t)} \cdot (1-\mu) \cdot (1-\varphi) \cdot (1+\xi)\right] \tag{2}$$

where: $\gamma =$ the growth rates of the main drivers of the demand: $\gamma_{\text{pop}}$ for population (parameter $P$ of the IPAT formula) and $\gamma_{\text{GDP}}$ (parameter $A$ of the IPAT formula) for GDP.

$\eta =$ efficiency of water distribution improvement, defined as the share of water lost before reaching end users out of the total withdrawals.

$\mu =$ efficiency of the end use of water representing the share of water wasted due to bad practices at user level.

$\varphi =$ evolution of the % share of water recycled and reused by the industry.

Note that parameter "$T$" of the IPAT formula is function of $\eta$, $\mu$ and $\varphi$.

$\xi =$ effect of climate change on irrigation, representing the additional increase, due to climate change, on the water demand for agriculture.

According to Eq. (2), water demand in the year $t$ evolves from that of the year $(t-1)$ in response to (1) the growth rate of the GDP and of the population, (2) of the variation in water efficiency (including both technological and organizational progress), (3) the efficiency of the end use (4) the degree of the water reuse and (5) the effects of climate on the agricultural water needs in order to maintain the same productivity. If there is no improvement at all in the efficiency of water and no climate change, the last four terms in the equation are equal to 1. The growth of water demand is then directly proportional to the GDP and the population growth.

We consider three sectors: agriculture, industry and municipal uses (urban and household water).

The population growth ($\gamma_{\text{pop}}$) is used as the primary driving force to estimate the water needs for agriculture. This implies that we assume that the amount of irrigation water per capita does not change over time, which can also mean maintaining the level of per capita food production. Meanwhile, the demand for irrigation water decreases as we improve the efficiency of agricultural water, and it increases to counter the negative effects of climate on yields. Parameter $\mu$ (final use improvement) is not included here since the efficiency of agricultural water already includes the improvement of the final use, and we assume that water recycling is not possible in agriculture (parameter $\varphi$ is therefore not included).

GDP growth ($\gamma_{\text{GDP}}$) is used as the main determinant of the municipal water demand (the drinking water coming from the network and mostly used by households and the tertiary sector) and the industrial water demand. Household's water needs are driven by the increase of the living standards and by more performing equipments that allows new behaviors.

The growth in the demand for municipal water is lowered thanks to the improved efficiency of the water distribution operators (factor $\eta$) on the one hand, and thanks to the reduction of wastage by end users, on the other (factor $\mu$). The improved efficiency reduces the amount of water needed while maintaining an equivalent level of service. Parameter captures both technological and behavioral changes (water sobriety).

Finally, the reuse of treated wastewater (factor $\varphi$) can ultimately limit the additional withdrawals of water in the environment. This is why we consider reused water as water saving in industry.

Each of the parameters of Eq. (2) ($\gamma$, $\eta$, $\mu$, $\varphi$, $\xi$) scales linearly, according to an annual average growth rate (AARG), calculated between the starting value (observed in 2005) and the targeted value in 2050 using the standard formula:

$$\text{AARG} = (\text{EV}/\text{BV})^{(1/n)} - 1 \tag{3}$$

where: EV = ending value, BV = beginning value $n =$ number of periods (in our case, 45 years).

### *Scenario*

We perform simulations under two scenarios: The first one is called "*trend scenario*" and includes only marginal changes in water demand policies. It focused mainly on an increase of water supply with low consideration of demand management. The second one is called "*adaptation scenario.*" It considers water demand management as a priority and includes a very significant improvement of the water efficiency in all the three sectors considered.

To distinguish between the two scenarios, we assume divergent evolutions of the parameters of water efficiency included in Eq. (2) ($\gamma$, $\eta$, $\mu$, $\varphi$,). In the adaptation scenario, we assume that countries achieve the best possible performance in terms of water efficiency (water used in % of water withdrawal). According to this, we target the efficiency of irrigation water at a value of 75 % (recommended by UNEP) and the efficiency of municipal and industrial water at 85 % (current level in Israel). We consider an improvement of the efficiency of final use of 1.8 % per year for the municipal and the industrial water (results obtained by Australia). Finally, regarding the reuse of wastewater, we assume that countries will comply with the international recommendations (50 % of industrial wastewater and municipal reused).

In the trend scenario, each country progress slowly in terms of efficiency. They close only 20 % of the gap between 2005 performances and best performances considered in the adaptation scenario for each of the parameter of Eq. (2) ($\gamma$, $\eta$, $\mu$, $\varphi$).

In both scenarios, starting value of parameters $\eta$ and $\mu$ is taken from UNEP/MAP/Blue Plan (UNEP, MAP 2009). Depending on countries, 2005 values range from 50 to 71 % for municipal water and from 36 to 63 % for irrigation water. Starting value for data on recycling rates (parameter $\varphi$) is from Trieb et al. (2008).

### *Electricity for water*

To compute the corresponding electricity need in the two water demand scenarios setup previously, we apply the following formula:

$$E(t) = \omega(t) \cdot \frac{\psi(t-1)}{\psi(t)} \cdot (1 + \theta) \qquad (4)$$

where $E(t)$ is the energy need to produce, treat and distribute water, $\omega(t)$ is the water demand as computed previously, $\psi(t-1)/\psi(t)$ is the energy efficiency improvement and $\theta$ is the energy needs to mobilize additional water.

Values for $\theta$ are taken from Thivet (2008) which estimates that 0.25 kWh is needed to produce and process a cubic meter of water in the South and the East of the Mediterranean Basin in 2005. According to the author, the satisfaction of water needs in the future will be based on the exploitation of water resources which are increasingly energy intensive. This could lead to a rise in energy needs up to 1 kWh to mobilize 1 $m^3$ of water in 2025. We assume that the ratio kWh per $m^3$ of water will change linearly between 2000 and 2025 on the basis of an annual average growth rate calculated according to formula (3). We then apply electricity consumption factors to our estimations of water demand in the trend scenario and in the adaptation scenario. We therefore implicitly assume that the mix of supply that meets demand in our scenario is the same one as used by Thivet (2008) and is similar in the two scenarios (trend and adaptation).

Furthermore, in order to take into account the *energy efficiency* dimension in our calculations, we consider that the countries also commit to improving by 20 % the energy efficiency in all economic sectors by 2025 (objective of the European Union up to 2020). For reasons of simplicity, we consider that this objective is achieved in terms of energy use for water and that the improvement is linear between 2005 and 2025 (the calculation is based on formula 3). We obtain an estimation of energy consumption in a third scenario called "*adaptation and energy efficiency* (*EE*)."

### *Energy bill*

To obtain an estimated magnitude of the consequences in terms of energy bill, we monetarily value the potential of energy savings. The electricity requirements are converted into 'ton of oil equivalent' (1 TOE = 11,630 kWh), and a value is given to the TOE by making assumptions on the future price of the oil barrel (1 TOE = 7.33 oil barrels). The primary energy used to produce the power needed for water is not 100 % made of oil. Nevertheless, hydrocarbons accounted for some 96 % of the sources used for electricity generation in the countries of North Africa in 2005. We implicitly assume that the evolution of oil prices drives the prices of other types of fuel. The oil barrel price of the starting period is taken from the WEO/IMF database. We perform our calculations by considering three scenarios of oil price evolution up to 2025 (175 US Dollar, 120 US Dollar and 75 US Dollar), and we apply a discount rate of 3 %.

### *Method discussion*

Although we strived to be consistent in our choices, the value of several parameters we use is taken from different studies and researches which are not necessarily based exactly on the same climate assumptions. We also assume linear relationships between our variables which is a strong simplification. For instance, transition from the current water demand practices to the most efficient one might not be linear and it is well known that the behaviors of ecological system are often nonlinear. The method captures mainly physical improvements. It does not include behavior of economic agents toward prices, and no assumption is made regarding, for instance, the issue of rebound effect. According to the "rebound effect," behavioral response to the introduction of an efficient technology may tend to offset the expected benefit. As an example, to buy a fuel efficient car may lead to drive more kilometers, resulting ultimately in much less decrease in fuel consumption than expected initially.

Regarding the coefficient of electricity needed for water, Thivet (2008) states that this estimation is very rough since (1) the overall estimation takes into account only the electricity needs and that (2) the differences between countries can be significant. Finally, the estimated cost of inaction relies on strong assumptions on both technical and energy price parameters. Our results should therefore be considered as rough estimates and interpreted cautiously, nevertheless our result is very close to the results obtained by more complex approaches. For comparison, Margat (2008) took into account both the expansion of the irrigated areas and needs of crops by variety. In his trend scenario, the water demand for irrigation in North Africa is 90 billion $m^3$ in 2025 against 96 $m^3$ in our scenario.

## Results

### *Water demand*

In both scenarios (trend and adaptation), the total demand in water is increasing very significantly between 2005 and 2050 and agriculture is the main water user and the main driver of change in the total water demand (Fig. 2). Nevertheless, striking differences appear between the two scenarios. In the trend scenario, the total demand is multiplied by 2.2 (increase of 117 billion of cubic meters), whereas, in the adaptation scenario, the demand is multiplied by 1.5 (increase of 49 billion of cubic meters). Compared to 2005, the distribution of water demand by sector in 2050 is also very different. In 2005, agriculture absorbs more than 80 % of the total demand, whereas in 2050, it accounts for 58 and 53 % in the trend and adaptation scenario, respectively. In both scenarios, the much lower share of agriculture is due to important increases in the demand for industry and households (it would be even lower if climate change would not tend to increase irrigation). In the adaptation scenario, the net amount of water used for irrigation in 2050 is, nevertheless, much lower than in the trend scenario (it is actually similar to the level of 2005), thanks to the strong water efficiency progress in this sector. Overall, the potential of water saving comes mostly (65 %) from irrigation (Fig. 2, central graph).

Given the combined effect of the rising living standards and of the population growth, whatever the scenario, the demand for drinking and industrial water is growing very fast over the studied period. It represents more than 22 % of the total demand in 2050 against around 10 % in 2005. In these two sectors, also the demand management provides impressive results. In the adaptation scenario, the water demand from household and industry is multiplied by 3.7, whereas the trend scenario foresees a fivefold increase.

Overall, if one compares the adaption scenario to the trend scenario, the resulting water saving in 2050 is around 68 billion of cubic meters which is as massive as the total water demand of Egypt in 2005 (Fig. 2, right graph). Accumulated savings over the period 2005–2050 are even more impressive, with around 1,300 billion $m^3$ for all the five countries. This huge water saving has effect on the energy use already in the shorter term of 2025.

### *Energy saving*

According to our calculations and by comparing the "*trend scenario*" with the "*adaptation scenario,*" we obtain an amount of energy saving of more than 20 terawatt-hour (TWh) (1 TWh = 1 billion kWh) in 2025 (Fig. 3). This amount is considerable. This is equivalent to 10 % of the

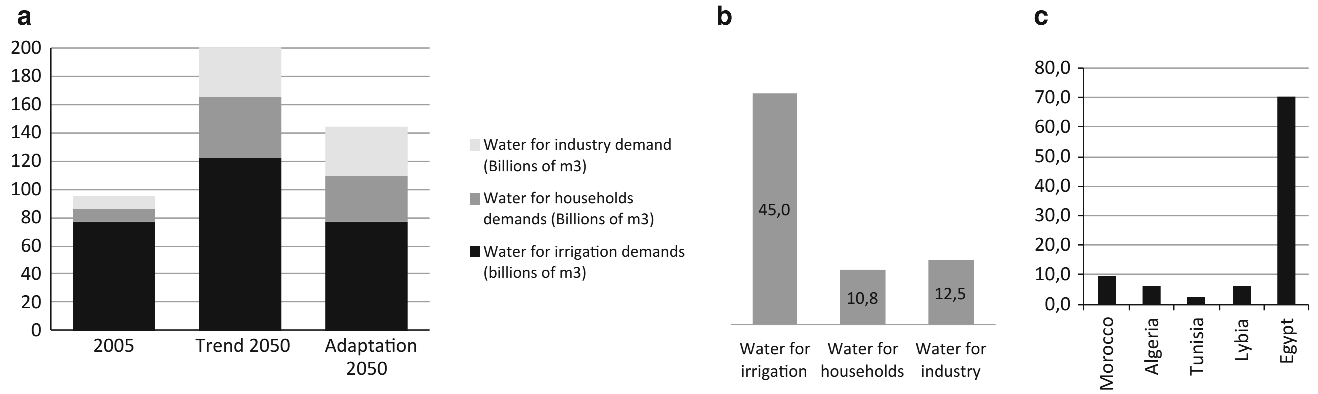

**Fig. 2** Water demand in North Africa, trend and adaptation scenarios. *Sources*: data 2005 are from UNEP/MAP/Plan Bleu (UNEP, MAP 2009). **a** North Africa 2050—total water demands in billions of $m^3$, trend and adaptation scenarios (with climate change). **b** Comparison of "trend" and "adaptation" scenario: Water saved in 2050 in billion $m^3$. **c** Total water demand in 2005 in the five North African countries, in billion $m^3$

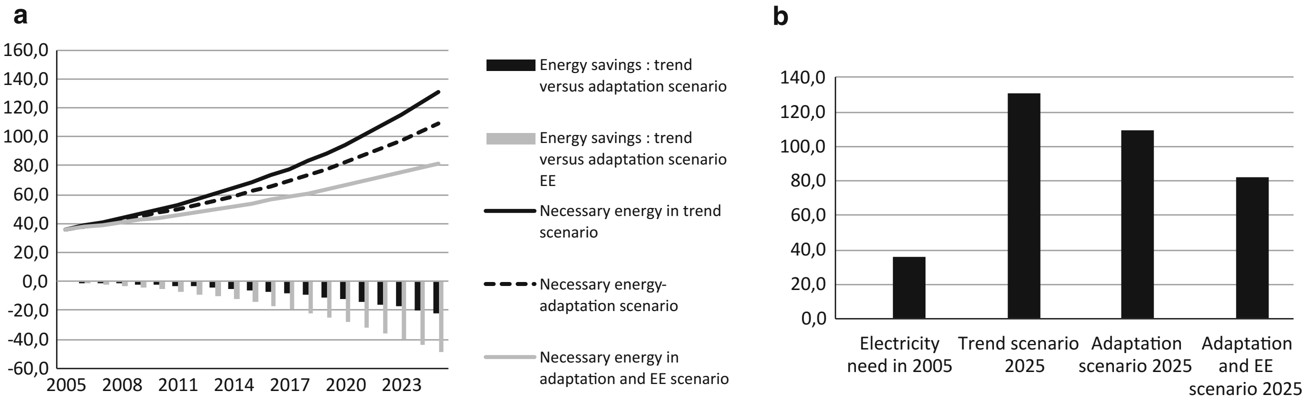

**Fig. 3** Electricity need for water. **a** Electricity saving for mobilization of water, in TWh. **b** Electricity needs for water in 2005 and 2025, according to different scenarios, in TWh

electricity consumption in North Africa in 2006. Accumulated over the period 2005–2025, the amount of energy savings is 166 TWh. This is the production of more than three power plants of 500 MW (a size relatively large in the countries of North Africa) for a year. Taking as reference a capital cost of 700 US Dollar per KW, this represents an investment of 350 million US Dollar for a 500 MW plant, that is to say, more than one billion US Dollar.

When applying the energy efficiency component to the adaptation scenario to quantify the so-called *adaptation and energy efficiency* (*EE*) scenario, the energy needed to mobilize the same amount of water decreases strongly. The energy saved is then 49 TWh in 2025 instead of 20 TWh, and the cumulative energy saving over this period amounts to more than 380 TWh, which is almost twice the electricity consumption in North Africa, in 2006 (199 TWh).

### *Energy bill*

If the electricity needs are converted into barrel oil equivalent and then into US Dollar following the approach explained in "Governance aspects: toward demand management" section, the corresponding financial savings accumulated over the period 2005–2025 are very important. If we compare the "*trend scenario*" with the "*adaptation and energy efficiency* (*EE*) *scenario*" (as described in "Water and energy: current situation" section), the cumulated energy bill saving over the period 2005–2025 is in the range of 30–48 billion US Dollar, depending on what oil price assumption is made (Fig. 4). If the barrel price goes up to 120 US Dollar in 2025, the saving is 40 billion US Dollar. For comparison, the GDP of Tunisia in 2011 is 46 billion US Dollar. This amount can be considered as a cost of nonaction in case the trend scenario would realize. This is also an amount to be compared with investment costs for implementing water demand management and energy efficiency.

As imperfect and simple this calculation is, three comments can make about the orders of magnitude that we get from our results. First, it is clear that water demand management reduces significantly the energy demand and a coupling with improved energy efficiency multiplies the

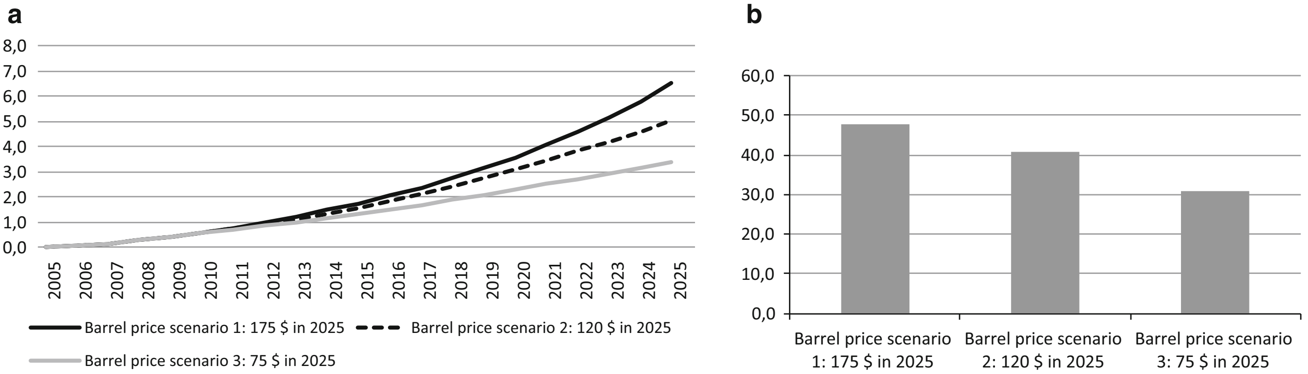

**Fig. 4** Cost of nonaction in terms of energy bill. **a** Energy bill savings in "adaptation scenario EE" compared to the "trend scenario," in billion USD. **b** Cumulated energy bill saving 2005–2025 in "adaptation scenario EE" compared to the "trend scenario," in billion USD

energy savings. Second, given the fact that electricity in North Africa is mainly produced from fossil fuels, we can consider that the adaptation options concerning water demand can be treated as indirect measures of climate change mitigation. Third, the electricity needed for the production of water will sharply increase, no matter the scenario, which will tend to increase the energy bill of importing countries and reduce the export capacity of producing countries such as Algeria or Libya.

The remaining question is: Would the order of magnitude in water saving, made possible thanks to demand management options, be large enough to solve the water scarcity issue in the region up to 2050?

## Consideration on water deficit and virtual water

From the natural resource point of view, the deficit or surplus in water is given by the comparison of the total demand for fresh water with the exploitable renewable fresh water resource (surface and underground). According to this concept, the situation of scarcity of renewable fresh water already afflicts seriously North Africa. In 2005, the total water demand exceeds by 18 billion $m^3$ the renewable exploitable water resources. This deficit is due to Egypt and Libya, and to a lesser extent, to Algeria (Morocco does not show a deficit of water at the national level; however, some parts of the South of the country are in chronic deficit). In the future, if we consider a linear steady fall of resources due to climate change, combined with our "*adaptation scenario,*" the water deficit is increased by 30 billion $m^3$ in 2050.

It is therefore obvious that taping into water efficiency can help a lot but is not enough to solve the long-term issue of water scarcity in North Africa. Demand side actions will need to be complemented by the production of nonconventional water (e.g., desalinated water) using energy efficient technologies and renewable energy (see Trieb et al. 2008). But, from the nontechnological side, another obvious adaptative measure to mitigate the water demand is to rely on virtual water through imports (Allan and Olmsted 2003; Allan 1993a, b, 1997, 2001b, 2003a, b). The virtual water traded globally is contained for about 80 % in food products (Chapagain and Hoekstra 2003, 2004; Oki et al. 2003a; Hoekstra and Hung 2003, 2005; Fraiture et al. 2004). Importing food from outside can therefore, in theory, reduce the water demand locally and limit the potential of water conflicts (Allan 1993a, b). In our goal of quantifying magnitudes of energy–water demand management options, the benefits of virtual water should also be considered in terms of potential water demand saving, energy savings and energy bill.

In Table 2, we provide an estimate of virtual water content in cereal, meat, animal fat and milk imports of North Africa (for simplification reason, we do not take into account other products, although they might be significant). We apply the world average conversion factors from Yang and Zehnder (2002). We use annual average figures of 5 years to consider that yearly imported amounts of virtual water vary significantly. The figures of production and imports are from FAO. The trade deficit of North Africa for cereals has been a landmark for 20 years, as shown in Fig. 5. It has been greatly exacerbated following the recent rise in the prices of agricultural products (since 2007), and public finances have been negatively affected, partly through food subsidies necessary to maintain social stability (Fig. 5). It is observed that the cereal imports exceeded the production in Algeria, Libya and Tunisia. But, imports in kg per capita differ significantly among countries. Libya, a very water poor country, stands significantly above the level of the other countries (Table 2).

Figure 5 also interestingly shows that, in reality, years of high import of virtual water (thus saving water at national level) correspond to years of drought and crop failure. During these years, virtual water played a key role to compensate for shortfalls in fresh water cereal (Yang and Zehnder 2002; Zeitoun et al. 2010). Through the three product groups that we consider, the region imported an average of 30 billion $m^3$ of virtual water over the period 2005–2009, which is significant, as it represents a volume equivalent to 40 % of the water used for irrigation in 2005.

To convert this amount of virtual water into energy saved locally, we consider the energy which would have been needed to desalinate such an amount of water using the current technologies. According to Siddiqi and Anadon (2011) and Boyer (2008), 4 kWh is needed in average to desalinate 1 cubic meter of water. The electricity amount saved is then around 120 TWh which is equivalent to 10 million of TOE (equivalent to 6 % of the total primary energy supply of North Africa in 2009). As imperfect and simple is this calculation, it suggests that local energy benefits of virtual water imports might be significant and may be considered. However, more investigations would be needed to confirm this conclusion. Indeed, virtual water imports require the consumption of considerable amount of energy, first due to international transportation, and second, due to local transportation for distributing imported products.

Up to know, virtual water is not considered as an adaptation option by policy makers in North Africa due to reasons related to food independence (Allan 2001a; Hakimian 2003; Fernandez 2007), exposure to international prices, implications for the security and vulnerability and livelihood strategies of actors within nation states (Zimmer and Renault 2003; Warner and Johnson 2007). If it becomes a proactive strategy in the future, the net energy saving should be considered but is not straightforward and

**Table 2** Average import per year of virtual water from North Africa across grain, meat, milk, animal fat and energy equivalent, 2005–2009

| | Algeria | Egypt | Libya | Morocco | Tunisia | Total |
|---|---|---|---|---|---|---|
| Grain production in kg/capita 2005–2009 | 105.8 | 293.7 | 35.9 | 205.0 | 188.0 | 828.5 |
| Import grain kg/capita or in m$^3$ of virtual water per capita from 2005 to 2009[a] | 237.6 | 128.6 | 380.2 | 162.7 | 261.9 | 1,170.9 |
| Eau virtuelle dans les importations de viande et graisse animale m$^3$/tête 2005–2009[a] | 8.9 | 9.4 | 17.7 | 2.5 | 2.7 | 41.1 |
| Virtual water imports in milk m$^3$/tête 2005–2009[a] | 31.0 | 4.1 | 25.5 | 6.0 | 3.4 | 70.1 |
| Total virtual water imports in billion m$^3$[b] | 9.4 | 10.9 | 2.5 | 5.3 | 2.7 | 30.9 |
| Equivalent in energy of billion of kWh (water desalination: 4 kWh per m$^3$) | 37.6 | 43.7 | 10.2 | 21.2 | 11.0 | 123.8 |

*Source*: Calculations based on FAO data, 2010

[a] We use the convertion factors given by Yang and Zehnder (2002): 1 kg = 1 m$^3$ cereal water, 1 kg of meat = 4 m$^3$ of water, milk 1 kg = 0.5 m$^3$ of water

[b] This total includes only cereals, meat, milk and animal fats. Other agricultural products are not included but are significant imports

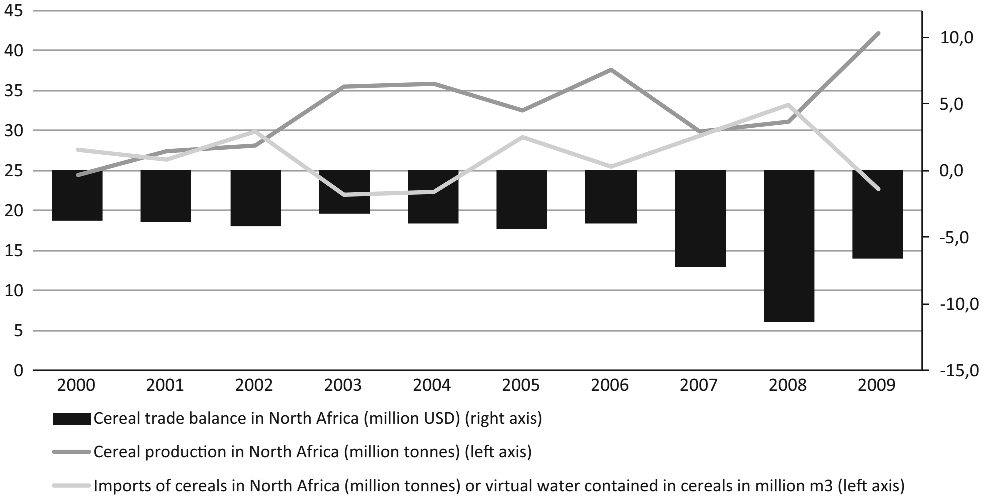

**Fig. 5** Cereal production, imports of virtual water through grains and grain trade deficit in North Africa, 2000–2009. *Source*: Authors calculation based on FAO data and virtual water conversion factors from Yang and Zehnder (2002)

specific measures to avoid negative effects would be needed.

## Discussions and conclusion

In this article, we explore the interactions between water–energy saving options in a climate change world and we analyze the current situation to conclude that demand management looks like an appropriate adaptation option in North Africa. We simulate the synergistic effects of sustainable energy with water demand management options by computing scenarios. We introduce a simple method for estimating order of magnitudes in terms of water demand, energy needs and energy bill over the next 20–45 years.

We show that water demand management is a very appropriate adaptation option with significant co-benefices in terms of energy bill. Depending on scenario and assumptions, the expected cumulated benefit in terms of energy bill over the period 2005–2025 could range between 30 and 48 billion US Dollar. Nevertheless, up to 2050, demand side management will need to be complemented by increase of water supply, from conventional and non-conventional water sources, to cover the water deficit of the region. It will be energy intensive and costly, which can be view as one more reason to put an emphasis on demand side options. No doubt that the energy saved that way will be welcome to cover needs for mobilizing additional water or to cover cost of importing virtual water.

Across countries, several experiences in water demand management show encouraging results. For example, in Tunisia, a pilot experiment in agriculture has reduced water consumption by 25 % and improved water efficiency by 33 % (Agrawala and Fankhauser 2008; Hamdane 2007). But, for the most part, it is widely agreed that implementing concrete actions of water demand management mainly constitutes pilot exercises more than resolute policies (Yang and Zehnder 2002, Benoit and Comeau 2005; Baroudy et al. 2005; Laamrani et al. 2007 or Sower et al. 2011). Observed actions aim mainly at solving occasional crisis or at seeking to increase income from water-intensive activities, including the production of agricultural goods for export. Water demand management policies face many obstacles. They are coming both from market failures (no value for environment, monopolies, private interests and unpaid innovations), technological issues and from a lack of information and education which turns out to strengthen the short-term financial interests.

For water demand management to become operational at a large scale, important governance reforms are required. A strong political commitment is the first condition of success to remove barriers, set an institutional and legal framework and raise economic awareness. Such reforms are particularly challenging due to the legal or illegal (related to corruption) private interests at stake but also due to policy coordination issues. Energy pricing and water pricing are, for instance, measures able to facilitating adaptation to climate change in the field of water and energy management. All countries recognize the importance of reforms in this area, particularly in order to empower users and to guide their behavior, especially in agriculture. However, a sharp rise in water price may encourage users to move toward the direct pumping from underground as soon as the price of water exceeds the cost of pumping. If energy prices are low, the outcome is likely to be the opposite of the one desired. In the same type of perverse effect, the social necessity of water allocation to agriculture is also amplified by subsidies to food crops that are paradoxically crops with high water consumption and low added value.

Sectoral policies functioning independently may therefore not guarantee long-term results because of the direct implications on other sectors. It is therefore, in theory, extremely beneficial to integrate sectoral policies such as water, energy and food. However, in reality, it is extremely difficult to de-compartmentalize the decision process. Decisions on energy, water, land use planning and agricultural infrastructures are usually made in disconnected institutional entities. On top of that, there is a need, within each sectoral policy, to accord equal importance to demand side management and to supply side options. If not, the increase in energy intensity of water could become a very critical issue in North Africa as in many arid areas in the world.

Fierce political will, long-term vision and international cooperation are probably the three factors that will build links between the fields concerned. Demand side management benefits could then be invested in R & D systems and in efficient low-emission technologies for water and energy. Given the market size in the Mediterranean Basin, the development of an industrial sector in all these areas might be seen as an economic opportunity. It is also a pathway to green growth and jobs creation. There are reasons for optimism. Several governments are planning to progress faster in these area, and multinational organizations begin to seriously consider these issues. It is, for instance, recommended by the United Nations to analyze the energy implications before any climate change adaptation investment in the agricultural sector and to consider results as highly strategic (FAO 2011). This kind of approach constitutes a doubtless step toward global food security and climate change management.

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