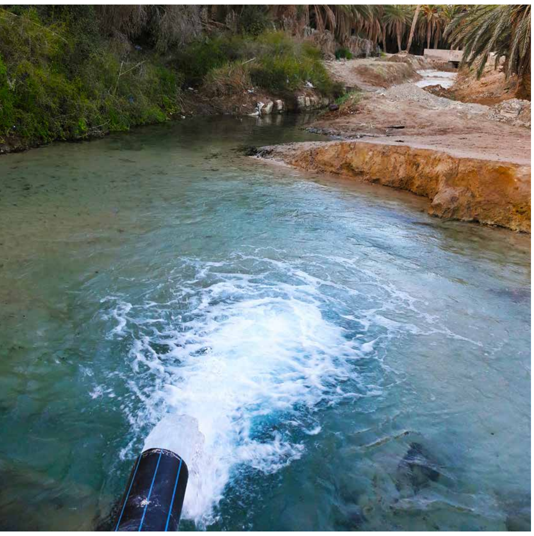
UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE

Reconciling resource uses: Assessment of the water-food-energy-ecosystems nexus in the North Western Sahara Aquifer System

Part A - "Nexus Challenges and Solutions"



Global Water Partnership Mediterranean

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SUMMARY

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ACRONYMS AND ABBREVIATIONS

CAPEX	Capital expenditure
CI	*Continental intercalaire* (Intercalary continental)
CT	*Complexe terminal* (Terminal complex)
FAO	Food and Agriculture Organization of the United Nations
GDA	Agricultural development group
GIS	Geographic information system
GWP	Global Water Partnership
GWP-Med	Global Water Partnership – Mediterranean
LCOE	Levelised cost of electricity
NWSAS	North Western Sahara Aquifer System
OPEX	Operating expenses
OSS	Sahara and Sahel Observatory
PV	Photovoltaic
RES	renewable energy sources
SDGs	Sustainable Development Goals
SIDA	Swedish International Development Cooperation Agency
TDS	Total dissolved solids
UNECE	United Nations Economic Commission for Europe
WACDEP	Water, Climate and Development Programme

LIST OF UNITS

°C	Degree Celsius
Bcm	Billion cubic meters
cap	Per capita
GWh	Gigawatt-hour
ha	hectare
km	Kilometre
km^2	Square kilometre
kW	Kilowatt
kWh	Kilowatt hour
l	Litre
m	Metre
m^2	Square metre
m^3	Cubic metre
mg	Milligram
Mm	Million metres
MW	Megawatt
s	Second
USD	United States Dollars

Executive summary

Coordination among the water, energy, food and environment sectors is fraught with difficulties, and the complexity increases substantially in transboundary contexts. The nexus approach to managing interlinked resources aims to enhance water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance while protecting ecosystems. Such an approach helps reconcile different sectoral objectives and supports progress towards the closely interlinked Sustainable Development Goals at the national and regional levels.

This report highlights the main results of a participatory assessment of the water-food-energy-ecosystems nexus in the North Western Sahara Aquifer System (NWSAS). Shared by Algeria, Libya and Tunisia, the aquifer is the biggest transboundary groundwater reserve of North Africa, extending over one million square kilometres. Its water resources are largely non-renewable, with limited replenishment. In addition, socioeconomic development in the basin over the last decades and technological progress in well-drilling have led to steadily growing water abstraction. Currently the combined abstraction from the aquifer by the three countries exceeds three times the natural rate of recharge. As a consequence, the countries are facing important challenges – depletion and the loss of groundwater pressure; salinization; degradation of soil and reduced agricultural productivity; increased energy demand to pump water; and demineralization.

Political will and action in the area have already laid a concrete basis for enhanced cooperation. Since the 1970s, Algeria, Libya and Tunisia have been developing cooperation in information exchange and consultation that inform the management of the shared aquifer. The NWSAS Consultation Mechanism, established in 2006, has a work programme with a budget, and operates through annual meetings of senior officials, ad hoc working groups and national committees. Recently, the countries initiated discussions to explore opportunities to enhance the Mechanism's functioning, autonomy and financial sustainability as well as to further strengthen transboundary cooperation. The countries have also programmed into their national policies and strategies for adaptation to climate change a set of actions that can help promote joint action by taking advantage of and building synergies among the sectors of the water-food-energy-ecosystems nexus. The strengthening of multi-sectoral and multi-level coordinated and synergetic actions through a full-scale nexus approach can help ensure a sustainable future of the North Western Sahara Aquifer System.

The NWSAS Nexus Assessment is an outcome of a participatory process that included national consultations and two transboundary workshops. The assessment mobilized representatives from the three countries and the four sectors, and engaged local and international multi-disciplinary experts. Through a transboundary dialogue, the nexus assessment has helped identify key linkages among energy, water, land, and ecosystem resources, together with potential solutions for making resource management sustainable and efficient.

Improving the management of NWSAS resources is highly important to the socioeconomic development of the three countries and the region as a whole. The aquifer system comprises two deep aquifers, one on top of the other, and is the unique source of fresh water in a highly arid environment with annual rainfall less than 150 millimetres and summer temperatures exceeding 40°C.

Agriculture is the largest water consumer in the three countries, and the water-intensity of irrigation in the NWSAS is very high: water consumption on average is around 11,000 m^3/ha but may reach 16,800 m^3/ha[1] . This level of water consumption in irrigation – exacerbated by inefficiency, inadequate infrastructure and poor agricultural practices – leads to salinization and to further loss of soil fertility.

Together with the naturally high mineral and low organic content in soils, this puts serious constraints on irrigation: out of almost a million hectares of soil mapped to date a little less than a tenth is considered irrigable. In this dry climate with high evaporation, traditional oasis-based agriculture remains the prevalent mode of production. Yet new industrial agriculture has developed over the past three decades, and agricultural expansion puts fragile and vulnerable pastoral ecosystems and important wetland habitats for migratory birds under pressure. The low physical and economic productivity of land and water exposes the local population to unprecedented economic vulnerability, which ultimately leads to emigration and rural exodus in search of other sources of income.

Fossil fuels are among the most abundant natural resources in these countries, and Algeria and Libya are net exporters and rank among the top worldwide producers of natural gas and crude oil. Rich in solar and wind energy, the countries nonetheless mostly rely on

[1] Water, Climate and Development Programme (2015). I*ntegration of climate change impacts in the NWSAS water resources management. Report of Phase A: Definition of the baseline and choice of climatic scenarios*

fossil fuel for the generation of electricity, while the implementation of ambitious plans for renewable technologies remains challenging – and progress towards decarbonization slow.

The tightly linked challenges experienced by the different sectors reinforce the strong nexus in the North Western Sahara Aquifer area. The key to the interdependence is the sectors' reliance on common groundwater resources that are becoming scarcer vis-à-vis increasing demands. Policy responses are linked too, through indirect and often unintended impacts of specific measures such as energy subsidies, renewable energy deployment, or the popularization of high-value crops. These intertwined sectoral challenges call for synergetic actions taken in the different sectors in a coordinated way.

These challenges are all directly or indirectly connected to water and have been clustered in three groups:

- Those related to the management of water from the perspective of economic development and water security
- Those related to the economic, social, and environmental sustainability of the agricultural sector and, more specifically, the oasis agro-systems
- Those related to energy security and energy developments, particularly renewable energy and its potential to help transform water management and agriculture

The nexus package includes 15 high-priority, implementable solutions ranging from governance and international cooperation, to economic and policy instruments, infrastructure and innovation. The solutions consist of 65 actions to be taken by actors in the water, energy, food, and environment sectors. While each solution pertains to a certain sector that leads its implementation, others outside the sector often play a key supporting role, and intersectoral cooperation ensures the effectiveness of solutions. At a more strategic level, implementing various solutions simultaneously and in a coordinated manner will also help achieve cross-sectoral goals like coherent planning for sustainable development, enhanced local resilience, and a circular economy, while still contributing to sectoral development, by minimizing intersectoral trade-offs and negative impacts, and maximizing synergies. This nexus approach to implementation would help achieve such common objectives as the 2030 Agenda for Sustainable Development and international climate action commitments under the Paris Agreement.

The benefits of a nexus approach to managing the NWSAS are multiple, and applying it has considerable potential to support further development of transboundary cooperation.

This Nexus Assessment of the NWSAS was carried out under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention), applying an assessment methodology[2] developed in its framework, in close cooperation with the Global Water Partnership Mediterranean and the Sahara and Sahel Observatory as part of the project, "Making water cooperation happen in the Mediterranean (Med Water Matchmaker)", funded by the Swedish International Development Cooperation Agency. The assessment also built on synergies with the Water, Climate and Development Programme (WACDEP) of the Global Water Partnership.

2 More information on the methodology are available at : http://www.unece.org/env/water/nexus.html

1. Introduction

1.1 Aim, objective, and target audience

Making optimal use of scarce natural resources for sustainable development is a challenging endeavour for governments that becomes even more complex in transboundary context. It implies maximising co-benefits, minimising trade-offs, and building synergies between different sectoral policies and across countries. To this end, a nexus approach provides a very useful framework for understanding the cross-sectoral interlinkages and identifying relevant implementable solutions leading to water, energy, and food security enhancement while also preserving ecosystems and their functions.

Applied to the North Western Sahara Aquifer System (NWSAS), shared between Algeria, Libya, and Tunisia, the nexus approach aims to enhance coherent policies and coordinated action towards sustainable management in the basin. More specifically, the nexus assessment has the following objectives:

- improve knowledge about the intersectoral linkages, co-benefits, trade-offs, and synergies
- explore and discover new opportunities for collaboration that may not have been looked into so far and suggest concrete policy measures and actions at national as well as transboundary level
- build capacity in the three countries to assess and address intersectoral impacts of resource use and management.

The primary target audience of the nexus assessment are the members of the NWSAS Consultation Mechanism, which is the joint body for transboundary cooperation in the NWSAS, as well as the officials from the ministries responsible for water, energy, agriculture and environment, in Algeria, Libya, and Tunisia. More broadly, the nexus assessment can be of interest to professional organisations (i.e. farmers' unions), non-governmental organisations (including water users' associations), research institutes, and other stakeholders.

The nexus assessment is conducted by the United Nations Economic Commission for Europe (UNECE), the Global Water Partnership Mediterranean (GWP-Med) and the Sahara and Sahel Observatory (OSS) in the framework of the GWP-Med led project "Making water cooperation happen in the Mediterranean" ("Med Water Matchmaker)" funded by the Swedish International Development Cooperation Agency (SIDA) and builds synergies with the GWP Water, Climate and Development Programme (WACDEP).

1.2 Why the NWSAS?

The NWSAS is the biggest transboundary groundwater reserve in North Africa, extending over 1 million km^2. However, its water resources are largely non-renewable, and their replenishment is limited to around 1 billion m^3/year. Over the last decades, the socioeconomic development in the basin, as well as the technological advances in well drilling led to steadily growing water abstraction. Today, the rate of withdrawals from the aquifer far exceeds the rate of its replenishment. Consequent water depletion, salinisation, loss of artesianism, soil degradation, reduction of agriculture productivity, and increased energy demand for water pumping and demineralisation are only some of the challenges faced by the NWSAS countries. Ensuring sustainable development in the basin requires multisectoral and multilevel coordinated and synergetic action.

At the same time, political will and action in the NWSAS area have, thus far, laid a concrete basis for enhanced cooperation. Through collaboration already in place since the seventies, Algeria, Libya, and Tunisia have succeeded in establishing cooperation in the field of information exchange and consultation to improve the management of an internationally shared aquifer, one of few cases worldwide. A NWSAS Consultation Mechanism was established in 2006 with the mandate to:

- produce indicators on water resources and demand
- elaborate water resource management scenarios for development in the basin
- reinforce and update the common database through exchange of data and information
- develop and manage common observation networks for the aquifer system.

The structure of the Consultation Mechanism includes the Council of Ministers, the Permanent Technical Committee comprising the water general directorates of the three countries (the National Agency of Hydraulic Resources in Algeria – ANRH, the General Water Resources Authority in Libya – GWRA, and the General Directorate of Water Resources in Tunisia – DGRE), the Coordination Unit, the ad hoc working groups, and the national committees.

Since the mechanism was established, the Consultation Mechanism has held annual meetings of the Permanent Technical Committee[3]. The Coordination Unit is in charge of preparing and implementing the work programme in accordance with the decisions of the Permanent Technical Committee and the adopted budget. Recently, the NWSAS countries entered into discussions on exploring opportunities to enhance the Consultation Mechanism's functioning, autonomy and financial sustainability, and consequently the transboundary cooperation.

The nexus assessment is expected to strengthen the knowledge base with solid technical work and multi-stakeholder consultation and therefore to contribute to and inform policy processes that aim to ensure the long-term sustainable management of the NWSAS and the enhancement of transboundary and cross-sectoral cooperation.

1.3 Assessment process

The nexus assessment follows the participatory methodology for assessing intersectoral links, trade-offs, and benefits in transboundary basins, specifically developed under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention) and adopted by its Meeting of the Parties. The methodology was refined with feedback from applications and input from key partner institutions, including GWP-Med, and was published in 2018[4].

Applied to the NWSAS, the methodology combined technical analytical work and a methodologically structured and inclusive consultation process involving alternating national and transboundary consultations. A first transboundary workshop (18–19 July 2017, Algiers, Algeria) was organised to identify the main challenges and intersectoral linkages, formulate objectives to be explored concurrently through a nexus approach, and outline management, policy, and infrastructure-related actions that could be taken. National workshops (1–2 April 2019 and 3–4 April 2019, Hammamet, Tunisia, for the Libyan, and Tunisian consultations, respectively)[5] were organised to detail solutions and actions and elaborate on how to achieve their implementation at national and transboundary level, in alignment with national sectoral strategies and ongoing initiatives and projects. A second transboundary workshop (18–19 June 2019, Hammamet, Tunisia) was held to prioritise and cluster the solutions into packages that will enable coordinated and synergetic action leveraging and cross-sectoral goals achievement.

FIGURE 1.
Key steps within the nexus assessment participatory process in the NWSAS (2017–2019)

[3] The Coordinator of the Consultation Mechanism is designated by his/her country for a two-year term on a rotating basis. The Council of Ministers have not met since the mechanism was created and the ad hoc working groups and national committees were not established in 2018.

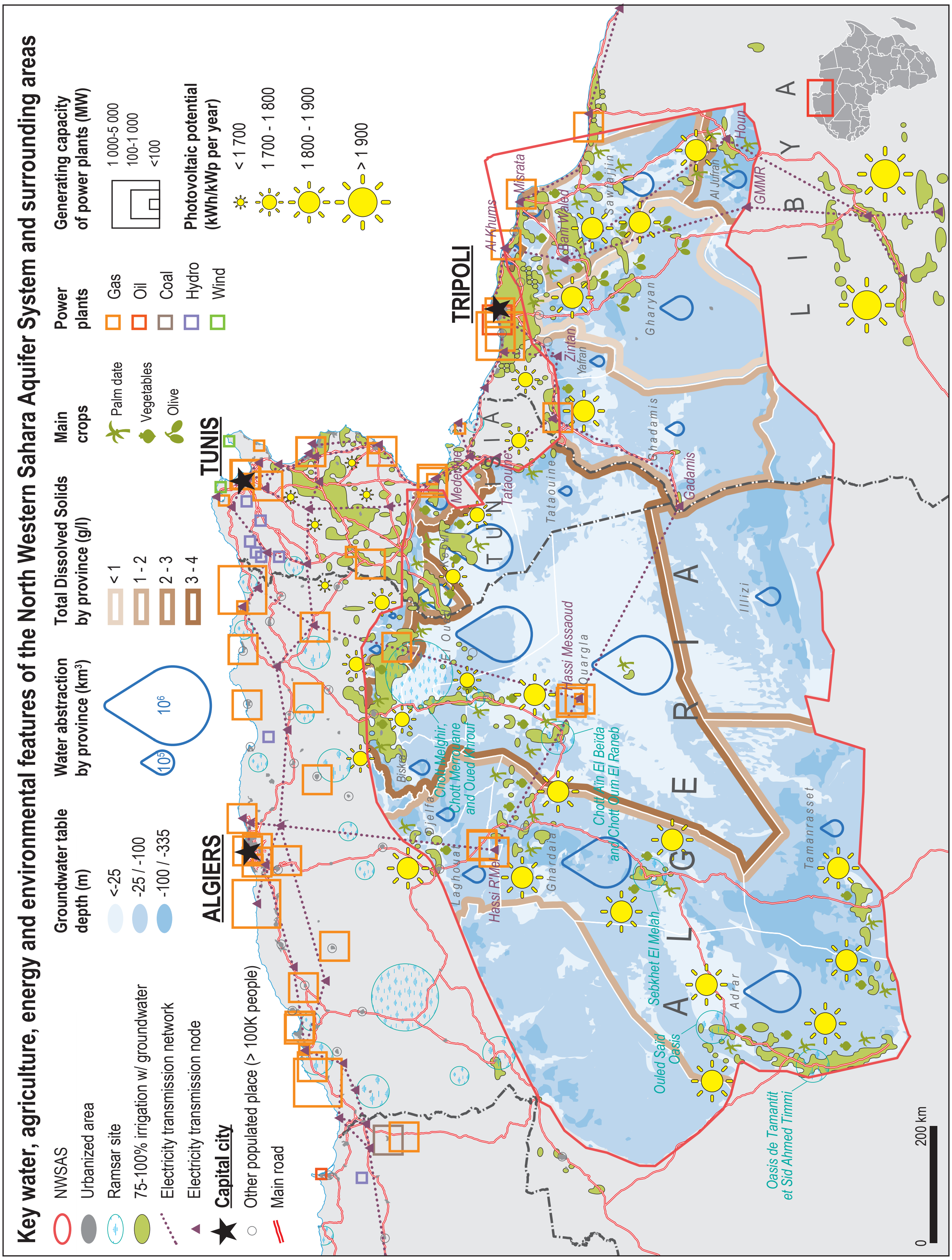
[4] United Nations Economic Commission for Europe (2018). Methodology for assessing the water-food-energy-ecosystem nexus in transboundary basins and experiences from its application: synthesis. Available at: http://www.unece.org/environmental-policy/conventions/water/envwaterpublicationspub/water/envwaterpublicationspub74/2018/methodology-for-assessing-the-water-food-energy-ecosystems-nexus-in-transboundary-basins-and-experiences-from-its-application-synthesis/doc.html

[5] Libyan stakeholders travelled to Tunisia for the Libyan national consultation. No national consultation was organised for Algeria, and therefore the consultation with Algerian authorities was limited to the two transboundary workshops, as well as correspondence with experts and authorities.

1.4 Structure of the report

The results of the nexus dialogue are displayed in a two-part report: this, Part A, "Nexus challenges and solutions" that draws upon the more detailed Part B, "Technical assessment of resources and sectors", which will be available online. Three main chapters are covered in Part A. Chapter 2 of the report provides a brief overview on the natural resources and ecosystems at country level, as well as a description of the socioeconomic situation. Chapter 3 describes the challenges related to the natural resources in the NWSAS and the suggested packages of solutions resulting from the nexus assessment. Chapter 4 presents the main features and illustrative results of a novel integrated resource model of the water-food-energy nexus in the NWSAS, developed as part of the nexus assessment, discussing its potential to quantify intersectoral linkages and inform decision-making. A full list of actions supporting implementation of the nexus solutions is presented in an annex, as is a list of organisations and actors that would play a key role in that regard.

FIGURE 2.
Map 1. Key water, agriculture, energy and environmental features of the NWSAS and surrounding areas



Sources: KTH Royal Institute of Technology in Stockholm, The World Bank, The Ramsar Convention, CIESIN GPW v.4, FAO, World Resources Institute, GRIP global roads database, The United Nations Geospatial Information Section, NaturalEarth, ESRI.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations © United Nations Economic Commission for Europe (2020)

(Cartography: Stéphane Kluser, Komplo)

2. Overview of the resources and their use

2.1 Geography, resources, and climate

The NWSAS is located in a desertic and arid area shared between Algeria (700,000 km^2), Libya (250,000 km^2), and Tunisia (80,000 km^2). It consists of two superimposed deep aquifers, the Intercalary Continental (CI; diverse sandstone and carbonate formations, among others) that reaches up to 3 000 m in some locations - and the Terminal Complex (CT; sandy and carbonate formations) - maximum 500 m deep - and it is interconnected with the Tunisian-Libyan Djeffara plain[6]. Annual average rainfall does not exceed 150 mm throughout the majority of the NWSAS basin, and temperatures are very high, exceeding 40°C during the summer season. Map 1 provides an overview of the key water, agriculture, energy and environmental features of the NWSAS and surrounding areas.

Water resources
The three countries of the NWSAS are water-scarce, with water availability of around 282 m^3/cap/year in Algeria, less than 150 m^3/cap/year in Libya, and 400 m^3/cap/year in Tunisia. Groundwater represents a significant share of the renewable resources (over 30 percent in Algeria, about 50 percent in Tunisia, and more than 80 percent in Libya)[7].

The NWSAS qualifies as a fossil aquifer due to its very limited water recharge, estimated at 1 billion m^3/year out of the basin's 60,000 billion m^3 fossil water reserves. Current withdrawals from the aquifer exceed three times its recharge capacity (3.171 billon m^3 in 2016). As a result, considerable drawdown is observed since the 1950s at the piezometric level (reaching 140 m in some areas of the Intercalary Continental and more than 50 m in the Terminal Complex), severely threatening the sustainability of the development in the basin.

Energy resources
Fossil fuels are among the most abundant natural resources within the NWSAS countries. While Tunisia is a net importer of fossil fuel products, Algeria, and Libya are net exporters, ranking among the world's top producers of natural gas and crude oil, respectively. In 2018, proven crude oil reserves were about 12.2 billion Bbl in Algeria, 48.4 billion Bbl in Libya, and 425 million Bbl in Tunisia[8]. Looking at the natural gas reserves, in 2018, the proven natural gas reserves were around 4,504 bcm in Algeria, 1,505 bcm in Libya and 65.13 bcm in Tunisia[9].

At the same time, the NWSAS countries are rich in solar and wind renewable energy sources due, respectively, to the high solar horizontal irradiation throughout the three countries, incrementing from north to south in the range of 1,500 to 2,500 kWh/m^2, and wind speeds as high as 9.5 m/s that can be found in the three countries at a height of 50 m, even faster at higher altitudes[10].

Despite vast renewable energy source availability, the NWSAS countries rely mostly on fossil fuels for electricity generation. For instance, in 2016, Algeria's electricity production was 70,997 GWh, of which 69,693 GWh were generated from natural gas, representing 98.16 percent of the total production. In Tunisia, it was 19,808 GWh, of which 18,961 GWh were generated from natural gas, representing 95.72 percent of the total production, and in Libya, it was 36,430 GWh, of which 22,802 GWh were generated from natural gas and 13,620 GWh from oil, representing 62.5 percent and 37.3 percent, respectively, of the total production[11].

The three countries have ambitious plans for deploying renewable energy technologies, but their implementation remains challenging, and progress towards decarbonisation remains slow. The Renewable Energy and Energy Efficiency Development Plan 2015–2030 in Algeria aims to install 4,500 MW of new renewable energy capacity by 2020 and a total of 22,000 MW by 2030. The Renewable Energy Strategic Plan 2013–2025 in Libya aims to achieve a 7 percent and 10 percent share of renewable energy in the electricity energy mix by 2020 and 2025, respectively. The Tunisian Solar Plan aims to increase the share of renewable energy to 30 percent by 2030, with wind power contributing 15 percent of the total electricity production, solar photovoltaic (PV) 10 percent and concentrated solar power 5 percent[12].

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6 Sahara and Sahel Observatory (2015). *Pour une meilleure valorisation de l'eau d'irrigation dans le bassin du SASS ; Diagnostic et recommandations* [Better use of irrigation water in the SASS basin; Diagnosis and recommendations]. In French. Available at: http://www.oss-online.org/sites/default/files/publications/OSS-SASS-Recomm-SASS_Fr.pdf

7 Water, Climate and Development Programme (2015). *Integration of climate change impacts in the NWSAS water resources management. Report of Phase A: Definition of the baseline and choice of climatic scenarios.*

8 Algeria: Organization of the Petroleum Export Countries (2019). *Brief History.* Available at: https://www.opec.org/opec_web/en/about_us/24.htm.
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9 Algeria and Libya: Organization of the Petroleum Export Countries (2019). *Data*. Available at: https://www.opec.org/opec_web/en/20.htm.

10 Data obtained from *Global Solar Atlas* and *Global Wind Atlas 2.0*, available at: https://globalwindatlas.info.

11 International Energy Agency (2016). *Key stats for the countries*. Available at: https://www.iea.org/countries/.

12 International Energy Agency and International Renewable Energy Agency (2016). *Renewable Energy and Energy Efficiency Development Plan 2015-2030*. Available at: https://www.iea.org/countries/algeria; International Energy Agency and International Renewable Energy Agency (2016). *Libya Renewable Energy Strategic Plan 2013-2025*. Available at: https://www.iea.org/countries/libya; Energy Information Administration (2014). *Tunisia country overview*. Available at: https://www.eia.gov/beta/international/analysis.php?iso=TUN.

Land resources

Soils in the NWSAS are generally poor in organic matter and have a high salt concentration. Their formation is due to the influence of the wind on the bedrock and the arid water regime. Their evolution is very limited, and the soil cover is known to have mainly heterogeneous properties. Out of almost a million hectares of the Sahara where the soil mapping was carried out, slightly less than a tenth of the soil was considered irrigable. Soil therefore appears to be a serious constraint to irrigated agriculture in the NWSAS. Furthermore, in this very dry climate with high evaporation, oases are the traditional agricultural mode. A new "industrial" agriculture has, however, developed over the past three decades.

Ecosystems and biodiversity

The NWSAS ecosystem is characteristic of the desertic areas and can be categorised into three main types: the agrosystems comprising the oases and the modern irrigated perimeters, the pastoral ecosystems extending from degraded forest formations to desert and freshwater wetlands (i.e. *garâas* (marshes), expanses of water), and salt water (i.e. *sabkhas* – arid mudflats of a non-marine closed basin, *chotts* – salt lakes typical of the Maghreb region that remain dry for most of the year). These fragile and vulnerable ecosystems are under pressure due to human activities. For instance, pastoral lands are converted to croplands to expand agricultural production. Wetlands, an important habitat for migratory birds from the Mediterranean to the Sahara, particularly in the winter, are receiving less water and are exposed to pollution.

Climate change

The main impacts of climate change in the NWSAS basin are increasing domestic and agricultural water demand, leading to additional pressure on water resources and the risk of their degradation. More than the quantitative risks related to additional pumping volumes and recharge reduction in the Djeffara plain, the quality risks are significant and are those presented by salinisation and flow reversal of *chotts* towards the water table as a result of decreasing piezometric levels. As a result, farmers cannot avoid expensive water quality improvement interventions such as installing desalination units, without which they will experience falling yields and loss of income. Crop yields can also fall with the combined effects of extreme temperatures and drought. By 2050, crop yields are predicted to be 25 percent lower than 2010 (32 percent for pomegranate and 15 percent for date palm). Falls in pastoral production of aboveground biomass and forage units could reach 70 percent, depending on the vulnerability of environments and ecosystems[13].

The NWSAS countries have all programmed adaptation actions in their national climate change adaptation policies and strategies. Although these do not specifically target the NWSAS oasis ecosystem, they can be used to build transboundary action that synergises and benefits from the intersectoral links of the water-food-energy-ecosystems nexus (promoting use of non-conventional waters, combatting desertification, improving agricultural resilience, using solar energy in agriculture, etc.).

2.2 Socioeconomic situation and the main water use in the NWSAS

Population

The NWSAS hosts a population of 4.8 million inhabitants. Around 70 percent of them live in urban areas. The highest density is to be found in Gabès (Tunisia) with 51 inhabitants/km² and the lowest in Adrar (Algeria) with 1 inhabitant/km². The growth rate is low in the three countries (around 2 percent) with the lowest rate in Tunisia (1 percent)[14].

Water use and agricultural performance in the NWSAS

Agriculture is the largest water consumer in the three countries (around 60 percent in Algeria and 80 percent in Libya and Tunisia). The total irrigated area in the NWSAS is around 250,000 ha (170,000 ha in Algeria, 40,000 ha in Libya and 40,000 in Tunisia). Irrigation efficiency is very low with an average of 42.4 percent throughout the basin. The bad management of irrigation affects the soils and their fertility (soil salinisation, hydromorphy caused by deficient drainage, fertility degradation). Soil losses are estimated at 4,300 ha/year of the 170,000 ha in Algeria and 300 ha/year of the 40,000 ha in Tunisia. Other effects are damage to the ecological quality of the land, reduced agricultural production capacity, and reduced productivity of the water used. For example, the current productivity of dates is 0.32 kg of dates/m³, when it is known to exceed 0.5. This low physical and economic productivity of the natural capital exposes the local population to unprecedented economic vulnerability that ultimately leads to emigration in search of other sources of revenue[15].

[13] The first quantitative assessment of the direct and indirect impacts of climate change in the NWSAS was carried out by GWP-Med under the Water, Climate and Development Programme (WACDEP).

[14] World Bank data. Available at: https://data.worldbank.org/

[15] Water, Climate and Development Programme (2015). *Integration of climate change impacts in the NWSAS water resources management. Report of Phase A: Definition of the baseline and choice of climatic scenarios*

3. Sectoral challenges and nexus solutions

Discussing challenges related to the natural resources in the NWSAS basin necessarily involves looking at the nexus through a "water lens". As a result, the challenges presented in this chapter, which emerged from a consultation with local stakeholders[16], are all directly or indirectly connected to water. Based on the discussion during the workshop, they have been clustered in three groups: those related to the management of water from the perspective of economic development and water security; those related to the sustainability (economic, social, and environmental) of the agricultural sector and more specifically, the 'oasis' agrosystems; and those related to energy security and energy developments in the basin, particularly when it comes to renewable energies and their potential for innovation in water management and agriculture.

This categorisation is useful to describe the issues that each sector is facing based on specific perspectives. However, taking a 'nexus approach' to policy-making means looking at different perspectives simultaneously and determining the trade-offs between sectoral policies and objectives on the one hand, and the common goals that should remain a priority for governments on the other. As resources become scarcer and more under pressure, this becomes a crucial exercise both to guarantee well-being and stability in the basin and to plan for future developments more strategically.

The challenges experienced by the different sectors are tightly linked, mainly because of the reliance of the sectors on common groundwater resources that are becoming scarcer due to increasing demands. The policy responses, however, are also linked through indirect and often unintended intersectoral impacts of specific measures such as energy subsidies, renewable energy deployment, or the popularisation of high-value crops. For this reason, in response to 'sectoral challenges', we propose to implement 'nexus solutions', which means sets of synergetic actions to be taken in the different sectors in a coordinated manner. The solutions presented in this report have been developed for the NWSAS. They are organised in a comprehensive 'package of solutions' that can be consulted as a map of coordinated actions that can be taken at different levels (local, national and transboundary) through cooperation and coordination. These packages are designed to address and anticipate the negative impact of strictly sectoral policy-making and to realise the potential benefits of cooperation.

3.1 Challenges in the water, energy, and food sectors

Sectoral policies reflect the challenges that different segments of governance are facing in the NWSAS in relation to natural resource management. Here we look at three broad sectors of water, food, and energy, defined as follows:

- The water sector: water mobilisation, conservation of fossil groundwater, irrigation, water services, treatment, quality improvement, and reuse.
- The energy sector: energy production, supply and access, power grid management.
- The food sector: agriculture and land use, food production, commercialisation and trade, nutrition and diet.

The policies of these sectors are shaped by specific developmental objectives, societal needs, and economic considerations related to producers, consumers, and users of water, energy, and food resources. In addition to these economic sectors, we also examine the environment sector, defined as follows:

- The environment sector: protection of ecosystems and their services[17] (provision, regulation, habitat, cultural) and biodiversity.

Essentially, environment policies and governance exist to preserve and protect ecosystems and biodiversity, that support life in general and are the ultimate critical assets sustaining the water, energy, and food sectors. Since environmental challenges result primarily from sectoral pressures, they are not analysed separately. They are underlying challenges within the three sectoral perspectives of water, energy, and food.

[16] Participatory workshop in Algiers in 2017. More information at: https://www.unece.org/info/media/presscurrent-press-h/environment/2017/assessment-launched-to-reinforce-cooperation-between-algeria-libya-and-tunisia-in-managing-shared-groundwater-resources/doc.html.

[17] A more detailed description of ecosystem services is available on the website of The Economics of Ecosystems and Biodiversity (TEEB), available at: http://www.teebweb.org/.

TABLE 1.
Sectoral perspectives from the water, food, and energy sectors on the common challenge of aquifer degradation

Common challenge	Water perspective	Energy perspective	Food perspective
NWSAS aquifer degradation compromising development	W1. Reducing vulnerability and dependence of economic activities on groundwater resources	E1. Managing increasing energy demand and reducing excessive pumping	F1. Managing increasing water demands and reducing irrigation losses
	W2. Managing the increasing risk of saline intrusion from chotts	E2. Supplying future demand for energy to be used in water treatment (brackish water, wastewater)	F2. Managing salinisation of water and soil in agriculture
	W3. Addressing ecosystem degradation and its impacts on public health	E3. Securing supply of electricity in rural areas	F3. Coping with the social impact of natural resource degradation

Source: Outcome of regional and intersectoral dialogue at the First regional NWSAS nexus workshop in Algiers (2017).

3.1.1 The water sector perspective

Today, the socioeconomic development of the NWSAS countries is intrinsically linked to groundwater use, the main water resource available to large shares of the population. If, on the one hand, agricultural policies motivate the expansion of irrigation from groundwater, on the other, governments struggle to develop and implement sufficient mitigation measures for water conservation and efficiency on a large scale. The impact of population growth and climate change worsen the situation. Today, some areas of the aquifer are facing depletion and shallow aquifers are at high risk of drying up.

Overall, water networks are characterised by high losses that are expensive to fix, and the same is true for irrigation schemes. Water consumption per farmer, per hectare reaches around 13,520 m^3/ha in Algeria, 9,134 m^3/ha in Libya and around 13,266 m^3/ha in Tunisia[18]. Less than half of the irrigated water supply is being used and the rest is being wasted due to inefficient irrigation systems that have an average efficiency of 42.4 percent in the region and can reach up to 60 percent in some parts of the region. In terms of volume, the estimated losses reach about 2,500 m^3/ha.[19] At the user end, water tariffs and irrigation charges (where they exist) do not provide motivation for rational use, water savings, and reuse. Legal frameworks to control groundwater use are insufficient or poorly enforced. At the level of governance, there are difficulties in reaching a balance between the centralisation and the decentralisation of water management. This is often compounded by limitations in the coordination of parties in decision-making mechanisms and in institutional capacity, especially at local level.

High water abstractions and poor drainage end up compromising the already delicate hydrological balance of the aquifer and increasing the risk of its salinisation, including through saline intrusion from chotts. The salinisation and pollution of groundwater in shallow aquifers decreased water usability, particularly for drinking and domestic supply but also for use in agriculture itself. The decrease in soil productivity and the reduction of agricultural yields (particularly for salt-sensitive crops) is often compensated by illegal extensions of irrigated perimeters and by higher use of fertilisers and phytosanitary products, which increase water abstraction and affect water quality.

The degradation of the NWSAS aquifer affects many groundwater dependent ecosystems such as *sabkhas*, national parks, *wadis* (valleys, ravines, or channels that remain dry except in the rainy season), springs, as well as wetlands and the Ramsar sites present in the basin area. In some cases, the lack of sewage networks in oases and settlements and the use of diesel pumps for irrigation compound the issue of water pollution and related public health issues, particularly where farmers are exposed to stagnant water effluents close to homes.

[18] Sahara and Sahel Observatory (2015). *Pour une meilleure valorisation de l'eau d'irrigation dans le bassin du SASS ; Diagnostic et recommandations* [Better use of irrigation water in the SASS basin; Diagnosis and recommendations]. In French. Available at: http://www.oss-online.org/sites/default/files/publications/OSS-SASS-Recomm-SASS_Fr.pdf.
[19] Water, Climate and Development Programme (2015). *Integration of climate change impacts in the NWSAS water resources management. Report of Phase A: Definition of the baseline and choice of climatic scenarios.*

TABLE 2.
Challenges in the water sector

W1. Reducing vulnerability and dependence of economic activities on groundwater resources	W2. Managing the increasing risk of saline intrusion from chotts	W3. Addressing ecosystem degradation and its impacts on public health
Main challenges to deal with: • Difficulties in arbitrating various water needs (including environmental) while ensuring priority for drinking water and agriculture. • Difficulties in implementing water and environmental regulations, particularly when it comes to imposing sanctions. • Costly maintenance of water networks, irrigation and drainage systems. • Difficulties in managing withdrawals of non-renewable groundwater from illegal wells.	**Main challenges to deal with:** • Salinisation of the waters and risk of saline intrusion in the shallow aquifers. • Increasing seawater intrusion in the Djeffara plain (Libya and Tunisia). • Worsening drinking water quality due to salinity and pollution. • Lack of/Poor management of drainage water in agriculture, which discharge without treatment contaminates shallow aquifers.	**Main challenges to deal with:** • Impact of localised water scarcity and environmental degradation on the local economy (notably farming and tourism). • Inadequate water supply and sanitation, increasing the risk of water-related diseases. • Contamination of discharge basins and wetlands, with an impact on communities and wildlife. • Need to reduce drinking water cuts in remote areas.

3.1.2 The energy sector perspective

Increasing energy demands in the NWSAS basin are mainly driven by the growth of the agricultural sector. Access to cheap energy sources contributes to the increase in groundwater irrigation from wells. Over time, the distribution of wells has expanded from the northern areas, spreading across the whole area of the aquifer, and drilling has become increasingly more difficult to regulate, control, and monitor.

High water abstraction rates resulted in significant drawdown of the water table, reduced piezometric heads, and caused depletion of shallow wells and 'foggaras' (ancient, traditional water supply systems in oases). In response to this, farmers tend to dig deeper wells (which, in turn, means higher pumping head and higher energy consumption and energy bills[20]). The presence of generous energy subsidies on electricity and diesel has so far supported these developments and has not provided motivation to improve water and energy efficiency in pumping systems.

As the availability of freshwater decreases, new energy is required to treat, desalinate, and demineralise water from unconventional sources, and at the same time there is a pressing need to treat the increasing amounts of wastewater produced. The energy requirements for brackish water desalination with reverse osmosis is 0.5 to 2.5 kWh/m^3 [21] and the energy requirement for wastewater treatment is 0.26 to 0.84 kWh/m^3 [22]. Depending on the water quality required for the final use, this energy can be higher (e.g. for drinking) or lower (for irrigation of non-edible plants), and water treatment in general comes with social and environmental impacts that need to be dealt with (e.g. disposal of saline brines, social acceptance, etc.).

Despite the high electrification rate in the three countries sharing the NWSAS aquifer, some rural areas are still experiencing intermittent access because energy demand (e.g. for space cooling) is growing, putting additional stress on the electrical grid. Among the options available, solar energy has a great potential both for domestic supply and export and is available both for large- and small-scale, and on-grid and off-grid, production. However, deploying renewable energy in the NWSAS countries (that are currently heavily reliant on fossil fuels) still requires a substantial economic and political effort.

[20] Sahara and Sahel Observatory (2015). *Pour une meilleure valorisation de l'eau d'irrigation dans le bassin du SASS ; Diagnostic et recommandations* [Better use of irrigation water in the SASS basin; Diagnosis and recommendations]. In French. Available at: http://www.oss-online.org/sites/default/files/publications/OSS-SASS-Recomm-SASS_Fr.pdf
[21] United Nations Economic and Social Commission for Western Asia (2013). *ESCWA Water Development Report 3: Role of Desalination in Addressing Water Scarcity*. Available at: https://www.unescwa.org/publications/escwa-water-development-report-3-role-desalination-addressing-water-scarcity.
[22] Guerrini, A., Romano, G. and Indipendenza, A. (2017). Energy Efficiency Drivers in Wastewater Treatment Plants: A Double Bootstrap DEA Analysis. *MDPI Sustainability*, **9**(1126).

TABLE 3.
Challenges in the energy sector

E1. Supplying the increasing demands for pumping	E2. Supplying future demand for energy to be used in water treatment (brackish water, wastewater, drainage water)	E3. Securing supply of electricity in rural areas
Main challenges to deal with: • Locally responding to the increasing pressure from irrigation on the electrical grid. • Addressing the economic impact of increasing pumping demands and increased cost of energy (e.g. review of subsidies) on the farmers' capacity to pay for energy.	**Main challenges to deal with:** • Difficulties in deploying (renewable) energy in remote locations, on a small scale, and off-grid. • Issues of affordability related to the deployment and complexity of maintenance of non-conventional water treatment technologies in rural contexts (e.g. brackish water demineralisation for irrigation). • Need to address the unintended consequences of the availability of cheap energy on intensive pumping of groundwater (and in turn higher energy demand).	**Main challenges to deal with:** • Reducing power blackouts in remote areas. • Difficulties in deploying solar energy to increase energy production sustainably (transforming fossil fuel-based energy systems). • Lack of clarity on future energy needs (accounting for water treatment and energy demands beyond pumping).

3.1.3 The food sector perspective

There are serious deficiencies in agricultural water resource management and governance in the NWSAS[23]. These originate in the development of agriculture on the one hand, and the socioeconomic constraints of farmers on the other. Farmers tend to seek higher productivity levels through an overall simplification of agricultural practices, leading to the disruption of traditional hydraulic systems and related organisational setups within oases.

As natural springs dry out and groundwater levels decrease and become more saline and polluted, fetching water becomes more tedious. However, at least in the short term, farmers have little incentive to reduce consumption or tackle inefficiencies because the cost of accessing water and energy (even from deeper wells) does not reflect the real cost of groundwater depletion. This considerably limits the execution of the technical and entrepreneurial solutions available to farmers to reduce groundwater consumption (e.g. reducing losses, reusing drainage water, using unconventional water sources, shifting to less thirsty crops, applying sustainable soil management).

The problem of salinisation is directly linked to poor irrigation and drainage practices. In fact, water mixes between the different layers of the aquifer due to the percolation of surplus irrigation water loaded with salts to groundwater and water leaks in those boreholes that capture at the same time several aquifers (phreatic, the Terminal Complex, and/or the Intercalary Continental). Seawater intrusion and reversed flow from chotts, and contamination from drainage water, municipal, urban, and industrial wastewater, all ultimately affect water usability for farming. In turn, agricultural soil is increasingly degraded and in order to cope, farmers tend to increase the use of chemicals or to expand agriculture to new areas (e.g. converting pastureland), increasing competition on resources.

Policy and regulatory measures aimed at controlling the number of wells, and the amount of groundwater abstracted (for instance, by increasing the cost of energy) are poorly implemented or hard to implement, also due to the risk of disproportionally affecting small farmers who are already the most vulnerable to the cost of accessing water, the impact of natural resources' degradation (soil and water) and extreme events (flood and droughts).

[23] Sahara and Sahel Observatory (2014). *Agricultural demonstration pilot in the SASS basin. Towards a Sustainable and Profitable Agriculture in the Sahara*. Available at: http://www.oss-online.org/sites/default/files/fichier/PDA-SASS-En.pdf.

TABLE 4.
Challenges in the food sector

F1. Managing increasing water demands and reducing irrigation losses	F2. Managing salinisation of water and soil in agriculture	F3. Coping with the social impact of natural resources' degradation
Main challenges to deal with: • Degraded infrastructure and poor management of irrigation and drainage systems. • Difficult implementation and monitoring of existing laws and regulatory frameworks for groundwater conservation. • Increasing inequalities between large and small farmers linked to the capacity to access water. • Insufficient coordination with key sectors (energy and water management) to fix the distortions from cheap energy and water at policy level. • Big gaps in finance for the necessary interventions in infrastructure, water management, training, and awareness-raising.	**Main challenges to deal with:** • Difficulties in adapting agricultural production to the degraded water and soil resources. • Technical and cultural obstacles to the reduction of salinisation from irrigation and drainage, as well as pollution loads (both chemical, e.g. fertilisers and pesticides, and biological, e.g. animal waste). • Financial obstacles to the demineralization of groundwater.	**Main challenges to deal with:** • Apparent dichotomy between socioeconomic development and sustainability of agriculture. • Heavy impact of yield reduction, water and decreasing soil productivity, and loss of cultivable land on the income of farmers. • Implications of land use changes, agricultural soil degradation, and abandonment of oases (aggravated by natural desertification and climate change). • Insufficient market for, and poor valorisation of, local products and local varieties of date palms (due to the high demand for the *deglet nour* variety). • Rural exodus (especially by new generations) and the neglect of traditional agricultural systems.

3.2 A 'nexus approach' to natural resource management in the NWSAS

The strategic policies of 'nexus sectors' can vary from country to country, following different ambitions, constraints, and needs. These factors can heavily shape governance structures, as well as the institutional and legal frameworks of reference. However, all sectors share at least the common goal of developing sustainably using the resources available (natural, human, and economic) in the best and most efficient way. Each sector must "do its part", reflecting this common goal in their sectoral strategies and policies, and it is crucial that the environment sector plays an active role in this effort, not only by supporting the water, energy, and food sectors in addressing environment-related issues but also by leading broader environmental action.

As sectoral challenges are deeply interlinked, uncoordinated action may lead to unsatisfactory results, if not to unintended consequences in other sectors. Table 5 illustrates the key intersectoral impacts that justify a more coordinated response by the sectors.

TABLE 5.
Summary of intersectoral impacts

↙	Water sector	Energy sector	Food sector	Environment sector
Water resources		Higher water withdrawals also driven by cheap, subsidized energy	High water demands and pollution from agriculture (driven by diets and markets)	Impact of steady environmental degradation (and lack of awareness) on water resources availability for all uses
Energy resources	Increasing energy demands for pumping and conveyance		Increasing energy demand for multiple uses and new demands (e.g. water desalination and treatment)	Higher energy demand for pumping due to the drying up of natural springs
Food resources	Lower yields due to soil salinisation (due to use of saline water) and where water is difficult to access	Challenges in food production in remote areas where energy access is difficult or expensive		Lower productivity aggravated by low awareness of environmental issues and climate change
Ecosystems	Consequences of groundwater depletion and degradation on ecosystem functioning and biodiversity	Greenhouse gas missions from fossil-fuels based energy systems; local pollution from diesel pumps" to "Greenhouse gas emissions from fossil-fuel based energy systems; local pollution from diesel pumps	Impact of agricultural practices (e.g. poor drainage) on soil quality and land use: shift away from traditional varieties (demand for e.g. *deglet nour* date)	

3.2.1 A 'package of nexus solutions' for the NWSAS

To ensure policy coherence (minimum trade-offs, minimum cross-sectoral negative impacts, maximum synergies) the action of the different sectors need to be 'synergetic'. The following paragraph introduces a multisectoral 'package of nexus solutions' and describes how sectors can coordinate on its implementation.

The package includes 15 high-priority and implementable solutions spanning from (1) governance and international cooperation, to (2) economic and policy instruments, to (3) infrastructure and innovation. Each solution consists of a set of 'actions' to be implemented by specific actors in one or more of the four sectors of water, energy, food, and environment. Notably, these solutions can be implemented simultaneously and in a coordinated manner to achieve 'cross-sectoral goals' (while simultaneously contributing to sectoral development goals), minimising intersectoral trade-offs and negative impacts, and maximising synergies.

Sections 3.2.2 and 3.2.3 illustrate how coordination supports the implementation of specific solutions (coordinated action under the leadership of a specific sector), and how it supports the achievement of cross-sectoral goals (cooperative and synergetic action).

Crucially, the package of solutions presented here is the outcome of a participatory process that involved representatives from the three countries and the four sectors, which consisted of two transboundary workshops and two national consultations (Figure 1). The process allowed for the:

1. identification of the main challenges and intersectoral linkages
2. definition of key objectives and detailing of solutions and actions for different sectors
3. prioritisation and implementability, considering past experience
4. elaboration of a package of 15 nexus solutions for the NWSAS.

Given that the solutions stem from working group discussions focused on national- and basin-level policy objectives, as well as the experience and lessons learned in the countries themselves, the solutions included are both high-priority and implementable.

The solutions are directly relevant for the 2030 Agenda for Sustainable Development , adopted by the United Nations General Assembly in 2015 and consisting of 17 sustainable development goals (SDGs) which span a wide spectrum of topics and issues. While contributing to many SDGs (Table 6 and Annex 1), the package of nexus solutions in the NWSAS is particularly relevant for the achievement of the water and sanitation goal (SDG 6), which includes sustainable water management and improving transboundary cooperation, including on aquifers; the goal to end hunger (SDG 2), which includes achieving food security and the promotion of sustainable agriculture; the goal to deliver affordable and clean energy (SDG 7), which includes providing access to sustainable energy for all; and the goal to preserve life on land (SDG 15), which includes the protection, restoration and sustainable management of ecosystems. The solutions also make a strong contribution to SDG 13 on action to combat climate change.

TABLE 6.
Package of solutions in the water, energy, food, and environment sectors

	Water	Energy	Food	Environment
Governance and international cooperation	**1.** Enhance local water management, including revitalising participatory models in oases and enhancing the enforcement of existing laws on water conservation. **2.** Reinforce transboundary cooperation for sustainable groundwater resource management.	**6.** Enhance mechanisms for the coordination of energy development with other sectoral plans, to anticipate trade-offs and build on intersectoral synergies.	**9.** Set up agricultural policies oriented towards rational, sustainable, and productive agriculture. **10.** Valorise local products and strengthen programmes for a more balanced diet while involving young people and women in the economic and social development of the oases.	**13.** Increase awareness of the trade-offs and synergies between different sectors in public institutions.
Economic and policy instruments	**3.** Set up dedicated policies and related incentives for wastewater reuse in agriculture and urban areas. **4.** Strengthen water demand management, including through water-saving programmes.	**7.** Develop a sustainable programme for diversified, multipurpose renewable energy and sustainably upscale small-scale solar irrigation.	**11.** Promote the circular economy including agroecological practices, through ad hoc economic measures and social instruments.	**14.** Consider environmental needs in the water balance of the aquifer.
Infrastructure and innovation	**5.** Upscale the use of non-conventional water resources through desalination and wastewater and drainage treatment.	**8.** Improve the reliability of the electricity grid in rural areas, thereby enhancing the integration of renewable energies for remote and multiple uses.	**12.** Enhance innovative practices and techniques for sustainable soil and crop management and invest in their upscaling and dissemination.	**15.** Systematise environmental and social impact assessment for all new infrastructure (large and small scale).

- 1 NO POVERTY — End poverty in all its forms everywhere
- 2 ZERO HUNGER — Zero hunger
- 5 GENDER EQUALITY — Achieve gender equality and empower all women and girls
- 6 CLEAN WATER AND SANITATION — Ensure access to water and sanitation for all
- 7 AFFORDABLE AND CLEAN ENERGY — Ensure access to affordable, reliable, sustainable and modern energy
- 8 DECENT WORK AND ECONOMIC GROWTH — Promote inclusive and sustainable economic growth, employment and decent work for all
- 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE — Build resilient infrastructure, promote sustainable industrialization and foster innovation
- 10 REDUCED INEQUALITIES — Reduce inequality within and among countries
- 11 SUSTAINABLE CITIES AND COMMUNITIES — Make cities inclusive, safe, resilient and sustainable
- 12 RESPONSIBLE CONSUMPTION AND PRODUCTION — Ensure sustainable consumption and production patterns
- 13 CLIMATE ACTION — Take urgent action to combat climate change and its impacts
- 15 LIFE ON LAND — Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss
- 17 PARTNERSHIPS FOR THE GOALS — Revitalize the global partnership for sustainable development

3.2.2 Coordinated action for the implementation of nexus solutions

Each nexus solution is composed of 65 actions to be taken by different actors in different sectors/fields of management. While each solution pertains to a certain sector and as such it is up to sectoral actors to lead its implementation, other actors within and outside the sector can play an important role in supporting the solution's implementation. Four examples are described below, and Annexes 2 and 3 include the detailed list of 65 actions supporting the implementation of each solution and the list of implementing actors (leading and supporting), respectively.

3.2.2.1 Upscaling of non-conventional water resources

An example of a solution that requires intersectoral coordination is Solution 5 (Infrastructure and innovation, led by the water sector), "upscale the use of non-conventional water resources through desalination and wastewater and drainage water treatment". As previously mentioned, these waters require energy-intensive treatment.

This solution contains crucial actions to be taken by the water sector, starting with the development of a clear intervention and financing strategy, a detailed inventory and assessment of the resources available and possible uses (e.g. urban green areas), the review of legal frameworks for safe non-conventional water use in relation to the international standards (i.e. those of the World Health Organization (WHO)), and awareness and training to overcome reticence and ensure safety. But then, crucially, it also requires that the other sectors take action through a plan to supply increasing energy demands, to better integrate renewable energy technologies in the water and agricultural sectors, and to improve deployment of related innovations in rural or oasis contexts (energy); a strategy for improving agricultural practices by upgrading irrigation and drainage systems and promoting less thirsty and/or salt-resistant (food) crops; and a bolder plan to attract environmentally friendly investments, undertake training, and awareness campaigns at local level through public and private partnerships (on the environment).

Experience in the use of non-conventional water resources

Algeria has developed an ambitious plan to make better use of wastewater (wastewater production in the country is currently estimated at 1.2 billion m^3/year and treatment capacity at 0.8 billion m^3), notably by using it in irrigation and using the sludge it generates as fertiliser. However, despite the efforts made by the state, the rate of wastewater reuse remains low, at around 20 percent. Algeria has begun the construction of 13 large seawater desalination stations. As of July 2018, 11 large stations with a capacity of 2.21 hm^3/day were in service, corresponding to 806.6 hm^3/year. The strategic objective of this programme is to ensure the water security of the populations of the coastal zone (drinking and sanitation) and to reallocate surface water from reservoirs to irrigation. A programme to build brackish water demineralisation stations has been initiated in the 'wilaya' (province) of Ouargla (11 stations in operation), and the wilayas of Tindouf, Adrar and Tamanrasset (one each in operation). An iron removal station was commissioned in December 2016 in Illizi.

In Tunisia, the number of wastewater treatment plants built by the National Sanitation Office (ONAS) increased from six in 1975 to 122 in 2018. The volumes treated increased from 6 Mm^3 in 1975 to 274 Mm^3 per year in 2018 out of a total collected volume of 277.2 Mm^3/year (i.e. a treatment rate of almost 99 percent of the water collected by ONAS). Nearly 50 percent of the treated water is produced in the Greater Tunis region. Desalination is practiced for the supply of drinking water (by the National Water Distribution Utility [SONEDE]) and industry (by the Tunisia Chemical Group) with appreciable capacities, and to a lesser extent for tourist and other industrial areas. For drinking water, 15 brackish water desalination plants (with a volume of 31.2 Mm^3 in 2018, i.e. 4.5 percent of the volume produced) and 5 iron removal boreholes (8.1 Mm^3 in 2018, i.e. 1.2 percent of the volume produced) are installed in the south of Tunisia. The first seawater desalination plant in Tunisia (Jerba) opened in 2018 with a capacity of 50,000 m^3/day. In the vast majority of cases, agricultural drainage water is not recycled and it is released in the environment without treatment, regardless of the risk of groundwater contamination.

In Libya, the desalination plants installed in the 1980s allow a water supply of between 20 and 30 Mm^3/year (despite the fall in production levels) while the installed capacity is 65 Mm^3/year. Many of the stations built in the years 1980–2000 are currently closed.

On the Algerian side of the NWSAS, two brackish water demineralisation units are operational. As part of the National Climate Plan, drainage water reuse for irrigation is planned in the El Oued and the Rig Valley region. In Tunisia, more than ten brackish water desalination plants are to be installed as part of the National Water Quality Improvement Programme, and many of those units are to be located within or close to the border of the NWSAS[24] (the desalination or demineralisation technology for the new plants will be either reverse osmosis or reverse electro dialysis).

[24] Information provided by the group discussion in the first transboundary nexus workshop. Algiers, July 2017. See https://www.unece.org/info/media/presscurrent-press-h/environment/2017/assessment-launched-to-reinforce-cooperation-between-algeria-libya-and-tunisia-in-managing-shared-groundwater-resources/doc.html.

TABLE 7.
Actions for upscaling non-conventional water resources

Action	Sector
5.1 Develop an intervention strategy with clear objectives and financing sources for brackish water and treated wastewater recovery.	WATER FOOD
5.2 Facilitate public and private investment and partnerships for desalination and wastewater treatment schemes.	WATER ENVIRONMENT
5.3 Promote the use of solar energy in projects for seawater desalination and/or demineralisation of brackish water.	WATER ENERGY
5.4 Develop and upscale solar water treatment and demineralisation units adapted to oasis conditions.	WATER ENERGY
5.5 Develop a resource diagnosis (volume, quality, and geographical distribution of treated wastewater available), as well as an inventory of the different uses of treated wastewater and demineralised brackish water (by farmers, tourists, schools, communities, etc.)	WATER
5.6 Carry out an inventory of crop species that can be irrigated by the treated wastewater without impacting health that are aligned with national regulations and international standards for export.	WATER FOOD ENVIRONMENT
5.7 Promote drainage water reuse in irrigation (in combination with sustainable soil management and safe disposal of pollutants).	WATER FOOD

The actors who should lead the implementation of these solutions are those with the mandate to decide on non-conventional water use in the countries: Ministry of Water Resources in Algeria, the General Directorate of Rural Engineering and Water Use (DGGREE) in Tunisia, and the General Water Resources Authority (GWRA) in Libya. Furthermore, the NWSAS Consultation Mechanism could provide a platform to coordinate action in transboundary areas of the basin and facilitate the exchange of knowledge and experience related to non-conventional water use across the countries.

3.2.2.2 Sustainable deployment of renewable energy in agriculture

Another example is Solution 7 (Economic and policy instruments, led by the energy sector), "develop a sustainable programme for diversified, multipurpose renewable energy and sustainably upscale small-scale solar irrigation".

Irrigation is the main source of demand in the agricultural sector in all three countries. Today, energy for irrigation in the basin is largely supplied by diesel pumps or electric pumps connected to the grid (in turn powered by fossil fuels) and while standalone solar PV pumps stand out as a valuable renewable energy alternative, there are a number of limitations related to its implementation, notably the cost of technology (see a quantitative analysis of this issue in Chapter 4).

Experience in the deployment of solar energy

Solar energy is a key resource in Algeria, Tunisia, Libya, and the NWSAS region, with daily average horizontal irradiation levels of around 2 kWh/m^2. However, in 2016 in Algeria the share of electricity generated using renewable energies was only about 0.8 percent, in Tunisia, it was 2.9 percent, and in Libya, less than 0.1 percent, with a negligible share of renewable energy used in the agricultural sector[25].

In Tunisia, a legal framework has been successfully developed to regulate and promote the adoption of renewable energy technologies, including standalone solar pumping systems[26]. Since 2009, more than 15,000 systems have been installed, mostly in the residential sector, but also in the agricultural sector. Technical and financial support is provided by the National Agency for Energy Management (ANME), including the possibility of feeding the surplus electricity to the grid[27]. Despite the relative success of the scheme, the use of solar power in agricultural activities is still economically challenging, particularly for small farmers, and the framework is not supported by mitigation measures to limit water withdrawals[28].

With its 2030 Renewable Energy policy, Algeria began taking steps to diversify its energy mix, mainly focusing on large-scale solar PV and wind power, but also introducing biomass, cogeneration, and geothermal technologies. It is estimated that around 343 MW of solar PV generation has already been installed in the region of Hauts-Plateaux and in the south of the country, for which one of the main energy uses is water pumping, and it is expected that another 150 MW (from independent power producer projects with capacities in the range of 10–50 MW) will be installed in the regions of Ghardaïa, Biskra, Ouargla, El Oued, Tendala, and Nakhla. However, no plan for small-scale solar pumping and irrigation has been implemented, as there are financial and economic hurdles to contend with. Some pilot projects have been conducted (e.g. the solar pumping pilot in the Reggane region of Adrar, where solar energy is used to pump water upstream of the "foggara" in combination with modern irrigation techniques downstream[29]).

In Libya, the use of solar PV is still at an early stage. The little PV capacity already in place (5 MW) is not used for agricultural purposes. To encourage the use of solar PV, the government introduced schemes for off-grid individual-level solar PV installations and began studying a net metering scheme[30].

One critical aspect that globally affects the competitiveness of renewable energy technology is the presence of subsidies on fossil fuels, and this is also the case in the NWSAS countries. The achievement of renewable energy targets is directly related to the commercial viability of the technologies available. In this respect, restructuring fossil subsidies is very important for the shift towards greater use of renewable energy, particularly in countries where the backbone of their economy is fossil fuel production, such as Algeria and Libya; however, it comes with high social and economic sensitivity[31].

Beyond solar PV, other renewable energy technologies and sources are available to supply local demand for power and heat. One such example is biomass from date palm plantations. Date palm is the most common crop grown in the Saharan Oasis. Its abundance and low moisture content make it well suited for the thermo-chemical conversion processes upon which waste-to-energy processes (gasification and pyrolysis) are based. If combined with sewage waste, this biomass can also be used to produce biogas through anaerobic digestion. The 10 MW waste-to-energy project at the Jebel Chakir landfill in Tunisia is a good example of effective, value-added use of agricultural waste, with olive processing contributing to about 3.2 million tons of feedstock annually[32]. The use of geothermal energy can also be upscaled from pilot projects implemented in Algeria (e.g. Saïda, Ouargla, and Touggourt), where geothermal energy is used in space heating and cultivation of melon and tomatoes in greenhouses[33]. Though the NWSAS, and more specifically the Intercalary Continental aquifer where water temperatures range between 30 and 80°C, geothermal energy has significant unfulfilled potential.

A scheme to support farmers to use solar irrigation may lead to better access to energy sources and a reduction of pollution from fossil fuels, but it is crucial that this is coupled with the required technical and economical tools to avoid this worsening the overexploitation of

[25] International Renewable Energy Agency. *Interactive Chart Gallery. Capacity and Generation Technologies*. Available at: http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=19.

[26] International Energy Agency and International Renewable Energy Agency (2019). *Joint policy and measures database*. Available at: https://www.iea.org/countries/tunisia.

[27] Renewable Energy Solutions for the Mediterranean (2016). *Country Profile, Tunisia*. Available at: https://www.res4med.org/wp-content/uploads/2017/11/Country-Profile-Tunisia-Report_05.12.2016.pdf.

[28] Consultation with local experts at the national consultation workshop, April 2019.

[29] Sahara and Sahel Observatory (2015). *Pour une meilleure valorisation de l'eau d'irrigation dans le bassin du SASS ; Diagnostic et recommandations* [Better use of irrigation water in the SASS basin; Diagnosis and recommendations]. In French. Available at: http://www.oss-online.org/sites/default/files/publications/OSS-SASS-Recomm-SASS_Fr.pdf

[30] Kadem, A. et al. (2018). Economic feasibility, design, and simulation of centralized PV power plant. *2018 9th International Renewable Energy Congress (IREC), Hammamet, Tunisia*: 1–6. Also available at: https://ieeexplore.ieee.org/document/8362448/

[31] For more information on subsidies for energy sources in the countries, see Part B of the report.

[32] Renewable Energy and Energy Efficiency Partnership (2012). *Tunisia*. Available at: https://www.reeep.org/tunisia-2012.

[33] Saibi, H. (2019). Geothermal Resources in Algeria. *Renewable and Sustainable Energy Reviews*, **13**(9): 2544–2552. Also available at: https://linkinghub.elsevier.com/retrieve/pii/S1364032109001014.

groundwater resources, and the countries lag behind on this. A multipurpose scheme that aggregates various users and different types of energy demand could distribute the cost of solar energy, potentially making it more affordable for small farmers.

TABLE 8.
Actions for sustainable deployment of renewable energy in the basin

Action	Sector
7.1 Develop a scheme to make solar irrigation affordable, reduce the use of fossil fuel-based irrigation, and integrate solar energy into regional and local rural development plans.	ENERGY FOOD
7.2 Ensure that Action 7.1 is accompanied by effective technical measures (i.e. monitoring meters) as well as legal and economical tools (e.g. fiscal incentives, regulatory measures) that limit the exploitation of groundwater resources.	ENERGY WATER FOOD ENVIRONMENT
7.3 Develop solar energy solutions that aggregate various energy demands and distribute the cost of solar energy across different users and/or activities (e.g. irrigation and water desalination, potable water conveyance, heating and lighting).	ENERGY WATER FOOD
7.4 Support the development and diversification of renewable energy sources by making use of all available resources including geothermal energy, biomass, and waste.	ENERGY WATER FOOD
7.5 Gradually restructure fossil subsidies to support and facilitate renewable energy deployment (by encouraging a shift away from diesel pumps).	ENERGY
7.6 Facilitate transboundary information and experience sharing on renewable energy development, to accelerate sustainable development in the basin.	ENERGY
7.7 Enhance capacity within administrations and trust between administrations and farmers, and raise awareness on renewable energy, energy efficiency, and rational use of water resources.	ENERGY WATER FOOD

In order for it to be successful, such a scheme needs to be framed within a broader policy for decentralised renewable energy production aimed at small and independent producers, hence the leading institutional actors for this solution are those in charge of renewable energy policy in the countries: the Ministry of Environment and Renewable Energy in Algeria, the Ministry of Industry and SMEs in Tunisia, and the Renewable Energy Authority in Libya. Then, given the existing linkages with other sectors at both a physical (groundwater use and environmental implications) and economical level (farmers' activity and revenues), it is crucial that accompanying actions are also taken in the water, food, and environment sectors[34].

Moreover, the coordination of renewable energy policies at transboundary level can help maximise the benefits of their sustainable deployment in the NWSAS basin. The countries could share information and experience, build capacity, and raise awareness on the potential of renewable energy, energy efficiency, and rational use of water resources, in turn better informing basin coordination at the transboundary level. For example, the NWSAS Consultation Mechanism issued a recommendation to limit irrigation in the areas identified as at high risk of severe exploitation. This is a successful case of transboundary cooperation that could be a starting point for the sustainable deployment of new and clean energy technologies in agriculture. At the same time,

[34] A toolkit for energy policy-makers to address sustainability of renewable energy in strategies, policies, and projects with a nexus approach is proposed in United Nations Economic Commission for Europe (2020). *Towards sustainable renewable energy investment and deployment: Trade-offs and opportunities with water resources and the environment*. Available at: http://www.unece.org/index.php?id=54348. See also United Nations Economic and Social Commission for West Asia (2017). *Water-Energy Nexus Operational Toolkit: Renewable Energy Module*. Available at: https://www.unescwa.org/publications/water-energy-nexus-renewable-energy-module.

experience shows serious issues in the enforcement of water and environmental laws on the ground (i.e. illegal wells continue to proliferate in the basin), among farmers, hence the importance of ensuring the participation of the water, food, and environment sectors.

3.2.2.3 Valorisation of local products and empowering women and youth

A third example is Solution 10 (Governance and international cooperation, led by the food sector), "valorise local products and strengthen programmes for a more balanced diet while involving young people and women in the economic and social development of the oases".

Local products are poorly valued assets that could boost sustainable development in oases through the valorisation of traditional practices and locally available know-how on the one hand and improved conservation of ecosystems and biodiversity on the other. Their potential extends far beyond environmentally friendly agriculture, as they can contribute to improving health through nutrition, as well as through employment and entrepreneurship in rural areas. Due to their marginalisation in the agricultural market, local products are often neglected by large-scale agricultural businesses, but their use can be driven by groups of women and youths, who are both the custodians of traditional practices and the most dynamic innovators.

Experience in the valorisation of local products

In the area of local product valorisation, Algeria made a considerable effort over the past few years to improve labelling-related regulations[35]. The decree 13-260 (7 July 2013) establishes the modality of ascertaining the quality of agricultural products with the following objectives:

- **valorising local products and know-how**
- **implementing a mechanism to grant quality certifications**
- **focusing on consumer awareness**
- **combatting falsification of agricultural products on national and international markets**
- **rural development.**

An agreement between Algeria and the European Union (UGP/Pa3) (18 September 2014) to certify the origins of agricultural products was based on four pillars:

- **strengthening related regulations and institutions**
- **identifying three pilot products, among which is the deglet nour date palm**
- **raising awareness and training the actors involved**
- **operationalisation of a recognition system.**

In 2015, an interministerial committee was established by the Ministry of Agriculture and Rural Development, including central management executives as well as representatives of professional organisations (in agriculture, agro-industry, and commerce) and consumers. The implementation of the labelling process has constraints, such as the complexity of the process and the high costs for producers, the lack of involvement of stakeholders (farmers, processors, distributors), and poor technical and communication support between the various players[36]. Despite these constraints, certain players manage to set up initiatives to valorise products intended in particular for export, like the companies Biodattes and Bionoor in Algeria for the export of deglet nour dates from Tolga, bearing the organic farming label[37].

The experience in Tunisia is also noteworthy. In 2010, the Ministry of Industry, Energy and Mines established the quality label for processed food called the 'Tunisia Food Quality Label'. This distinction is granted to any product that can prove its unique or traditional superior quality. For example, since 2015, Tunisia has had its own food quality label dedicated to harissa. This quality label allows farmers to invest, position themselves, and consolidate the reputation of Tunisian products in the eyes of foreign consumers.

This valorisation of all Tunisian products is supported by the "Market Access Project for Agrifood and Terroir Products" (also known as PAMPAT project) that began in October 2013. It is a programme managed by the United Nations Industrial Development Organization, with Swiss funding. The financial envelope for the project is 4 million euros for the period from the end of 2013 to the end of 2019. In this area of valorisation of local products, Tunisia went even further, by establishing and organising an annual Tunisian competition for local products. The first edition of the competition was held in December 2017 in Tunis, and was organised by the Agency for the Promotion of Agricultural Investment under the aegis of the Ministry of Agriculture, Water Resources and Fisheries, and in collaboration with the Ministry of Industry and SMEs, the Ministry of Tourism and Handicrafts and the Tunis Science City, with the support of the PAMPAT project.

In order to strengthen the value chains of local products, it is crucial to leverage and facilitate the development of local professional organisations and cooperatives. The establishment of labels to attest organic agricultural practices or specific geographical origins can facilitate the expansion of a market for these products, as well as the reorganisation of scattered, donor-funded projects into a broader, integrated strategy. In this context, financing is most needed for providing relevant training to farmers, e.g. on sustainable agricultural practices and innovation.

The fact that traditional agriculture in the NWSAS region is a common feature of the three countries may justify proposals to valorise local products by looking at international markets (deglet nour dates, for example, could be labelled as NWSAS/Saharan products, rather than national). This could strengthen international cooperation in border regions of the aquifer, simultaneously providing the benefits of cooperation in the NWSAS basin beyond water management[38].

[35] Cheriet, F. (2017). La valorisation des produits de terroir en Algérie: démarches en cours, contraintes institutionnelles et perspectives. *Working Papers MOISA 201702*, UMR MOISA: Marchés, Organisations, Institutions et Stratégies d'Acteurs: CIHEAM-IAMM, CIRAD, INRA, Montpellier SupAgro [English summary]. Also available at: https://ideas.repec.org/p/umr/wpaper/201702.html.

[36] Ibid.

[37] Hadjou, L. et al. (2014). Evaluation de «l'effet préférence» de la diaspora algérienne en France pour les produits de terroir. *Mediterranean Journal of Economics, Agriculture and Environment* **13**(3): 13–22.

[38] For a description of past and prospective benefits of cooperation in the NWSAS, see United Nations Economic Commission for Europe (in preparation). *Scoping the benefits of transboundary water cooperation in the North-Western Sahara Aquifer System basin*.

The valorisation of local products should occur throughout the value chain, from awareness-raising among consumers with specific programmes in the public sector (e.g. schools), to the diversification of production, the reinforcement of traditional practices, the re-establishment of local value chains, and the support given to innovative and sustainable agricultural practices among small producers[39]. Supporting socioeconomic development on the ground is a more effective way of encouraging good water and soil management practices (and even ecosystem restoration) among farmers than scattered awareness campaigns.

The inclusion of women in agriculture transverses specific policy and legal measures (e.g. improving women's rights to own land and access water, labour, and finance), as well as fiscal and social support. There are segments of production that are already typically led by women (e.g. production of goat cheese, sorting and processing of dates, manufacture of products from palm trees, production of weavings and clothing), as well as specific jobs and skills linked to oasis traditions that they can help to pass on to the next generations (e.g. local handicrafts). Cooperatives that support economic diversification and knowledge transfer can accelerate efforts to improve education, poverty eradication, and better integration of women. Through similar means, effectively engaging and including youth (and young women in particular) in sustainable development programmes can accelerate entrepreneurship and innovation.

This solution has the potential to build positive synergies across sectors, not only because innovation in agriculture (e.g. solar pumps, non-conventional water use) is usually best implemented by young entrepreneurs, but also because the response to many cross-sectoral challenges (e.g. enhancing local resilience to basin challenges, e.g. climate change, see 3.2.3.2) requires integrating this innovation with traditional knowledge and skills.

TABLE 9.
Actions for local product valorisation and women and youth empowerment

Action	Sector
10.1 Strengthen the value chains of local, organic products and seasonal fruit and vegetables cultivated in oases using traditional agricultural practices.	FOOD WATER
10.2 Promote a more balanced and sustainable diet through specific programmes aimed at reducing food waste and improving nutrition through organic and varied food (e.g. in schools).	FOOD ENVIRONMENT
10.3 Support the socioeconomic inclusion of young people and women in the oases, including by increasing awareness of its importance and potential benefits.	FOOD WATER ENVIRONMENT
10.4 Build strategic partnerships (public and private, cross-sectoral) to implement 10.1, 10.2, and 10.3.	FOOD WATER ENERGY ENVIRONMENT

The actors who should lead the implementation of this solution at the policy level are the Ministries of Agriculture in the three countries, in coordination with other relevant ministries (Commerce, Trade, Tourism and Handicrafts, Industry and SMEs, Women – see Annex 3 for specifications) as well as with relevant non-governmental organisations (e.g. RADDO, that supports sustainable development in the broader Saharan region) and research centres and universities. Crucially, its implementation also requires the engagement of local actors (i.e. governorates, *wilayas* in Tunisia and Algeria, *chabiyat* and *mu'tamar sha'bi assasi* in Libya), local professional groups and associations, and women's and youth groups. This type of project is typically supported by international donors (e.g. World Bank, FAO, International Fund for Agricultural Development, United Nations Development Programme, etc.), but to mobilise the required resources it is crucial that:

[39] Food and Agriculture Organization of the United Nations (2017). *How can value chains be shaped to improve nutrition?* Available at: http://www.fao.org/3/a-i7605e.pdf.

1. sustainability and traditional agriculture are recognised as priorities for national governments and are appropriately integrated in agricultural and rural development plans

2. the implementation mobilises strategic partnerships (across the public and private sectors, but also across sectors) that can build on pilot projects and systematically upscale them

3.2.2.4 Definition of the environmental needs of water

The fourth example is Solution 14 (Economic and policy instruments, led by the environment sector), "consider environmental needs in the water balance of the aquifer".

The environmental demand for water is a major gap that needs to be filled in order to consider environmental needs in the water balance of the aquifer to include demands beyond sectoral demands from water consuming sectors. Environmental needs include those that support the key ecosystems in the NWSAS (e.g. *sabkhas*, national parks, *wadis*, wetlands) and related biodiversity (e.g. migratory birds). Other than through improved water conservation and improvements in water quality, aquatic ecosystems related to groundwater may be sustained by planning for compensation flows through local irrigation and/or aquifer recharge.

To properly inform the water balance and policy decisions, environmental needs for the different locations and times of the year should be described and should include information on water quality requirements. This information would allow clearer environmental policies to be developed, based on specific trade-offs with the different economic sectors and the most urgent areas of intervention for policy-makers at all levels.

This solution closely relates to transboundary cooperation in the NWSAS basin (Solution 2). A deeper knowledge of environmental needs would significantly improve the water balance of the countries and the basin and the ability to consider all water requirements when establishing abstraction limits for the aquifer. It would meaningfully inform water-related and integrated modelling exercises (including the integrated water-food-energy nexus model of the NWSAS presented in Chapter 4) and water-related planning and investments (e.g. irrigation, wastewater treatment, groundwater recharge).

TABLE 10.
Actions for the definition and the consideration of environmental needs in the water balance of the aquifer

Action	Sector
14.1 Conduct studies and investigations to identify ecological demands for water in the most rational and scientifically sound way possible. This should specify hotspots, temporal variations, the characteristics of the water required (e.g. salinity levels), and the impacts of climate change.	ENVIRONMENT
14.2 Assess the sector-specific and cumulative impact of the various water uses in the NWSAS on biodiversity and ecosystem services.	ENVIRONMENT WATER FOOD ENERGY
14.3 Disseminate the results of the analyses (14.1 and 14.2) with the specific aim of mainstreaming the water balance of the aquifer and other resource modelling exercises related to the NWSAS (see Solution 2).	ENVIRONMENT WATER FOOD ENERGY
14.4 Coordinate with the different sectors to develop sustainable, integrated, and coherent development policies in the basin based on the analyses.	ENVIRONMENT WATER FOOD ENERGY

The implementation of this solution should be led by ministries in charge of the environment in close cooperation with the water-, energy-, and food-sector authorities in the three countries and with cooperation platforms at the basin level, most evidently the NWSAS Coordination Mechanism.

3.2.3 Synergetic implementation of the nexus solutions towards cross-sectoral goals

The nexus solutions can reinforce each other towards shared, cross-sectoral goals, such as those for sustainable development or climate action, because they are meant to be implemented synergistically. By explicitly targeting intersectoral synergies, sectoral plans can be coordinated to multiply benefits and to make the most of the resources allocated in the different sectors.

The following paragraphs illustrate three examples that have been proposed, discussed, and adjusted together with stakeholders, taking the solutions from a more operational level (actions) to a more strategic one (strategic goals). This was done to facilitate the presentation of the package to high-level decision-makers and allow for its uptake in plans and strategies for the basin.

3.2.3.1 Coherent planning for sustainable development in the NWSAS

Improving the coherence of various sectoral policies and plans to achieve sustainable development more efficiently (in terms of natural resources, but also in terms of financing) is the main idea behind the nexus approach. In a transboundary basin like the NWSAS, increased coherence can be sought not only at national level but also across national development strategies, with a view to improving the efficacy of groundwater protection and preservation, and also to building on countries' complementarities and common interests.

Of the solutions contained in the package, six of them explicitly contribute towards enhancing policy coherence: solutions 2, 6, and 9 indicate the areas where each sector can lead this effort (groundwater management, energy development, and sustainable agriculture), while 13, 14, and 15 point at three aspects that should be led by the environment sector to avoid a bias towards any economic sector and at the same time ensure that the needs of ecosystems are carefully accounted for (which is important for health and well-being), achieved through increased awareness of trade-offs and synergies in institutions, improved water balance of the aquifer, and systematic environmental and social impact assessments of infrastructural investments.

TABLE 11.
Package of solutions for coherent planning for sustainable development in the NWSAS

	Water	Energy	Food	Environment
Governance and international cooperation	**2.** Reinforce transboundary cooperation for sustainable groundwater resource management.	**6.** Enhance mechanisms for the coordination of energy development with other sectoral plans, to anticipate trade-offs and build on intersectoral synergies.	**9.** Set up agricultural policies oriented towards rational, sustainable, and productive agriculture.	**13.** Increase awareness of the trade-offs and synergies between different sectors in public institutions.
Economic and policy instruments				**14.** Consider environmental needs in the water balance of the aquifer.
Infrastructure and innovation				**15.** Systematise environmental and social impact assessment for all new infrastructure (large and small scale).

3.2.3.2 Enhanced local resilience to basin challenges

From a local development perspective, it is also possible to combine solutions into another set that works with synergies. Given that the package of solutions was developed to reflect the specific reality of the NWSAS, there are eight solutions in the package that include local-level action to enhance resilience to the challenges faced by local communities:

- participatory water management
- deployment of small- and large-scale solar power in the basin
- valorisation of local products (also through increased participation of women and youths in agriculture)
- creation of a circular economy
- improvement of awareness on environmental issues and nexus interlinkages.

As they have multisectoral mandates, local administrations are able to implement intersectoral synergies. Of course, the impact of local action can only be seen at basin level if an effort is made to upscale solutions and coordinate at subregional, national, and even transboundary level, as appropriate.

TABLE 12.
Package of solutions for enhanced local resilience to basin challenges

	Water	Energy	Food	Environment
Governance and international cooperation	1. Enhance local water management, including revitalising participatory models in oases and enhancing the enforcement of existing laws on water conservation.		10. Valorise local products and strengthen programmes for a more balanced diet while involving young people and women in the economic and social development of the oases.	13. Increase awareness of the trade-offs and synergies between different sectors in public institutions.
Economic and policy Instruments	4. Strengthen water demand management, including through water-saving programmes.	7. Develop a sustainable programme for diversified, multipurpose renewable energy and sustainably upscale small-scale solar irrigation.	11. Promote the circular economy including agroecological practices, through ad hoc economic measures and social instrument.	
Infrastructure and innovation		8. Improve the reliability of the electricity grid in rural areas, thereby enhancing the integration of renewables for remote and multiple uses.	12. Enhance innovative practices and techniques for sustainable soil and crop management and invest in their upscaling and dissemination.	

3.2.3.3 Creating a circular economy through non-conventional water, renewable energy, and agroecological practices

The last example focuses on the nexus in terms of physical interlinkages between resources, highlighting the synergies that exist at the level of the characteristics of natural resources, farming practices, and technology. Making the NWSAS economy circular requires, in practice, setting up a system where water is never wasted but rather valued, hence reused, treated, and "produced" from non-conventional sources. Similarly, it means valuing renewable energy sources and using them effectively to add value to economic activities beyond irrigation (e.g. food processing or cold storage) and making better use of – and therefore preserving and restoring – soil resources through appropriate agroecological practices. The following areas have high potential in the NWSAS:

- Use of non-conventional water, wastewater and drainage water treatment and reuse.
- Groundwater recharge and interseasonal underground storage.
- Recycling of plastic used in agriculture (e.g. PVC used for drip irrigation).
- Use of by-products to improve soil management (e.g. mulch).
- Promotion of bioenergy (e.g. biomass from industrial production of dates, biogas/biomethane from animal manure, biofuels from halophytes – a salt-resistant crop suitable for the NWSAS context – biofertilisers like compost.
- Production of traditional and/or innovative biomaterials for packaging (e.g. biodegradable plastic made from cereals or potato starch) and

for eco-construction and insulation (palm trunks, palms, straw, wool).

- Valorisation of local handicraft products (embroidery, baskets, woven objects, decorative objects, etc.) made from agricultural by-products/ waste.

Once again, the success of the implementation of this solution is dependent on the ability to frame these technical interventions, particularly those that involve the introduction of new infrastructure, in the broader picture of environmental sustainability and social impact.

TABLE 13.
Package of solutions for creating a circular economy through non-conventional water, renewable energy and agroecological practices

	Water	Energy	Food	Environment
Governance and international cooperation				
Economic and policy Instruments	**3.** Set up dedicated policies and related incentives for wastewater reuse in agriculture and urban areas.	**7.** Develop a sustainable programme for diversified, multipurpose renewable energy and sustainably upscale small-scale solar irrigation.	**11.** Promote the circular economy including agroecological practices, through ad hoc economic measures and social instrument.	
Infrastructure and innovation	**5.** Upscale the use of non-conventional water resources through desalination and wastewater and drainage water treatment.			**15.** Systematise environmental and social impact assessment for all new infrastructure (large and small scale).

4. A GIS-based water-food-energy model for the NWSAS

This chapter illustrates the main features of a novel integrated resource model for the agriculture-water-energy nexus in the NWSAS, developed as part of the nexus assessment. It presents some illustrative results to demonstrate the model's potential to quantify inter-sectoral linkages, thereby providing a valuable tool for supporting decision-making in the areas of water, energy, and food policy. A very important characteristic of this model is that it has been developed using an open source tool[40] to facilitate its dissemination and further development by local experts and decision-makers.

The model captures key elements of the agricultural sector and its impact on water and energy resources, highlighting interlinkages among them and addressing selected nexus issues. The model relies on geographic information system (GIS) methods to model the spatially explicit dynamics of the system. In a vast area like the NWSAS basin, physical conditions (e.g. cropland area and types, groundwater depth), natural resources (e.g. solar irradiation, wind speed), and economic parameters (e.g. fossil fuel prices, technology costs) may vary widely from location to location. GIS methods allow the interaction between such location-dependent parameters to be evaluated and analysed. Annex 4 provides supplementary material on the data used and related sources.

This version of the model was based on local data from the countries and the main assumptions were tailored with local experts[41] to represent the characteristics of the region (e.g. crop types, the crop calendar, irrigation techniques, type of pumps). The agricultural sector was modelled using open source land cover GIS datasets. The GIS data showed the cropland area distribution throughout the basin at a resolution of 20 m^2. This was then calibrated, cleaning up sources of misclassification as sparse vegetation, and rain-fed and surface water-irrigated croplands, matching provincial statistics on cropland irrigated by groundwater resources. Due to a lack of information to create a detailed crop map, the resulting cropland extent was categorised by crop types cultivated in each province (mainly date palms, vegetables and olives), assuming an equal crop share distribution throughout each cropland extent within the province. Water requirements for irrigation were then estimated for each crop type in each region under three irrigation technology scenarios. Furthermore, the associated electrical energy requirements for pumping and desalination of brackish water were computed. Electricity from the grid and three standalone electricity supply options were compared: wind power, solar PV systems, and diesel generators, and the lowest cost option was highlighted for each region. Finally, a sensitivity analysis was performed to evaluate the effect of a cost reduction on renewable energy technology and an increase in fossil fuel prices.

4.1 Methodology overview

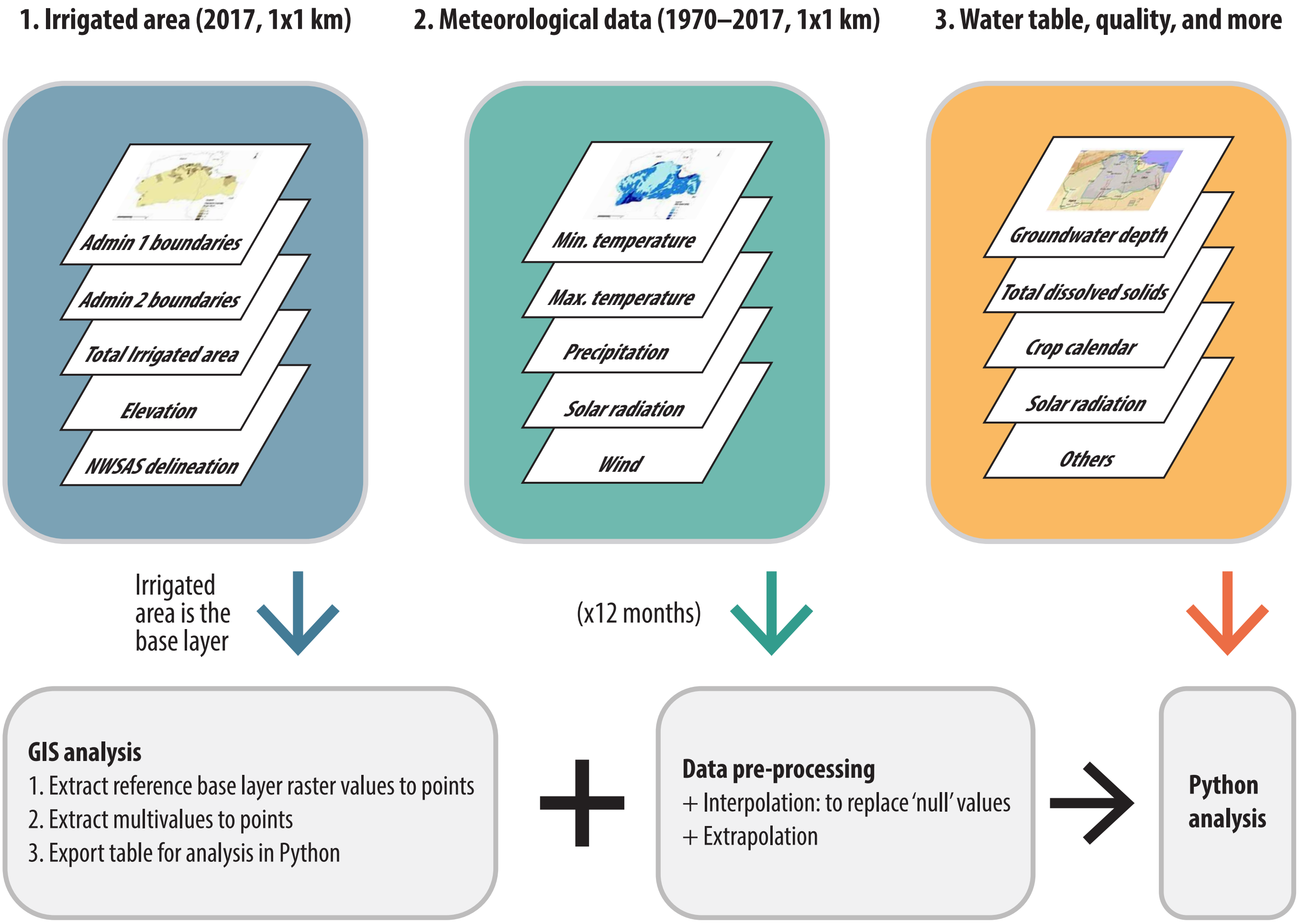
The schematic of the methodology[42] used for this study is presented in Figure 3. The steps mainly involved the collection of relevant GIS data layers (see Annex 4) and the processing of such data in GIS software, projecting layers into a common coordinate reference system, downscaling or upscaling and extrapolating the data when necessary. Afterwards, a data package containing all GIS layers in a common data frame was exported and processed using the Python programming language. Several Python scripts were executed to compute water requirements for irrigation, electrical energy requirements for pumping and desalination of brackish water and the lowest cost electricity supply options.

40 More information available at https://github.com/KTH-dESA/NWSAS.

41 Mainly the Sahara and Sahel Observatory, but some input was also provided by the Libyan Nexus Committee, and the stakeholders who participated in the national consultation workshops.

42 This methodology builds on the previous work by Pegios (2018) (Pegios, K. (2018). A *GIS-based approach for productive uses of electricity – The case study of water and electricity demand for agriculture in Tanzania*. University of Thessaly, Volos, Greece. Available at https://ir.lib.uth.gr/xmlui/bitstream/handle/11615/49064/17915.pdf?sequence=1) that is mainly adapted from: Allen, R.G. et al. (1998). *Crop evapotranspiration — guidelines for computing crop water requirements*. FAO Irrigation and drainage paper 56; Kay, M. and Hatcho, N. (1992). *Irrigation Water Management Training Manual. Small-Scale Pumped Irrigation: Energy and Cost*. Food and Agriculture Organization.

FIGURE 3.
Schematic representation of methodology for estimating electricity demand for groundwater irrigation



To estimate the irrigation water requirements, the evapotranspiration throughout the area was computed. 'Evapotranspiration' is the process by which water is transferred from the land to the atmosphere through absorption from the soil and other surfaces and transpiration from plants. It was computed using the FAO Penman-Monteith equation[43] and monthly GIS climate datasets such as precipitation, wind speed, and minimum, average, and maximum temperature. Specific properties of the selected crop types were used for the analysis, as were crop calendars and crop coefficient values. The crop calendar describes the monthly growing season of each crop type. These are divided into the initial season (i.e. planting), crop development, mid-season (i.e. growing), and the late season (i.e. harvesting). The crop coefficient is a crop-specific parameter used in conjunction with the evapotranspiration and effective rainfall to predict the water requirements of the crop type. The effective rainfall was subsequently calculated for each grid cell. Knowing the crop-specific evapotranspiration, the crop calendar, and effective rainfall allowed the irrigation water requirements to be computed for each crop type on a monthly basis. Furthermore, **three different irrigation technologies where studied**: low-efficiency surface irrigation (i.e. 45 percent), high-efficiency surface irrigation (i.e. 65 percent) and drip irrigation (i.e. 85 percent efficiency).

Electricity demand calculation: Using the estimated irrigation water requirements and data on the depth of groundwater, the electrical energy requirements for pumping groundwater to the surface was estimated. For this, basic hydraulic equations were used. Moreover, an estimation of the electrical energy requirements for brackish water desalination was performed. Water quality levels expressed in total dissolved solids (TDS) were used for each province, based on data from FAO and local experts. Three different TDS threshold levels (i.e. 2,000, 2,500 and 3,000 mg/l) were used to decide if the source water needed to be desalinated, with the aim of evaluating the effect that salt-resistant crops may have in electrical energy requirements.

[43] Allen, R.G. et al. (1998). *Crop evapotranspiration — guidelines for computing crop water requirements*. FAO Irrigation and drainage paper 56.

To supply the electrical energy needs, three standalone power generation options were evaluated: wind power, solar PV systems, and diesel generators. Technology-specific economic variables such as capital expenditure (CAPEX) and operating expenses (OPEX), as well as country-specific variables such as the cost of diesel and the cost of electricity from the grid were used to compute the levelised cost of electricity (LCOE) for each technology. The LCOE value is a life cycle cost concept that calculates an electricity value that will make the cost of a power plant break even over its lifetime. It accounts for all physical assets and resources required to deliver one unit of electricity output, involving all the expenses (i.e. investment costs, operating and maintenance expenses, fuel cost) and the revenues generated from electricity generation sales[44]. The LCOE value was then used to compare the different supply options in each country and highlight the lowest cost option. The LCOE values of each technology can vary widely from region to region; they are dependent on site-specific parameters such as the power capacity required (due to energy demands, which are dependent on water demand, water table depth, and pumping efficiency) and the natural resources available (such as solar irradiation and wind speed).

Different supply options are currently being used in each country. A summary of the literature[45] and consultation with local experts determines that in Algeria and Tunisia, a mix of diesel and electric pumps are used while in Libya, all pumps are electric and are connected to the grid. Due to the lack of publicly available data[46], it was assumed that in Libya all pumps are powered by the grid while in Algeria and Tunisia, all pumps are powered using diesel generators. This assumption is supported by the fact that the cost of generating 1 kWh from diesel generators[47] is about 0.02 USD in Algeria and 0.06 USD/kWh in Tunisia, which is lower than the price of electricity from the grid, at 0.03 and 0.1 USD/kWh, respectively[48]. Therefore, in this analysis we compare the competitiveness of solar PV pumps and small-scale wind turbine pumps with the cheapest option as summarised in Table 14.

TABLE 14.
Summary of the energy supply technologies compared in each country

Country	Technologies compared
Algeria	Diesel pumps, solar PV pumps, and small-scale wind turbine pumps.
Libya	Electric pumps powered by the grid*, solar PV pumps, and small-scale wind turbine pumps.
Tunisia	Diesel pumps, solar PV pumps, and small-scale wind turbine pumps.

*The only pumps connected to the grid; all the others are standalone options.

Finally, a sensitivity analysis was conducted to study the impact of parameters on the modelling outcomes in selected cases. Three different cost levels were evaluated, changing CAPEX cost for wind and solar PV technologies, diesel cost for diesel generators, and electricity cost for grid-powered pumps.

[44] Reichelstein, S. and Yorston, M. (2013). The prospects for cost competitive solar PV power. *Energy Policy*, **55**(April 2013): 117–127. Also available at: https://doi.org/10.1016/j.enpol.2012.11.003.
[45] Nabila L. et al. (2014). Design of photo voltaic pumping system using water tank storage for a remote area in Algeria. *2014 5th International Renewable Energy Congress (IREC)*, Hammamet, Tunisia, 1-5. Available at: https://ieeexplore.ieee.org/document/6826981; Ahmed, I. et al. (2017). Energy transition in Algeria's desert: current status and future perspectives. *Renewable and Sustainable Energy: An International Journal (RSEJ)*, 1(1). Available at: https://www.researchgate.net/publication/314287634_ENERGY_TRANSITION_IN_ALGERIA'S_DESERT_CURRENT_STATE_AND_FUTURE_PERSPECTIVES.
[46] Medium and low voltage line network maps for the three countries are not publicly available. Therefore, it was difficult to map the distribution of the electric pumps in Algeria and Tunisia, where they use a mix of diesel and electric pumps.
[47] With an energy content of 10.52 kWh per litre of diesel (Kay and Hatcho, 1992). The prices of diesel in Algeria and Tunisia are shown in Table 15, sensitivity level 1.
[48] Arlet, Jean (2017). *Electricity Tariffs, Power Outages and Firm Performance: A Comparative Analysis*. World Bank. Available at: http://pubdocs.worldbank.org/en/444681490076354657/Electricity-Tariffs-Power-Outages-and-Firm-Performance.pdf.

TABLE 15.
Summary of the sensitivity analysis inputs

Technologies	Parameter	Units	Sensitivity levels			Source(s)
			1	2	3	
Diesel generators	Capital cost (CAPEX)	USD/kW	938	938	938	World Bank (2016)[49]
	Operations and maintenance	USD/kWh	0.1	0.1	0.1	
	Lifetime	Years	10	10	10	
	Fuel cost (Algeria)	USD/litre	0.17	0.21	0.26	
	Fuel cost (Tunisia)	USD/litre	0.62	0.78	0.93	
Electric pumps	Capital cost (CAPEX)	USD/kW	845	845	845	World Bank (2016); World Bank (2017)[50]
	Operations and maintenance	USD/kWh	0.1	0.1	0.1	
	Lifetime	Years	10	10	10	
	Fuel cost (Libya)	USD/kWh	0.168	0.21	0.252	
Wind	Capital cost (CAPEX)	USD/kW	1,300	1,105	910	International Renewable Energy (2012)[51]
	Operations and maintenance	USD/kWh	0.02	0.02	0.02	
	Lifetime	Years	20	20	20	
Solar PV	Capital cost (CAPEX)	USD/kW	1,140	970	680	Gager and Lahham (2016)[52]; International Renewable Energy (2012)[53]
	Operations and maintenance	USD/kWh	0.01	0.01	0.01	
	Lifetime	Years	15	15	15	

A description of the data sources used and an in-depth explanation of the methodology used is presented in Annex 3 and a forthcoming academic publication[54].

4.2 Key results

Inefficient irrigation techniques are a major problem in the NWSAS basin. It is known that more than 72 percent of the irrigated land uses surface irrigation techniques, with an average efficiency of 42.4 percent and in the best cases reaching up to 60 percent. The rest of the irrigated land uses sprinkler irrigation and drip irrigation, with 26 percent and 2 percent shares, respectively[55]. The resulting water demand per hectare by province for the three scenarios (surface irrigation – 45 percent efficiency, improved irrigation – 65 percent efficiency,

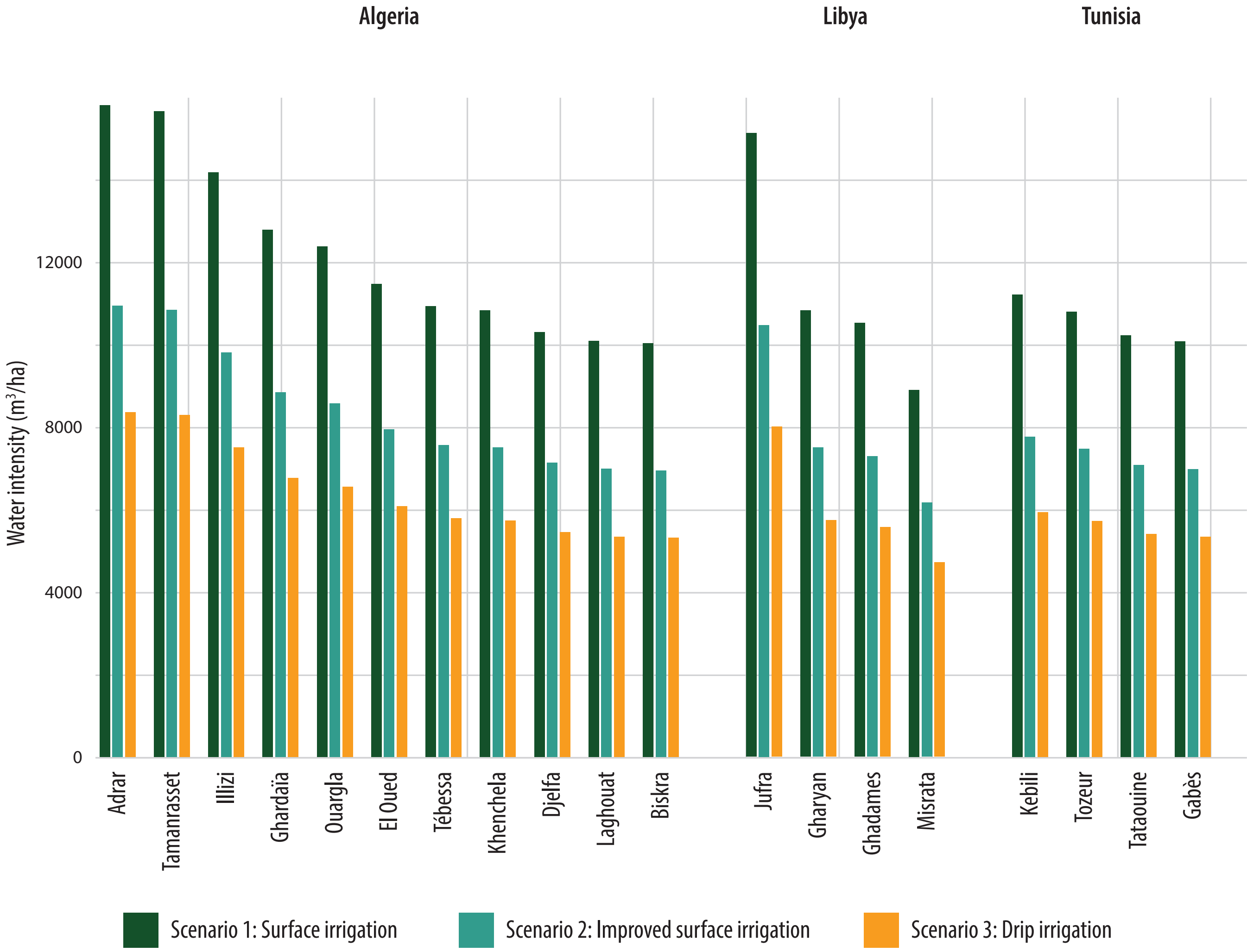
[49] World Bank (2016). Pump price for diesel fuel (US$ per liter) - Algeria, Tunisia, Libya. Available at: https://data.worldbank.org/indicator/EP.PMP.DESL.CD?end=2016&locations=DZ-TN-LY&start=2016&view=bar;
[50] ibid; Arlet, Jean (2017). *Electricity Tariffs, Power Outages and Firm Performance: A Comparative Analysis*. World Bank. Available at: http://pubdocs.worldbank.org/en/444681490076354657/Electricity-Tariffs-Power-Outages-and-Firm-Performance.pdf
[51] International Renewable Energy Agency (2012). Wind Power. *Renewable energy technologies: Cost analysis series*, 1 Power Sector (5/5).
[52] Gager, E. and Lahham, N. (2019). *The impact of solar pumping in Tunisia*
[53] International Renewable Energy Agency (2012). Solar Photovoltaics. *Renewable energy technologies: Cost analysis series*, 1 Power Sector (4/5).
[54] Almulla et al. (in preparation).
[55] Water, Climate and Development Programme (2015). *Integration of climate change impacts in the NWSAS water resources management. Report of Phase A: Definition of the baseline and choice of climatic scenarios.*

drip irrigation – 85 percent efficiency) is presented in Figure 4. Improving the efficiency of the irrigation system has the potential to save up to 47 percent of the water abstracted in the NWSAS area, which can save a volume of 5,500 m³/ha on average, and in some places, such as Adrar, Tamanrasset (Algeria), and Jufra (Libya), it can reach more than 7,000 m³/ha. In terms of total water consumption (see Figure 5), today, Algeria accounts for 71.82 percent (2,332.8 Mm³/yr in Scenario 1) of the irrigation water consumed in the NWSAS, with El Oued, Ghardaïa, Ouargla, and Adrar accounting for 86.48 percent of that water. The Libyan part of the NWSAS has a share of 14.06 percent (456.67 Mm³/yr in Scenario 1), and Tunisia 14.12 percent (458.73 Mm³/yr in Scenario 1), with Kebili representing 66.97 percent (307.22 Mm³/yr in Scenario 1) of the Tunisian share.

It should be noted that the savings achieved through higher efficiency can be easily lost to a higher water demand. Evidence shows that the expansion of irrigated agriculture and the shift towards more water-intensive crops are fairly common 'rebound effects' of water efficiency measures throughout the Middle East and North Africa region[56].

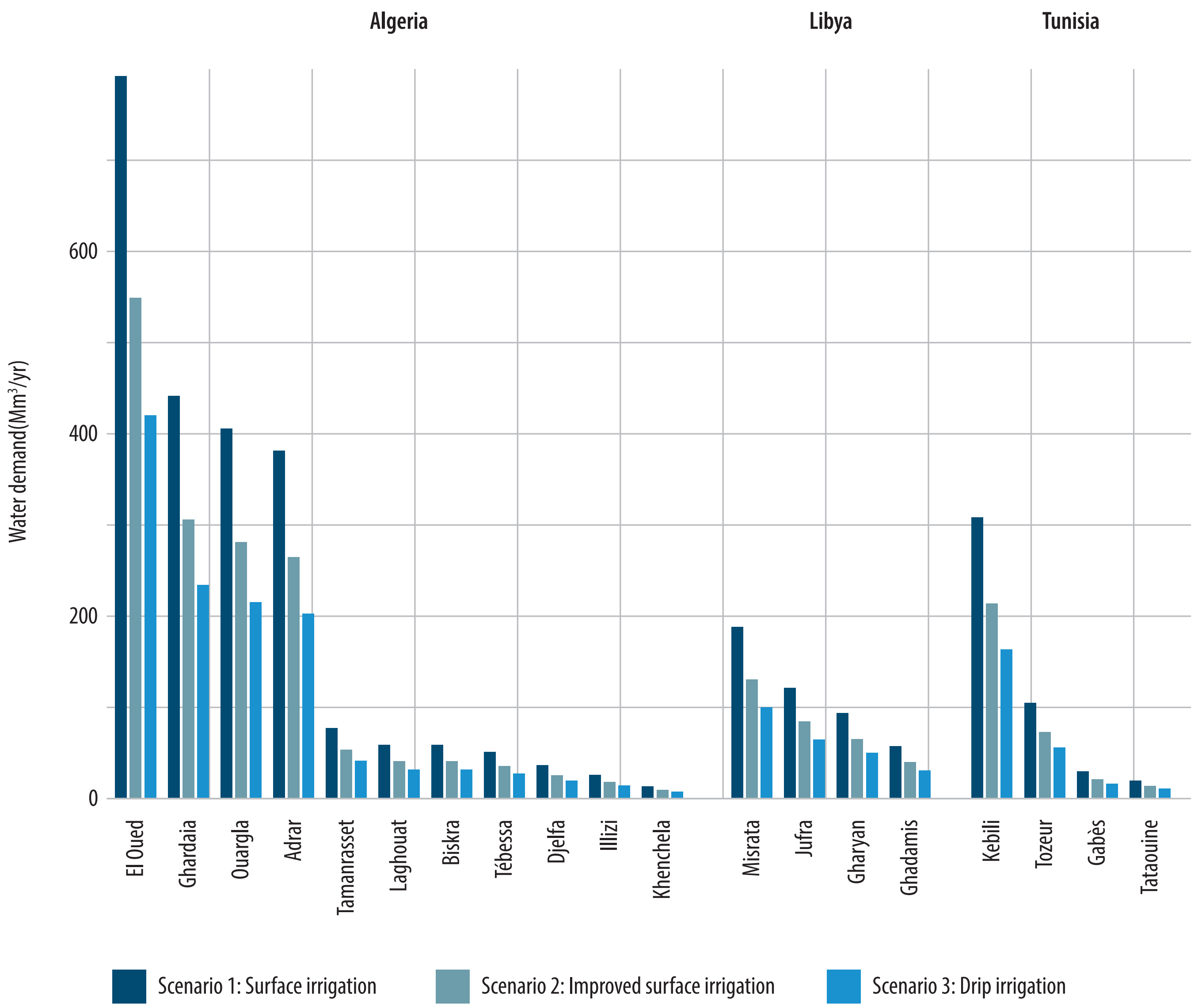
FIGURE 4.

Irrigation water intensity (water applied per hectare) in the NWSAS basin using different irrigation techniques



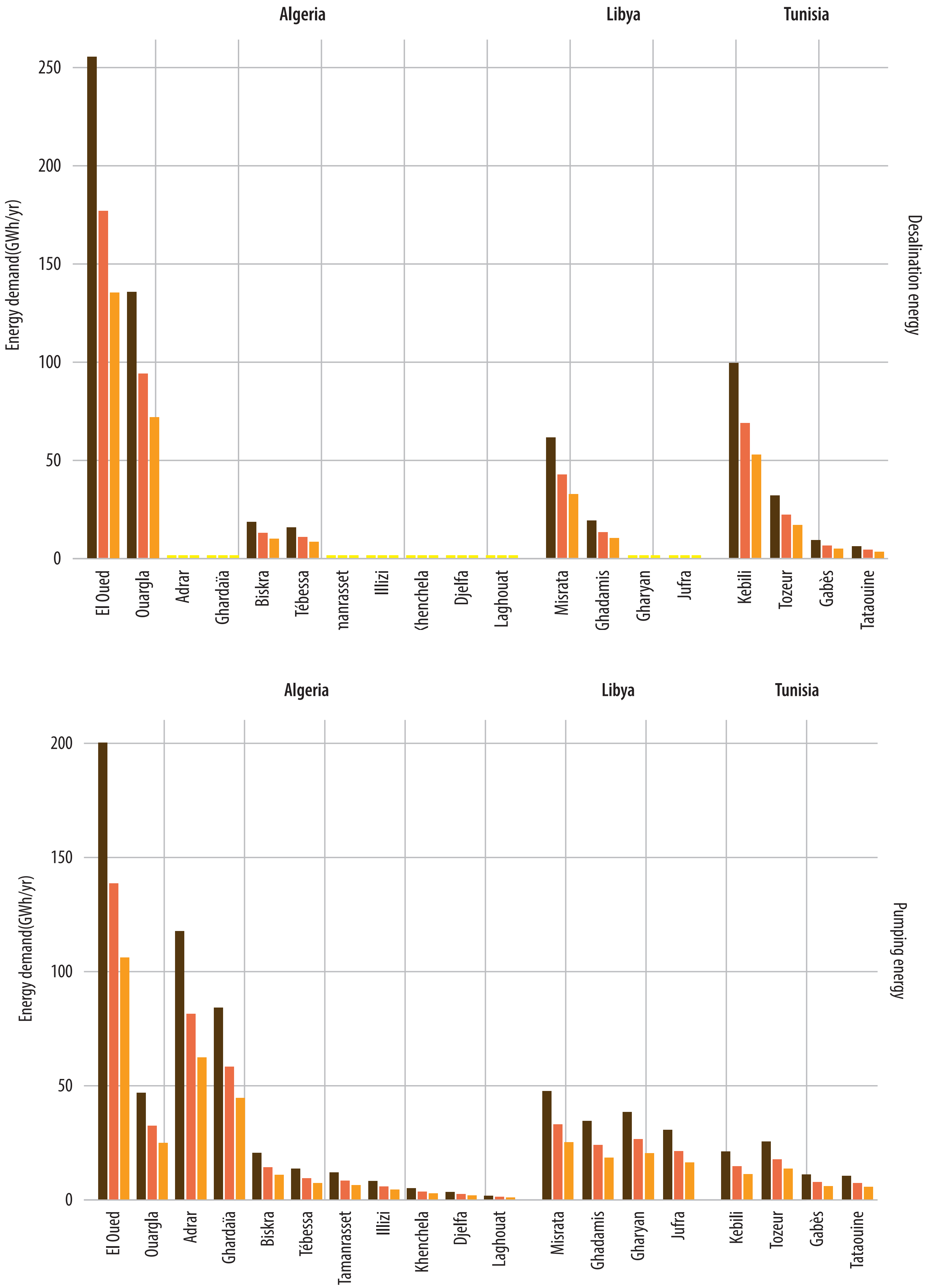
[56] Hoff, H. et al. (2019). A Nexus Approach for the MENA Region—From Concept to Knowledge to Action. *Frontiers in Environmental Science*, **7**. Also available at: https://doi.org/10.3389/fenvs.2019.00048; Villholth,K.G. et al. (2018). *Advances in groundwater governance*. CRC Press/Balkema, Leiden, The Netherlands. ISBN: 9780367890100; GIZ and Nexus Dialogue Programme (2018). *Tunisia, The Water-Energy-Food Security Nexus Country Profile*. Available at: https://www.water-energy-food.org/resources/resources-detail/nexus-country-profile-tunisia/.

FIGURE 5.
Irrigation water demand in the NWSAS basin using different irrigation techniques



The energy demand for pumping groundwater for cropland irrigation in the NWSAS region reaches about 730 GWh per year. The Algerian side of the basin accounts for about 70 percent (512 GWh/yr) of the demand, with El Oued, Adrar, and Ghardaïa alone representing 55 percent of the NWSAS pumping energy demand (78 percent of the Algerian demand). This is explained by the high volume of water being pumped annually in those three provinces. The Libyan pumping energy requirement reaches 150 GWh/yr and a share in the NWSAS of around 21 percent, with the highest demand in Misrata and an almost equal energy requirement in the other provinces. Finally, the Tunisian pumping energy requirements are around 67 GWh/yr, representing a share in the NWSAS of around 9 percent. The provinces with the highest demand in Tunisia are Kébili and Tozeur, respectively. The latter is a particularly interesting result: although the annual amount of water being pumped in Kébili is higher than in Tozeur, the energy requirement is higher in Tozeur. This is mainly due to the depth of the water table level that reaches an average depth of 43 m in Tozeur, almost twice that of Kébili, at 26 m.

FIGURE 6.
Energy demand for groundwater pumping and brackish water desalination at 2,500 ± 500 TDS threshold



Energy for desalination shows a different pattern, especially on the Algerian side of the basin. El Oued ranges from 264 to 246 GWh/yr of energy for brackish water desalination in the 2,000 to 3,000 TDS threshold range, which represents about 40 percent of the energy for desalination requirements in the entire NWSAS basin. El Oued is followed by Ouargla, with 140 to 131 GWh/yr of energy for desalination, but in the latter case, the energy required for pumping is only in the fifth place among the provinces in the NWSAS basin. This is due to the low groundwater depth and high TDS levels presented in this province. On the other hand, some provinces present a high demand for energy for pumping and no energy for desalination requirements in the three evaluated TDS thresholds, i.e. Adrar, Ghardaïa, Gharyan, and Jufra. Moreover, Tébessa (Algeria), Tozeur (Tunisia), and Gabès (Tunisia) show no energy for desalination requirements where a threshold of 3,000 TDS is considered. However, for the thresholds of 2,500 TDS and 2,000 TDS, the required energy for desalination in some of these cases is even larger than the energy required for pumping. Where a threshold of 2,000 TDS is considered, the total energy for desalination demand in the NWSAS basin reaches approximately 685 GWh/yr, but if the threshold is raised to 3,000 TDS, the total energy demand for desalination is reduced to 574 GWh/yr. This represents around a 16 percent (110 GWh/yr) reduction.

Such dynamics suggest that cultivating the most salt-resistant cops can help avoid the use of desalination and is a good alternative for agricultural areas located in zones of highly saline water resources. In other words, in the planning process for desalination projects, the types of crops should be taken into consideration, and wise agricultural choices should be made regarding the acceptable salinity levels and salinity tolerance of the crops cultivated, as this might offset the need for desalination.

Moving from the demand to the supply side, the current structure of the model takes into the account the techno-economic characteristics of the selected technologies in each country (see Tables 12 and 13). The model also accounts for solar irradiation and wind speed at each location (input from GIS layers), as well as fuel prices, and it has already computed the electricity demand at each grid cell (as shown in the previous steps). At this stage, it finds the most cost-effective option to supply the required amount of energy based on its LCOE. Initial results provide some interesting insight that would merit further investigation. Notably, the model shows that the competitiveness of solar PV irrigation is more sensitive to a drop in the investment cost than to a decrease in diesel subsidies. These results are described in more detail below.

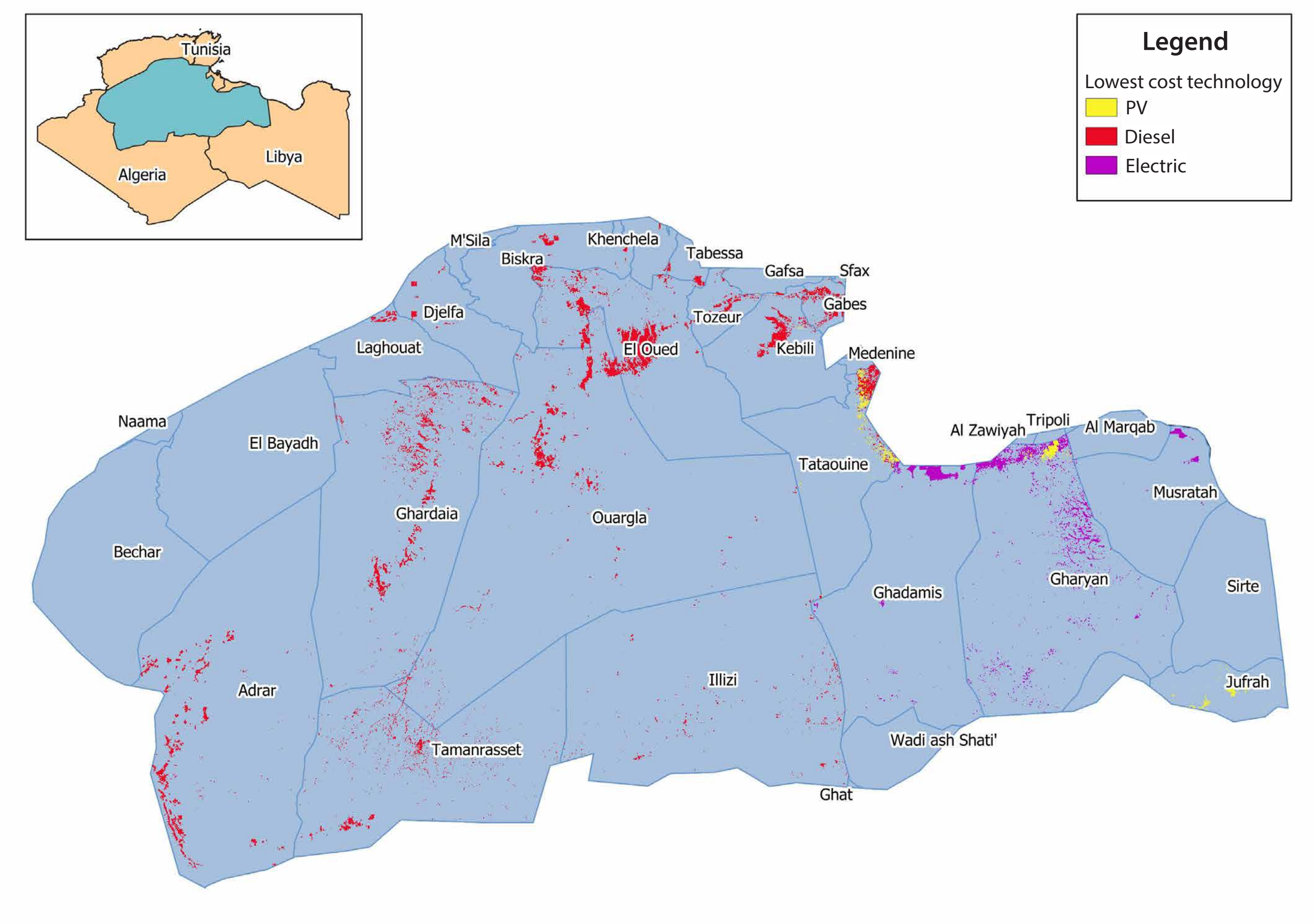
A. Impact of technology cost

The current photovoltaic (PV) energy cost of around 1,140 USD/KW[57] and subsidised fossil fuel prices in the region make the conventional fossil fuel-based options or the existing grid the most cost-effective options for supplying electricity. This can be seen in Figure 7, which shows the entire region supplied by either diesel gensets or electricity from the grid (produced almost entirely by fossil fuel). This might change in the near future in the event of a drop in PV cost in the region following the learning curve and a decrease in technology costs[58].

[57] Cost based on recent study on solar pumping in Tunisia: Gager, E. and Lahham, N. (2019). *The impact of solar pumping in Tunisia*. Same cost assumed for Algeria and Libya.

[58] According to the World Energy Outlook 2018, Solar PV cost in the Middle East is expected to drop 44 percent by 2030 compared with 2017 under the new policy scenario and by 54 percent by 2030 under the Sustainable Development Scenario. Source: International Energy Agency (2018). *World Energy Model. Scenario analysis of future energy trends. Report — November 2019. Policies database. NPS and SDS assumptions*. Available at: https://www.iea.org/reports/world-energy-model/policies-database#abstract

FIGURE 7.
The lowest cost supply option technology mix in Scenario 1 (CAPEX level 1)

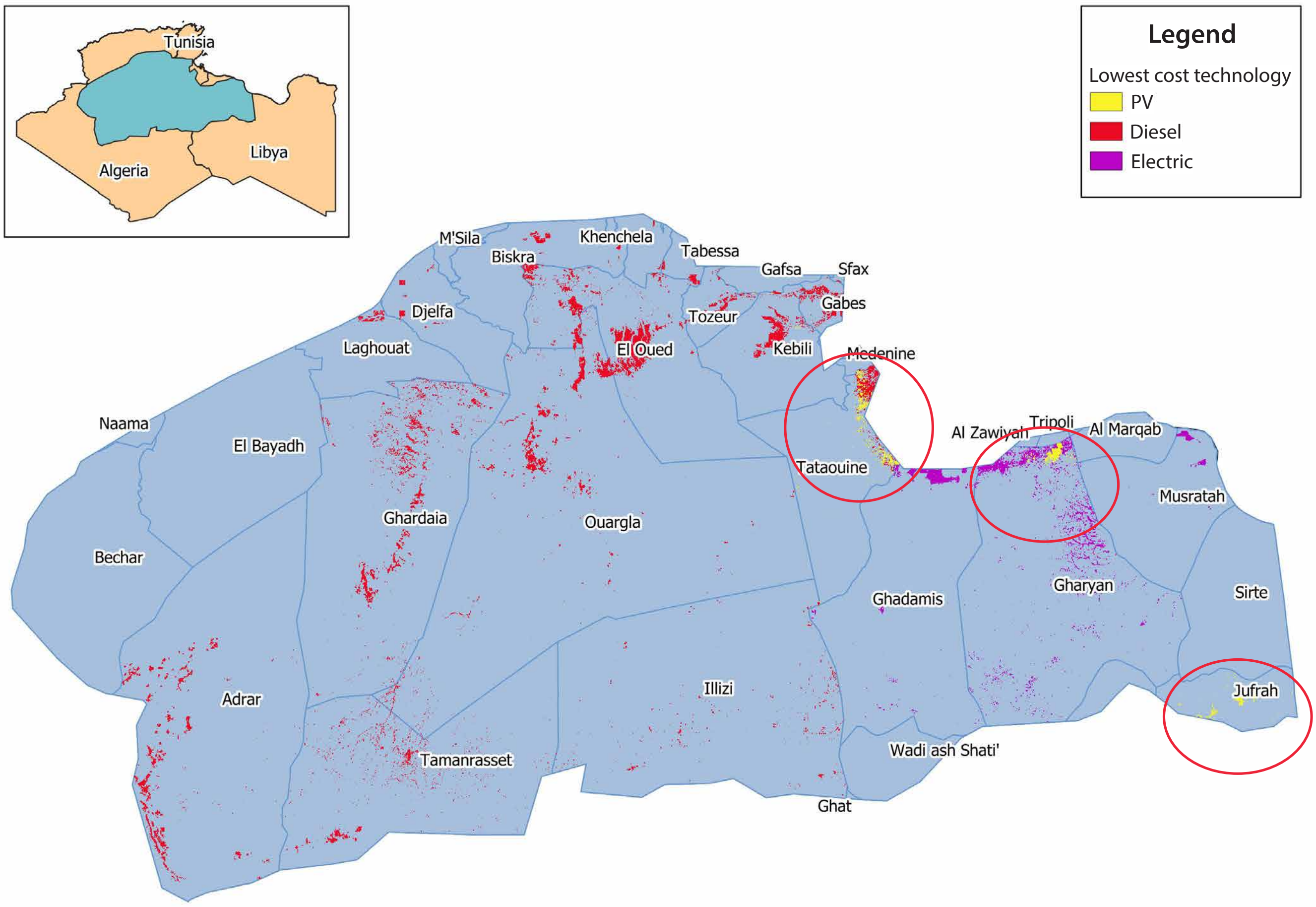


With a reduction in technology costs to 970 USD/KW (15 percent below the current level), solar PV starts being competitive in the Tunisian and Libyan markets, as shown in Figure 8. More specifically, Tataouine (which receives high solar irradiation due to its location in the southern part of Tunisia) will start shifting to solar before any Algerian province because the cost of diesel in Tunisia (0.62 USD/litre) is higher than in Algeria (0.17 USD/litre)[59].

On the Libyan side, solar PV will first start penetrating in Jufra and the northern part of Gharyan because these are the two Libyan provinces with the highest water demand for irrigation (m^3/ha) (see Figure 8). This model simply shows that as the cost of PV technology drops, where water demand is high, standalone PV pumps that come with zero operating costs can soon become attractive for farmers, even if electricity from the grid is cheap.

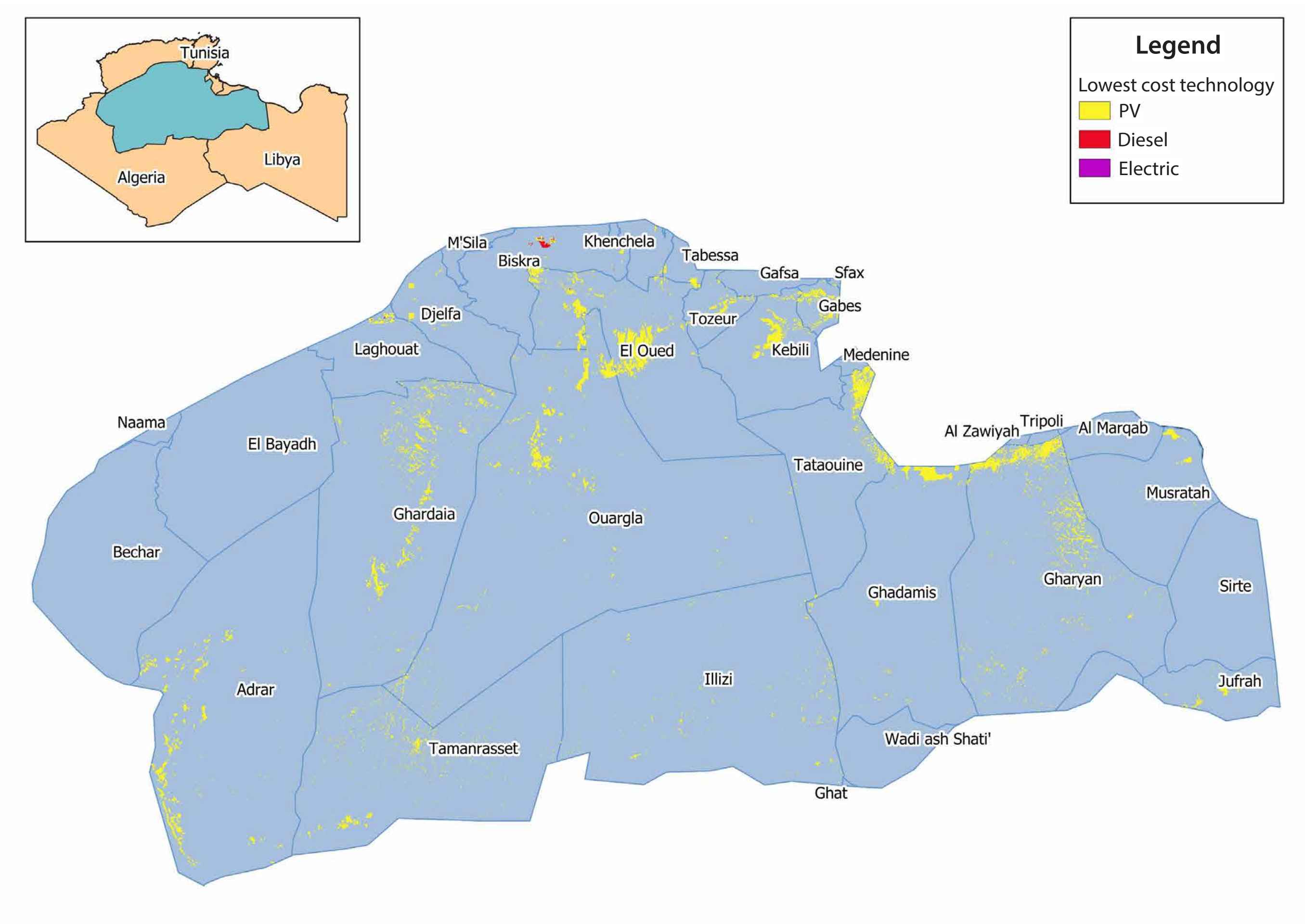
[59] World Bank (2016). *Pump price for diesel fuel (US$ per liter) - Algeria, Tunisia, Libya*. Available at: https://data.worldbank.org/indicator/EP.PMP.DESL.CD?end=2016&locations=DZ-TN-LY&start=2016&view=bar.

FIGURE 8.
The lowest cost supply option technology mix in Scenario 2 (CAPEX level 2).



With a further drop in solar PV costs to 680 USD/KW (30 percent below the current level), solar energy will be the most cost-effective option in the entire NWSAS region, as shown in Figure 9.

FIGURE 9.
The lowest cost supply option technology mix in Scenario 3 (CAPEX level 3)

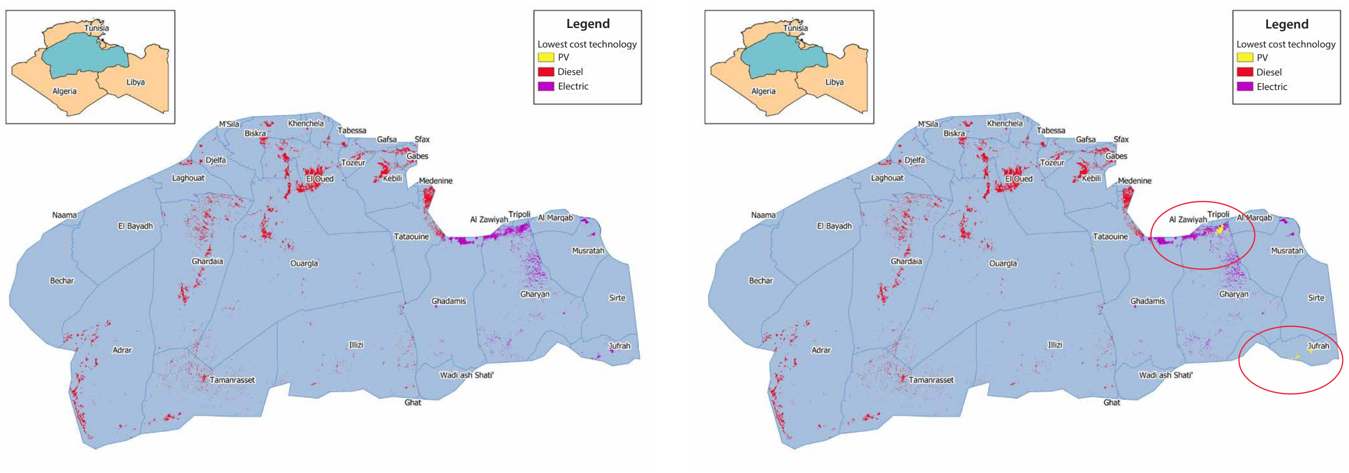


Note that the model does not select wind turbines in any location under any scenario condition. This means that small-scale wind turbines are not economically competitive with the other technologies studied in the case, under any of the three CAPEX levels.

B. Impact of fuel price

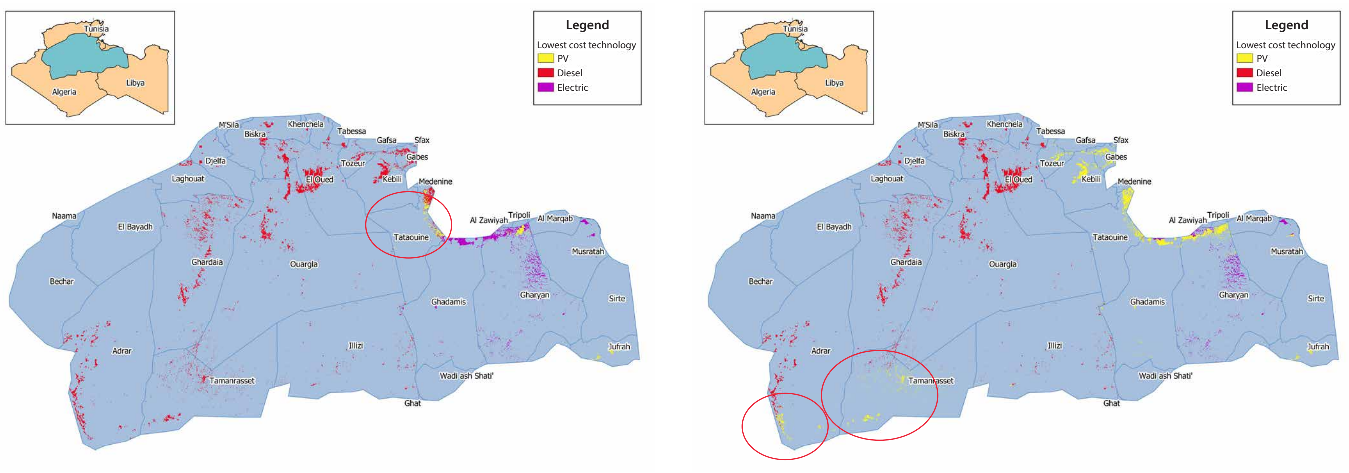
In this section, we examine the impact of increased fossil fuel price due to a change in fuel (diesel or electricity) subsidies on the supply side. Three levels were examined: the current level, a 30 percent increase, and a 50 percent increase, as shown in Table 15. In the following paragraphs, a comparison is made between the current level (Fuel level 1) and a 50 percent increase (Fuel level 3) to show the two extreme cases, combined with technology cost (CAPEX) levels 1 and 2 (as already shown, for CAPEX level 3 solar PV would be the lowest cost option throughout the basin area).

FIGURE 10.
Comparison between the electricity supply options at CAPEX level 1 for different levels of fuel subsidy



In the CAPEX 1 case (i.e. technology cost of 1,140 USD/KW), increasing the fuel price by 50 percent will result in limited solar penetration, in the Libyan market only. The provinces with higher water intensity (Jufra and Gharyan) will shift to solar to meet the energy requirement for pumping instead of the current electric pumps running on electricity from the national grid. Note that as shown earlier, even without the increase in fuel price, these two provinces will shift to solar anyway at the CAPEX level of 970 USD/KW.

FIGURE 11.
Comparison between the electricity supply options at CAPEX level 2 for different levels of fuel subsidy



In the CAPEX 2 case (i.e. technology cost of 970 USD/KW), solar PV appears in Tataouine (Tunisia), Jufra, and Gharyan (Libya) (Figure 11, left). However, with a 50 percent increase in fuel price, solar PV will be the lowest cost option in all Tunisian provinces (due to high diesel cost) and most Libyan provinces where the solar radiation and irrigation requirements are high. Solar PV will also start penetrating the Algerian market in provinces with high solar irradiation like Adrar and Tamanrasset, as shown in Figure 11 (right).

From this comparison it can be concluded that the competitiveness of off-grid solar PV for irrigation in the NWSAS region is more sensitive to the drop in investment cost than to a change in fuel subsidies. This means that from the perspective of agriculture, setting up an effective support system for farmers to afford solar technology would be more effective than lifting consumer subsidies to farmers. On the other hand, providing farmers with an irrigation technology that has no operational cost could result in higher water abstraction, which would add pressure to the already stressed aquifer[60]. This is a crucial question that points to the importance of

[60] Belaud, G. et al. (2020). *Special issue: Innovations in irrigation systems in Africa. Irrigation and Drainage*, **69**(S1):177–185.

combining PV policy with appropriate water efficiency and/or conservation measures (see Chapter 3).

The complex implications of these modelling insights motivate more in-depth analysis, first of all to consolidate the modelling inputs with additional important parameters that might affect the outcomes. For example, considering the map of the electricity grid network's transmission and distribution lines would allow a more accurate distribution of grid-powered pumps to be estimated. Also, using the actual cost of electricity generation in each country, instead of the consumer prices that are used in this analysis to reflect the consumer side, would make the LCOE comparison more precisely reflect producers' costs and the required drop in solar PV costs that would make PV investments competitive in those markets beyond standalone PV pumps. Such enhancements would facilitate investigating the competitiveness of multipurpose solar projects including large-scale power production.

5. Conclusions and recommendations

This report addresses the challenges facing the water, food, energy, and environment sectors in the NWSAS basin and proposes a cooperative, coordinated response to the common issue of groundwater degradation in the NWSAS. The challenges and solutions have been identified and developed together with the authorities and stakeholders from the three aquifer-sharing countries, who took part in the participatory process of the nexus assessment, including through multisectoral working group discussions at both transboundary and national levels.

The challenges are described from the different sectoral perspectives, and reflect the variety of challenges encountered in the energy, food, water, and environment sectors, which partly originate outside the basin area (water, energy, and food security), from environmental degradation, and from intersectoral impacts. The delicate socioeconomic situation and the highly irrigation-dependent agriculture in the NWSAS region are major challenges to address. This situation shows that the sectors are interlinked not only due to the heavy reliance of all sectors on a common, increasingly degraded, and depleted groundwater resource, but also due to the interlinkages that exist at the policy level regarding the economics of resource use and pricing, practices and innovation in the food and water sectors, and the response to climate change. The expansion of water use for irrigation is facilitated by the availability of cheap fossil fuels and electricity, while in contrast the use of alternative water sources and wastewater treatment is limited by the high cost of the necessary infrastructure and technology.

This report proposes a package of nexus solutions, each consisting of a set of actions to be taken in the different sectors, and also gives an indication of the best-suited actors to lead their implementation and facilitate the establishment of the necessary partnerships across sectors. The sectors need to strengthen action in their own domains (e.g. water demand management, the implementation of legal and regulatory frameworks for water or for land use, and renewable energy planning) but can also find significant support and powerful synergies if intersectoral cooperation is strengthened (e.g. energy recovery from wastewater, improving environmental practices in agriculture for water and soil preservation and to increase yields, and empowering women and young people to implement innovation in rural areas). The preparation of the 'nexus solutions' was based on the countries' strategic policy objectives and their experiences and lessons learned from implementing similar solutions, hence they can be considered to be high-priority and implementable. The package of nexus solutions, being the result of an official process that makes a case for cooperation beyond the area of water resources, provides a baseline for discussions about developing cooperation and reinforcing coordination to gain multiple benefits.

The nexus solutions aim to activate intersectoral cooperation, both to enhance the effectiveness of the solutions led by each sector (actions) and to more efficiently achieve strategic objectives that are or would merit being on the agenda in all sectors (cross-sectoral goals). The nexus actions would facilitate coherent achievement of common objectives, such as the 2030 Agenda for Sustainable Development, and international climate action commitments such as the Paris Agreement. To that end, the package of solutions could be used to frame project proposals for multisectoral activities, programmes, or projects in the NWSAS. Because of the policy coherence embedded in the coordination of sectoral actions, and the way they can be 'packaged', the nexus solutions can be used by the countries to:

1. draft proposals to international donors interested in financing sustainable development or environmental and climate funds

2. better coordinate the implementation of water, energy, and agricultural policies and projects that have intersectoral impacts.

The package of solutions for "coherent planning for sustainable development in the NWSAS" is a basin-wide action plan that reduces trade-offs and increases synergies between sectoral policies in the NWSAS; "enhanced local resilience to basin challenges" could be the starting point for a climate adaptation plan in the basin, and "creating a circular economy through non-conventional water and renewable energy" can be used to synergise water and energy action for the sustainable development of oases.

While the solutions target intersectoral cooperation mainly at national and local/subnational levels where policies are developed and implemented, some of the solutions target international and transboundary cooperation. The report points to the potential benefits that could be gained by using local products from the region, and illustrates the importance of improving the information on environmental needs in the basin to help develop a detailed water balance of the aquifer that includes all sectoral water needs (in quantity and quality, by location), and their relative trends over time.

At the basis of the nexus analysis lies the in-depth analysis of the sectors in relation to natural resources (see Part B of the report), including the development of an integrated water-food-energy-ecosystem nexus model aiming to quantify key interlinkages (e.g. water and energy used for food production) and model the impact of policy actions. For illustration purposes, the model was used to evaluate the competitiveness of off-grid solar pumping (versus other means of energy supply) to supply future demands of the agricultural sector (irrigation and desalination), considering different costs of fuels and levels of subsidies. The model shows that if the cost of PV technology drops to a certain level, standalone PV pumps with zero operating costs become more attractive for farmers where water demand is high, even if electricity from the grid is cheap (subsidised). This suggests that making PV technology more affordable is an effective way to promote solar energy in agriculture, but it also shows that without planning, solar energy has the potential to seriously aggravate groundwater depletion.

The integrated nexus model can be used to inform decision-making in the areas of irrigated agriculture and energy system planning (e.g. optimal grid expansion, low-cost technologies for water treatment and wastewater reuse), but there are still some important data gaps that need to be filled, such as GIS-based information on water consumption and extension of irrigated areas, and distribution of pumping technologies and related energy sources in the basin. The nexus model was developed building on the existing hydrogeological model of the NWSAS and using an open source tool to ensure transparency of data use and to encourage wider dissemination, uptake by relevant institutions, and use to inform policy and decision-making.

Annex 1. List of Sustainable Development Goals (SDGs) and Targets related to the implementation of the package of solutions

SDG	Targets
SDG 1: End poverty in all its forms everywhere	1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters
SDG 2: Zero hunger	2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.
	2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.
	2.A Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries.
SDG 5: Achieve gender equality and empower all women and girls	5.A Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources, in accordance with national laws
SDG 6: Ensure access to water and sanitation for all	6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all
	6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
	6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
	6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
	6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
	6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
	6.A By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
	6.B Support and strengthen the participation of local communities in improving water and sanitation management

SDG	Targets
SDG 7: Ensure access to affordable, reliable, sustainable and modern energy	7.1 By 2030, ensure universal access to affordable, reliable and modern energy services
	7.2 By 2030, increase substantially the share of renewable energy in the global energy mix
	7.3 By 2030, double the global rate of improvement in energy efficiency
	7.A By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology
	7.B By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support
SDG 8: Promote inclusive and sustainable economic growth, employment and decent work for all	8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead
	8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products
SDG 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation	9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all
	9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities
	9.A Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States 18
	9.B Support domestic technology development, research and innovation in developing countries, including by ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities
SDG 10: Reduce inequality within and among countries	10.2 By 2030, empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status
SDG 11: Make cities inclusive, safe, resilient and sustainable	11.A Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning

SDG	Targets
SDG 12: Ensure sustainable consumption and production patterns	12.2 By 2030, achieve the sustainable management and efficient use of natural resources
	12.A Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production
	12.C Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities
SDG 13: Take urgent action to combat climate change and its impacts	13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
	13.2 Integrate climate change measures into national policies, strategies and planning
	13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
SDG 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements
	15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world
	15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species
	15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts
	15.A Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems
SDG 17: Revitalize the global partnership for sustainable development	17.14 Enhance policy coherence for sustainable development
	17.16 Enhance the global partnership for sustainable development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the sustainable development goals in all countries, in particular developing countries
	17.17 Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships
	17.3 Mobilize additional financial resources for developing countries from multiple sources

Annex 2. List of actions supporting the implementation of the nexus solutions

Each nexus solution includes a set of actions. Solutions 1–5 are to be taken primarily in the water sector, 6–8 in the energy sector, 9–12 in the food sector, and 13–15 in the environment sector. The leading and implementing actors for each solution are summarised in Annex 3.

1. Enhance local water management, including revitalising participatory models in oases and enhancing the enforcement of existing laws on water conservation.

1.1 Develop and strengthen partnerships between state structures, non-governmental organisations, and private and civil society associations in the water sector to disseminate integrated water resources management. In particular, strengthen the relationship between water user associations/agricultural development groups (GDA), and the government regarding technical and financial arrangements, providing an institutional and regulatory framework for the progressive empowerment of GDAs (Tunisia), and strengthen local non-governmental organisations and professional development organisations by empowering users (Algeria and Libya).

1.2 Strengthen the monitoring of existing laws' implementation related to licences for new drilling, recovery of new agricultural land, and application of appropriate technical and economic measures for agricultural activities.

1.3 Conduct a mapping of organisations and key actors involved in water management at different levels in the NWSAS basin to inform 1.1.

1.4 Propose an action plan for interventions and their incorporation in sectoral and territorial/local development plans.

1.5 Develop an institutional and operational capacity-building plan for organisations and actors identified in 1.3 on integrated water resources management and operationalise intersectoral cooperation.

2. Reinforce transboundary cooperation for sustainable groundwater resource management.

2.1 Enhance the institutional setting to: 1) improve knowledge of the policies adopted by the three governments, 2) compare them by identifying which area is each government's focus, and 3) observe the guidelines of the measures adopted, e.g. expert groups.

2.2 Upgrade modelling tools including the hydrogeological/groundwater, water quality, socioeconomic, and integrated water-food-energy-ecosystem nexus models of the transboundary aquifer. Encourage the use of these tools to inform decision-making at all levels.

2.3 Inform policy decisions related to water, food/agriculture, energy, and environment taken by NWSAS countries based on the transboundary recommendations from the Consultation Mechanism of the NWSAS.

3. Set up dedicated policies and related incentives for wastewater reuse in agriculture and urban areas.

3.1 Exchange knowledge and experiences among the three countries concerning the use of treated wastewater, main practices, legislation and enforcement, standards of treatment and use, and preventive measures for storage and distribution.

3.2 Develop a master plan for the reuse of wastewater in the various sectors with input from all interested sectors.

3.3 Facilitate investments in wastewater treatment, and energy recovery from wastewater where applicable, to improve quality of wastewater and coverage of treatment.

3.4 Strengthen intersectoral coordination and consultation in designing water reuse policies and developing practical guidance (agriculture, environment, health).

3.5 Organise training, coaching, and extension programmes for specific uses, as well as communication and awareness campaigns on safe wastewater reuse.

3.6 Encourage the safe reuse of treated wastewater in municipalities and touristic facilities.

3.7 Support and incentivise investments for agricultural wastewater reuse in irrigation and interseasonal storage.

4. Strengthen water demand management, including through water-saving programmes.

4.1 Encourage water efficiency and conservation practices in the different sectors, notably:

- **Agriculture:** encourage irrigators to procure irrigation systems that increase irrigation efficiency and preserve resources (e.g. irrigation warning systems for the optimal use of soil moisture), optimising volumes and timing for crops and reducing evaporation losses, as well as water conservation and good environmental practices (e.g. crop selection based on their water needs, interseasonal storage, improved drainage, sustainable soil management) by making investments more accessible and cost-effective (e.g. incentivising the use of locally manufactured material adapted to irrigation) and by providing training to use, operate, and maintain effective irrigation systems.

- **Industry:** provide financial and/or tax incentives for the industrial and mining sectors (oil, phosphate, etc.) to encourage them to adopt technologies in order to increase the productivity and efficiency of water resources and reduce losses and leaks; incentivise water recycling (use of alternative water resources such as brackish water, treated wastewater, and desalinated water, and closed loops for cooling needs), dematerialisation (choice of water-saving production process) and the adoption of new technologies such as electrocoagulation systems as part of effluent treatment facilities.

- **Other sectors:** encourage the rationalisation of water demand from all users (households, local authorities, hotels, etc.) with targeted interventions for each user type.

4.2 Establish an adequate pricing system for water provision/services which reflects the real cost of supply and different users' capacity to pay. This makes it possible to develop an economic instrument for demand management and conservation of water resources in the medium to long term. The water pricing system should support the water sector to gradually catch up on cost recovery. Water charges should be based on two principles:

- applying differential prices according to regions and the contributive capacity of users by sector

- maintaining consistency between the price and the nature of services provided to users (e.g. farmers) depending on the water source, its quality, type of activity, mode of operation, etc.

4.3 Facilitate investments in the rehabilitation and modernisation of community networks with a view to improving their performance (e.g. metering), and quality of service, keeping the cost of providing water affordable for all users.

4.4 Develop a financial incentive scheme for the promotion of modern and efficient irrigation techniques among small farmers. To be successful, this scheme should consider the multiple costs borne by farmers for water, energy, and agricultural inputs, and the gains from production.

5. Upscale the use of non-conventional water resources through desalination and wastewater and drainage water treatment.

5.1 Develop an intervention strategy with clear objectives and financing sources for brackish water and treated wastewater recovery.

5.2 Facilitate public and private investment and partnerships for desalination and wastewater treatment schemes.

5.3 Promote the use of solar energy in projects for seawater desalination and/or demineralisation of brackish water (possible use of the water-energy-food-ecosystem nexus model developed in the assessment[61]), accompanied by beneficial use or responsible disposal of the saline brines.

5.4 Develop and upscale solar water treatment and demineralisation units adapted to oasis conditions.

5.5 Develop a resource diagnosis (volume, quality, and geographical distribution of treated wastewater available), as well as an inventory of the different uses of treated wastewater and demineralised brackish water (by farmers, tourists, schools, communities, etc.)

5.6 Carry out an inventory of crop species that can be irrigated by the treated wastewater without impacting health that are aligned with national regulations and international standards for export.

5.7 Promote drainage water reuse in irrigation (in combination with sustainable soil management and safe disposal of pollutants).

[61] See Chapter 4 for a description of the model.

6. Enhance mechanisms for the coordination of energy development with other sectoral plans, to anticipate trade-offs and build on intersectoral synergies.

6.1 Set up national coordination mechanisms between energy and other sectors to overcome challenges and ensure an integrated energy strategy.

6.2 Investigate how the energy sector can cooperate with other sectors, and the synergies and opportunities available from energy development (e.g. clean agricultural development, energy recovery from agricultural waste and municipal wastewater, etc.) and collaborate with these sectors, including them in planning and operations.

6.3 Set up a transboundary energy group of experts involving energy ministries, utilities, and other experts (e.g. from academia), to analyse energy trends that could have a significant impact on the NWSAS basin land and water resources (from the expansion of small-scale solar energy to new fossil fuel extraction plans), thereby motivating the energy sector to be more involved in dialogues at the transboundary level.

7. Develop a sustainable programme for diversified, multipurpose renewable energy and sustainably upscale small-scale solar irrigation.

7.1 Develop a scheme to make solar irrigation affordable, reduce the use of fossil fuel-based irrigation, and integrate solar energy into regional and local rural development plans.

7.2 Ensure that Action 7.1 is accompanied by effective technical measures (i.e. metering) as well as legal and economical tools (e.g. fiscal incentives, regulatory measures) that limit the exploitation of groundwater resources.

7.3 Develop solar energy solutions that aggregate various energy demands and distribute the cost of solar energy across different users and/or activities (e.g. irrigation and water desalination, potable water conveyance, heating and lighting).

7.4 Support the development and diversification of renewable energy sources by making use of all available resources including geothermal energy, biomass, and waste.

7.5 Gradually restructure fossil subsidies to support and facilitate renewable energy deployment (by encouraging a shift away from diesel pumps).

7.6 Facilitate transboundary information and experience sharing on renewable energy development, to accelerate sustainable development in the basin.

7.7 Enhance capacity within administrations and trust between administrations and farmers, and raise awareness on renewable energy, energy efficiency, and rational use of water resources.

8. Improve the reliability of the electricity grid in rural areas, thereby enhancing the integration of renewable energies for remote and multiple uses.

8.1 Strengthen the grid in the NWSAS region to be able to support future demand and to accommodate intermittent renewable energy. This might require maintaining or upgrading the current transmission network and substations, as well as adding new transmission lines and substations.

8.2 Develop the interconnection between the northern grid and southern grid in the Sahara, in the case of Algeria.

8.3 Properly maintain and/or repair transmission lines and substations damaged in the conflict in Libya.

8.4 Develop financial support schemes and technical setups to support individuals to generate solar energy and sell surplus electricity to the grid.

8.5 Support and upscale the smart metering system as a step towards the development of grids.

8.6 Strengthen grid interconnections at the transboundary level to enhance electricity exchange between countries, with a view to expanding renewable energy and solar production in the region.

9. Set up agricultural policies oriented towards rational, sustainable, and productive agriculture.

9.1 Use the guidelines developed by FAO to address pressing issues of land tenure, to improve equitable access to natural resources and their sustainable management.

9.2 Develop and/or strengthen integrated rural development and agricultural policy strategies based on a dialogue with local populations and marginalised, vulnerable groups, and respond to their concerns.

9.3 Promote responsible agricultural investments, taking into account socioeconomic and environmental aspects, as well as the need to adapt to climate change. Notably, agricultural diversification (e.g. crops and livestock farming), the (re-) introduction of organic and traditional practices, ecotourism, and landscape conservation. Discourage intensive production and monocultures.

9.4 Within the framework of integrated policies (9.2), set up the necessary mechanisms to provide technical supervision and support to local stakeholders.

10. Valorise local products and strengthen programmes for a more balanced diet while involving young people and women in the economic and social development of the oases.

10.1 Strengthen the value chains of local, organic products and seasonal fruit and vegetables cultivated in oases using traditional agricultural practices.

10.2 Promote a more balanced and sustainable diet through specific programmes aimed at reducing food waste and improving nutrition through organic and varied food (e.g. in schools).

10.3 Support the socioeconomic inclusion of young people and women in the oases, including by increasing awareness of its importance and potential benefits.

10.4 Build strategic partnerships (public and private, cross-sectoral) to implement 10.1, 10.2, and 10.3.

11. Promote the circular economy including agroecological practices, through ad hoc economic measures and social instruments.

11.1 Identify the main obstacles to the development of the circular economy in oases and the areas of high potential (e.g. bioenergy, bioplastics[62]), and develop action plans to work with these areas.

11.2 Integrate the circular economy into relevant legal frameworks (updating them to facilitate innovation, sectoral and cross-sectoral action plans, e.g. for water management, distributed energy production, waste and agriculture), and regional policies for sustainable development, climate adaptation, and mitigation.

11.3 Support farmers in the agroecological transition (diversify their revenues, improve their water and energy productivity, and reduce their vulnerability to climate change) by sustaining the necessary investments through incentives and risk reduction, support for decision-making, use of local know-how, and benchmarking of agroecological practices (traditional and modern).

11.4 Facilitate support measures for farmers through multidisciplinary research and strategic partnerships (e.g. between universities and farmer groups, sustainable tourism operators, and farmers who produce organic and traditional food).

11.5 Encourage the association of farmers to improve their ability to implement innovative projects, upscale solutions in resource management efficiency and conservation, and apply for funding.

12. Enhance innovative practices and techniques for sustainable soil and crop management and invest in their upscaling and dissemination.

12.1 Adopt varied, adapted, and innovative agricultural practices like crop diversification in plots, crop rotation, pastures, transhumance, the integration of traditional and/or new crops that are resistant to water and saline stress (e.g. olives, almonds, argan, quinoa), and the introduction of hydroponics.

12.2 Improve the technical performance of production through conservation agricultural practices in soil management; rational use of chemicals and irrigation based on the real needs of crops, weather conditions, and calendars; and efficient and/or innovative technologies e.g. drip irrigation, smart irrigation software, and geothermal greenhouses.

12.3 Disseminate innovations in the farmer environment through demonstration platforms to ensure that farmers access knowledge and innovation, and to better align applied research to respond to their needs and concerns.

13. Increase awareness of the trade-offs and synergies between different sectors in public institutions.

13.1 Use the nexus approach to promote 1) coordination between public institutions in different sectors, by identifying cross-sectoral synergies that could be further explored and used, as well as measures and actions that could reduce ten-

[62] See a list of high-potential options in the NWSAS in section 3.2.3.3 Creating a circular economy through non-conventional water and renewable energy.

sions or conflicts related to multiple uses and needs, 2) transboundary cooperation among the three aquifer-sharing countries (Algeria, Tunisia and Libya) to optimise their use of resources, increase efficiency and improve policy coherence and 3) build capacity to assess and address cross-sectoral impacts with the support of specific tools like the water-food-energy-ecosystem integrated model developed for the NWSAS.

14. Consider environmental needs in the water balance of the aquifer.

14.1 Conduct studies and investigations to identify ecological demands for water in the most rational and scientifically sound way possible. This should specify hotspots, temporal variations, the characteristics of the water required (e.g. salinity levels), and the impacts of climate change.

14.2 Assess the sector-specific and cumulative impact of the various water uses in the NWSAS on biodiversity and ecosystem services.

14.3 Disseminate the results of the analyses (14.1 and 14.2) with the specific aim of mainstreaming the water balance of the aquifer and other resource modelling exercises related to the NWSAS (see Solution 2).

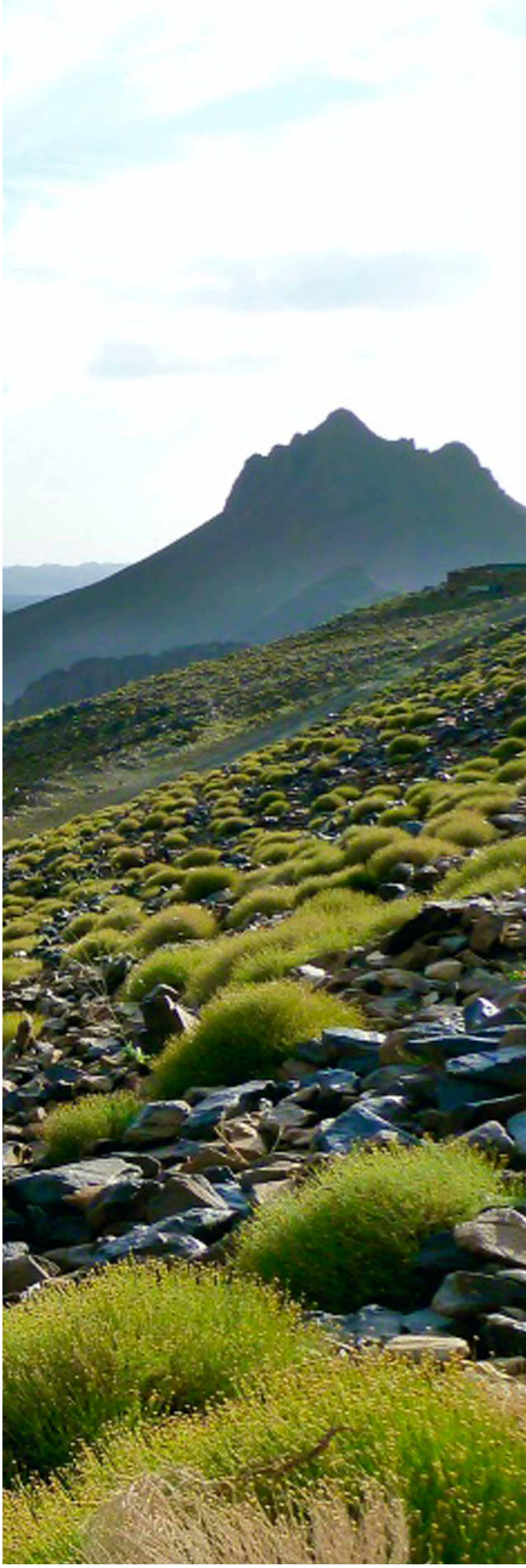
14.4 Coordinate with the different sectors to develop sustainable, integrated, and coherent development policies in the basin based on the analyses.

15. Systematise environmental and social impact assessment for all new infrastructure (large and small scale).

15.1 Carry out environmental and social impact assessments for all infrastructure and in particular for all energy projects, ranging from centralised power generation, national grid extensions, and transboundary interconnections to distributed power generation integrated in agriculture.

15.2 Take effective mitigation measures for identifying environmental and social impacts and risks (in the environmental and social impact assessment) through environmental and social management plans.

15.3 Establish an effective coordination mechanism between sectors as a key enabler to systematise the use of environmental and social impact assessments in the countries and the basin.



Annex 3. List of actors implementing the nexus solutions

Table 16 matches the 15 nexus solutions (columns 1–15) to specific implementing actors in the countries (national, local, and regional with national representation) and at the NWSAS (transboundary) level. The leading actors are marked with "L" and the supporting actors are marked with "S".

TABLE 16.
Implementing actors of the nexus solutions

THE 15 NEXUS SOLUTIONS

1. Enhance local water management, including revitalising participatory models in oases and enhancing the enforcement of existing laws on water conservation.
2. Reinforce transboundary cooperation for sustainable groundwater resource management.
3. Set up dedicated policies and related incentives for wastewater reuse in agriculture and urban areas.
4. Strengthen water demand management, including through water-saving programmes.
5. Upscale the use of non-conventional water resources through desalination and wastewater and drainage water treatment.
6. Enhance mechanisms for the coordination of energy development with other sectoral plans, to anticipate trade-offs and build on intersectoral synergies.
7. Develop a sustainable programme for diversified, multipurpose renewable energy and sustainably upscale small-scale solar irrigation.
8. Improve the reliability of the electricity grid in rural areas, thereby enhancing the integration of renewable energies for remote and multiple uses.
9. Set up agricultural policies oriented towards rational, sustainable, and productive agriculture.
10. Valorise local products and strengthen programmes for a more balanced diet while involving young people and women in the economic and social development of the oases.
11. Promote the circular economy including agroecological practices, through ad hoc economic measures and social instruments.
12. Enhance innovative practices and techniques for sustainable soil and crop management and invest in their upscaling and dissemination.
13. Increase awareness of the trade-offs and synergies between different sectors in public institutions.
14. Consider environmental needs in the water balance of the aquifer.
15. Systematise environmental and social impact assessment for all new infrastructure (large and small scale).

Implementing actors/solutions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Algeria															
Ministry of Water Resources	L	L	L	L	L	S	S					S	S	S	S
National Agency for Water Resources	S	L	S	S	S								S	S	
National Office for Irrigation and Drainage	S	S	L	L	L		S		S		S	S	S		
National Agency for Integrated Water Resources Management	S	S	S	S	S		S		S		S	S	S	S	
Hydrographic Basin Agencies	S	S	S	S	S		S		S			S	S	S	
National Agency for Dams and Transfers		S		S									S		
Algerian Water Authority	S	S	S	S	S								S		
The National Department of Sanitation		S	S	S	S								S		
Directorate for Agricultural Hydraulics – Ministry of Water Resources	L	S	S	S	S		S		S		S	S	S		
Directorate of Water Resources of the Wilayas	S	S	S	S	S		S					S	S		
National Advisory Council for Water Resources	S	S	S	S	S	S							S	S	
Water users' associations	S	S	S	S	S		S	S	S		S	S	S		
Ministry of Industry, Energy and Mines		S				L	L	S				S	S	S	S
Department of Renewable Energy – Ministry of Environment and Renewable Energy			S		S	S	L	S			S	S	S		
National Agency for the Promotion and Rationalisation of Energy Use		S	S		S	S	S	S			S	S	S		
National Company of Electricity and Gas						S	S	L					S		S

Implementing actors/solutions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Renewable Energy Development Center		S	S	S	S	S	S	S			S	S	S		
Ministry of Agriculture and Rural Development	S	S	S	S	S	S	S		L	L	L	L	S	S	S
National Institute of Irrigation and Drainage	S	S	S	S	S		S		S	S	S	S	S		
National Office of Agricultural Lands									S		S	S	S		
Directorate of Agricultural Development in Arid and Semi-Arid Areas	S	S	S	S	S		S		L	S	L	L	S	S	
Directorate of Agricultural Services of the Wilayas	S	S	S	S	S		S		S	S	S	S	S		
Commission for the Agricultural Development of Saharan regions	S	S	S	S	S		S		S	S	S	S	S	S	
Regional Agriculture Agencies (Chamber of Agriculture and Directorate of Agricultural Services)	S	S	S	S	S		S		S	S	S	S	S		
Universities and research centres (National Institute for Agricultural Research, Technical Institute for the Development of Saharan Agriculture)	S	S	S	S	S		S		S	S	S	S	S	S	
National Agricultural Investment Development Fund			S	S	S		S		S	S	S	S	S		
Department of Environment – Ministry of Environment and Renewable Energy		S	S		S	S	S	S			S	S	L	L	L
National Observatory of the Environment and Sustainable Development			S		S		S		S				S	S	S
National Agency on Climate Change		S	S	S	S		S	S	S	S	S	S	L	S	S
Wilayas and communes	S	S	S	S	S		S	S	S	S	S		S		
Ministry of Trade									S	S	S		S		
Ministry of Tourism and Crafts										S	S		S		
Ministry of Industry and SMEs						S		S		S	S		S		S
Ministry of Health			S		S					S	S		S	S	
Universities and research centres i.e. Centre for Scientific and Technical Research on Arid Regions	S	S	S	S	S	S	S	S	S	S	S	S	S	S	
Non-governmental agencies in various sectors (handicraft, youth, entrepreneurship, etc.) e.g. RADDO, Béni-Isguen Association for the Protection of Environment (APEB)	S	S	S	S	S		S	S	S	S	S	S	S	S	
Libya															
General Water Authority	L	L	S	L	S	S	S		S			S	S	S	S
General Desalination Company of Libya	S	S	S	S	S		S						S		
General Company for Water and Wastewater	S	S	L	S	L		S					S	S	S	
Great Man-Made River Authority		S		S			S						S	S	
Ministry of Electricity and Renewable Energy		S				L	S	L				S	S	S	S
Renewable Energy Authority		S	S		S	S	L	S				S	S		
General Electricity Company of Libya						S	S	S					S		S
National Oil Corporation						S		S					S		S
Ministry of Agriculture, Animal and Marine Wealth	S	S	S	S	S	S	S		L	L	S	L	S	S	S
National Committee to Combat Desertification	S	S	S	S	S		S		S	S		S	S	S	

Implementing actors/solutions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Agricultural Land Tenure Agency									S			S	S		
Regional agricultural agencies (Chamber of Agriculture and Directorate of Agricultural Services)	S	S	S	S	S		S		S	S	S	S	S		
Environment General Authority		S	S			S	S	S	S			S	L	L	L
Department of Conservation of Nature and Natural Resources	S	S		S	S					S		S	S	L	S
Muhafadhat and Chabiyat	S	S	S	S	S		S	S	S	S	S		S		
Ministry of Housing and Utilities			S		S	S	S	S		S			S		
Ministry of Health			S		S					S			S	S	
Ministry of Women's Affairs and Development	S									S	S	S	S		
Research schools and centres	S		S	S	S	S	S	S	S	S		S	S	S	
Non-governmental organisations in various sectors (handicraft, youth, entrepreneurship, etc.) and Libyan Consumer Protection Association	S	S	S	S	S	S	S	S	S	S		S	S	S	
Tunisia															
Ministry of Agriculture, Water Resources and Fisheries – Secretary of State for Water Resources	L	L	L	L	L	S	S				S	L	S	S	S
General Directorate of Water Resources	S	L	S	S	S		S						S	S	
General Directorate for Rural Engineering and Water Use	L	S	L	S	L		S		S		S	S	S		
Office of Planning and Hydraulic Balance	S	S	S	L	S		S						S	S	
General Directorate of Land Use Planning and Conservation	S	S		S							S	L	S		
National Water Distribution Utility	S	S	S	S	S								S		
Regional Departments for Agricultural Development	S	S	S	S	S		S		S		S	S	S		
Agricultural Development Organisations	S	S	S	S	S		S		S		S	S	S	S	
Ministry of Energy, Mines and Energy Transition		S	S		S	L	L	S			S		S	S	S
National Agency for Energy Management		S	S		S	S	L	S			S	S	S		
Tunisian Company of Electricity and Gas						S	S	L					S		S
Ministry of Industry and SMEs						S	S	S			S		S	S	S
Agency for the Promotion of Industry and Innovation					S	S	S	S			S		S		
Tunisian Association of Green Development and Renewable Energies	S	S	S		S	S	S	S			S	S	S		
Ministry of Agriculture, Water Resources and Fisheries									L	L	L	S	S	S	S
General Directorate for Studies and Agricultural Development	S	S	S	S	S		S		L	L	L	S	S	S	
General Directorate for Financing, Investments and Professional Organizations	S	S	S	S	S		S		S	S	S	S	S		
Office of Livestock and Pasture	S	S	S	S	S				S	S	S	S	S		
General Directorate of Forestry														S	
Agency for the Promotion of Agricultural Investments			S	S	S		S		S	S	S	S	S		
Agricultural Land Agency									S		S	S	S		
Mutual Agricultural Services Society	S		S		S		S		S	S	S	S	S		

Implementing actors/solutions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tunisian Union of Agriculture and Fisheries	S	S	S	S	S		S		S	S	S	S	S		
Universities and research centres (National Agronomic Institute, Regional Center for Research in Oasian Agriculture, Institute of Arid Regions)	S	S	S	S	S		S		S	S	S	S	S	S	
Ministry of Environment		S	S		S	S	S	S	S	S	S	S	L	L	L
National Sanitation Office			S	S	S								S		
National Environmental Protection Agency			S		S								S	L	L
Tunisian Observatory for the Environment and Sustainable Development			S		S								S	S	S
Non-governmental agencies (e.g. RADDO, Association for the Protection of the Chenini Oasis, Nakhla, Tunisian Association of Permaculture)	S	S	S	S	S		S		S	S		S	S	S	
Southern Development Office		S	S	S	S	S	S	S		S			S		
Governorates and municipalities	S	S	S	S	S		S	S	S	S	S		S		
Ministry for Women, Family Affairs and Children	S									S	S		S		
Ministry of Trade									S	S			S		
Ministry of Tourism and Crafts										S		S	S		
Ministry of Health			S		S					S		S	S	S	
Ministry of Justice and Human Rights	S												S		
Ministry of Development, Investment and International Cooperation			S	S	S	S		S					S		
Non-governmental agencies in various sectors (handicraft, youth, entrepreneurship etc.) e.g. RADDO	S	S	S	S	S	S	S	S	S	S		S	S	S	
NWSAS															
Consultation Mechanism, Coordination Unit	S	L	S	S	S	S	S	S	S	S	S	S	L	S	S
Working Groups to be established: Energy							S	S					S		
Working Groups to be established: Agriculture									S	S	S	S	S		
Working Groups to be established: Environment													S	S	

Annex 4. Supplementary material for the integrated model for the NWSAS

This annex gives the overview of the datasets used to develop the model and their sources. This section should be read with the modelling chapter to achieve complete understanding of the methodology, assumptions, and use of the datasets.

List of GIS datasets

The following climatic datasets were obtained from different online sources and were used to estimate water and energy demands as specified in Table 17.

TABLE 17.
Summary table of the GIS layers used in this analysis

#	Dataset	Type	Resolution	Spatial scope	Source
1	Administrative boundaries	Vector polygon	-	Administrative levels	Fick and Hijmans (2017)[63]
2	Elevation (m)	Raster	1 km × 1 km	Water/energy demand	CGIAR-CSI (2004-2020)[64]
3	Cropland area (ha)	Raster	20 m x 20 m	Water/energy demand	European Space Agency (2016)[65]
4	Irrigated harvested area (ha)	Raster	20 m x 20 m		European Space Agency (2016)
5	Minimum monthly temperature (ºC)	Raster	1 km × 1 km	Water demand	Fick and Hijmans (2017)
6	Maximum monthly temperature (ºC)	Raster	1 km × 1 km	Water demand	Fick and Hijmans (2017)
7	Average monthly temperature (°C)	Raster	1 km × 1 km	Water demand	Fick and Hijmans (2017)
8	Monthly solar radiation (kJ m^{-2} day^{-1})	Raster	1 km × 1 km	Water demand/energy supply	Fick and Hijmans (2017)
9	Monthly wind speed (m s^{-1})	Raster	1 km × 1 km	Water demand	Fick and Hijmans (2017)
10	Monthly precipitation (mm)	Raster	1 km × 1 km	Water demand	Fick and Hijmans (2017)
11	Water table depth (m)	Raster	1 km × 1 km	Energy demand	Fan, Li, and Miguez-Macho (2013)[66]

63 Fick, S.E. and Hijmans, R.J..(2017). Worldclim 2: New 1-km spatial resolution climate surface for global land area. *International Journal of Climatology*, 37(12).
64 CGIAR Consortium for Spatial Information (2020). *CGIAR Consortium for Spatial Information, DEM-SRTM 90m Digital Elevation Data* version 4. Available at: http://srtm.csi.cgiar.org/.
65 European Space Agency (2016). *CCI land cover – S2 prototype land cover 20m map of Africa 2016*. Available at: http://2016africalandcover20m.esrin.esa.int/.
66 Fan, Y., Li, H. and Miguez-Macho, G. (2013). Global patterns of groundwater table depth. *Science*, **339**(5):940–943.

Crop data

Additionally, Table 18 provides a summary of the data extracted from the relevant literature for start day, end day, and K_c value of each growing season for the selected crops in this study. It also shows the distribution of each type of crop in each province of the NWSAS. Crop selection and the distribution of crops in each province were based on consultation with OSS.

TABLE 18.
Crop calendar and assumed distribution in the NWSAS region

Growing cycle	Crop	Dates	Vegetable	Olives
Planting	init_start	01/11	01/11	01/03
	init_end	30/03	25/11	30/03
	Kc ini	0.56	0.5	0.45
Growing	dev_start	31/03	26/11	31/03
	dev_end	04/05	31/12	30/06
	mid_start	05/05	01/01	01/07
	mid_end	30/09	07/02	31/08
	Kc mid	0.7	1	0.55
Harvesting	late_start	01/10	08/02	01/09
	late_end	31/10	28/02	30/11
	Kc end	0.56	0.8	0.6
Sources		Zaid and Klein[67]; Sonneveld et al. (2018)[68]	Allen et al. (1998)[69]	Steduto et al. (2012)[70]
Distribution in the NWSAS provinces (% of irrigated cropland area)		In most provinces: date palm (50%) and vegetables (50%), except for: Gharyan (Libya): olives (70%) and vegetables (30%) Jufra (Libya): dates (70%) and vegetables (30%)		

Water table depth

The depth to water table was used as an input to calculate the energy requirement for pumping. Data for water table depth were obtained from Fan, Li, and Miguez-Sancho (2013), which shows global observations of water table depth compiled from government archives and the relevant literature, along with the use of a groundwater model, affected by modern climate, terrain, and sea level, to fill in data gaps and infer patterns.

The average, minimum and maximum water table levels for each province were extracted from the GIS dataset and compared with the values provided by OSS as shown in Table 19. Since the latter was not in GIS format and was an average value for the entire province, which would affect the results, the analysts decided to use the GIS dataset values to be able to capture the spatial variation shown in Figure 12.

[67] Zaid and Klein Chapter XI: Date Palm Technical Calendar. Available at: http://www.fao.org/3/Y4360E/y4360e00.htm#Contents.
[68] Sonneveld, B.G.J.S. et al. (2018). The future of date palm cultivation in the Lower Jordan Valley of the West Bank. *Applied Water Science*, **8**(113). Also available at: https://doi.org/10.1007/s13201-018-0746-2
[69] Allen, R.G. et al. (1998). *Crop evapotranspiration — guidelines for computing crop* water requirements. FAO Irrigation and drainage paper 56.
[70] Steduto, P. et al. (2012). *Crop yield response to water*. FAO Irrigation and drainage paper 56.

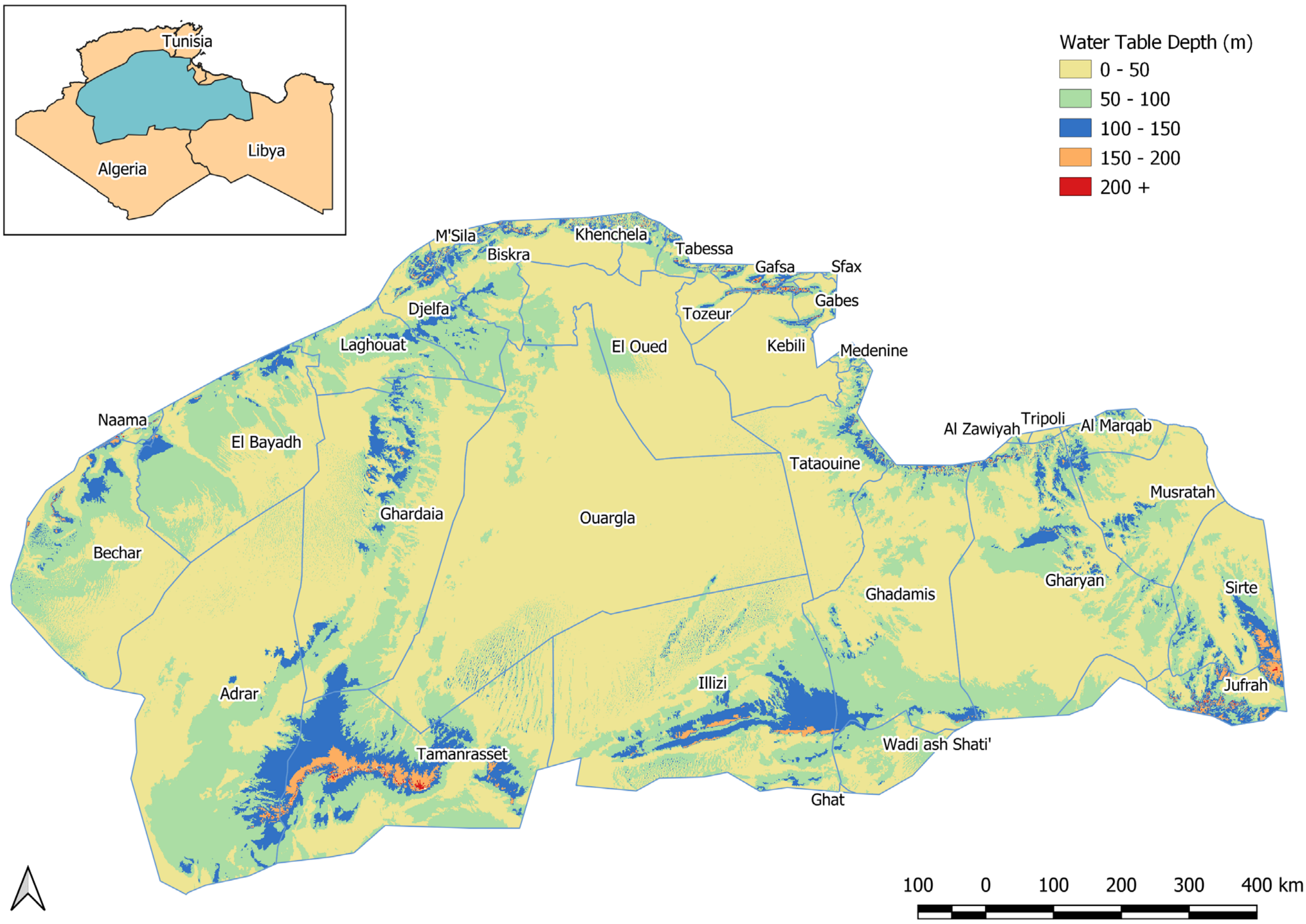
TABLE 19.
Summary of water table depth for each province

Country	Province	Groundwater depth (m)[71]			Average Water table depth (m)[72]	
		avg	min	max	Terminal Complex (CT)	Intercalary Continental (CI)
Algeria	Adrar	37	0	166	15 to 27	-
	Biskra	62	5	178	NA	NA
	Djelfa	44	0	180	122	-
	El Oued	35	0	81	122	28
	Ghardaïa	44	0	158	42	-
	Illizi	66	0	161	152	79
	Khenchela	83	46	192	-	27
	Laghouat	12	0	77	53	69
	Ouargla	22	0	116	110	20
	Tamanrasset	72	0	226	44	-
	Tébessa	40	19	58	-	28
Libya	Ghadamis	87	0	235	69	38
	Gharyan	62	0	318	255	-
	Jufra	57	0	252	50	29
	Misrata	27	0	130	111	39
Tunisia	Gabès	74	3	224	51	-
	Kebili	26	0	235	8	26
	Tataouine	79	0	208	74	-
	Tozeur	43	0	186	39	40

Sources: Fan, Li, and Miguez-Macho (2013) and OSS

[71] Fan, Y., Li, H. and Miguez-Macho, G. (2013). Global patterns of groundwater table depth. *Science*, **339**(5):940–943.
[72] Sahara and Sahel Observatory (2019).

FIGURE 12.
Water table depth in NWSAS region (m)



Source: Fan, Li, and Miguez-Macho (2013)[73]

Total Dissolved Solids
The method used to estimate energy requirements for desalination is based on TDS levels. Since these data were not available from the online GIS sources, we used the **average value** for TDS level in each province provided by OSS. Table 20 shows the minimum, average, and maximum values for TDS levels.

[73] Fan, Y., Li, H. and Miguez-Macho, G. (2013). Global patterns of groundwater table depth. *Science*, **339**(5):940–943.

TABLE 20.
Summary of TDS values for each province

Country	Province	TDS mg/l		
		avg	min	Max
Algeria	Adrar	1,457	400	5,200
	Biskra	3,168	858	8,816
	Djelfa	2000	1,500	2,500
	El Oued	3,299	1,632	8,002
	Ghardaïa	1,287	160	3,592
	Illizi	2,104	348	8,166
	Khenchela	2,500	2,000	3,000
	Laghouat	1,250	1,000	1,500
	Ouargla	3,845	1,170	10,010
	Tamanrasset	1,750	1,000	2,500
	Tébessa	2,673	1,700	4,360
Libya	Ghadames	1,250	1,088	1,412
	Gharyan	969	769	1,333
	Jufra	2,410	1,935	2,884
	Misrata	2,830	2,000	3,660
Tunisia	Gabès	2,858	1,400	4,350
	Kebili	3,322	630	15,400
	Tataouine	3,105	790	7,200
	Tozeur	2,580	760	5,300

Source: OSS

Convention on the Protection and Use of Transboundary Watercourses and International Lakes

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Reconciling resource uses: Assessment of the water-food-energy-ecosystems nexus in the North Western Sahara Aquifer System

Part A - "Nexus Challenges and Solutions"

Coordination between the water, energy, food and environment sectors is fraught with difficulties, the complexity of which substantially increases in transboundary contexts. The "nexus approach" to manage interlinked resources aims to enhance water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance, while also protecting ecosystems. Such an approach supports reconciling different sectoral objectives and progressing towards the closely interlinked Sustainable Development Goals at national and regional levels.

This report highlights the main results of an assessment of the water-food-energy-ecosystems nexus in the North-Western Sahara Aquifer System (NWSAS), shared by Algeria, Libya and Tunisia. The aquifer system is one of the largest transboundary groundwater reserves of North Africa, extending over one million square kilometres and subject to increased water demands. Improving the management of the basin's resources and responding to challenges is of high importance for the socio-economic development of the three countries, as well as the entire region.

The NWSAS nexus assessment is the main outcome of a participatory process with two transboundary workshops and national consultations, mobilising representatives from the three countries and four sectors, in addition to multi-disciplinary local and international experts. Through a transboundary dialogue, the nexus assessment helped to identify the key interlinkages between energy, water, land and ecosystem resources, as well as potential solutions to improve their management, thus enhancing sustainability and efficiency. Implementing various solutions simultaneously and in a coordinated manner will help to achieve cross-sectoral goals while contributing to sectoral development, by minimising intersectoral trade-offs and negative impacts, and maximising synergies.

Implementing a nexus approach to manage the NWSAS not only has multiple benefits, but also considerable potential to support further development of transboundary cooperation.

The NWSAS nexus assessment was carried out under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention), implemented by the Global Water Partnership Mediterranean (GWP-Med), the United Nations Economic Commission for Europe (UNECE) and the Sahara and Sahel Observatory (OSS), as part of the "Making water cooperation happen in the Mediterranean" project, funded by the Swedish International Development Cooperation Agency (Sida) and in synergy with the GWP Water, Climate and Development Programme (WACDEP).

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