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Proceedings of the Workshop on Water-Energy-Food-Ecosystems (WEFE) Nexus and Sustainable Development Goals (SDGs)

Brussels (Belgium)
January 25-26, 2018

Editors: Barchiesi, S., Carmona-Moreno, C., Dondeynaz, C., Biedler, M.

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Introduction.

In recent years, the Nexus concept has become widely used in the international development community, not least since the Bonn 2011 Nexus Conference. While the Millennium Development Goals did not include a goal on energy and had no focus on the WEFE Nexus, the global development policy context was significantly changed with the 2030 Agenda and its Sustainable Development Goals (SDGs, 2015), the Paris Agreement on Climate Change (2015), the Addis Ababa Action Agenda on Financing for Development (2015), the New Urban Agenda (2016), the New European Consensus on Development – "Our world, our dignity, our future" (2017) that underline the importance of policy coherence and integrated approaches across traditional development sectors.

Current EU development policy provides a general frame and background that justifies a Nexus approach and methodology. Thus, the new European Consensus on Development: "Our World, our Dignity, our Future" (June 2017) emphasises an integrated approach to development and strongly supports the 2030 Agenda with its 17 Sustainable Development Goals (SDGs) that were adopted in September 2015 as a global framework for sustainable development action. The 2030 Agenda itself emphasises an integrated approach that can facilitate a Nexus methodology. As stated by the DEVCO Director General Stefano Manservisi in an interview on 14 June 2018 with DEVEX: **"The SDGs are obliging us to work in an integrated way and not in silos".**

DG DEVCO and JRC have been supporting works on the Nexus and originally addressed the water-energy-food security (WEF) Nexus, but it soon became clear that ecosystems represent essential conditions for ensuring the sustainability of the development solutions. Thus, Water, Energy, Food security rely on resources and services provided by healthy ecosystems, and, consequently, these should therefore be integrated into the NEXUS approach. In the following sections, the terms "WEFE Nexus" or "Nexus" in short refers to this concept unless otherwise stated.

DG DEVCO and JRC jointly organised a consultation of international experts on the Water-Energy-Food-Ecosystems Nexus ("WEFE Nexus") that was held in Brussels on 25-26 January 2018.

This NEXUS experts' consultation was oriented towards moving forward on the implementation and operationalisation of the Nexus approach with the objective of improving the sustainability of intervention projects and programmes involving water–energy–food security, and therefore, to contribute to simultaneous achievement of related SDGs.

The work presented here outlined the importance and benefits of the WEFE Nexus as an approach and methodology for the implementation of the EU development policies and cooperation. It aimed at integrating governance and management across water, energy and food security areas while attempting to balance different uses of ecosystem resources and services.

These works do not intend to replicate the existing WEFE Nexus studies but in a very summary way integrates scientific and practical knowledge towards providing guidelines and solutions for successful WEFE Nexus implementation. In this context, it proposes practical solutions for solving Nexus implementation problems and poses the investment opportunities.

The geographical scale is national (policy planning and development), regional and transboundary (River basins, Trade of Energy and Agricultural Products) including both urban and rural areas. The geographical focus comprises the regions addressed in the EC WEFE Nexus Dialogues programme: Africa, Central Asia, Latin America, Middle East and North Africa (MENA).

The workshop managed to collectively review a series of thematic contributions on:

1) Sustainable Technological Approaches and Solutions to WEFE NEXUS challenges;
2) Data, Tools and Models for assessing the Nexus;
3) Nexus Governance, Institutions, Cooperation Frameworks, Finance, Investments and Feasibility.

With this purpose, guidance questions were developed to stimulate the expert discussions in the different thematic areas. The results of these discussions were a series of considerations and recommendations addressed to the institutions and organisations interested in dealing with the Nexus in practice.

The guidance questions are a mix of specific to less specific and bridging issues across themes. The objective of the guidance questions can be divided in two different groups: a) the first pair of questions in each topic would spur more detailed and comprehensive reflections due to the generic nature of the topics; by contrast, b) the second pair of questions was designed to elevate the discussion to the heart of the matter, i.e. how to operationalise a Nexus system as a whole.

These conclusions and recommendations are certainly not exhaustive given the breadth of Nexus issues but are based on regionally identified priorities and, therefore, represent a good basis for identifying common points of agreement and a way forward on how to operationalise the Nexus approach. The conclusions of each chapter have been articulated as follow: a) lessons learned and best practices; b) knowledge gaps and implementation challenges; and, c) areas of further research and other practical actions.

The final conclusions and recommendations that will be the core of the Position Paper make special reference to the EU policy framework for development cooperation, particularly the "New European Consensus on Development" and to the relevant SDGs.

Although these proceedings are mainly addressed to the NEXUS scientific community, the target audience for the Position Paper will be staff of: i) DG DEVCO and other European Commission Directorates-General and Agencies that are most directly involved in development cooperation with water, energy, food security and environment; ii) EU Delegations in developing countries and emerging economies in Africa, Asia, Latin America, and the EU neighbourhood (MENA) region working in these areas; and, iii) Cooperation Agencies of the EU Member States.

This document also presents a short annex listing the relevant policy documents, directly or indirectly related to the WEFE Nexus, to assist the reader.

Finally, the Editors want to thank all the experts, those who participated since the beginning and those who joined this work along the way. They understand that their effort is not just about synthesising information, but also about making scientific and technical knowledge available to contribute to more sustainable development and, ultimately, to help create a better world.

Chapter 1. Sustainable Technological Approaches and Solutions to WEFE Nexus Challenges.

A series of technological solutions emerge in applying WEFE Nexus solutions in practice. Specific technologies correspond to projects and investments. However, it is not always clear which are the most appropriate technological solutions. In this context, the different contributions of the experts illustrate in this chapter the technological advances and their benefits in the WEFE Nexus including among others: energy efficiency technologies, water saving irrigation systems, hydropower, bioenergy, desalination, efficient crops practices, …

Several recommendations in this chapter mainly revolve around technological innovations in the energy sector. Case knowledge indicates that the choice of hybrid technologies, for instance combining several sources (of energy and/or water), can fit local conditions and improve sustainability of energy/water sources for agricultural/irrigation purpose. Off-grid solutions to satisfy energy and water needs were also found to be cost effective at local scale (e.g. farm scale) even though there are still technological challenges with providing a steady supply and also storage for intermittent use of off-grid solutions.

A key conclusion for all sectors is the need for further development of inter-sectorial knowledge, understanding and collaboration. Training in applying the Nexus approach must specifically address the intervention level and its challenges (transboundary, national, regional, and local), and associated with capacity building actions especially in less developed regions/organised sectors. Professionals in each sector need to know more about and understand the thinking and methods applied in the other sectors. Moreover, collaboration between sectors needs to be very operational oriented.

The sub-themes proposed to drive the roundtable discussions in this topic were:

- The role of off-grid solutions e.g. for water pumping or desalination in breaking the fossil-fuel economic dependency, including of food security;
- From waste to resources: The risks and opportunities of turning wastewater and agricultural waste into nutrients and energy;
- The levels at which to employ a Nexus approach to competency and capacity building to promote "Nexus thinking" across sectors, countries and responsibilities;
- The definition, utility and use of a Nexus Project Toolkit for Inclusive Green Growth and Sustainable Development.

Renewable energy for irrigation in the MENA Region

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ABSTRACT: The sustainable development goals (SDGs) bring new momentum, allowing renewable energy to be a catalyst of equity, alleviation of poverty, and access to primary resources (water, energy, food) in remote areas that were without access and opportunities for these primary resources in the past. This contribution to the position paper presents a framework to increase renewable energy penetration in the Arab countries of the MENA region in support of irrigated agriculture. It presents technological, policy, capital and human capacity challenges and opportunities for renewable energy sources, including solar, wind, hydropower, and bioenergy. The contribution concludes by discussing readiness for renewable energy in the Arab world, and is intended to help guide discussions toward the renewable energy transition. The core and cross-cutting role of water in achieving multiple SDGs can be observed with clarity: water availability and access is directly linked with poverty, health, economic growth, education, social justice, as well as food and energy securities. It has been reported that blackouts due to water shortages in some regions on Africa can cause an annual decrease of 2-4% in GDP.

Introduction

Irrigation demands and gaps

Rain-fed agriculture accounts for two thirds of the total cropland in the Middle East and North Africa (MENA). This region is also one of the most water scarce in the world, having an annual per capita water availability of 1,100m^3 (compare to the global average of 8,900m^3 per year). By 2025, this is projected to reach only 550m3 per year[1].

Climate change models project several scenarios for the MENA. Most climate models for MENA project drier conditions; all projections conclude that the demand for irrigation water will increase between 15 to 33% by 2050 (Figure 1). In addition, as the climate results in drier conditions, available water resources in the region could be reduced by more than 40%.[2] For these reasons and because climate change can also decrease crop yields and affect water productivity, the water gap in the agriculture sector is a major concern for the water, energy and food securities of the region. Many countries have counteracted this water gap by over-extracting groundwater. Hydrological models predict that the groundwater recharge will decrease up to 40% in the Gulf region alone: even the wetter parts of MENA are expected to experience a considerable reduction (38% in Morocco, 34% in Iraq, 22% in Iran).[3]

Supplemental irrigation in the region is a must for counteracting the effects of climate change and potentially increasing yields in MENA's different agro-ecological zones. There is a gap between the actual and potential yields with supplemental irrigation (between 0.5 – 5 t/ha), therefore there is vast room for improvement[4]. A wide range of strategies and technologies are currently available that could potentially increase yields, but these approaches must be site specific.

[1] World Bank, 2012
[2] Idem
[3] Idem
[4] Anderson, 2016

For example, ICARDA has shown (Figure 2) in recent studies that small amounts of supplemental irrigation in rain-fed croplands can increase wheat grain yields by 30% up to 400%, depending on the rainfall at a specific region in Syria (Haddad, 2011).[5]

	2000–09	2020–30	2040–50
Total Demand	261	319	393
Irrigation	213	237	265
Urban	28	50	88
Industry	20	32	40
Total Supply	219	200	194
Surface water[a]	171	153	153
Groundwater	48	47	41
Total Unmet demand	42[b]	119	199
Irrigation	36	91	136
Urban	4	16	43
Industry	3	12	20

Source: FutureWater 2011.
a. Surface water includes river flows into the MENA Region.
b. Summation does not add up due to rounding.

Figure 1. MENA annual water demand and supply (km3) under average climate change scenario (between 2000 and 2050).

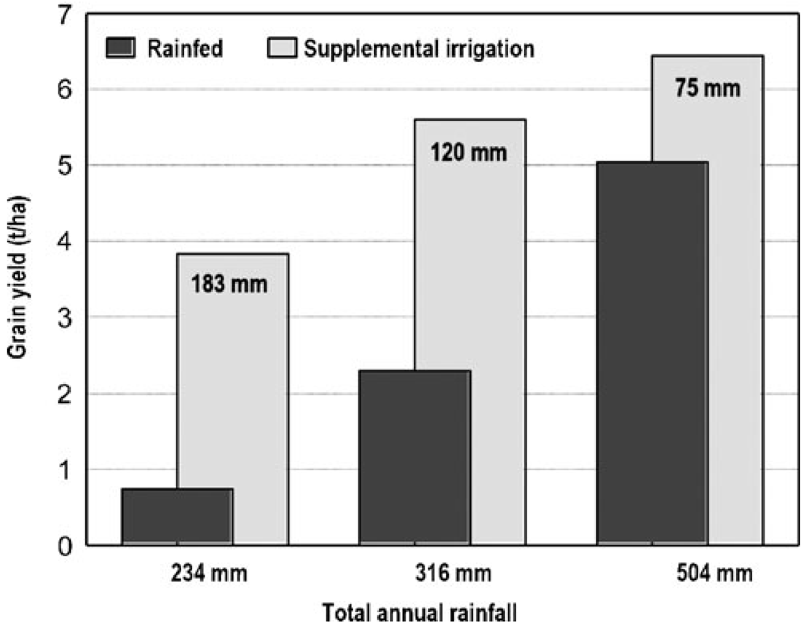

Figure 2. Impact of supplemental irrigation on rainfed wheat yield in northern Syria in dry, normal and wet years, with supplemental irrigation of 183, 120 and 75mm. Source: Oweiss, 1997.

On the other hand, irrigated agriculture is the largest consumer of ground, and freshwater more generally, in the region, and the challenges are real, including: 1) securing sufficient water supply; 2) increasing water productivity (amount of water required per ton of produce); 3) providing reliable energy to transport water and make it available in all croplands; and 4) reducing the energy footprint of these operations. Synergies and trade-offs in the water-energy-food nexus are evident and are affected by external factors such as geographical conditions, socioeconomic aspects, local human capacity, and policies.

[5] Haddad, 2011

Soil-water-plant relationship and the need for new agriculture model

A quantitative analysis of the agricultural water gaps is important moving forward; however, the food production system community must also look afresh toward securing a sustainable agriculture system. In addition to crop yield and food production, such a system should also consider the nutritional aspects of food production and the values of other resources used in food production. These resources include the water and energy footprints, land and soil quality, air and carbon emission. With such systems level consideration, a water–energy-food nexus trade-off analysis emerges that dictates certain optimal levels of a food production system that is renewable and sustainable from a holistic perspective and at the economic, social, and environmental levels.[6, 7]

Renewable Energy, the WEF Nexus and the SDGs

The interconnectedness of the water-energy-food nexus makes it clear that the energy demands of agricultural processes will have a significant impact on food and water securities. Remote areas that are not connected to the grid may be the most vulnerable in terms of securing energy requirements for food and water production. Therefore, the technologies that countries include in their energy portfolio will not only impact SDG 7 (ensuring access to affordable, reliable, sustainable, and modern energy for all), but will also affect the capacity of a country to ensure the availability of water and sanitation (SDG 6) and the achievement of food and nutrition security through the promotion of sustainable agriculture (SDG 2). Decision support tools that use a nexus approach to evaluate the effects of different energy mixes is highly valuable to ensuring food and water securities, not only at local but also at a regional (transboundary) levels. Coherent policy making and strategic planning should go beyond simple synergies and trade-offs to take into account the multiple interlinkages between the sectors.

Water transport (ground water and surface pumping) represents a major energy requirement in irrigated croplands. Agricultural lands that are physically far from available fresh water face considerable high energy costs for transporting water, making the issue of affordability very important. Conversely, some croplands in remote areas, even if closer to fresh water sources, might not be connected to the grid and therefore face access issues as well. Renewable energy in the water supply industry can play a key role in operations such as pumping, desalination, heating and wastewater treatment. Although energy from renewable sources will not reduce the energy intensity of such operations, it certainly will be crucial for enhancing access to water and energy8.

Renewable energy technologies for power and water production must be carefully evaluated before being adopted into a national or regional portfolio, and must take into consideration the broader impacts on other sectors. The use of decision support tools with a Nexus approach has proven to provide relevant qualitative and quantitative information crucial for decision makers to see when adopting new technologies.

It is important to keep in mind that introducing renewable energy for irrigation and other food production operations is but one piece of the puzzle. Other important components for moving into renewable agriculture include crop improvement through genetics, cropping system optimization, water harvesting to increase water availability to crops, and other practices to ensure the sustainability of food production at economic, social and environmental levels. Water harvesting practices are not new to the Region: some of the oldest practices exist there. These can be localized to store water directly in the root zone, in cisterns or reservoirs, and be integrated with irrigation practices. Therefore, a holistic water–energy–food system is necessary to augment technological solutions to food production.

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[6] Mohtar, Assi and Daher, 2017
[7] Mohtar, 2017
[8] IRENA, 2014

Renewable Energy in the Arab World

Figure 3 shows the availability of renewable energy sources in the Middle East and North Africa region. This map agrees with data interpolated from a global dataset produced by NASA's Surface meteorology and Solar Energy (SSE) program. It is clear that the Arab region shows significant resource availability for solar energy9. The Atlantic part of North Africa has a significant potential for wind energy.

It is interesting to observe how renewable energy has integrated into existing energy systems, having a complementary, non-'competing' role along with conventional power. This is important especially for countries looking to diversify their energy mix and economy and for which the target is to break dependency on a single fuel.

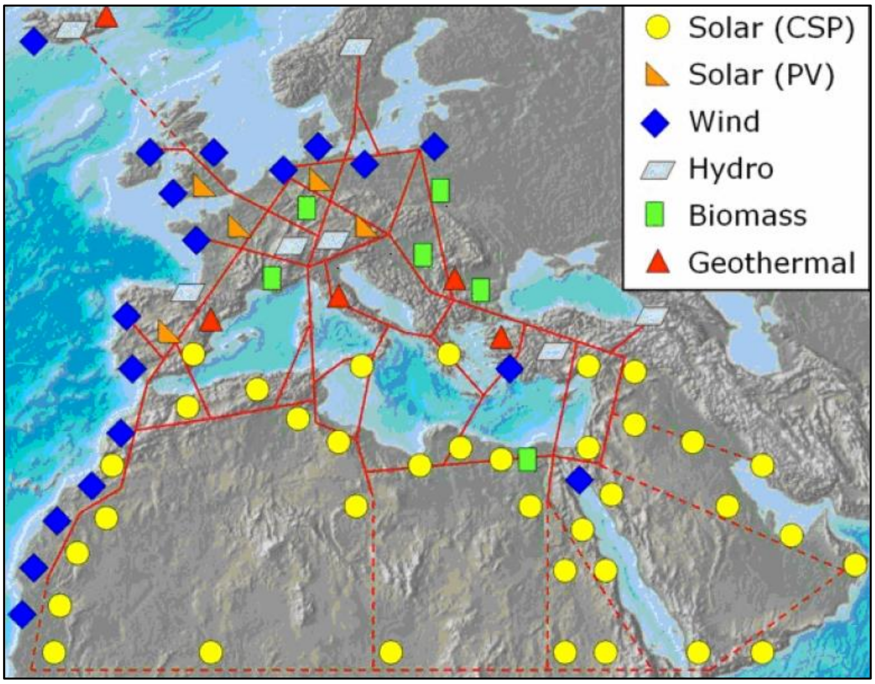

Figure 3. Renewable energy map for the Arab World. *Source:* DESERTEC, 2013.

The choices of renewable energy (RE) technologies in the water sector are highly dependent on local geographical and climate conditions as well as human capacities and cost. Developing low cost local technologies remains a big challenge throughout the MENA region.

Renewable energy source water pumping systems can be described in 5 major groups: 1) solar photovoltaic systems, 2) solar thermal systems, 3) wind energy systems, 4) bioenergy systems and 5) hybrid renewable energy water pumping systems.[10] For the MENA, solar photovoltaics is the most widely used technology, and the one that most makes sense, given the climatic and geographical conditions. Solar photovoltaics are followed by wind pumping systems. Solar thermal and bioenergy systems are unpopular. Hybrid solar/wind systems would make sense in the region and have a lot of potential, but the technology is not fully developed.

Success stories and case studies using RE technologies for water pumping are widely reported. These technologies still need further research for wider implementation include: optimization of PV panels (tilt angles), cooling of PV panels, reducing dust accumulation in PV panels, development of new materials for PV, and reduction of power loss, among others.[11]

[9] NASA, 2014.
[10] Gopal, 2013
[11] Idem

Technology choices should be evaluated systematically, taking into consideration the 6 main factors described in the ESCWA Regional Policy Toolkit[12]:

1. Resource requirements (sustainability - water and energy footprint)
2. Economic aspects (all costs associated, land requirements, etc.)
3. Environmental impact (air, water, soil, biodiversity impacts)
4. Human capacity requirements (local skills required)
5. Technical requirements and robustness (considering local components)
6. Social-cultural criteria (awareness institutional requirements, responsibilities).

Renewable energy readiness of a country and global competitiveness index

The EU-GCC (European Union-Gulf Cooperation Council) network describes important criteria that can be used to evaluate how ready a country is to implement renewable energy technologies. Three factors are of utmost importance:

1. **Infrastructure**: including natural resources. Country overall infrastructure, grid capacity, market infrastructure, electricity access rate and projected demand. As mentioned, Arab agriculture faces limited natural resources.

2. **Institutions**: both public and private institutions. Energy, key policies, access to renewable energy finance, macroeconomic environment. Specifically in the MENA, budgets for R&D are insufficient to localize technologies, adopt them, and implement policies.

3. **Human capital**: technical and commercial skills, technology adoption and diffusion and awareness among consumers, investors and decision makers. For example, in the Arab world, there is little work being done towards crop improvement: technologies are available but their adoption is hindered by geographical, economic and human capacity realities.

Taking into account these 3 main criteria or pillars, the EU-GCC study generated scores for several countries in the Gulf sub-region. The methodology defined in this study could be used to generate similar data for other countries in the MENA. The scores shown indicate that, in the GCC countries, the human capital factor for renewable energy deployment is the weakest factor (Figure 4); the policy and institutional aspect comes in the middle; and the infrastructure scores indicate that this aspect is relatively strong.[13]

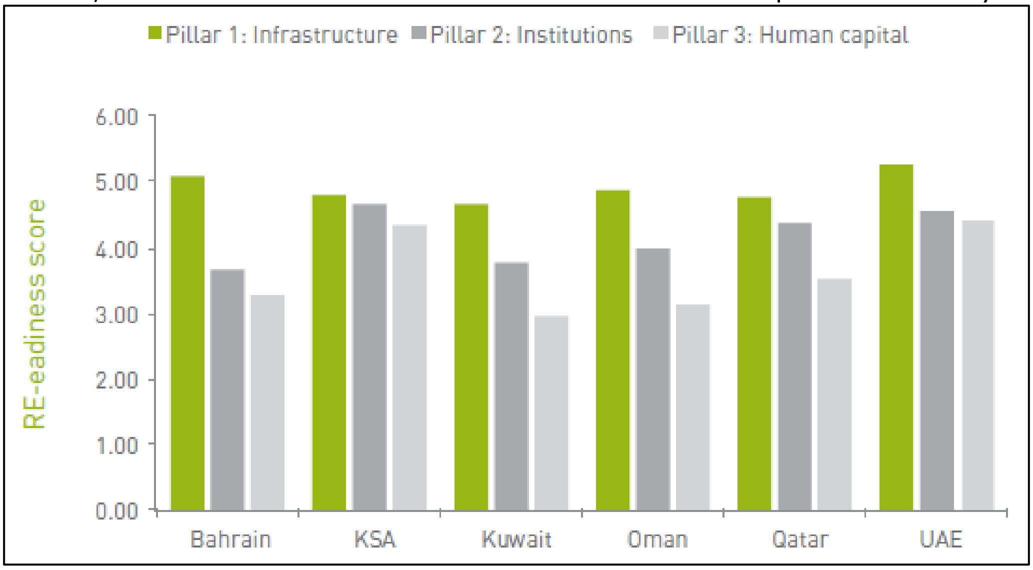

Figure 4. The GCC countries' attractiveness index on renewable energy development pillars. *Source:* EU-GCC, 2013.

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[12] ESCWA, 2016
[13] ESCWA, 2016

While the RE technologies have reached a relative level of maturity in global markets, these technologies are still not competitive in the MENA region. It is here that the active involvement of governments will determine how ready they will be to adopt RE into their energy mix and enter the markets at a more competitive level. It is commendable that many countries in the Region have already established national targets for their RE mix, with dates for achieving it; additional support is now required to implement policies, capacity building, localization and deployment of technologies. A few barriers that further limit competitiveness in the region are: 1) bureaucracy and inefficient institutional structures, 2) lack of policy support, and 3) fossil fuel/electricity subsidies.[14]

Key Findings

Distributed renewable energy has a big role to play in the water and food security of the MENA region. It can help provide the enabling energy source for distributed water and food production in remote rural areas, where access to water and food are at risk. Towards energy as an enabler to human water and food security, we note the following findings:

1. A new business model for renewable and sustainable agriculture must be established for the arid and semiarid regions of MENA; this can be accomplished by looking into nutrition, water, energy, land values in addition to the economics of production.
2. Technology scorecards taking into consideration the aspects mentioned above (resource requirements, economic aspects, environmental impact, human capacity requirements, technical requirements and robustness, and social-cultural criteria) can help with the choice of a technology that is suited to the local conditions.
3. A renewable energy plan is needed to help transition towards a renewable energy portfolio in the MENA region; such a plan should include assessment of the regional integration of primary resources security.

Discussion, Conclusions and Recommendations

The following concluding remarks are highlighted:

- Research is needed to understand how water scarcity affects communities at different levels and how this affects SDG implementation.
- Local data is needed to define the level of sustainable production to be achieved for each eco-zone in the MENA; these eco-zones are areas with similar social, environmental and economic conditions, and wherein the elements of the new model for agriculture described above can be established.
- Implementation of a set of guidelines establishing which technology is most suited for local conditions in the specific region of MENA.
- Last but not least, a regional effort to develop a renewable readiness plan must be established to help countries in the region achieve their goals and to share knowledge in implementation of renewable and nonrenewable energy integration. These plans should focus on various elements including, policies and incentives, localization of knowledge, capacity building and manufacturing and industries.

References:

Anderson, W., Johansen, C., and Siddique, K.M. (2016). Addressing the yield gap in rainfed crops: a review. Agronomy for Sustainable Development. 36:18

DESERTEC (2013). Global "Energiewende": The DESERTEC concept for Climate Protection and Development. Available from http://www.desertec.org/#!desertec-atlas/pznkq.

[14] ESCWA, 2016

ESCWA, 2016. Developing the Capacity of ESCWA Member Countries to Address the Water and Energy Nexus for Achieving Sustainable Development Goals: Regional Policy Toolkit. ESCWA, Beirut.

EU-GCC (2013). Renewable Energy Readiness Assessment Report: The GCC Countries 2011 – 2012. Masdar Institute of Technology. Study under EU-GCC Clean Energy Network. 2013. Available from http://eugcc.epu.ntua.gr/LinkClick.aspx?fileticket=ZLVAyWw9x_8%3d&tabid=448.

FutureWater. 2011. Middle-East Northern Africa Water Outlook. Final Report, commissioned by the World Bank, W. Immerzeel, P. Droogers, W. Terink, J. Hoogeveen, P. Hellegers, and M. Bierkens (auth.). Future Water Report 98, Wageningen, the Netherlands. www.worldbank.org/mna/watergap.

Gopal, M.Mohanraj, P.Chandramohan and P.Chandrasekar. Renewable energy source water pumping systems—A literature review. Renewable and Sustainable Energy Reviews Volume 25, September 2013, Pages 351-370

Haddad, N., Duwayri, M., Oweis, T. et al. The potential of small-scale rainfed agriculture to strengthen food security in Arab countries. Food Sec. (2011) 3(Suppl 1): 163. https://doi.org/10.1007/s12571-010-0099-7

International Renewable Energy Agency (IRENA) (2014). Pan Arab Renewable Energy Strategy 2030. Available online at http://www.irena.org/DocumentDownloads/Publications/IRENA_Pan-Arab_Strategy_June%202014.pdf

Mohtar,Rabi H., AT Assi, BT Daher. (2017). Current Water for Food Situational Analysis in the Arab Region and Expected Changes Due to Dynamic Externalities. The Water, Energy, and Food Security Nexus in the Arab Region, 193-208. DOI: 10.1007/978-3-319-48408-2_10

Mohtar, R.H., 2017. A Call for a New Business Model Valuing Water Use and Production: the Water, Energy and Food Nexus Holistic System Approach. Water International. Volume 42, Issue 6: Groundwater and Climate Change – Multi-Level Law and Policy Perspectives. Pgs 773-776. DOI: 10.1080/02508060.2017.1353238

Mugagga, Frank & B. Nabaasa, Benon. (2016). The centrality of water resources to the realization of Sustainable Development Goals (SDG). A review of potentials and constraints on the African continent. International Soil and Water Conservation Research. 4.10.1016/j.iswcr.2016.05.004.

National Aeronautics and Space Administration (NASA) (2014). Surface meteorology and Solar Energy: A renewable energy resource web site (release 6.0). Available from http://eosweb.larc.nasa.gov/sse/.

Oweis, T., & Hachum, A. (2009). Supplemental irrigation for improved rainfed agriculture in WANA region. In S. P. Wani, J. Rockström, & T. Oweis (Eds.), Rainfed agriculture: unlocking the potential. Comprehensive Assessment of Water Management in Agriculture Series 7. London: CABI.

World Bank, 2012. Renewable Energy Desalination: An Emerging Solution to Close the Water Gap in the Middle East and North Africa. — (MENA development report) — ISBN 978-0-8213-9457-1

Prospects of Desalination using Solar Energy in the MENA Region

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ABSTRACT: This paper analyses the state of the art of the use of solar energy (SE) to run water desalination plants in the MENA region. It first highlights the challenges and the needs in terms of desalination projects to meet the increasing water demand due to economic and population growth, and the impact of climate change on water resources. The importance of SE is then emphasized as well as its role in decreasing the costs and reducing the environmental impact of other powering means including the CO_2 footprint, and thus making solar desalination a sustainable technology. Until recently, only small-scale desalination plants in remote areas with no grid electricity used renewable energy (RE). As R&D has intensified, several pilot desalination plants have operated successfully using SE. The MENA region has vast SE potential. Developing solar-powered desalination technologies, producing energy from the desalination brines and reducing the energy required for desalination should be a top priority in MENA countries. R&D partnerships and investments to identify optimal technical solutions and products for desalination and cogeneration powered by RE could improve the region’s social, environmental and economic conditions.

Introduction

The MENA region will be facing the major challenge of a widening gap in water supplies and demand by 2025. This is attributed to limited renewable water sources and anticipated high population growth. The increases in water requirements for the dynamic socio-economic development of the region will also be affected negatively by climate change. Overcoming the expected water deficit in 2025 will require an estimated 237 billion cubic meter (bcm) to make it necessary to augment supply through increased dependency on desalination, increased water reuse of adequately treated wastewater sources and the mining of the non-renewable groundwater.

Desalination is becoming increasingly important a solution to the region’s water problem. Many water stressed countries in MENA are increasing their water supplies with desalination to meet the needs of the continuous growth of population and industrial, tourism and agriculture developments. Desalinated water can no longer be considered a marginal resource because some countries such as Qatar and Kuwait rely 100% on it for domestic and industrial use, whereas Saudi Arabia (SA) reliance is nearly 60% (Ghaffour, 2009). The reason behind these huge capacities in the region is the technological improvements which led to a drop in the cost of desalination. Currently, the global market is led by SA with a total cumulative capacity of 15,378,543 m3/day followed by the United States producing 11,815,772 m3/day and the United Arab Emirates (UAE) with 10,721,554 m3/day (See Figures 1 & 2).

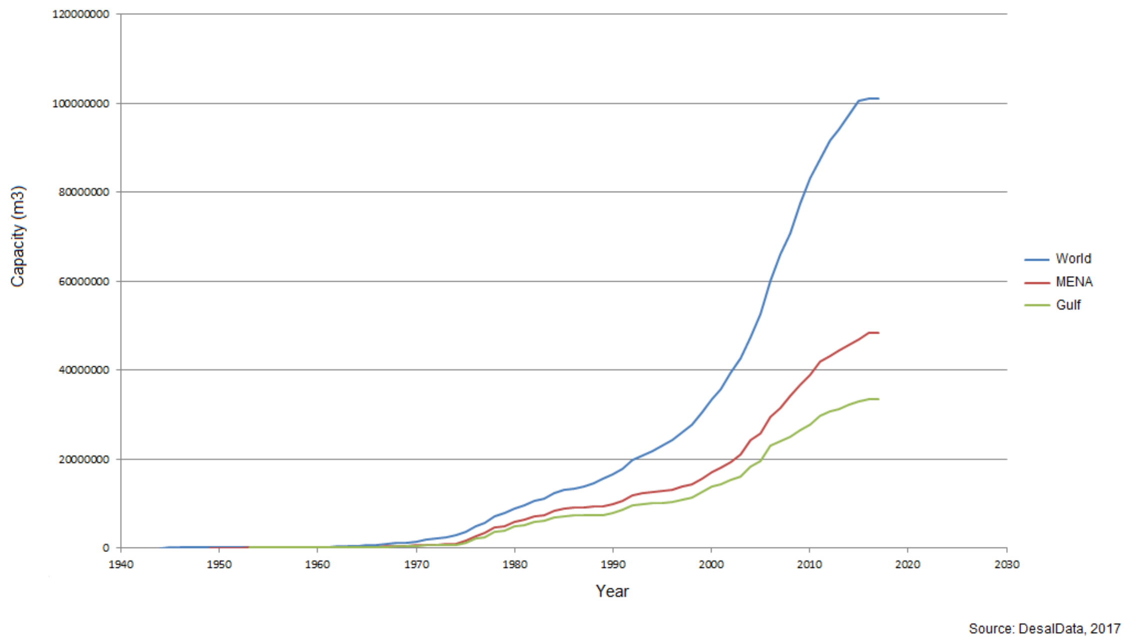

Figure 1. Cumulative Contracted Capacities Globally and per Region since 1944

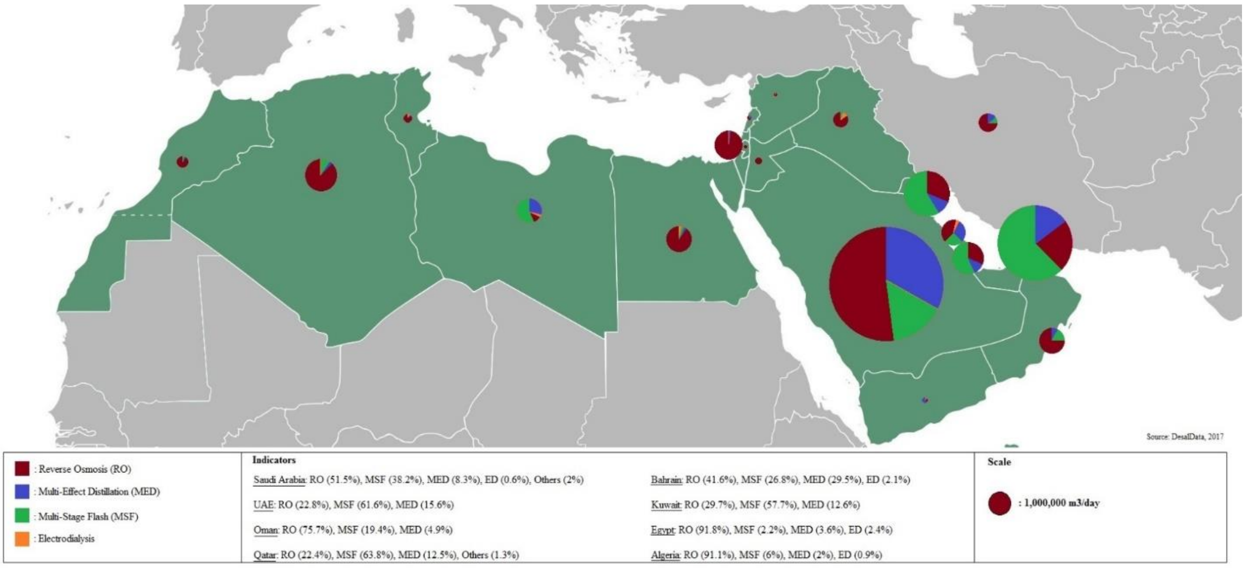

Figure 2. Symbol Map of the MENA Desalination Capacities and the Technology Used

State of the art

Two basic technologies have been widely used to separate salts from ocean water: thermal evaporation and membrane separation. In the last 10 years, reverse osmosis (RO) technology has come to dominate desalination markets, due mainly to its low investment and total water costs achieved by lowering the energy consumption to about 3 KWh/m^3 (Ghaffour et al., 2013).

Since the energy requirements in desalination processes play a decisive role, it appears attractive to consider RE, because it offers a sustainable and secure way to desalinate water. There is a great potential to develop solar desalination technologies especially in MENA region where the solar source is abundant and the installed photovoltaic (PV) costs are declining. Until recently, only small desalination plants in remote areas with no grid electricity and no skilled manpower used RE, but as R&D has intensified, several pilot desalination plants in the MENA region have operated successfully using mainly solar energy (SE).

Moreover, the combination of desalination with RE generation, even if not directly powered by it, can facilitate its penetration in the grid (compensation). This can not only enhance the renewable component of energy generation by absorbing its surplus and storing it in water, but can be crucial in weak grids that otherwise could not accommodate the renewable component, like in the case of small islands (Tzen et al. 2012). Increasing efforts are devoted to improving the efficiencies of the RE conversions, desalination technologies and their optimal coupling to make them viable for small and medium scale applications.

On the other hand, there is a great potential for solar desalination to grow further in the MENA region. There are several ambitious projects in SA and the UAE to develop large solar desalination plants, including a project in the area of Al-Khafji on SA's eastern coast and one in the area of Ras Al-Khaima in the UAE. Both plants are set to become operational by 2020 and will be among the largest in the world (the initial phase of Al-Khafji solar desalination plant will produce 30,000 m^3/day, and this capacity will double in the next few years). The Al-Khafji one will be a disassociated RO and PV system. RO will take energy from the grid and PV will be injected in the grid, compensating the energy load. A similar principle is behind a desalination plant that has recently been announced by Abengoa in Agadir (Morocco). The benefits are clear: not only does it cut costs, it also reduces carbon-dioxide emissions and fossil-fuel dependency.

A number of different technologies allow the exploitation of RE resources, providing energy as heat, power or even a combination of both. Possible combinations with desalination technologies are shown in Table 1 (El Kharraz 2015, Al-Karaghouli et al., 2011 & IRENA 2012). RO coupled with solar PV is one of the most popular combinations in the MENA region. The main challenge of RE desalination is that desalination technologies generally work in steady-state conditions but RE sources are usually non-stationary. Therefore, it follows that:

- RE generation needs adjustments for continuous supply (energy storage), or compensation by connecting SE output to the existing grid, feeding the desalination plan directly from it as in Al-Khafji and many other medium scale plants.
- Desalination technologies have an advantage that can adapt to variable operation or operate under variable energy input like membrane distillation and adsorption desalination or hybrid systems (Ghaffour et al., 2015). Several MENA research institutions like MEDRC in Oman, Masdar in UAE, KAUST in SA, and CIEMAT in Spain, are heavily involved in developing novel RE integrated systems.

Table 1. Coupling options of solar energy with the different desalination processes

	Conventional Desalination processes			
Solar Technology	MSF	MED	MVC	RO
Concentrating Parabolic Collectors (Solar thermoelectric station producing both electricity and eventually heat through a cogeneration arrangement)	X	X	X	X
Flat Plate/Evacuated Tubular Collectors	X	X		
Salt Gradient Solar Pond	X	X		
Photovoltaic (PV)			X	X

* MSF: Multi-Stage Flash Distillation; MED: Multiple-Effect Distillation; MVC: Mechanical Vapor Compression

Solar still is one of the explored options for RE desalination. Many modifications to improve their performance have been made. These include adding SE collectors, incorporating a number of effects to recover the latent heat of condensation, improving the configurations and flow patterns to increase the heat transfer rates, and using less expensive materials of construction to reduce the cost. The solar still has many advantages like the low water cost, simplicity and durability. According to the literature its production rates are 5 to 8 l/ m^2 day. A glasshouse of 1,000 m^3 will have a water production between 5,000 to 8,000 l/ day. This is 1,825 to 2,920 m^3 of fresh water per year. The water production costs can be estimated at 1.09 to 1.74 \$/m^3 of fresh water, quite competitive and not much higher than the cost of water produced by conventional ways, yet here we are comparing very small to very large scales costs. A solar still pilot will be installed in the upcoming months at MEDRC facilities in Oman.

Several successful solar desalination projects have been implemented in the MENA region, but at small scale. In Oman, SE has been a key area for the Research Council, Sultan Qaboos University and MEDRC (See RO-PV unit at MEDRC, Figure 3), and as an example desalination plants using concentrated solar power (CSP) technologies have been evaluated for Wilayat Duqum in Oman. Several solar desalination projects have been implemented in the MENA region at small scale (See Annex 1).

Figure 3. Desalination for agriculture in Oman, project funded by Agriculture and Fisheries Development Fund (RO unit fed by solar PV at MEDRC facilities, North Al-Hail, Oman)

Key findings

The MENA region has vast SE potential. Developing solar-powered desalination technologies, producing energy from the brine water salinity and reducing the energy required for desalination should be a top priority in MENA countries. R&D partnership and investments to identify optimal technical solutions and products for desalination and cogeneration powered by RE could improve the region's social, environmental and economic condition.

For PV, battery storage remains costly, and for CSP, thermal energy can be stored relatively inexpensively. Intermittent operation is a particular concern when dispatchable power is required. For water production, the situation is more complicated. While water storage is relatively inexpensive, intermittent use of a desalination plant to meet baseload water demand requires oversizing the plant relative to what would be needed under steady operation.

On the other hand, when power tariffs vary during the day, energy cost savings through intermittent operation may offset the high capital cost of a larger plant.

Recently, a number of utility-scale PV projects in high insolation regions have been bid at prices ranging from \$0.03 to \$0.06/kWhe, and further price decreases are expected.

These systems do not include storage and are not designed to be dispatchable. Utility-scale PV systems at a scale of hundreds of megawatts are situated in arid regions with high insolation and relatively flat, unproductive land. While favorable local factors, including financing, have enabled this pricing, the potential to use this technology cost-effectively, if intermittently, to desalinate water with a near-zero carbon footprint is promising (Lienhard et al., 2016).

Furthermore, attention was paid by researchers in the last years to two different options for possible coupling between solar system and a desalination unit (PV/RO and ST/ Multiple-Effect Distillation 'MED'), in order to:

i) accurately estimate the production cost of desalinated water; including ways to single out the possible factors to fill the gap between the production cost by solar and conventional technologies; and

ii) address other basic aspects of a solar system such as the initial investment and required area.

Overall water production cost is influenced by several local factors, like the market status of solar systems, financing conditions, labor and pre-treatment cost, fuel and electricity price. The selection of the appropriate solar desalination technology (Solar stills, Solar Collectors, Solar Pond, and PV with its three types: Stand-alone systems, Grid-connected systems, and Hybrid systems) depends on a number of factors. These include plant size, feed water salinity, remoteness, availability of grid electricity, technical infrastructure and the type of solar technology available.

Discussion

For comparing the cost between the different options, the reference value for the water production cost in the case of conventional desalination can be assumed equal to 1 $\$/m^3$ for medium to small size desalination processes connected to the grid. The desalination system typically used in a stand-alone configuration is a RO process coupled with a diesel powered generator; due to the additional charges for transporting and fuel storage, water production cost can rise up to 1.5 $\$/m^3$. While in the case of solar (PV) coupled with RO, the water production cost is 2 $\$/m^3$, and for MED/SGSP (solar-powered multi-effect evaporation/Thermal desalination by salinity-gradient solar ponds), the water production cost is: 1.5 $\$/m^3$.

Continued innovations will reduce the cost of MED and RO desalination. While desalination is a relatively small market for CSP, CSP can meet the large and growing energy demand. The cost of CSP desalination likely will decrease in response to technical innovation, new materials, and efficiency improvements, just as desalination did when RO was first introduced.

For MSF (Multi-Stage Flash) desalination, CSP energy source is not economically competitive due to high capital costs for both energy and desalination technologies. It should be noted that CSP systems costs incorporate costs of thermal storage capacity up to six hours. This leads to capital costs of 6,300 USD/kWe and 5,700/kWe for CSP parabolic trough and CSP tower, respectively (Bitar & Ahmad, 2017).

A transition to SE offers the prospect of increasing supplies of desalinated water while significantly reducing CO_2 emissions (El Kharraz, J., 2017). Deploying CSP for seawater desalination is one modern approach. PV can also be used for BW treatment and for powering water pumping stations. However, the success of solar desalination technologies at commercial scales depends on the economic cost of converting SE into electricity. Current solar technology does not lend itself to large-scale desalination projects, but is useful at smaller scales, especially in remote areas with no grid electricity. In such areas, decentralized solar desalination plants offer independence and protection from price rises from utility or water companies, but the benefits of solar go far beyond desalination. Once installed, clean energy can also be used for soil fumigation and for drying animal feed for winter use. Thus deploying renewable solutions for increasing water supply also creates opportunities in intersecting areas.

Integrated molten salt energy storage technology provides twice the generation compared to the same size PV project. It allows solar to operate as base-load generation and dispatch when energy is needed most at a fraction of the cost of battery and other storage technologies. In fact, it enables CSP plants to operate like a conventional fossil fuel or nuclear power plant, reliably generating electricity when it's needed most - but without the harmful emissions and without any fuel cost.

Less than 1% of MENA's land mass would be required to provide solar power for the needs of the entire region. To achieve this, the political framework must adapt: dismantle subsidies for fossil fuels, encourage joint investments and cross border grid expansion with MENA countries. The optimal solution will depend on a combination of factors such as size of the installation needed, level of insulation and grid availability which will reflect on economic cost over environmental cost.

Conclusions and Recommendations

Policy makers need to consider the different choices for desalination based on locally available RE sources. For instance, SE, in particular heat from CSP for thermal desalination and electricity from solar PV and CSP for RO, is a key solution in the MENA region. In addition, solar desalination is a good example of the water-energy-food nexus implementation if combined with food production through greenhouses practices and other similar projects. As the demand for food, water and energy is expected to rise by 30–40 per cent by 2030, solar desalination is called to contribute significantly to SDGs 2 (food security), 6 (water) and 7 (energy). For instance, energy generation contribution in Saudi Arabia will increase 4.4-5.5% by 2032 in terms of Solar PV and by 11.7-17.2 in terms of Solar CSP. In addition, most energy strategies within the Arab world have set goals of increasing the share of RE in the energy make-up; for example Tunisia, is aiming for 30% share of RE in the electricity mix by 2030 whereas Morocco hopes to reach 12% by 2020, Egypt an ambitious 20% by 2020. It is worth to mention also that the one of the targets in the Arab Region is: "By 2020, develop alternative and practical solutions for using non-conventional water resources with focus on the use of renewable energy in water desalination and water treatment for meeting the increasing water demand in the Arab Region". Therefore, investing in RE makes sense from a water perspective. If Arab countries meet their set target shares of RE in the overall energy mix significant savings would be made in water withdrawals, consumption and their associated energy spending. RE-based freshwater generation should be seen as a valuable economic investment that reduces external, social, and environmental costs. In addition, if we use simple solar-driven small systems, it is simpler and less costly than conventional ones.

The MENA region needs to localize knowledge. Currently, there are not enough qualified staff to operate modern desalination technologies, including solar desalination plants. This is why, it is important to invest in training, knowledge transfer and capacity building. By designing incentives for local businesses, governments can attract domestic investments in manufacturing key components and cultivating local innovations to attain economic sustainability. However, government enterprises should not continue to build and operate desalination plants as before; steps should be taken to attract local investors using set targets for locally produced products and labor force and to manage these assets minimizing the life-cycle cost of water and environmental impact. Like private enterprises, government enterprises should value energy at world market prices and provide incentives for in-house R&D departments to promote innovations in technology and operation. Therefore, it is recommended to:

- Develop a comprehensive regulatory framework related to desalination and provide incentives to reduce the carbon footprint as well as the environmental impact,
- Support the existing technology centres and science parks in the MENA region,
- Expand and support technical and vocational training programs in desalination (including e-learning),
- Set up extensive educational specializations and social partnerships in desalination and water treatment,

- Increase regional R&D cooperation to ensure that the MENA region becomes an innovation hub in desalination technology.

References:

Ghaffour, N., The challenge of capacity building strategies and perspectives for desalination for sustainable water use in MENA, Desalination & Water Treatment 5 (2009) 48-53.

Ghaffour, N., Missimer, T.M., Amy, G.L., Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability, Desalination 309 (2013) 197-207.

Tzen E., Zaragoza, G., Padilla, D.C. (2012). Solar Desalination, Comprehensive Renewable Energy. Elsevier Publications.

El Kharraz, J. (2015), Solar desalination in the MENA region, Arab Water World (AWW) magazine, pp. 16–18.

Al-Karaghouli, A.A. et al. (2011), Renewable Energy Opportunities in Water Desalination, Desalination, Trends and Technologies, Michael Schorr (Ed.), ISBN: 978-953-307-311-8, InTech. http://cdn.intechopen.com/pdfs/13758/InTech-Renewable_energy_opportunities_in_water_desalination.pdf

IRENA, "Water Desalination using renewable energy – Technology brief" (2012). http://www.irena.org/DocumentDownloads/Publications/Water_Desalination_Using_Renewable_Energy_-_Technology_Brief.pdf

Ghaffour, N., Bundschuh, J., Mahmoudi, H., Goosen, M., Renewable energy-driven desalination technologies: A comprehensive review on challenges and potential applications of integrated systems, Desalination 356 (2015) 94-114.

Lienhard, J. H., V Gregory P. Thiel David M. Warsinger Leonardo D. Banchik, "Low Carbon Desalination Status and Research, Development, and Demonstration Needs Report of a workshop conducted at the Massachusetts Institute of Technology in association with the Global Clean Water Desalination Alliance", October 17-18, 2016

Almulla A., Hamad A., Integrating hybrid systems with existing thermal desalination plants, Desalination 174 (2005) 171–192

Bitar R. W., et Ahmad Al., 2017, "Solar Vs Nuclear: Which is cheaper for Water Desalination?", Policy Brief #2, AUB Policy Institute. http://website.aub.edu.lb/ifi/publications/Documents/policy_memos/2016-2017/20170215_solar_nuclear.pdf

El Kharraz, J., 2017, "Fresh Water scarcity in the Middle East and North Africa: The need for practical solutions", the Global Young Academy magazine: GYA connections — Issue 5 | pp. 14-19. https://globalyoungacademy.net/wp-content/uploads/2017/05/Connections-issue-5_lowres_AK3.pdf

ANNEX - Solar desalination projects implemented in the MENA region at small scale

1. Autonomous Desalination System Concepts for Sea Water and Brackish Water (BW) in Rural Areas with REs – ADIRA project (2003-2007): Four PV-RO systems have been installed subsequently in 4 locations of Morocco, where feed water was BW from inland wells (salinity 2.5 – 8.7 g/L). Such systems produce 5 m^3/day (PV capacity: 8 kWp), sufficient for 100 people, covering their food and sanitation needs.
2. Autonomous PV-RO unit in Tunisia (since 2006): The village of Ksar Ghilène first African location with 2 years' operating PV-RO system. This project targeted 300 inhabitants with no access to electric grid (nearest at 150 km) or fresh water. The system desalinated raw water with salinity of 3.5 g/l, and operated more than 3100 h producing 6,000 m^3 of drinking water in 27 months.
3. King Abdullah Initiative for Solar desalination - SA: The initiative is expected to reduce production costs of desalinated water from 0.67-1.47 $/$m^3$ to 0.27 -0.40 $/$m^3$. It is the world's first large-scale desalination plant to be powered by SE in SA.
4. Ben Guerdan solar powered BWRO in Tunisia: with a capacity of 1800 m^3/d, in operation since 2013.
5. A solar–MED plant built in Umm Al Nar, Abu-Dhabi has a desalination capacity of 120 m^3/d. The thermal energy required for MED is provided by solar thermal collectors.
6. The Layyah plant in Sharjah (UAE) integrates RO with MSF and MED thermal systems (Almulla, 2005).

Towards the circularization of the energy cycle by implementation of hydroelectricity production in existing hydraulic systems

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ABSTRACT: Hydropower potential is widely recognizable as the most important low-carbon electricity source. Nevertheless, implementation struggles with restrictions and negative image. High construction cost and social and environmental impact additionally discourage new developers. Installation of new hydropower plants in existing water infrastructures, without hindering their primary functions, is an attractive solution, saving construction costs and minimizing environmental impact. Moreover, it may contribute to the reduction of the global footprint of existing hydraulic infrastructures. Here we discuss several possible solutions to implement hydropower production systems in existing hydraulic infrastructures, referring to technic and economic feasibility and how this open avenues to global footprint reduction. A case study of the implementation of a hydropower plant associated to an existing irrigation system in Ethiopia is presented. In this case the electrical energy can be extracted from an existing system without hindering its main function linked to food production, representing an added value for the owner, for the local population and for the environment. The further development and investigation of synergetic approaches as the ones here presented are required to achieve the sustainable development goals, according to which water availability must be secured for both food and low-carbon energy production.

Introduction

The link between water, energy and food is inextricable since water is essential for human direct consumption, crops production and hydropower electricity provision. Population growth, rapid urbanization, changing diets, economic development and climate change impose a rising demand and stress for food and energy production (WWAP: World Water Assessment Programme, 2012, 2014). Thus, synergetic approaches to respond to both food and energy needs, requiring an integrated management of water, are essential to respond to the WEF Nexus, and in particular to attain the Sustainable Development Goals 2, 6 and 7.

Hydropower is one of the oldest renewable energy sources and by far the most important source of low-carbon energy in the world. Hydropower relies on water passing through turbines to generate electricity by conversion of mechanical energy. Inserted in the global energy production mix, hydropower also offers the opportunity to serve as a major source of global energy storage (Barbour, Wilson, Radcliffe, Ding, & Li, 2016). Installation of hydropower plants in the greenfield imposes environmental and social impacts which have to be tackled before construction to achieve a sustainable and impact friendly energy source.

In human infrastructures, the hydraulic energy contained in flowing water is frequently purposely dissipated for operational reasons; i.e. the energy is simply lost or wasted. The loss of mass (water leakage) and the excess of momentum (which may provoke pipe bursts for instance) are well perceived by humans. However, the waste of energy in hydraulic systems has no visual or sensorial expression, which justifies the common qualification given to this availability of energy, the "hidden treasure". Hence, one of the main directions for the decarbonisation of the sources of energy, in the context of hydroelectricity, must be the fight against this energy waste which is hidden in the existing hydraulic infrastructure.

The development of alternative hydropower plants incorporated in existing hydro-technical structures, used primarily for other purposes, represents an additional and profitable solution for energy generation with low impact (Marence, Ingabire, & Taks, 2016). Furthermore, the use (or re-use) of the so-called wasted energy contributes to the (partial) circularisation of the energy cycle in hydraulic infrastructures contributing to reduce (or even revert in a long term) the anthropogenic impact of such systems.

Hydropower incorporated in the existing hydraulic infrastructures, where electricity generation was not a primary objective, is an attractive solution for implementation in developed and developing energy systems from different perspectives:

- environmental and social boundaries on the existing and operating hydro-technical structures are known, defined and mostly accepted,
- installation of the new hydropower in existing system save construction costs and large infrastructural works, also reducing construction time and GHGs emissions during the construction phase,
- lower construction costs with shorter payback ratio makes the solutions attractive for investment,
- reduced uncertainty to the resource availability and known boundary conditions in terms of obtainable water flow and energy head,
- reduction of the operational costs by synergies in the operation,
- modifications for the additional purpose gives the possibility for social and environmental improvements.

Identification and implementation of hydropower in such non-traditional options can be seen as the search for the so-mentioned hidden treasure. Possible solutions may be found in: municipal and agricultural water systems (respectively in urban and rural environments); existing dams and hydropower plants; and industrial processes and hydraulic circulation systems. Some of these options are shown in Figure 1.

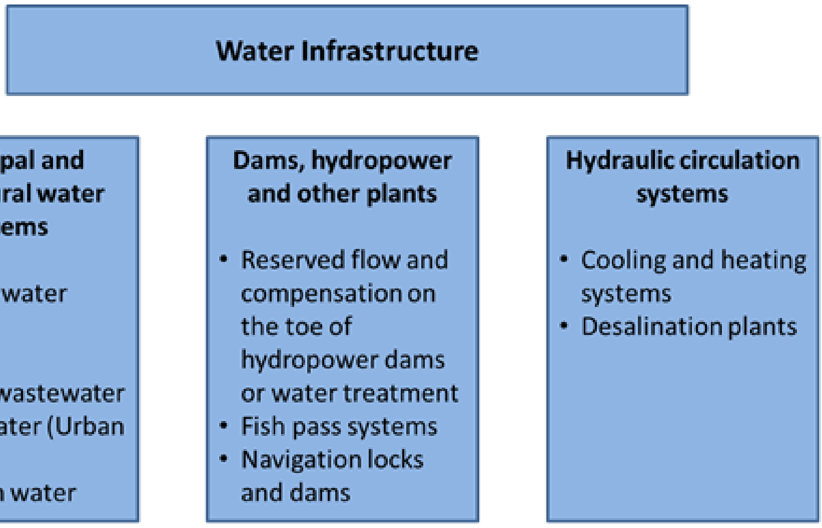

Figure 1. Water infrastructures suitable for additional hydropower implementation (Marence et al., 2016).

Key concepts for additional hydropower implementation

Municipal and agricultural water systems

Urban water supply systems are complex large technological systems (Hornberger & Hess, 2015), the purpose of which is to extract, treat, convey and distribute water to consumers. As such, they are energy consuming systems with their own carbon and energy footprint. The search for low-carbon cities usually neglects the role and the potential for electricity production which is (often literally) buried in water supply networks, a built and essential element of the urban settlements. The potential is stronger in mountainous or hilly regions, where water intakes are situated at higher altitude and excess pressure must be reduced before consumption. This reduction is performed by energy dissipation in specially constructed valves saving system pipes from bursting and permitting the operational use of water.

The pressure reduction by the installation of turbines in drinking water supply systems is already used, for instance, in Alpine areas and in steep mountainous islands (Vieira & Ramos, 2008). The installation of turbines in conveyance pipelines is technically easier compared with a distribution network because flow and pressure in the first are less fluctuating. Drinking water turbines must satisfy sanitary requirements without any influence on the water quality and allowing full water supply independently of the turbine operation.

Bölli & Feibe (2015) refer to an overlying potential of hydropower production of about 35 GWh per year in the water supply system of SONEDE, the Tunisian water supply utility. The study by Samora, Manso, Franca, Schleiss and Ramos (2016), which focused on the hydropower potential of the water supply network of the city of Fribourg, in Switzerland, shows that about 40% of the energy spent for pumping water for this system is wasted by the network. According to Bergkamp (2015), the energy to supply treated water and to dispose wastewater is responsible for 3-8% of the global GHGs emissions. Taking into account that urban settlements produce about 70% of the carbon emissions in the world (Wade, 2014), one may argue that there exists a large potential for reducing global GHGs emission with such adaptations in water supply conveyance pipelines and distribution networks.

Also the municipal sewage systems have potential for hydropower production. In this case, the natural head that generally exists between the residential area and the disposal of treated water in nature can be used. In the case of untreated water, the energy system may need to deal with solid debris. Recently, Bousquet, Samora, Manso, Rossi and Heller (2017) estimated the hydropower potential of the use of wastewater systems in Switzerland and identified nineteen profitable sites with a total 9.3 GWh/year of potential electrical energy production.

Irrigation systems are mostly built with a function to maximize the irrigated area and transport water as far as possible. In the toe of irrigation dams, at the upstream section of the irrigation network, the excess of energy needs often to be dissipated by special valves (Figure 2). In some cases, where the downstream channel network presents drops, the difference of level in these singularities may be used for energy extraction. A case study is presented in Section 3 regarding an irrigation system in Ethiopia, where examples of these two types of energy extraction were analysed.

a) b)

Figure 2. Example of pressure reducers installed at the dam toe, upstream irrigation networks: a) Odivelas dam; and, b) Gostei dam, both in Portugal.

Dams, hydropower and other plants

Dams store water for different uses and requirements. More than 70% of world dams are built for a single purpose and irrigation is the most common use. Just 17.4% of world dams are built for hydropower and energy generation (ICOLD, 2017). Most of the dams built for other purposes have the possibility for additional energy generation. The potential and appeal of such solutions is demonstrated by the case of USA where more than 80 000 non-powered dams have been detected with a total potential of additional 12 GW (Hadjerioua, Wei, & Kao, 2012).

Existing hydropower plants have potential for additional upgrade that could be done by refurbishment and installation of modern equipment with higher efficiency and higher load factor. Also, the implementation of energy converters associated to ecological measures, such as fish ladders and bypasses, and ecological minimal flow releases, is desirable since in these energy is often available and needs to be dissipated.

Additional possibilities are the installation of hydropower plants in ship navigation locks where the flowing water needed for filling and emptying these may be used for energy generation. Weirs controlling navigation levels, are another possible source for energy generation. On the river Waal, in the Netherlands, three navigation weirs include hydropower plants (Manders, Höffken, & Van Der Vleuten, 2016).

Hydraulic circulation systems

Similar to drinking water systems, industrial cooling or heating systems and water processing systems can result in a pressure excess that can be recovered through hydro turbines instead of lost in energy dissipators.

The water abstraction for the cooling systems of thermal power plants represents from 10 to 50% (depending on the country and region) of the total freshwater withdrawals (WWAP: World Water Assessment Programme, 2014). This water, after temperature exchange, is released back into the river. The head difference between the river and the process station depends on the configuration and river flood characteristics, but in most case stays unexplored.

Some desalination plants use reverse osmosis to separate water from dissolved salts through semipermeable membranes under high pressure (from 40 to 80 bars). The residue of water containing salt, still at high pressure, could be flown through a turbine in order to recover part of the energy used for the initial compression.

Case study: implementation of hydropower production in the existing irrigation systems of the Kessem and Tandaho reservoirs, in Ethiopia

Often in developing countries, the installed capacity for hydroelectricity generation falls far short from their potential. In particular, Ethiopia has a capacity of 1500 MW for small hydropower with 6 MW installed capacity, thus only 0.4% of its potential (United Nations Industrial Development Organization & International Center on Small Hydro Power, 2016). According to the World Bank, in this country only 22.2% of the population in rural areas has access to electricity. Without provision of electricity to this large population, sustainable development and eradication of poverty and illiteracy is hindered. This situation urges for opportunities for electrical energy production, namely in existing water infrastructures such as reservoirs and irrigation canals which are near the communities.

The Kessem and Tandaho irrigation reservoirs are located in the lower Awash river basin in Ethiopia (Figure 3). The reservoirs collect and store rainfall and river flow water during the rainy season and a controlled outlet flow is used for irrigation of agricultural land, used mostly for sugar cane production. Estimations of the potential for electrical energy production were made for two types of hydropower plants corresponding to: the use of the head available at the toe of the Kessem, before this is released to the irrigation network; the use of existing drops in the 44 km irrigation channel downstream of the Tandaho dam.

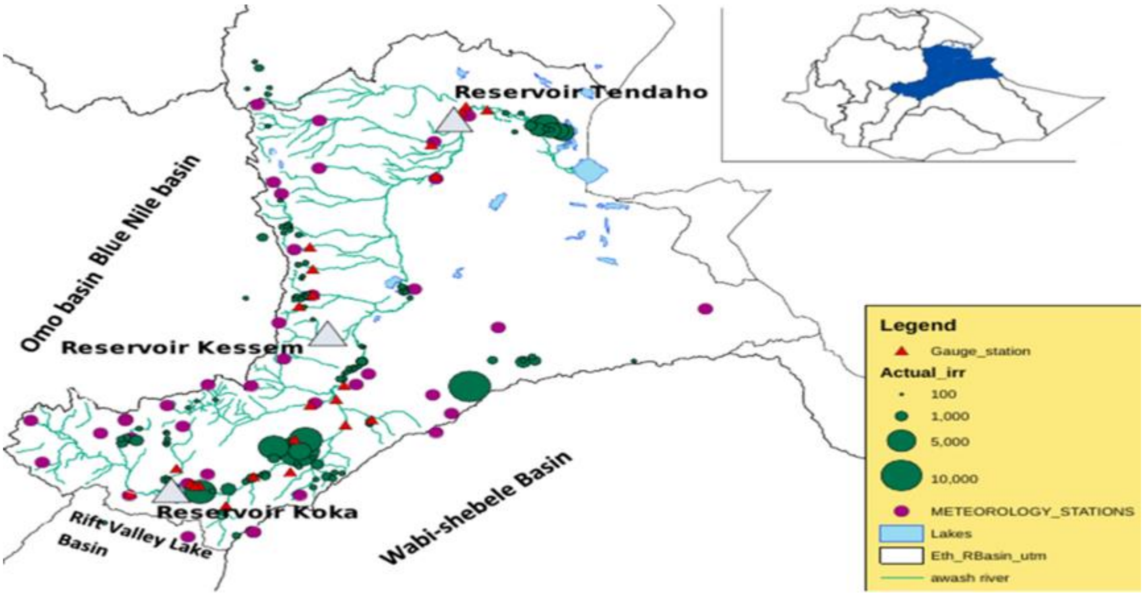

Figure 3. Schematic layout of Awash River basin gauging stations, irrigation capacity and meteorological stations (Müller, R., Gebretsadik, 2016).

The Kessem dam has a height of about 90 m. The potential head and flow for hydropower production downstream Kessem dam were estimated from a simulation of a mean year of operation of the irrigation system. The storage water routing is performed as a function of the depth-volume curve of the reservoir, taking into account monthly irrigation needs and inflowing hydrological data from more than 30 years. A possible yearly energy production of 31.8 GWh was estimated.

The Tandaho canal (Figure 4) is regulated based on crop water requirements. The irrigation network downstream of the Tandaho dam, after satisfying minimal flow regulations in the river, is diverted to a concrete artificial channel with a minimum operating discharge of 18 m^3/s. The channel has a continuous slope of 0.01% with several concentrated drops of 1.2 to 3.0 m. Six of these hydraulic drops may be used to extract energy by means of a screw turbine, with a reference production value per drop of 1.75 GWh per year. In the study area two small villages and sugar factories are near to the irrigation structures.

Figure 4. Head regulator of Tandaho irrigation canal and water diversion to the command area.

Both solutions associated to the two irrigation systems belonging to the lower Awash valley could produce as much as 42 GWh of hydroelectricity, which could supply the national grid or be used locally to support regional development or to support agricultural production. Using the data in (Bruckner et al., 2014) as reference as well as the study by Zhang et al. (2015), where CO_2 emissions of small hydropower plants in southwest China were comprehensively discussed, a total reduction of more than 30 000 ton of CO_2 emitted per year could be expected with the implementation of such hydraulic generators when compared to fossil-fuel sources. In both cases, CO_2 emissions associated to the construction of the plant and to the presence of the reservoir are minimized. The installation of the hydropower plant associated to the irrigation systems would thus contribute to reduce their global impact.

The implementation of energy extraction plants in existing hydraulic structures must consider the uninterrupted operation of the facility and the minimization of the original function of the irrigation system which is agricultural production. The original function and the crops needs dictate the operation and available water for energy production, and priority for the use of the available water stored in the reservoir must be given to irrigation.

Discussion, conclusions and recommendations

Hydraulic systems supporting food production, water and sanitation supply, industry and hydroelectricity production have common engineering mechanisms of storage and conduction of water. Thus, the implementation of synergetic multi-purpose systems infolding the several uses here mentioned is the best way to respond to the Water-Food-Energy Nexus, at the same time contribution to the fulfilment of the Sustainable Development Goals, in particular SDGs 2, 6 and 7.

Hydropower rehabilitation and optimization, together with the installation of power plants in existing hydraulic structures (the so-called hidden treasure), need to be tapped. There is a considerable potential for rehabilitation, life extension, upgrading and optimization of existing hydropower facilities by improving energy efficiency and at the same time guaranteeing the safety of aging plants. Rehabilitation and upgrading of existing plants can be made by using modern technologies and comprehensive planning while minimizing environmental and social impacts.

Moreover, and as shown here with examples in urban and rural areas, large infrastructures and industrial applications, the installation of hydroelectricity production equipment in existing hydraulic systems gives additional possibilities for low-carbon energy generation. The presented example shows a high potential for additional energy production by hydropower installed in an irrigation infrastructure. The existing structures may often be used with minimal or no extra social and environmental impacts. Furthermore, these solutions can contribute to reduce or even cancel the negative impact of the existing infrastructure as above shown.

Investigation of synergetic approaches as the ones here discussed are required to achieve the SDGs, according to which water availability must be secured for both food and low-carbon energy production. Research on the optimization and management of multi-purpose systems as well as on technological solutions aiming at the (partial) circularization of the energy cycle in hydraulic systems, is urgently required.

References:

Barbour, E., Wilson, I. A. G., Radcliffe, J., Ding, Y., & Li, Y. (2016). A review of pumped hydro energy storage development in significant international electricity markets. Renewable and Sustainable Energy Reviews, 61, 421–432. https://doi.org/10.1016/j.rser.2016.04.019

Bergkamp, G. (2015, April). Energy and Carbon Neutral Water Cities. IWA Blog. Retrieved from http://www.iwa-network.org/energy-and-carbon-neutral-water-cities/

Bölli, M., & Feibe, H. (2015). Low hanging fruits : hydropower in existing water infrastructure. ESI Africa, 1, 76–77.

Bruckner, T., Bashmakov, I. A., Mulugetta, Y., Chum, H., de la Vega Navarro, A., Edmonds, J., E. Hertwich, D. Honnery, D. Infield, M. Kainuma, S. Khennas, S. Kim, H. B. Nimir, K. Riahi, N. Strachan, R. Wiser, and X. Z. (2014). Climate Change 2014: Mitigation of climate change. IPCC Fifth Assessment Report, 527–532. https://doi.org/10.1017/CBO9781107415416

Bousquet, C., Samora, I., Manso, P., Rossi, L., Heller, Schleiss, A.J. (2017). Assessment of hydropower potential in wastewater systems and application to Switzerland. Renewable Energy, 113, 64–73.

Hadjerioua, B., Wei, Y., & Kao, S.-C. (2012). An assessment of energy potential at non-powered dams in the United States. U.S. DEPARTMENT OF ENERGY. https://doi.org/10.2172/1039957

Hornberger, G., & Hess, D. (2015). Water conservation and hydrological transitions in cities in the United States. Water Resources, 51(6), 4635–4649. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/2015WR016943/full

ICOLD. (2017). Dams & the World’s water. Paris: International Commission on Large Dams. Retrieved from www.icold-cigb.org

Manders, T. N., Höffken, J. I., & Van Der Vleuten, E. B. A. (2016). Small-scale hydropower in the Netherlands: Problems and strategies of system builders. Renewable and Sustainable Energy Reviews, 59, 1493–1503. https://doi.org/10.1016/j.rser.2015.12.100

Marence, M., Ingabire, J. S., & Taks, B. (2016). Integration of hydropower plant within an existing weir – “a hidden treasure.” In M. Erpicum, S., Dewals, B., Archambeau, P., & Pirotton (Ed.), Sustainable Hydraulics in the Era of Global Change (pp. 974–978). London: Taylor & Francis Group.

Müller, R., Gebretsadik, H. Y. & S. N. (2016). Towards an optimal integrated reservoir system management for the Awash River Basin, Ethiopia. In 7th International Water Resources Management Conference of ICWRS (p. IWRM2016-95-2). Bochum.

Samora, I., Manso, P., Franca, M., Schleiss, A., & Ramos, H. (2016). Energy Recovery Using Micro-Hydropower Technology in Water Supply Systems: The Case Study of the City of Fribourg. Water, 8(8), 344. https://doi.org/10.3390/w8080344

United Nations Industrial Development Organization, & International Center on Small Hydro Power. (2016). The World Small Hydropower Development Report. Retrieved from http://www.unido.org/fileadmin/user_media_upgrade/What_we_do/Topics/Energy_access/WSHPDR_2013_Executive_Summary.pdf

Vieira, F., & Ramos, H. (2008). Hybrid solution and pump-storage optimization in water supply system efficiency: A case study. Energy Policy, 36(11), 4142–4148.

Wade, L. (2014). Giving cities a road map to reducing their carbon footprint. Retrieved from http://www.sciencemag.org/news/2014/12/giving-cities-road-map-reducing-their-carbon-footprint

WWAP: World Water Assessment Programme. (2012). The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. (UNESCO, Ed.), UN Water Reports. Paris. Retrieved from http://unesdoc.unesco.org/images/0021/002156/215644e.pdf

WWAP: World Water Assessment Programme. (2014). The United Nations World Water Development Report 2014: Water and Energy (UNESCO, Vol. 1). PAris. https://doi.org/978-92-3-104259-1

Zhang, J., Luo, C.-Y., Curtis, Z., Deng, S., Wu, Y., & Li, Y. (2015). Carbon dioxide emission accounting for small hydropower plants—A case study in southwest China. Renewable and Sustainable Energy Reviews, 47, 755–761. https://doi.org/10.1016/j.rser.2015.03.027

Integrating existing African infrastructures into the Water Energy Food Ecosystem nexus approach

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ABSTRACT: Energy access rates in sub-Saharan Africa are the lowest worldwide. In order to achieve the Sustainable Development Goals in Africa and provide modern electricity services, significant power capacities need to be installed. The proposed article presents an alternative approach, where existing water infrastructure is utilized to host renewable energy capacities in a nexus approach. This approach introduces an industrial symbiosis, where part of the infrastructure is already in place and addition of electricity production infrastructure can be achieved at a lower cost. The electrification of existing non-powered dams, the installation of solar photovoltaic (PV) systems on the face of existing dams and the coverage of irrigation canals with solar PV systems are examples of the solutions to be studied.

KEYWORDS: water energy food ecosystem nexus; existing infrastructure; renewable energy; non-powered dams; harmony search

Introduction

In order to achieve the Sustainable Development Goals (SDGs) in Africa and provide modern electricity services, significant power capacities need to be installed. In the developing world the energy access rates are the lowest in Sub-Saharan Africa (SSA), while the West African countries these rates are even lower than in SSA in general. The Population increase in West African is among the highest in the region (high and also it includes Nigeria, the most populated country of Africa. Moreover), many of the countries have low GDP/capita figures; therefore the investment needed to reach the SDG goal of universal access requires disproportionate efforts. Table 1 presents basic information of energy access, GDP/capita and population growth in Africa, SSA and the West Africa countries, specifically. It also includes the relevant figure of North Africa, where universal electrification has been achieved, for comparison.

Table 1. West Africa compared to Sub-Saharan Africa (Sources: IEA,2016; CIA, 2017; WB,2017)

Region	Population without access to electricity (million)	National electrification rate (%)	GDP/capita (US$)	Population growth (%)
Africa	634	45.2%	-	-
Sub-Saharan Africa	632	35.2%	1450	-
North Africa	1	99%	7,124.7*	1.77*
West Africa	199	45.8%	-	-
Benin	7	29%	789.4	2.7
Burkina Faso	14	18%	649.7	3
Cabo Verde	0	96%	2997.8	1.3
Côte d'Ivoire	8	62%	1526.2	1.8
Gambia	1	45%	473.2	2.1
Ghana	8	72%	1513.5	2.2
Guinea	9	26%	508.1	2.6
Guinea-Bissau	1	21%	620.2	1.9
Liberia	4	10%	455.4	2.5
Mali	13	26%	780.5	3.0
Mauritania	3	29%	1077.6	2.2
Niger	16	15%	363.2	3.2
Nigeria	98	45%	2,178.0	2.4
Senegal	6	61%	958.1	2.4
Sierra Leone	5	14%	496.0	2.4
Togo	5	27%	578.5	2.6
North Africa	1	99%	7,124.7*	1.77*

*Also including Middle East.

State of the art, Theory and Methods

The Water Energy Food Ecosystem (WEFE) nexus offers the opportunity to the interacting domains to support a significant utilization of the renewable energy (RE) potential. These domains are interlinked in a complex and dynamic system, where water ecosystems, energy access and food production affect each other. The African continent offers a unique playground for WEFE solutions, as it faces challenges in both water and energy access (quantity and quality). Moreover, its increasing population (see Table 1) further increases the pressure for increased food production. At the same time the unique African ecosystem needs to be preserved and applied solutions to ensure sustainable approaches that utilize indigenous and clean resources. The present study analyses the four relevant domains of the WEFE nexus approach, in the context of West Africa so that actions in one area (water and food production) have impacts on the other (energy), as well as on ecosystems. It identifies opportunities in these sectors to upscale the existing RE potential faster, more effectively and with a lower cost, compared to traditional/conventional approaches. The analysis builds on the observation that energy potential in different existing infrastructure is neglected, although its utilization may lead to significant energy production. Accordingly, the present paper uses a methodology that helps to identify the low-hanging fruits of indigenous energy sources that lie in existing infrastructure in West African countries (Szabó et al, 2016). This identification builds on a methodology that geo-locates relevant infrastructures in West Africa that may allow to create WEFE Nexus solutions. It builds on the authors' previous work on spatial analysis of the renewable energy potential in SSA (Szabó et al, 2016), (Szabó et al, 2011) and opens the opportunity to extend the energy policy support tool (RE2nAF Tool) to the other domain of the WEFE nexus.

Following this rationale, the developed methodology builds a spatial model based on datasets of existing West African infrastructure that have potential to be updated/modified for energy generation. Specific criteria are used to select the most suitable existing infrastructure for the special WEFE nexus purpose. The developed methodology allows the estimation of the expected power output and the involved cost to upgrade the selected infrastructure. The main advantage of this approach is that it does not only set up new clean energy producing capacities, but does so in a lower cost due to the fact that an important part of the needed infrastructure elements is already in place. This is important because it allows overcoming the biggest financial disadvantage of RE technologies: the high up-front costs that, under certain conditions, may even become prohibitive in West Africa. Decreasing the capital investment cost is particularly important in the African context: despite the significant technology cost decrease in RE technologies (mainly in photovoltaics and wind) the higher financial risks in Africa (country-related, political, inflation, defaulted loans) increase the finance costs and the corresponding interest rates make most of the energy projects financially not feasible.

The major infrastructure and activities relevant for the renewable energy sector in West Africa are identified and classified on the 4 WEFE Nexus domains (see Figure 1).

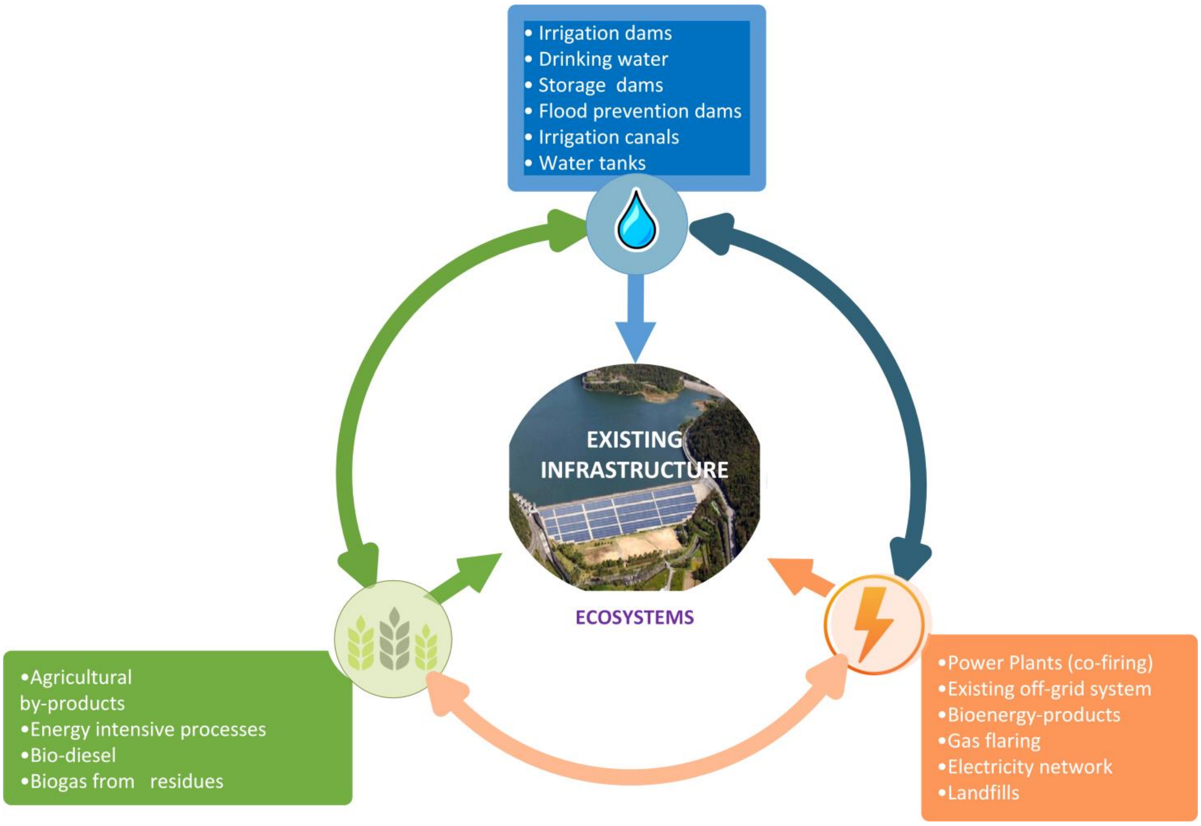

Figure 1. Identified infrastructure in the context of water, food (agriculture) and energy being inextricably linked with additional RE potential as well as impacts on ecosystems

The present analysis selected the following types of infrastructure with the potential to be integrated in a WEFE nexus approach: non-powered dams that serve a non-energy purpose (e.g. irrigation, flood mitigation, drinking water provision); the free surface over irrigation canals and the face of dams that can accommodate solar photovoltaic (PV) systems; co-firing of agricultural and food residues in existing thermal power-plants.

Key findings

WATER domain

In West Africa, the existing infrastructure in the water sector has the highest potential for additional renewable energy production. The authors processed, harmonized and combined datasets of dams and water reservoirs (GRanD Database, HydroSHEDS, AICD, IRENA) with various non-energy related purposes. Such dams are also known as non-powered dams (NPDs). Following this data assimilation process, their untapped hydropower potential and the expected electricity production were estimated. Estimations were based on information related to the dam height, the estimated hydraulic head, the reservoir capacity and the seasonality of the flows (permanent/temporal). The created dataset was also supported with information derived from aerial images, which was particularly useful to detect false records, inaccuracies and fine-tune the geographical coordinates of the NPDs. Figure 2 shows the analysed dams and reservoirs. The red dots indicate dams that are already used for energy production. The blue dots show those existing dams where our analysis indicates as suitable for transformation to hydroelectric facilities. It is clear that West Africa hosts the highest number of suitable non-powered dams along with Southern Africa.

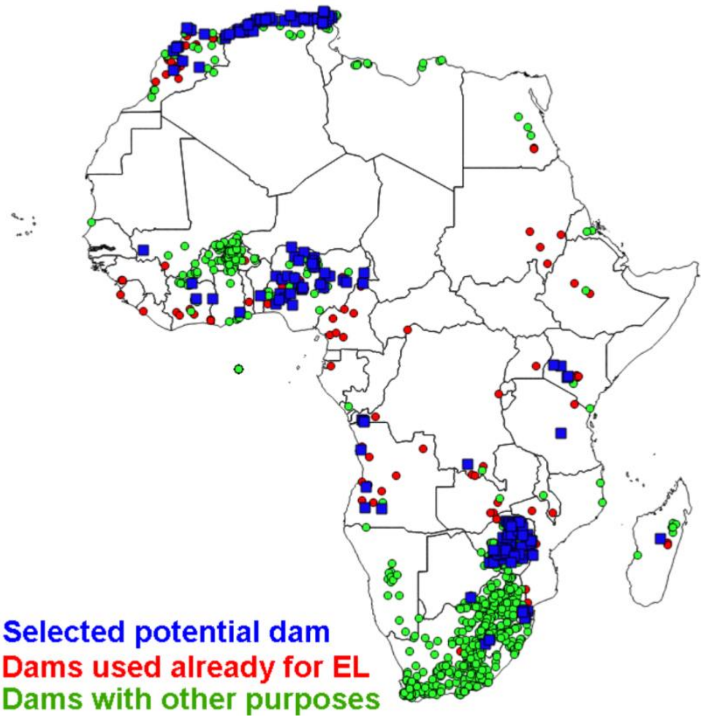

Figure 2. Analysis of existing dams in Africa and detection of the non-electrified dams (NPDs)

The lack of systematic databases that contain geo-information on irrigation canals in West Africa prevented a more detailed analysis of the potential of adequate set of canals that could provide a good area for PV installation as was performed in European regions (Kougias et al., 2016.a). Covering canals with PV systems is mutually beneficial for both the solar PV output and the water conveying system. Electricity output is supported by increased efficiency of the solar PV modules due to the reduced temperature and the water cooling effect. At the same time, there are clear indications that the shading effect of the modules results in sizeable reduction of water evaporation losses. Naturally, evaporation depends on local climatic conditions; in the case of Southern Europe – North Africa a conservative estimation performed by the authors revealed a reduction of the evaporation by 34.4%, compared to non-covered canals (Kougias et al., 2016.a).

Future work may also include water storage tanks, irrigation systems and sewage treatment systems that could support demand-side management actions that enable the integration of higher renewable shares in the power systems. Their pumping/releasing functions can be scheduled according to the RE generation and balance the variable energy production.

ENERGY domain

Additional and very important existing energy production facilities that can be complemented with low-cost renewable energy generation are existing mini-grids. The existing power lines allow the integration and distribution of RE capacities that will supplement the output of the existing mini grid. However, to the authors' best knowledge there is no detailed and accurate dataset that contains rural mini-grids for Africa. To overcome this limitation, the authors analysed NASA night light images coupled with existing electricity network information and geo-locations of other relevant activities e.g. industrial, mining activities. If the identified lighted locations overlap with inhabited areas, a second-level, and higher-resolution analysis identified the type of existing power production i.e. mini-hydro or diesel based off-grid systems. Both of the latter have a potential to be upgraded with solar PV and create a larger hybrid system. Adding PV to these mini-grids has an additional positive effect on the existing systems as PV production could offset fossil fuel use, and therefore the related fuel, transport and environmental costs. With Mini-hydro hybridisation with PV can have a beneficial effect in balancing low-hydropower output. D, since during the dryer, low precipitation seasons solar PV systems generally produce more electricity (Kougias et al., 2016.b). This characteristic could partially balance the limited hydropower production due to lower water discharge. The present analysis identified seven such locations were identified in West Africa (5 places in Nigeria and 2 in Mali), where hybridisation with PV is possible.

Contrary to this relatively small number, gas flaring is observed in many places in West Africa where it has become quite an environmental challenge. As pipeline infrastructure is underdeveloped,, gas is only used locally. However, introducing the use of gas cartridges in cooking would allow a widespread use of gas in the gas-producing and neighbouring countries and former gas flaring locations could be transformed into gas cartridge production sites in a cost effective manner. Despite this is not a RE project per se, the avoided greenhouse gas (GHG) emissions and environmental effects render such a project as a priority.

FOOD domain

In the food domain we selected energy related projects in the biomass and by-product production. Existing coal power-plants are prime locations for biomass co-firing, if the agricultural by-products are available in large quantities in the proximity of the power plants. The authors have identified such locations in Southern and North-West Africa, where the coal is a primary source of electricity and at the same time sizeable sugarcane production fields are located in the vicinity of the power-plants. Bagasse is a sugarcane side product and can be used for additional and renewable utilisation of these power plants as is in the case of Mauritius (Ramjeawon, 2008), where the existing coal power plants operate up to 10% of their time burning this biomass resource as their fuel. Although in West Africa the use of bagasse is not readily in place, similar approaches can lead to new initiatives for biomass utilization. Figure 3 illustrates the sugarcane production in Africa, showing a relatively low potential in the Western countries. Ivory Coast and its neighbouring countries host most of the production, where the utilization and co-firing of bagasse could be examined.

An additional option is other biogas and biofuel production that relies on other by-products by of animal grazing and crop products, but also relates to the waste management. In this aspect (Scarlat et al., 2015) have a pan-African study has been published [17], with estimating the energy potential based on the estimated of wastes of settlements' waste.

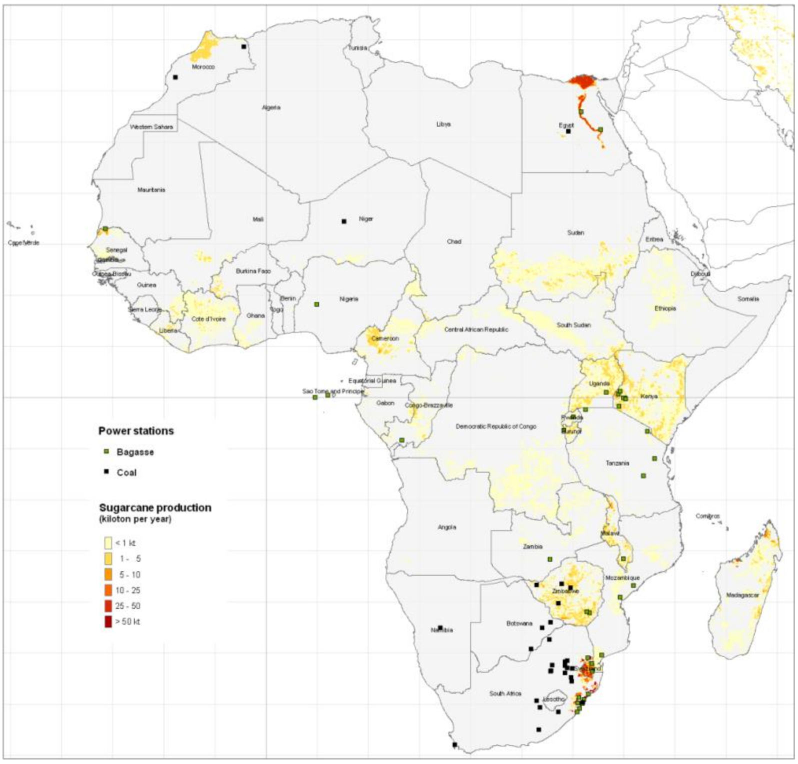

Figure 3. Sugarcane production in Africa and potential co-firing locations

Discussion, Conclusions and Recommendations

The analysis of the renewable energy potential under the Nexus framework revealed that water infrastructure, like dams and canals, are at the core of all Water-Energy-Food-Ecosystem Nexus domains. Therefore, utilising already existing water infrastructure for additional energy purposes offers a win-win situation for all related Nexus objectives. The advantages of using existing infrastructures in West Africa (like electrifying non-powered dams or PV installation on dams and canals) are multiple, for instance, faster implementation due to the already existing road network or easier licensing. Despite the prospective market potential, investments are hindered by a insufficient perception of high risk. As a prime example, dam construction is a complex technical process that has a significant cost. In a hydropower project, dam construction can represent up to 60% of the total cost. In the case of the transformation of non-powered dams (Patsialis et al., 2016), the up-front cost part is decreased by 40-60% (Szabó et al, 2016). Thus, electrifying existing dams by adding hydropower equipment produces sustainable electricity in a low cost and lower investment risk environment. There is also the potential to utilize the large flat area of the downstream face of dams for PV and create hybrid systems (Kougias, et al., 2016.b). Other direct links to the WEFE Nexus when transforming already existing hydro infrastructure are:

- Energy: Proximity to the electricity grid
- Energy: Increased efficiency of the hydro-PV hybrid system and possible application on energy storage station (in case of PV integrated to dams)
- Food: Electrification of rural/remote agricultural areas
- Ecosystems: Minimisation of additional land use and environmental impacts
- Ecosystems

We identified 42 low-hanging fruit infrastructure components in West Africa under the Water-Energy-Food-Ecosystem Nexus framework (i.e. 35 electrifiable dams and 7 PV-complementable settlements) and from those 28 will be eligible as viable options with a total hydropower capacity of 5.3 MW. The Nexus related advantages could attract new investors and by gaining the necessary business experience they can scale up financing of other Nexus projects, thus helping put development of these countries on a sustainable pathway.

References:

International Energy Agency IEA, World Energy Outlook (2016)

Central Intelligence Agency. Factbook, C. I. A. The world factbook (2017). https://www.cia.gov/library/publications/the-world-factbook

The World Bank. World Bank national accounts data, and OECD National Accounts data files (2017). https://data.worldbank.org/indicator/NY.GDP.PCAP.CD

Szabó, S., Moner-Girona, M., Kougias, I., Bailis, R., & Bódis, K. (2016). Identification of advantageous electricity generation options in sub-Saharan Africa integrating existing resources. Nature Energy, 1, 16140.

Szabó, S., Bódis, K., Huld, T., & Moner-Girona, M. (2011). Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension. Environmental Research Letters, 6(3), 034002.

European Commission Joint Research Centre. Renewable Energies Rural Electrification Africa: RE2nAF Tool. http://re.jrc.ec.europa.eu/re2naf.html

Patsialis, T., Kougias, I., Kazakis, N., Theodossiou, N., & Droege, P. (2016). Supporting Renewables' Penetration in Remote Areas through the Transformation of Non-Powered Dams. Energies, 9(12), 1054.

Kougias, I., Bódis, K., Jäger-Waldau, A., Moner-Girona, M., Monforti-Ferrario, F., Ossenbrink, H., & Szabó, S. (2016.a). The potential of water infrastructure to accommodate solar PV systems in Mediterranean islands. Solar Energy, 136, 174-182.

Kougias, I., S Szabó, F Monforti-Ferrario, T Huld, K Bódis: A methodology for optimization of the complementarity between small-hydropower plants and solar PV systems. 2016.b. Renewable Energy 87, 1023-1030

Kougias, I., Bódis, K., Jäger-Waldau, A., Monforti-Ferrario, F., & Szabó, S. (2016.c). Exploiting existing dams for solar PV system installations. Progress in Photovoltaics: Research and Applications, 24(2), 229-239.

GRanD, Global Reservoir and Dam database; FAO Aquastat, global water information system of Food and Agriculture Organization of the UN. http://www.gwsp.org/products/grand-database.html

HydroSHEDS, Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales. https://www.hydrosheds.org/

The World Bank: Africa's Infrastructure: National Data. Africa Infrastructure Country Diagnostic (AICD). http://data.worldbank.org/data-catalog/africa-infrastructure

K. Bódis: Geospatial data layers provided for the global atlas of the International Renewable Energy Agency (IRENA) http://bookshop.europa.eu/en/metadata-pbLDNA26482/

Ramjeawon, T. (2008). Life cycle assessment of electricity generation from bagasse in Mauritius. Journal of Cleaner Production, 16(16), 1727-1734.

Scarlat, N., Motola, V., Dallemand, J. F., Monforti-Ferrario, F., & Mofor, L. (2015). Evaluation of energy potential of municipal solid waste from African urban areas. Renewable and Sustainable Energy Reviews, 50, 1269-1286.

Szabó, S., Bódis, K., Huld, T., & Moner-Girona, M. (2013). Sustainable energy planning: Leapfrogging the energy poverty gap in Africa. Renewable and Sustainable Energy Reviews, 28, 500-509.

ANNEX 1 – Selected DAMS

The image on the dam will appear by clicking on the given link in the second column.

COUNTRY	DAM NAME	CLASS	ESTIMATED SIZE [MW]
Benin	Ilauko	small/medium	2.00
Cameroon	Chidifi	mini	0.20
Cameroon	Mokolo	mini	0.20
Ghana	Afife	not recommended	n/a
Ghana	Akosombo	not recommended	n/a
Ghana	Dawhenya	not recommended	n/a
Ghana	Inchaban	not recommended	n/a
Ghana	Kanyanbia	not recommended	n/a
Ghana	Kulpawn	not recommended	n/a
Ghana	Sissili	not recommended	n/a
Ghana	Vea	not recommended	n/a
Nigeria	Asa	mini	0.20
Nigeria	Asejire	mini	0.10
Nigeria	Bakolori	mini	0.20
Nigeria	Balanga	mini	0.10
Nigeria	Challawa Gorge Dam	not recommended	n/a
Nigeria	Erinle	mini	0.20
Nigeria	Ero	mini	0.10
Nigeria	Gari	mini	0.10
Nigeria	Goronyo	mini	0.10
Nigeria	Gubi	mini	0.10
Nigeria	Gusau	not recommended	n/a
Nigeria	Jibiya	mini	0.10
Nigeria	Kiri	mini	0.10
Nigeria	Kontagora	mini	0.20
Nigeria	Kubli	mini	0.10
Nigeria	Omi	small/medium	0.50
Nigeria	Pankshin	mini	0.10
Nigeria	Ruwan Kanya	mini	0.10
Nigeria	Suleja	mini	0.10
Nigeria	Tagwai	mini	0.10
Nigeria	Tiga	mini	0.10
Nigeria	Tudun Wada	mini	0.10
Nigeria	Usman	not recommended	n/a
Nigeria	Watari	mini	0.10

ANNEX 2 – Selected settlements for off-grid PV complement based on lighted areas

COUNTRY	SETTLEMENT	POPULATION 2015	DISTANCE from GRID [m]
Mali	Gao	121,519	159,878
Mali	Mopti Commune	183,108	170,696
Nigeria	Azare	217,468	60,811
Nigeria	Gashua	158,848	81,541
Nigeria	Kishi	73,221	59,439
Nigeria	Nguru	111,138	65,795
Nigeria	Shaki	84,436	80,281

The potential of biomass agricultural waste recovery as char in Western Africa

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ABSTRACT: In developing countries, such as the Western African ones, char production appears as a promising solution to recover organic waste, such as agricultural waste. The process sequences of this value chain starts with feedstock conversion to char by pyrolysis or hydrothermal carbonization, followed by optional char upgrading by thermal or mechanical post-treatments, and finally to various uses of char, including solid fuel as replacement of wood charcoal, material for soil improvement, material for gas/water treatment, additive in anaerobic digestion, or, in a longer term perspective, material for electrochemical energy storage. While diverse initiatives have been launched in Western Africa, large scale implementation of the value chain still faces several issues. Future technical studies are especially recommended to interlink feedstock properties, process conditions, char properties and resulting performance. Efforts should also be made to develop robust and cheap technologies and by-product recovery. In parallel, non-technical work is encouraged. It should especially deal with the design of sustainable business models in relation with scale and market targeted as well as the different actors along the whole value chain. Social acceptance should also be considered through multi-actor approach and training activities. Finally, it may also be relevant to increase public authority involvement to support technology spreading.

Introduction

Organic waste, notably agricultural waste, is potentially available in large amounts in developing countries such as the Western African ones (FAO, 2017). Dry waste, like cereal straw or corn cob, is commonly either left or burnt on field, or stored and used for animal feeding. Similarly, wet waste, like cow or sheep manure, is either simply left on site or it may also be recovered through anaerobic digestion or composting. This situation induces several major issues, in particular fast release of carbon in atmosphere, air pollution due to toxic emissions in the case of uncontrolled burning, risk of insect infestation in the case of uncontrolled storage, risk of pathogens spreading in the case of wet waste disposal and also biological recovery, as well as production of waste during anaerobic digestion, i.e. digestate, that is difficult to handle.

To cope with these issues and therefore contribute to solve the Water Energy Food Nexus in practice, one technological solution is the conversion of organic waste like agricultural ones through thermal processes into a carbon-rich material, called char, and that may be used in various applications, as illustrated in Figure 1. This paper aims at providing an overview of:

i) the main steps of this value chain,
ii) the remaining issues towards its large scale implementation, and
iii) related recommendations of future work to achieve it.

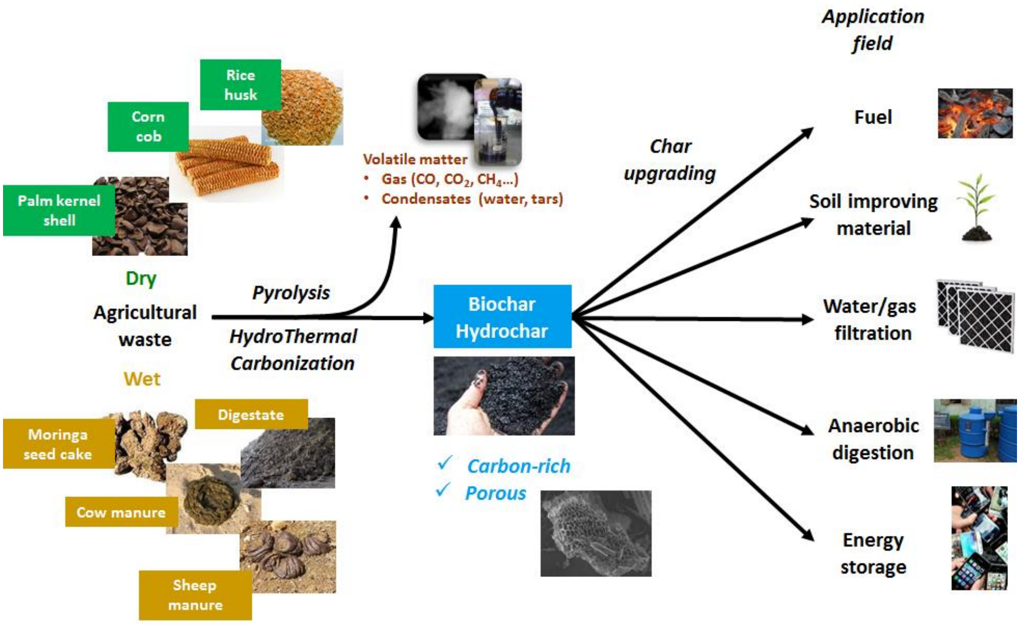

Figure 1. Overview of char value chain based on agricultural waste.

Overview of Char value chain

Char production

When heated in absence of oxygen, agricultural waste, including digestate, releases some volatile compounds, including gas, such as carbon monoxide (CO) or methane (CH4), and condensates, namely water and tars. It also gives rise to a carbon-rich, porous solid. This solid, whose properties are closer to coal than those of raw waste, is usually called "biochar" when the thermal process used is slow pyrolysis and "hydrochar" in the case of hydrothermal carbonization (HTC). The main characteristics of these processes are summarized in Table 1 is important to note that pyrolysis is suitable with dry waste only since it requires heating between 350 and 600°C under inert atmosphere. Pyrolysis is usually performed at atmospheric pressure, and is associated to slow heating rate in the range of a few °C.min-^{1} as well as to long residence time of several hours. Such conditions enable to reach char yields up to 35 w% of dry biomass (Libra et al., 2011). In the case of HTC, char yield is even higher and lies in the range of 50-80 w% of dry biomass. In contrast to pyrolysis, this process has the major advantage of being suitable with wet waste, since it is typically operated between 180 and 250°C in water above saturated pressure. However, while pyrolysis is well-mastered on different scales, from very small and robust reactors to larger and more advanced ones (see an example of a unit employed in Senegal in Figure 2), HTC is still at the demonstration stage, which corresponds to a Technology Readiness Level (TRL) of 6 to 7 (see an example of a pilot specifically designed for use in developing countries in Figure 3). Noteworthy is the major influence of process conditions, as well as of feedstock used, on char physico-chemical properties such as adsorption capacity or pH (Libra et al., 2011).

Table 1. Main characteristics of char production processes

	Pyrolysis	**HTC**
Waste type	Dry	Wet
T (°C)	350-600	180-250
Gaseous atmosphere	1 bar inert	Water above saturated P
Heating rate (°C.min^{-1})	#10	#10
Residence time (hour)	1-5	1-10
Char yield (% dry weight biomass)	20-30	45-70
Maturity level	Commercial	Demonstration

Figure 2. Example of slow pyrolysis units: on the left, small unit employed in Uganda (Paing, 2015); on the right, large unit employed in Senegal (Pro-natura, 2017).

Figure 3. Example of a HTC pilot unit (Riu Lohri et al., 2013).

Char upgrading

The bio/hydrochar properties may be upgraded in order to fulfil specifications required by the different applications. The main process types are mechanical processes, as well as thermal processes, usually referred to as "activation".

Mechanical processes

Mechanical processes include pelletizing and briquetting. Both of them are well-established processes and consist in applying pressure to char, possibly mixed with binding agent such as clay. The product obtained has a defined shape, either of a cylindrical pellet with a few cm height and several mm diameter, or of a cylindrical, cubic or spherical briquette with characteristic dimension ranging from 1 to more than 10 cm (see the example of briquetting in Figure 4). This upgraded char has the advantage of being denser and uniform, which facilitates its transport, storage and further use in applications such as combustion. However, these processes require energy, which significantly increases the final product cost. It is noteworthy that briquetting seems to be more developed at the moment in Africa than pelletizing, certainly because of the low cost of this process and its suitability with small-scale units.

Figure 4. Production of char briquettes in Uganda (Inclusive Business Hub, 2017).

Thermal processes

Thermal processes mainly encompass "chemical activation" through reaction with liquids like zinc chloride ($ZnCl_2$) and "physical activation" through heating up to temperatures typically between 700-900°C in the presence of reactive gas, generally steam or carbon dioxide (CO_2). These processes enable char to develop very high specific surface area, typically of more than 1000 $m^2.g^{-1}$, and of a porous network that can go from micropores (below 2 nm) to macropores (above 50 nm) depending on the operating conditions of the treatment. The upgraded char has therefore great adsorption capacity. However, the cost of such processes leads to a significant increase of the final product cost. Moreover, such upgrading, while being quite well-mastered, is more suitable with large scale units and seems therefore difficult to include in a value chain developed at local scale – which is a priori the most favourable scale in Western Africa.

Char applications

Hereafter is given a brief overview of the principle, advantages and drawbacks as well as of the status of the different char applications.

Solid biofuel

Char can be used as solid biofuel, mainly in stoves for cooking in household and also possibly in larger boilers for further combined heat and electricity production. Char can therefore help to substitute wood charcoal used for cooking and constitute a solution to the critical issue of deforestation in Western Africa, and of environmental issues related like greenhouse gas emissions and ecosystem disturbance. Moreover, when this solid biofuel is burnt, especially in modern stoves, such as gasification ones, toxic emissions are reduced during conversion and thus the dramatic issue of household air pollution can be partly solved. Nevertheless, the high ash amount in agricultural waste compared with that in wood decreases the efficiency of such solid fuel and the high concentration in species like potassium (K) and silica (Si) may lead, mostly in the case of large combustion units, to agglomeration during burning or corrosion of the units (Vassilev et al., 2014).

Soil improving material

Char can also be used in agricultural fields as soil improving material. This application is the most popular and mature one. Adding char to soil has been found to increase crop yield, to increase water retention and to increase soil stability. Moreover, it releases carbon much more slowly than biomass left on field and thus contributes to carbon sequestration. However, at the moment, the link remains unclear between feedstock used, production process conditions and resulting char performance. Moreover, depending on crop and soil, results obtained with the same char may be either positive or negative (Jeffery et al., 2011). Another issue to be mentioned is the high char amount that is said to be required per soil volume. For instance, as illustrated in Figure 5, laboratory scale tests led to excellent results when comparing crops grown with and without biochar, but with 40 v% of char mixed with soil (Biogrow, 2017).

Figure 5. Result of a growth test led on lettuce with and without biochar in soil (Biogrow, 2017).

Water/gas filtration

Another type of application is the treatment of waste water or gases like Volatile Organic Compounds (VOC) or the hydrogen sulfide (H2S) found in the biogas from an anaerobic digester. Char may indeed be used as adsorbent in filters or as adsorbent and carrier material for pollutant bioconversion when mixed with compost in biofilters. This technique has proven its efficiency while being relatively cheap (Kanjanarong et al., 2017). However, as previously mentioned, the link remains unclear between feedstock used for char production, process conditions and performance. This is for instance highlighted in Figure 6, where three profiles of breakthrough curves can be observed for four biomass types. Moreover, the process of filtration itself still requires optimization and the issue of char regeneration should also be considered.

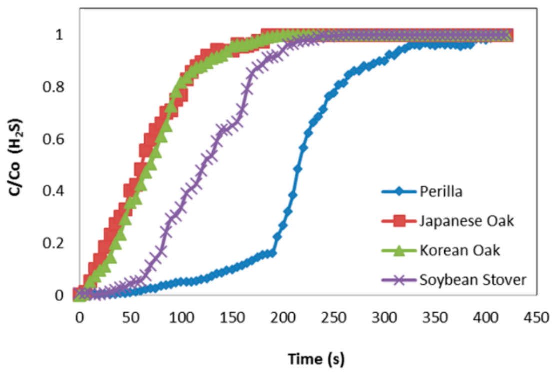

Figure 6. Breakthrough curve obtained with chars from different biomass types (Sethupathi et al., 2017)

Anaerobic digestion

A new field of application has also been recently raising interest. The idea is to use char as additive or "catalyst" in anaerobic digesters so as to enhance process efficiency. More precisely, char could increase the kinetics of CH4 production, as evidenced in Figure 7, and could also increase CH_4 yield. Such application, which is fully in line with the bio-refinery concept, could be of great interest in developing countries where anaerobic digesters tend to become widespread. However, this application is still at an early stage of research, and, even more than for the applications mentioned in the previous sections , the link is unclear between feedstock used to produce char, process conditions and resulting performance of char in anaerobic digester. Indeed, missing knowledge is not only on the link between feedstock/process conditions and char properties required, but also on the char properties required themselves, because mechanisms involving char in anaerobic digestion are poorly understood.

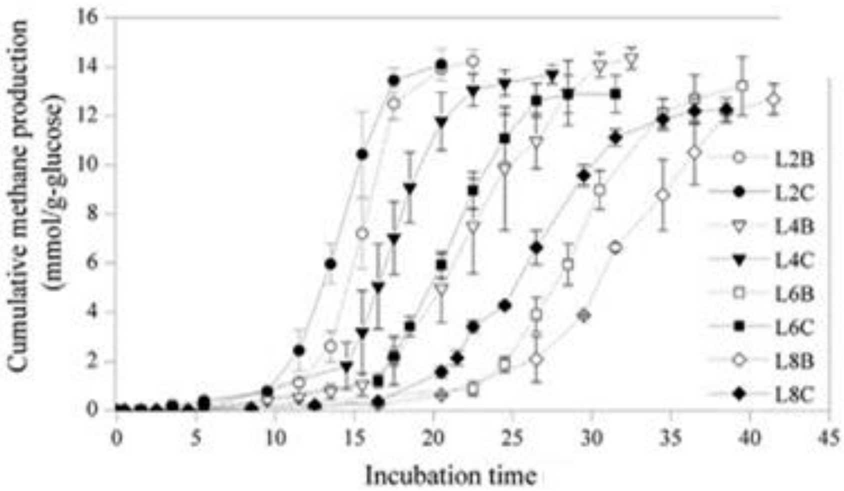

Figure 7. Kinetics of CH4 production obtained using different conditions without (white) and with (black) char added (Luo et al., 2015).

Energy storage

Char may also find application in the field of electrochemical storage. Char may indeed be used as electrode in supercapacitors and lithium (Li) or sodium (Na) ion batteries, and as catalyst or support of catalysts in fuel cell. Such applications seem very attractive because they are of very high added-value. Moreover, in the case of supercapacitors and batteries, they are related to existing markets with huge and continuous growth, notably driven by electronic devices, and their feasibility has already been proven (Deng et al., 2016), even if optimization is required. As for all the other applications, such optimization would require to understand the link between feedstock properties, in particular composition, process operating conditions, char properties and resulting performance. The development of such applications in the Western African context is however somewhat questionable because they do not fit in the concept of char local use and also because they may be seen as far from the current priority issues to be solved, like wood charcoal cooking.

Discussion, conclusions and recommendations: Issues to be solved towards large scale implementation

There have been several research studies and project initiatives aiming at moving towards the implementation of char value chain in Western Africa – always for production of solid fuel or soil improving material. For instance, one can cite two joint European-African projects, namely Bebi (Bebi, 2017), that ended in 2013, and Biocharplus, which led to the creation of the Africa Biochar Partnership in 2016 (Biocharplus, 2017). Despite these initiatives, wider implementation of char value chains in Western Africa is still limited by several technical and non-technical issues.

Technical issues

First, as highlighted above, there is a major need to understand the link between feedstock properties, process operating conditions, char properties and resulting performance in the different applications. Systematic studies that would test the various feedstock available in the different applications are still missing. Such studies would draw out correlations and thus enable i) to optimize process conditions versus feedstock and application as well as ii) to use difficult waste through feedstock blending.

In parallel, technological work should be considered in order to develop technologies suitable with the Western African context, i.e. technologies that would be in priority robust and cheap, while remaining efficient.

The issue of process byproducts recovery should also be addressed because these byproducts, mainly liquid, may constitute both sources of environmental pollution when released without control and sources of additional profitability for the process. For instance, their use in agronomy and in anaerobic digestion needs to be assessed.

Non-technical issues

Besides technical issues, one crucial aspect towards char value chain implementation is the **business model**. Two main questions should be addressed:

- First, the **actors along the whole value chain,** from feedstock to product: it is crucial to determine the actor that is willing to invest on char production and upgrading. This actor could be either the feedstock producer or the char end-user, possibly gathered in cooperatives. It is also of importance to consider the companies that would design, construct, and operate the maintenance of the char production and upgrading units. It is noteworthy that if these companies are local/national and employ local/national workers, the set-up of the char value chain would induce high indirect benefits for the local economies and as a consequence for the national economy.
- Then, in relation with the first question, the **scale and market** associated: a priori the local micro and small scales, i.e. those of household and farmer respectively, appear to be the favorable ones in Western Africa. Indeed, these scales seem to be relevant both in terms of feedstock available, i.e. the agricultural waste from farms, and of char end-uses, i.e. cooking fuel in houses, which seems to be the short-term priority, or also soil improving material in farms or gas/water treatment at the exit of digesters located either in farms or houses. Moreover, considering such scales for feedstock and end-uses implies the development of small – and possibly mobile - units of char conversion. These units are generally more robust and cheaper than larger ones, both in terms of investment and operating costs, and therefore suitable for the Western-African context. However, large scale may not be completely set aside. Indeed, such scale may be of interest in the case of feedstock like agroindustry residues, which are available in high amounts at the production plant, and of applications like power generation, which may require significant investments and thus for which the economy of scale can be important.

Another non-technical aspect that should be taken in consideration for successful implementation is **social acceptance**, especially since households are targeted end-users. A striking illustration is the failure of some trials of wood charcoal replacement by biogas cookstoves because of the poor taste of food cooked according to users. It is of great importance to **adopt a multiactor approach in projects** and to **strengthen training activities** in order to raise the awareness of stakeholders and more generally of population, notably regarding air pollution risks linked with cooking, pathogens associated to waste and opportunities of char use in this context.

Lastly, the issue of governance and role of public authorities should be taken into account. There is undoubtedly a need of funding to **support large research/demonstration projects involving public and private bodies together** and **federate efforts** that are currently existing but in a scattered way. Moreover, incentives may be seen as a tool to initiate investment by the actors identified along the value chain and therefore spreading of the solution before self-profitability is reached.

General conclusions

The char value chain based on organic waste, such as agricultural waste, appears to be highly promising in Western Africa in the perspective of the Sustainable Development Goals achievement, with at least 9 of these goals being addressed.

This in particular true because char must be seen as a plural word: it encompasses various types of materials depending on feedstock and thermal conversion process conditions used and can therefore be suitable for different applications, from very basic to more advanced ones. These various char end-uses interestingly make this material as potential contributor to solve on different scales the issues related to the Water Energy Food Nexus in an economically and environmentally sustainable way. In the Western African context, the development of the local value chain enabling substitution of wood charcoal for cooking clearly appears as a short term priority, while other local applications in agriculture to increase crop production or in combination with anaerobic digestion systems to increase methane yield or to clean biogas should not be set aside. This would logically benefit households and farmers on a local scale, as well as possible local or national engineering companies and, as a consequence, also benefit national economies.

At the moment, the implementation of these value chains implies to address several remaining technical and non-technical issues. Such issues should be solved mainly through efforts in research and development projects, demonstrations and trainings involving all the potential stakeholders along the value chain.

References:

FAO. FAOSTAT Data. (2017). Available at: http://www.fao.org/faostat/en/#home.

Libra, J. A. et al. Hydrothermal carbonization of biomass residuals: a comparative review of the chemistry, processes and applications of wet and dry pyrolysis. Biofuels 2, 71–106 (2011).

Paing, H. H. Group researches and tests clean cooking products for the developing world. (2015).

Pro-natura. Une technologie agricole innovante grâce au biochar qui augmente les rendements agricoles de manière écologique. (2017). Available at: https://www.pronatura.org/?page_id=521.

Riu Lohri, C., Robbiani, Z. & Zurbrügg, C. Hydrothermal Carbonization (HTC): A Pressure Cooker for Biowaste. Sandec News (2013).

Inclusive Business Hub. Eco-Fuel Africa: Sustainable charcoal in Uganda. http://www.inclusivebusinesshub.org/project/project-profile-eco-fuel-africa-sustainable-charcoal-in-uganda/ (2017).

Vassilev, S. V., Baxter, D. & Vassileva, C. G. An overview of the behaviour of biomass during combustion: Part II. Ash fusion and ash formation mechanisms of biomass types. Fuel 117, 152–183 (2014).

Jeffery, S., Verheijen, F. G. A., Velde, M. van der & Bastos, A. C. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agric. Ecosyst. Environ. 144, 175–187 (2011).

Biogrow. About Biochar. http://biogrow.co.nz/biochar/biochar-fertilisers (2017).

Kanjanarong, J. et al. Removal of hydrogen sulfide generated during anaerobic treatment of sulfate-laden wastewater using biochar: Evaluation of efficiency and mechanisms. Bioresour. Technol. 234, 115–121 (2017).

Sethupathi, S. et al. Biochars as Potential Adsorbers of CH_4, CO_2 and H_2S. Sustainability 9, 121 (2017).

Luo, C., Lü, F., Shao, L. & He, P. Application of eco-compatible biochar in anaerobic digestion to relieve acid stress and promote the selective colonization of functional microbes. Water Res. 68, 710–718 (2015).

Deng, J., Li, M. & Wang, Y. Biomass-derived carbon: synthesis and applications in energy storage and conversion. Green Chem. 18, 4824–4854 (2016).

Bebi. EUROPEAID - BEBI - Agricultural and environmental Benefits from Biochar use in ACP Countries. (2017). Available at: https://www.uniud.it/it/ricerca/strutture-e-competenze/progetti-1/europeaid-bebi-agricultural-and-environmental-benefits-from-biochar-use-in-acp-countries.

Biocharplus. Biocharplus: Energy, health, agricultural and environmental benefits from biochar use: building capacities in ACP Countries. (2017). Available at: https://sites.google.com/site/biocharplusproject/.

Chapter Conclusions and Recommendations

Lessons learned and best practices

1. Depending on the context, off-grid solutions to energy needs can be locally cost-effective. For example, stand-alone photovoltaic-reverse osmosis desalination for decentralized-water supply. In Spain, some farmers have opted to use photovoltaic or solar energy for irrigation pumping even while they were still on the main energy grid. However, stand-alone plants struggle with the variability of the energy source as intermittent use to meet baseload water demand requires oversizing the desalination plant compared to what would be needed under steady operation. Another situation of trade-off in the use of small-scale alternative energies, especially in the context of limited freshwater resources like on small islands, may occur between desalination for local consumption versus water pumping and irrigation.
2. **Battery storage systems and/or hybrid technologies such as solar, wind, and fossil fuel combinations can offer flexibility in meeting demand at times of unavailable supply.** At midday, when the irradiation values are at its highest, the average farm's direct electricity demand decreases, but the unused energy can be temporarily stored in a battery bank. Especially in cloudy conditions, the battery supplies additional electricity to maintain the operation and supply the farm with power, even after sunset. Should the battery storage fail to provide sufficient energy, a diesel generator could be ready as an emergency backup.
3. System assessments (for two or more securities of supply) e.g. technology scorecards that take into consideration resource requirements, economic aspects, environmental impact, human capacity requirements, technical requirements and robustness, and social-cultural criteria can help with the choice of a technology that is suited to the local conditions. For example, deployment of photovoltaic panels without considering the use water to periodically clean the panel surfaces from e.g. is a risk for the sustainability of the solution.
4. Wastewater is in steady supply and can be used to produce new water, energy or fertilizers. The ability to make better use of wastewater other than through treated wastewater is from bio-solids. These are semi-solid or liquid materials resulting from treatment of domestic sewage that have been sufficiently processed to permit these materials to be land-applied safely. The term bio-solids or digestate distinguishes high quality, treated sewage sludge from raw sewage sludge and from sewage sludge containing large amounts of pollutants.
5. A viable alternative to agricultural land-spreading of wastewater that could also improve energy efficiency of the process chain of waste management is anaerobic digestion as a means of sludge treatment and energy recovery. This has led to wastewater treatment plants becoming self-sufficient for their energy needs. Energy can be either produced on site through Combined Heat and Power technology or exported to local natural gas utilities, local industrial users or power producers, or a vehicle fleet as fuel.
6. **Turning solid waste into a resource seems to present fewer risks than wastewater. Char made from crop residues or other wet agricultural waste like manure, in particular**, can substitute wood charcoal as energy carrier for cooking in rural areas and other local-level applications for food production (as soil improving material), energy production (in combination with anaerobic digestion), or water production (as filter through cleaning).
7. Utilising existing infrastructure for additional energy production also presents a win-win situation for Nexus objectives: deployment is faster thanks to the existing road and power networks as well as the greater ease of licensing, lower investment risk and costs, including environmental. The same applies to

agricultural by-products: Existing thermal power plants are prime locations for biomass co-firing.

8. Since water scarcity became a more prominent and widespread limiting factor, the Nexus has gained traction as a water sector's concept to draw the attention of other more powerful sectors on the importance of water as the key resource for achieving all securities.
9. The first step in the development of a Nexus Project Toolkit to guide the process of identification and implementation of Nexus projects is a **quantitative analysis of the benefits of a Nexus approach on the individual sectors. Some good fit-for-purpose methodologies already exist (e.g. SEAs** or as developed by research projects[15]) that can be adopted and/or adapted to this end.

Knowledge gaps and implementation challenges

10. **There are still technological challenges associated with providing a steady supply but also storage for intermittent use for off-grid solutions**; for example, variable power input has serious effects on reverse osmosis membrane operability and durability due to unpredictability and therefore start-stop cycles or partial load operation. Presently, battery storage systems also remain very expensive and have limited life spans, followed by waste disposal challenges. Finally, **effective off-grid systems will still require institutional, economic and, to some degree, infrastructural decentralization**, which can be difficult to put in place before sustainable off-grid or micro-grid spots can be demonstrated as technically viable.
11. Focusing on off-grid solutions as part of the goal of increasing the share of renewables in the energy make-up may distract from the other crucial goal of modernising and connecting energy networks and markets. A modern, interconnected energy network can allow a greater share of energy to come from renewable sources, thus achieving national targets as set by e.g. Arab countries, and lower costs for businesses and households. It will also mean energy can be shared across regions, helping countries to better withstand outages.
12. The typically small size of off-grid solutions is suitable for energy production but not necessarily a Nexus approach. For example, solar desalination is a good example of Nexus implementation if combined with food production through greenhouses practices or similar projects. The other side of the equation is promotion of less energy-intensive lifestyles together with more efficient management practices in the agriculture and water sectors.
13. One of the most common practices for wastewater or sewage sludge disposal involves its application on agricultural land. The presence of pharmaceutical and personal care products (i.e. emerging contaminants), metals and pathogens but also minerals like salt within the effluent or sludge may contaminate soil and water bodies and end up affecting food products and, ultimately, human and animal health. Where is not for lack of regulation, quality control or market development that invariably require political mobilization and coordination of potentially fragmented institutions, social acceptance and public perception of waste will act as a barrier to adoption and use.
14. **The quality of supplied treated wastewater has to reflect the possible uses e.g. agriculture, domestic or industrial consumption**. For use in agriculture, this has also to be according to the sensitivity of the crop (for both health and agronomic reasons), the hydrologic characteristics of the project area or the soil. Through crop restriction and election of irrigation systems which minimize health risk, the degree of wastewater treatment prior to land application

[15] https://www.sim4nexus.eu/ simulates policies based on the resource constraints of an area;
http://www.wefnexustool.org quantifies the interrelations and trade-offs between the water, energy, and transportation sectors under different scenarios.

can be reduced. The presence of nutrients such as phosphate can become an advantage due to possible saving in fertilizers. However, the amount of nutrients provided by treated wastewater along the irrigation period is not necessarily synchronized with crop requirements and the availability of nutrients depends on the chemical forms.

15. In char production and application, there is a need to assess and characterize the feedstock of crop residues available. Due consideration should for example go to competition with other uses such as livestock feed, soil maintenance, and as construction materials for housing. Competition with biofuels is only with second generation biofuels that are from non-edible biomass waste. As various applications are possible with a limited feedstock, priorities need to be defined according to context and location. Climate change variabilities and extremes affecting crops can be a barrier to establishing a char value chain sustainably. On the other hand, waste which is produced from existing biomass and/or agricultural activities has a minimal environmental footprint added in terms of seasonal solar radiation and rainfall compared to alternatives. In the Arab region, liquid biofuels produced from straw or wood and biogas from anaerobic digestion of residues would be the most applicable modern bioenergy options as opposed to sources e.g. fuelwood and charcoal.

16. Consuming waste products will require active consumer's education to overcome acceptance thresholds. For char, this would be the social acceptance of switching from wood charcoal to biogas cookstoves, which taste different on food. In building the char value chain, there are also different actors and markets to involve associated with scales whether household (micro), farm (small), or agroindustry (large) that will need to be considered in planning. In connection to this kind of decision, modern energy provides opportunities for rural development, job creation and positive social impacts.

17. Change in the degree with which the Nexus approach has been taken on board and operationalized is experienced in e.g. the creation and functioning of **joint Ministries of Energy and Water. The way these are compartmentalized in the respective departments, however, still speaks to the implementation challenge. Similarly, large infrastructure projects** normally involve consultations with all sectors in this day and age, though final decisions may still end up being made by the most politically influential set of activities and priorities.

18. A challenge to the development of Nexus Project Toolkit can be to avoid emphasis on one sector. There is therefore a need for an independent function to oversee this type of process. Also, the need is perhaps greatest for any tool or capacity building to be applied at the institutional and policy level in order to bridge the gap at the science-policy interface that has to do with effective uptake but also with policy development process and commissioning of the "right research".

Areas of further research and other practical actions

19. Off-grid solutions can be an avenue for piloting both Nexus-relevant technologies and processes thanks to their flexibility due to the micro to small scale but there is a need for better assessments of impacts, such as the environmental and economic costs or even in full Life Cycle Analyses[16] as well as the implications of wider ranges of applications needed based on different types of water or energy consumption.

20. Renewable energy-based off-grid solutions have a role in supplementing fossil fuel reliance rather than representing a generic alternative to them. They have the

[16] Characteristics of the area that would need quantifying include: Water Requirement (m3), Energy Requirement (KJ), Financial Investment (Cost), Carbon Footprint (ton CO2), Land Requirement (ha), Biomass Production (ton), Self-sufficiency (%), Land Productivity (ton/ha), Land Degradation (soil health), Human Health.

potential to reduce the water used, increase food security and water availability in remote areas. Energy subsidies and other financing mechanisms can be used to promote e.g. solar-powered irrigation systems over fossil fuels and to regulate water use, such as by making payments conditional on the use of water-efficient agricultural practices. On the other hand, such subsidies could distort the benefits and costs of solar-powered systems and mask their long-term competitiveness compared with other energy sources.

21. The small size of **off-grid solutions** remains a scale that is flexible and operational. **Business models and market penetration strategies for these should be explored in more detail to look at potential opportunities beyond cost considerations.** A new business model for renewable and sustainable agriculture for e.g. the arid and semiarid regions of MENA could be accomplished by looking into nutrition, water, energy, and land values in addition to the economics of production. Market penetration of small-scale solar desalination could be increased by development of different systems, e.g. co-generation of both water and power, "Zero Liquid Brine Discharge" for combinations of reverse osmosis and thermal plants, and integration of reverse osmosis as “flexible load” in renewable-energy dominated grids.

22. One of the targets in the national energy strategies of water scarce countries often is to develop alternative and practical solutions for using non-conventional water resources, focused on the use of renewable energy in water desalination and water treatment to meet the increasing freshwater demand. Consequently, investing in renewable energies seems to make sense from a water perspective and renewable energy-based freshwater generation should be seen as a valuable economic investment that reduces external, social, and environmental costs. In this context, reduction in greenhouse gas (GHG) emissions from biogas and digestate use helps meet Nationally Determined Contributions (NDCs) under the Paris Agreement on climate change. Tools like the Energy Performance and Carbon Emissions Assessment and Monitoring (ECAM) have been developed and made openly available to enable water utilities to measure and manage their GHG emissions and energy consumptions at system-wide level.[17]

23. A certification or ecolabel for the wastewater treatment process or digestate may help with the social acceptance of utilising waste-based products such as compost. ISO guidelines already exist on treated wastewater use for irrigation projects. These provide guidance for healthy, hydrological, environmental and good operation, monitoring, and maintenance of water reuse projects for unrestricted and restricted irrigation of agricultural crops, gardens, and landscape areas using treated wastewater.[18]

24. In addition to the considerable potential for rehabilitation, life extension, upgrading and optimization of existing hydropower facilities, **existing hydraulic infrastructure provides opportunity for additional low-carbon energy generation with minimal or no extra social and environmental costs.** There is, in particular, a high potential for additional energy production by installing small hydropower facilities in irrigation infrastructures or other hydraulic circulation systems such as for municipal water supply and discharge or cooling.

25. Research on the optimization and management of multi-purpose systems, as well as on technological solutions aiming at the circularization of the energy cycle in hydraulic systems, is urgently required. A starting point for that is a better understanding of what potential exists and where. Furthermore, several technological options available and programmes are in progress in e.g. Africa, including small-hydro, seeking to improve energy access along with availability.

[17] https://www.water-energy-food.org/news/2017-09-25-tools-worlds-first-holistic-tool-to-measure-and-report-greenhouse-gas-emissions-from-urban-water-services-launched/

[18] https://www.iso.org/obp/ui/#iso:std:62756:en

26. Training and building of competence around the Nexus is important as for technical experts as for decision-makers. The strategic level needs to be aware of what the Nexus approach entails in order to enable collaboration between sectors. A less conventional approach to training, with different formats and focusing on exposure, will be more effective at the high level. At the local level, capacity building can focus on demonstrations and awareness campaigns to ensure social acceptance of Nexus solutions if needed. This can be delivered by NGOs or universities, for instance. An intermediary level will also be required to work on gathering information and data, and success stories. At this level, universities can also partner up[19] for the development and delivery interdisciplinary programmes with common Nexus modules for different sectorial curricula.

27. Interdisciplinary curricula in higher education as per the previous point can support application and use of a Nexus Project Toolkit. Some ideas for orienting such development would be to not go down directly onto technologies, but rather providing guidance on how to apply a Nexus project, how to go from cumulating pilot Nexus projects to a bigger scale, or how a Nexus approach helps countries reach their SDGs.

[19] https://www.un-ihe.org/news/launch-universities%E2%80%99-partnership-water-cooperation-diplomacy

Chapter 2. Data, Tools and Models for assessing the Nexus.

With the objective of performing an adequate intersectorial analysis in the frame of a WEFE NEXUS project is essential to previously identify the available data and tools. It is therefore important to have a standardised process for collecting and analysing data but also integrating data coming from the different WEFE Nexus sectors. Moreover, at the practical level, a wide variety of approaches, instruments and models regarding WEFE Nexus assessment and project implementation have appeared in the last years. Therefore, the first consequence of this multiplicity of new NEXUS tools is that the policy-decision makers have expressed difficulties to identify the most appropriate to address specific needs.

This chapter provides a guide with the available mainstream WEFE Nexus tools for analysing different aspects such as hydrological and agronomic modelling, energy efficiency, energy supply and demand, food production & security, economic assessment, hydro-economic modelling, institutional analysis, multi-stakeholder analysis etc. Additionally, it introduces lessons learnt regarding efficient time and spatial scales for applying Nexus projects.

In general, NEXUS experts found that the data available is generally insufficient for appropriate Nexus assessment. Consequently, there is a general need to improve data collection across the different sectors and scales. In the particular case of biophysical data where ground data is particularly lacking, remote sensing has been highlighted as a means of bridging and supplementing this gap, at least in certain thematic areas. Field surveys can also be used as ways of collecting local and traditional knowledge that would complement biophysical and socio-economic data and a way to concretise what the real issues are. This is key to supporting decision making in terms of food security, poverty reduction, sustainable basin management, and inclusive development.

The sub-themes proposed to drive the roundtable discussions for this topic were:

- The challenges to integrate or link quantitative models focusing on multiple Nexus pillars and dimensions i.e. Water, Energy, Land, Climate Change, Environment, and others;
- The trade-off between the level of sophistication of Nexus Decision Support Tools and the level of integration across scales for effective modelling and meaningful decision-making;
- The opportunities and risks of an open source approach to Nexus tools and data sharing as opposed to commercial packages and solutions;
- The importance of establishing a Nexus Cooperation Framework at multi-sectorial, country or transboundary levels from assessment to resource- or benefit-sharing agreements.

Water-Energy-Food Nexus: methodologies and data

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ABSTRACT: The Nexus approach is often presented as an evolution and improvement of the existing Integrated Water Resources Management as it promotes a multi-centric approach integrating water, energy, and food policy objectives. Being a relatively new concept and being complex due to the inter-linkages between water food and energy, the Nexus has no clear definition and no agreed conceptual framework for implementation. This paper discusses how to move from concepts to implementation detailing some of the tools and approaches used to address the Nexus along with their data requirements. We discuss the current approaches in detail, including both qualitative and quantitative methodologies used to perform WEF Nexus assessments. We show that the availability of data and their integration from different policy sectors remain a strong limiting factor in quantitative assessments of the WEF Nexus. We conclude highlighting relevant aspects to be considered when designing a WEF Nexus assessment.

Introduction

The Nexus approach is often presented as an evolution and improvement of the existing Integrated Water Resources Management (IWRM). It has gained attention in the recent years as it is multi-centric and integrates water, energy and food policy objectives (Benson et al., 2015). The Nexus approach treats food, water and energy as an interrelated system of systems (Eftelioglu, 2017), and seeks to reduce antagonism and to assess trade-offs and synergies between these three inter-linked pillars in view of a more sustainable development and use of natural resources.

By their interlinked nature, water, food and energy require integrated and transdisciplinary approaches for addressing their nexus (Sønderberg Petersen L., Larsen H.H. , 2016) across a large span of temporal and spatial scales. However, integration goes beyond the three sectors and should include social, political and governance aspects. In addition, the Nexus approach should consider trade-offs, not only across sectors but also among different users of the same sectors (Sønderberg Petersen, 2016).

In this context, data and appropriate methodologies are needed to inform on these complex inter-linkages, in the present situation and also under different future scenarios, to help policy makers in decision making. This paper discusses how to move from concepts to implementation, detailing some of the tools and approaches used to address the Nexus along with their data requirements.

Tools and methodologies for assessing the Water-Energy-Food Nexus

Being a relatively new concept and being complex due to the inter-linkages between water food and energy (WEF), the Nexus has no clear definition and no agreed conceptual framework for implementation. The term Nexus has been used extensively, however very little literature is available on concrete examples of Nexus studies.

An additional difficulty lies in the fact that the Nexus approach covers, in theory, a wide array of temporal and spatial scales ranging from local to regional, national and global, with all scales being related and impacting each other: global initiatives to combat climate change undoubtedly have an impact on local management as well as sectorial policies such as energy are usually designed at the national scale with strong implications at the local scale (e.g., hydropower and irrigation).

The existing frameworks usually propose a sequential approach to address the WEF Nexus and can be summarized as follows: 1) assessment of current status and trends; 2) assessment of the linkages to quantify trade-offs and synergies; 3) development of plausible scenarios and associated uncertainties, and identification of adaptation solutions; and 4) selection through consultation of the most appropriate interventions in terms of economic, social, environmental and governance criteria. Additional steps might include implementation and monitoring and improvement (FAO, 2014; Bizikova et al., 2013).

The existing tools used in WEF studies address one or many of the steps described above. Sønderberg Petersen et al. (2016), based on Granit et al. (2013), classify the tools used in Nexus assessments into four categories listed below in order of increasing data requirements:

- qualitative indicators based methods;
- hydro-economic modelling;
- integrated Water-Energy-Food Nexus; and
- operational systems.

Differently, Endo et al. (2015) used a simplified classification schemes limited to qualitative and quantitative assessments tools. Following this classification scheme, we discuss here the most common tools used in WEF Nexus assessments while describing the different methodologies, data requirements and temporal and spatial scales of application (Figure 1). Most of the tools in use are based on System Thinking (Reynolds and Holvell, 2010) which is an approach that helps understand the non-linear behavior, linkages and interactions of complex systems, and provide information to support decision-making.

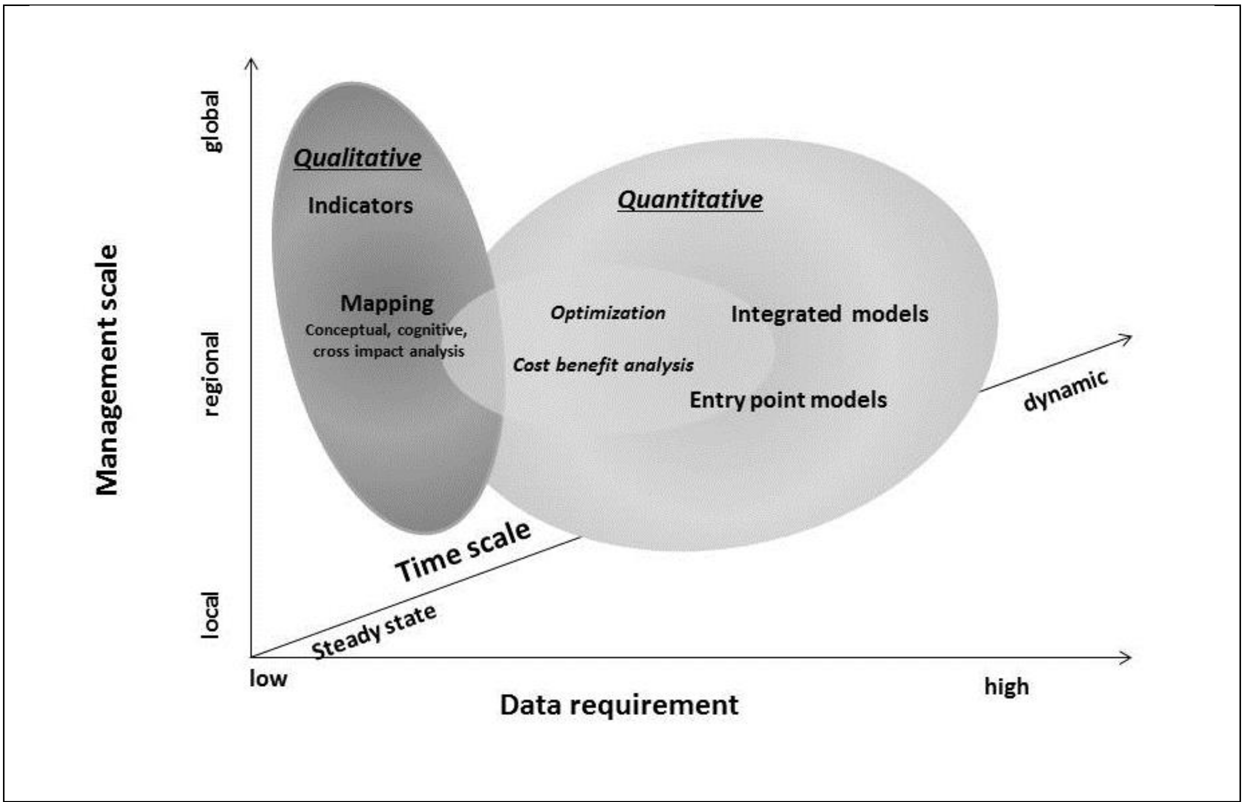

Figure 1. Classification of tools used in WEF Nexus assessments

Qualitative approaches

Qualitative approaches are used in the FAO Nexus Assessment Framework as a mean to layout the context of the analysis to understand the priorities, and the environmental, economic and societal trade-offs. They often rely on describing and mapping the system through interaction with various stakeholders. The mapping consists of nodes, which represent the different concepts that describe the behavior of the system, and arcs, which represent the relationship between any two nodes and the attributes which include the strength and direction of the relationship. Using such a cognitive model, one can simulate the effects of possible actions considering the perceived influences between the different elements of the system.

Endo et al. (2015) also used locally Ontology Engineering that is defined as formal representations of a set of concepts within a domain and the relationships between those concepts. The result can be a conceptual map that can be used to identify the problem to be addressed. Fuzzy cognitive mapping "draws a causal picture. It ties facts and things and processes to values and policies and objectives" (Kosko, 1986).

Questionnaire surveys have also been used to assess how local population's security is affected due to natural or social shocks. For example, Endo et al. (2015) developed the questionnaire on the WEF system using the concepts of accessibility, utilization and management. They found the questionnaire useful in deriving knowledge on the local population economic, livelihood and food security under various WEF scenarios. A similar approach could be used at macro-region levels where questionnaires could be filled by experts panels, stakeholders etc. to derive a set of global indicators.

Cross impact analysis has also been used to analyze the dependencies and interdependencies among sectors in order to predict plausible scenarios of the future. This approach relies on expert panels that are asked to derive probabilities and conditional probabilities of occurrence (impact) of events. For instance the Transboundary Waters Opportunity Analysis (Philips et al., 2008) was developed to promote a sustainable and equitable use of water resources, and identify opportunities for development opportunities. The analysis is matrix based and uses four key development opportunities, namely: i) hydropower and power trading, ii) primary production, iii) urban and industrial development, and iv) environment and ecosystem services as well as two categories of freshwater sources (surface and groundwater). The approach consists in identifying potential benefits at the basin level that are then analyzed by all riparian countries to select win-win solutions.

Finally, Daher and Mohtar (2015) have proposed an approach based on indicators. They developed the Water-Energy-Food Nexus Tool that combined resources indices (ratio of required resources and allowable capacity) including water, land, energy, carbon, financial into a sustainable indicator that should support decision makers in their choice of the most appropriate scenario.

Quantitative approaches

FAO, in its conceptual framework, adopts quantitative assessments for scenario analysis, for instance to evaluate the impact of alterative scenarios of intervention. Quantitative methods can also be used to assess actual status in order to identify priorities.

Quantitative approaches are usually more data intensive than qualitative approaches. However, data requirements are also controlled by the scale of application. Global issues require large scale dataset, while local problems require intensive local data collection in order to adequately capture the local reality.

Most of the available quantitative models usually focus on one or two of the Nexus pillars (Miralles-Wilhelm, 2016), and often do not include external factors impacting the water, energy and water sectors, such as land use, demography, or environmental protection making their use for policy option selection rather limited. Indeed the translation of modelling studies in the Nexus context into policy decision is limited. A list of some of the tools currently in use for WEF Nexus assessments is given in FAO (2014) and IRENA (2015).

In our classification (Figure 1), we distinguish as reported by IRENA (2015) between entry point models that assess the influence of one sector onto the other sectors, and fully integrated models that consider the bi-directional interactions between all sectors. Integrated models explicitly represent, with a wide range of complexity, the mechanisms and the processes and feedbacks involved in water, food, and energy cycles. The complexity stems not only from the description of the processes, but also from the spatial and temporal representation of the system boundaries (Bouraoui and Grizzetti, 2014). Integrated physical models are then often associated to an economic module and linked to optimization and cost-benefit analysis tools to evaluate the sustainability of alternative scenarios and also define efficient resource allocation strategies.

Few attempts have been made to address the WEF Nexus by integrating different pieces of software such as CLEWS (Howell, 2013), which puts together the energy model (LEAP), the water model (WEAP) and the land-use model (AEZ). In CLEWS, interactions between the three modules are managed by exchanging data in an iterative manner. The model is semi-spatially explicit with simplified representations of the water cycles and crop growth. Other integrated approaches such as CGAM provide spatially aggregated quantifications of the WEF Nexus. The Pacific Northwest National Laboratory developed the PRIMA (Platform for Regional Integrated Modeling and Analysis) to simulate the complex interactions among climate, energy, water, and land at decision-relevant spatial scales. However, most of the applications so far have focused on the water-energy Nexus and water-food Nexus, and these studies usually remain in the scientific sphere and are not implemented at the policy- or decision- making level (Leck et al. 2015).

Efforts have also been made to link integrated physical model with optimization techniques for water allocation purposes or identification of the most appropriate water saving measures (i.e., hydro-economic modelling). For instance, Udias et al. (2016) linked the water resources model LISFLOOD with a multi-criteria optimization model to assess spatially explicit combinations of measures, which could help reduce the gap between water demand and water availability while taking into account ecological, water quality, flood risk and economic aspects in the Danube River Basin. Pastori et al. (2015) used a multi-objective optimization approach to identify optimum crop and land management patterns in different African countries. They provided trade-off alternatives that maximize crop production by choosing the adequate crop, fertilization, and irrigation management sequences while limiting the impact on the environment. Cost benefit analysis and optimization techniques have also been used along with qualitative approaches to support stakeholder choices among different alternatives and also, for instance, in the selection of appropriate weights when combining different indicators.

Data constraints

Several tools as described before have been developed and used in the context of the WEF Nexus. However, our understanding and representation of the interactions and trade-offs are often limited by data availability, collection and management (Eftelioglu et al. 2017). Indeed data are the foundation for validating and improving the model (Wolfe et al., 2016). Eftelioglu et al. (2017) list limited observability and accounting of the interactions between the resources, computational requirements and lack of organized and harmonized data-sharing protocols as severe limitations to our in-depth understanding of the WEF Nexus. Similarly, IRENA (2015) points out the difficulty in gathering relevant data due to the cross-sectorial and multi-scale nature of the Nexus.

Most of the data available are usually focused on one sector, with however a few attempts to capture some of the inter-connections with other sectors: water use in irrigation for instance. However, most of the data fail to encompass a comprehensive overview of the inter-linkages. This is where a large effort is still to be undertaken. In addition, data on water, energy and food sectors are also collected under different institutions or departments according to the priorities and objectives of the respective sectorial policies, and often at different spatial and temporal scales that hamper an easy harmonization. Furthermore, a rigorous assessment of the WEF Nexus requires collecting data in the long term as so to use these time series to understand if the data (including measurements, model predictions, trends, and projections) alongside its derived indicators and results change coherently with the relative management decisions and interventions so they can be used routinely for assessments and evaluation.

It is also of key importance to integrate uncertainty when collecting data. Indeed, data is collected to represent the past or the near present. Extrapolating data to predict trends and trajectories requires the integration of uncertainties in projections. Uncertainty is also embedded in the measured data used to represent the baseline or past assessments, and it is also present when resulting from model predictions (climate change, for instance). All these uncertainties need to be recognized, quantified and incorporated in the assessments to increase the reliability and acceptability of the Nexus assessments.

Data acquisition and accessibility is recognized as the limiting factor to a successful implementation of the WEF assessment, and convergence thinking has been proposed to overcome discipline boundaries and integrate knowledge from the physical, biological, social, economic and mathematical sciences (Wolfe et al., 2016). Comparability of data across sectors is challenging due to the lack of harmonized protocols to gather, share and interpret the information. As part of its Nexus Platform, UNU-FLORES advocates a harmonization of data collection protocols and access to complete data, and calls for a unified monitoring framework (UNU-FLORES, 2015). To facilitate the exchange of data and information across disciplines, an integrated data management framework is needed. This framework should allow assimilation of data from different spatial representation starting from a commonly agreed metadata. An additional limitation to data sharing is linked to proprietary and confidentiality issues (McCarl et al., 2017). Data gaps need to be determined and models are a natural alternative for identifying additional data requirements. Prospective analysis will also be needed to generate data about future technological developments and how these can be assimilated by the current tools.

Conclusions and recommendations

Moving from the concept to the implementation of the WEF Nexus in river basin management is challenging. A holistic conceptual framework is needed to describe the inter-linkages between water, energy and food, and appropriate quantification tools that consider the multiple spatial scales involved in the scope of the impacts of the actions, from local to regional to global (and transboundary for water issues). This is in part addressed by the qualitative and quantitative approaches discussed here. The availability of data and their integration from different policy sectors remains a strong limiting factor in quantitative assessments of WEF Nexus, especially in countries lacking sufficient investments on data infrastructures. Important advances in this regard might be represented by satellite data, citizens' participation in data collection or automated sensors in monitoring. Importantly, the WEF Nexus should include stakeholders in the analysis of inter-linkages and impacts. This involves considering interdisciplinary and transdisciplinary analysis, that should be reflected in the data, tools and expertise deployed in a WEF Nexus assessment. Impacts on the environment at the local, regional and the global scales should be embedded in WEF Nexus assessments as well as issues related to inequalities in the distribution of impacts. The ecosystem services approach (de Groot et al. 2010) could be useful in this regard to understand the effects of policy actions on different perspectives, including the analysis of beneficiaries, and also to help translate the results of WEF Nexus assessments to policy makers and people.

Based on these considerations, we can formulate the recommendation to consider the following aspects when designing a WEF Nexus assessment and choosing the methodology for quantification:

- data availability,
- temporal scale and the spatial scale of impacts,
- stakeholder involvement,

- impacts on ecosystems at the local, regional and global scale,
- inequalities in the distribution of impacts on people's well-being,
- interdisciplinary attributes of experts and tools, and
- communication needs in translating results to policy makers and people.

By integrating objectives from different sectorial policies, assessments based on Nexus approach and methodologies result particularly appropriate for achieving the SDGs taking into account the complex interlinkages between the different goals.

References:

Benson, D., Gain, A. K., and Rouillard, J. J. (2015). Water governance in a comparative perspective: From IWRM to a 'nexus' approach? Water Alternatives, 8, 756–773.

Bizikova L, Roy D., Swanson D, Venema H.D., McCandles M. (2013). The Water–Energy–Food Security Nexus: Towards a practical planning and decision-support framework for landscape investment and risk management. IISD report, February 2013.

Bouraoui, F., Grizzetti, B. (2014). Modelling mitigation options to reduce diffuse nitrogen water pollution from agriculture. Science of the Total Environment, 468-469, 1267-1277.

Daher B.T. & Mohtar R.H. (2015). Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making, Water International, 40:5-6, 748-771.

de Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7, 260-272.

Eftelioglu E., Jiang Z., Tang X., Shekhar S. (2017). The Nexus of Food, Energy, and Water Resources: Visions and Challenges in Spatial Computing. In Griffith D., Chun Y., Dean D. (eds) Advances in Geocomputation. Advances in Geographic Information Science. Springer.

Endo, A., Tsurita, I., Burnett, K., Orencio, P.M., 2015. A review of the current state of research on the water, energy, and food nexus (2015) Journal of Hydrology: Regional Studies, 11, 20-30.

FAO (2014). Walking the Nexus talk: Assessing the Water-Energy-Food Nexus in the context of the sustainable energy for all initiative environment and natural resources. Working Paper No. 58 – FAO, Rome.

Granit, J.; Fogde, M.; Hoff, H.; Joyce, J.; Karlberg, L.; Kuylenstierna, J.; Rosemarin, A. Unpacking the Water-Energy-Food Nexus: Tools for Assessment and Cooperation along a Continuum. In Cooperation for a Water Wise World—Partnerships for Sustainable Development; Report Nr. 32,45–50. Stockholm International Water Institute: Stockholm, Sweden.

Howell M., et al., 2013. Integrated analysis of climate change, land-use, energy and water strategies. Nature Climate Change 3, 621–626.

IRENA, 2015. Renewable Energy in the Water, Energy, and Food Nexus. International Renewable Energy Publication, Abu Dhabi.

Kosko B. (1986). Fuzzy Cognitive Maps. International Journal of Man-Machine Studies. 24, 65–75.

Leck H., Conway D., Bradshaw M., Rees J. (2015). Tracing the Water–Energy–Food Nexus: Description, Theory and Practice. Geography Compass, 9, 445–460.

McCarl B.A., Yang Y., Schwabe K., and Engel B.A. (2017). Modeling and Data for WEF Nexus Analysis: A Review of Issues. FEW Nexus Workshop on Integrated Science, Engineering, and Policy: A Multi Stakeholder Dialogue January 26 -27, 2017, College Station Texas.

Miralles-Wilhelm, F. (2016). Development and application of integrative modeling tools in support of food-energy-water nexus planning—a research agenda. Journal of Environmental Studies and Sciences 6: 3.

Pastori, M., Udías, A., Bouraoui, F., Aloe, A., Bidoglio, G. (2015). Multi-objective optimization for improved agricultural water and nitrogen management in selected regions of Africa. International Series in Operations Research and Management Science, 224,. 241-258.

Phillips, D.J.H., Allan, J.A., Claassen, M., Granit, J., Jägerskog, A., Kistin, E., Patrick, M., and Turton A. (2008). The TWO Analysis: Introducing a Methodology for the Transboundary Waters Opportunity Analysis. Report Nr. 23. SIWI, Stockholm.

Reynolds M., Holvell S. (2010). Systems Approaches to Managing Change: A Practical Guide. Springer.

Sønderberg Petersen L., Larsen H.H. (eds) 2016, DTU International Energy Report 2016: The Energy-Water-Food Nexus - from local to global aspects. Technical University of Denmark (DTU).

Udias, A., Gentile, A., Burek, P., De Roo, A., Bouraoui, F., Vandecasteele, I., Lavalle, C., Bidoglio, G. (2016). Multi-criteria framework to assess large scale water resources policy measures. Water (Switzerland), 8, 370.

UNU-FLROES (2015). Nexus Observatory Platform. https://nexusobservatory.flore.unu.edu/ Last access 02/10/2017

Wolfe, M.L., Ting, K.C., Scott, N. et al. (2016). Engineering solutions for food-energy-water systems: it is more than engineering. Journal of Environmental Studies and Sciences 6, 172-182.

Tools for Water Security Contributing to WEFE Nexus

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ABSTRACT: The UNESCO International Hydrological Programme (UNESCO-IHP) contributes to dealing with complex interlinkages, and rapid environmental and demographical pressures through holistic, transdisciplinary and environmentally sound approaches to water resources management in line with water-related and sustainable development international agendas. The need for reliable information to successfully deal with complexity in managing water has led to the development and promotion of a number of tools and methodologies. These combine various types of data that harness Information and Communications Technology (ICT) as well as modelling to address water security challenges and tentatively the WEFE nexus. They include, among others, the deployment of hydro-climate monitoring systems in Latin America and Africa, capacity building for flood warning and management in Pakistan and Afghanistan, and climate risk management in urban areas. To address these challenges, the UNESCO-IHP launched its Water Information Network System (IHP-WINS) in January 2017. IHP-WINS is an open-access, data- and knowledge-sharing platform for water-related issues at all levels, and is freely available to UNESCO Member States and all other water stakeholders. UNESCO-IHP promotes open access to innovative, free and open-source software and applications for water management, particularly for partners in developing countries. The different examples presented in this paper show how integrating various data sources, ICT and hydro-climate modelling can provide enabling tools for achieving water security that also contribute to identifying and implementing WEFE Nexus opportunities.

Background

In many regions of the world, changes in precipitation and melting of snow and ice are altering hydrological systems and consequently affecting water resources in terms of quantity and quality (IPCC, 2014). Despite the fundamental value of freshwater to public health, agriculture, industry, prosperity and security, challenges related to water scarcity, pollution, poor sanitation and water-related disasters confront billions of people worldwide. Almost half of the world's population will be living in areas of high water stress by 2030.

Currently and globally, approximately 80% of the world's population already suffer serious threats to its water security, as measured by indicators covering the different criteria of water availability, accessibility, safety and quality and management, and therefore including water quantity, water demand per need or pollution. Still nearly a billion people do not have proper access to safe water and 2.5 billion to safe sanitation (UNESCO/WWDR, 2017). From those enjoying these services, more than 60% do not have a proper and reliable service due to intermittent supply. About 500 million people live in areas where water consumption exceeds the locally renewable water resources by a factor of 2 (Mekonnen and Hoekstra, 2016).

Water-related risks will further increase as a result of growing climate instability, population growth and forced migration; all of which will put additional pressure on the water resources of both the host and neighbouring countries. One of the greatest challenges for the hydrological community is to identify appropriate and timely adaptation measures in this continuously changing environment, and establish sectorial interlinkages towards achieving the Sustainable Development Goals (SDGs) and targets under the Paris Agreement and the Sendai Framework for Disaster Risk Reduction.

UNESCO's International Hydrological Programme (IHP) has long been implementing projects related to knowledge generation and capacity building for water security under global changes, including climate variability and change, population growth, urbanization and economic development. The IHP is in particular studying the impacts of global change on water resource systems, including ways to enhance resilience to climate-related disasters, and address both urban and rural water needs. To successfully deal with complexity in water management, tools and methodologies combining various types of data that harness Information and Communications Technology (ICT) as well as modelling were developed, and are being promoted and implemented. These include the deployment of a hydro-climate monitoring system in Latin America and Africa, capacity building for flood warning and management in Pakistan and Afghanistan, climate risk management in urban areas, and the Water Information Network System.

Hydro-climate monitoring for improved water management and food security in Africa and Latin America

Through its initiatives related to hydrological changes, UNESCO-IHP supports countries in identifying and addressing their information gaps and needs when it comes to managing the risks resulting from the changing hydrological and climatic impacts. It does that by strengthening global, regional and local capacities and by providing access to data and policy recommendations for more integrated hydro-climate risk management. To that effect, UNESCO-IHP supported the development of an integrated flood and drought monitoring and forecasting system for Africa and Latin America (Verbist et al., 2016). The system (http://stream.princeton.edu/) developed by the University of Princeton in the United States combines remote-sensing data on precipitation, vegetation and atmospheric analysis with macro-hydrological modelling through the use of a Variable Infiltration Capacity (VIC) land-surface hydrological model (Liang et al., 1994). The system tracks hydrological conditions including extremes (e.g. floods and droughts) in near real time and allows medium-term and seasonal forecast. It therefore provides monitoring capabilities for meteorological, hydrological and agricultural drought and flood conditions which is particularly useful in developing regions where institutional capacity for monitoring and early warning is generally lacking and access to information and technology prevents the development of such systems locally. In addition, the system has the advantage of providing a standardized format for any of the components of the water balance, thus enabling a comprehensive analysis of drought and flood hazards at local, national and regional level. In essence, the system provides information on precipitation, temperature, radiation and wind speed, drought indicators (i.e. Standardized Precipitation Index - SPI, soil moisture, Normalized Difference Vegetation Index - NDVI, evapotranspiration) and flood indicators (i.e. surface runoff and streamflow). The information can be obtained either spatially or for point locations, for specific dates, months or annual timescales, and is compared with the normally expected conditions or percentiles. The system was successfully deployed in Western, Eastern and Southern Africa combined with training of experts and is used as a complementary information system by regional institutions to monitor agro-hydro-meteorological conditions particularly during the rainy seasons.

Similarly, UNESCO-IHP has collaborated with the Centre for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine, on the development of tools to provide near real-time global satellite precipitation estimates at high spatial and temporal resolutions, including the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Cloud Classification System (PERSIANN-CCS) (Hsu et al., 2010). This specific system provides essential information for emergency planning and management of hydrological risks, such as floods, droughts, and other extreme weather events. For example, the Namibia Hydrological Services (NHS) uses this system to prepare daily bulletins with information on flood and drought conditions for local communities. The system is now available through the iRain mobile application, specially designed to facilitate people's involvement in collecting local data for global precipitation monitoring (http://en.unesco.org/news/irain-new-mobile-app-promote-citizen-science-and-support-water-management). iRain allows users to visualize real-time global satellite precipitation observations, track extreme precipitation events worldwide, and report local rainfall information using a crowd-sourcing functionality to supplement this data and also provide ground information which can improve remote sensing precipitation estimations.

Key findings

In developing and low-income regions such as Latin America and Africa, data needed for implementation of drought monitoring systems are scattered over multiple agencies that are dependent on different ministries. This requires collaboration across ministries through a multi-sectorial approach, which often cannot be effectively implemented without direct support from high-level policy makers. Monitoring and early warning systems require combining data sources from national weather and hydrological services, agricultural extension services and public databases as well as data streams from international partners providing remote sensing datasets to fill data gaps and global/regional weather and climate model outputs. The challenge of this approach is that it requires technological solutions that allow the integration of multiple data sources with different temporal and spatial resolutions. An additional challenge is that these sources often have a complex data structure and data exchange formats that need to be treated to allow their integration in a seamlessly working system.

Drought Vulnerability Atlas and Observatory in Chile and Peru

In close collaboration with the Chilean Ministry of Agriculture, the Food and Agriculture Organization (FAO) and the International Research Institute for Climate and Society (IRI), the Chilean Agroclimatic Observatory system (www.climatedatalibrary.cl/UNEA/maproom/) was launched in June 2013. A similar observation system was developed in collaboration with the Autoridad Nacional del Agua (ANA) in Peru in 2014 (http://ons.snirh.gob.pe/Peru/maproom/). These systems allow for the creation of integrated indices, taking into account a number of different drought indicators. The systems build upon the Climate Data Library (CDL), a tool that allows the collection of all raw databases of national and international institutions relevant to drought monitoring (Del Corral et al., 2012). Data of numerous formats can be added, with which additional indicators can be calculated using advanced arithmetic or geo-statistical functions. In order to provide effective decision-support tools, a user-friendly interface was built on top of the CDL, called the "maproom", which holds relevant drought indices on meteorological, hydrological and agricultural drought, and combines information from national and international datasets.

Support was also provided by UNESCO for the development of an (agricultural) drought vulnerability atlas for Chile, focussing on vulnerability of rural communities, using indicators related to agricultural production and rural poverty (i.e. Sensitivity, Exposure and Adaptation Capacity) and covering socio-economic, biophysical and institutional aspects. In order to provide an objective and actionable drought index, information from meteorological, hydrological and agricultural drought indicators were integrated into a Combined Drought Index (CDI) for Chile, which was based upon the CDI developed for the European Drought Observatory (Sepulcro-Canto et al., 2012). Three standardized drought alert phases have been defined by their drought intensities. The standardizing of these alert phases for the whole of the country allows for an implementation of a more objective drought management response.

Key findings

The development of a national drought observatory in Chile and Peru provided an example of how to build a system to support integrated risk management decisions related to the WEFE nexus. By gathering all relevant national actors around the table to share data and information, the observatories have seen a continuous expansion from a purely drought focus to include indicators of agricultural crop failure risk and hydropower generation evaluation in real time. It has also driven the need to identify socio-economical drivers of drought vulnerability, which often include environmental aspects such as water quality. As such, the observatories are a key contributor to effective (drought) risk management polices related to the WEFE nexus and also highlighted in the Sendai Framework and the SDGs.

Strengthened Capacity for Flood Warning and Management in Pakistan

Following the devastating 2010 floods in Pakistan, UNESCO successfully implemented, in partnership with Japan International Cooperation Agency (JICA), a major project enhancing capacity on flood warning and management. The objectives of this project were to reduce human and socio-economic impacts of floods in Pakistan, while improving the social, economic, and possible ecological benefits from flood activities and fostering safer human settlements near floodplains. A new flood forecasting and early warning system for the Indus River was developed, enabling the use of satellite-based rainfall observation data to complement the limited capacity of the ground observation system in Pakistan. A new model was developed for the Lower Indus area affected by the 2010 floods that has enabled Pakistani agencies to conduct flood inundation analysis and develop hazard maps. Following expansion of the model to the Eastern Rivers (Jhelum, Chenab, Ravi and Sutlej), a prototype of the current unified Indus Integrated Flood Management System (Indus-IFAS) (http://www.icharm.pwri.go.jp/research/ifas/) covering the whole Indus River Basin was delivered. The technical capacity of more than 1,000 experts from various agencies in Pakistan was enhanced for flood management forecasting, early warning and flood hazard mapping and analysis. Strengthened cooperation with other Indus river basin countries (i.e. Afghanistan, India and China) for transboundary flood management and data sharing was also promoted by UNESCO.

Key findings

The establishment of a multi-stakeholder platform comprising partners dealing with flood management was critical. Training programmes on flood management for officials and experts from Afghanistan were mainly provided by Pakistani officials and experts. This was the first case of this type of exchange in the region, and has helped strengthen cooperation between experts of the two countries.

Climate risk management within urban areas

According to the UN, 54% of the world's population lives in urban areas, a proportion that is expected to increase to 66% by 2050. It is projected that 2.5 billion people will be added to urban populations by 2050, 90% of which will be in Asia and Africa (UN, 2014). In 1990, there were ten "megacities" (cities with ten million inhabitants or more), which were home to 153 million people or slightly less than 7% of the global urban population at that time. As of 2014, there are 28 megacities worldwide; home to 453 million people or about 12 percent of the world's urban dwellers. and by 2030, the world is projected to have up to 41 Megacities (UN, 2014).

Megacities exert significant pressure to water resources located well outside their spatial coverage, covering quite often more than the river basin they are located in (e.g. Mexico City). This requires substantial amounts of energy. The rapid accumulation of people in these metropoles will translate into furthering the challenge of providing water and sanitation related services from both a water resources and an energy point of view.

Smart water management employ ICT technology to enable urban water systems to be designed, controlled and maintained in a way that allows optimization of water quantity, water quality and the water energy footprint. By employing various sensors (pressure, element related etc.) and automated systems (SCADA etc.), leaks can be identified rapidly minimizing the loss of the valuable resource and the quality of water can be guaranteed to the last client at the end of the water supply system.

UNESCO-IHP has been spearheading work on Smart Water System technologies in efforts to contribute tangible solutions to the WEFE nexus, including raising awareness around these, training experts and disseminating examples from pilots that may be replicated in other Megacities. Through its work on 'Urban Waters', UNESCO has developed knowledge materials (see the Urban Water Series: https://en.unesco.org/uwmp/resources#Urban) that address the present challenges faced by cities worldwide. Through the publication of a monograph on water in 15 emblematic Megacities, UNESCO has shared best practices to adapt to climate change and reduce the water and energy footprint in cities globally.

UNESCO is also working on the establishment of a collaborative platform to support Megacities on adapting to or mitigating the effects of climate change related to water. In addition to learning from each other's experience and exchanging best practices, participating Megacities will need to partner with the right technical, academic, and financial institutions, and design and implement their individual responses to the challenge. The platform (www.eaumega.org) will be using IHP-WINS as a knowledge-sharing tool for its implementation.

Key findings

Technologies and systems for smart water management need to be identified and made available through wide dissemination among cities' water utilities, particularly in developing countries. It is important to look at the interlinkages of energy and water footprints in both water supply and energy production and at relevant policies to develop that can promote these smart technologies and systems to reduce the footprints. It is important also to promote establishment of platforms for knowledge production, exchange and dissemination as demonstrated by the next example.

Water Information Network and Promotion of Water Free Open Access Software

IHP's Water Information Network System (IHP-WINS) provides an open-access, knowledge-sharing, online platform, which was launched in January 2017 (UNESCO, 2017a). The platform is made available for free by UNESCO-IHP to UNESCO Member States, all other water stakeholders, partners and individuals. It aims at facilitating access to knowledge, while users are encouraged to share data. As a result, the platform is continuously enriched with new data and information coming from various sources. In particular, IHP-WINS allows for sharing and access to water-related GIS data at various scales, which users can combine to create maps tailored to their needs (Figure 1). By superimposing information on the spatial extent of transboundary aquifers and groundwater pollution risk, transboundary resources potentially at risk can quickly be identified. From this approach, areas where cooperation between states for water management should be encouraged can be developed. Transparency and respect of authorship is guaranteed and all information provided benefits from metadata in a standardized format. The latter format embeds a Digital Object Identifier (DOI), which allows for an accurate identification and crediting of any contribution. The platform also aims at stimulating inter-disciplinary collaboration, professional networking and mentoring through working groups where users can exchange and provide feedback on their's and other's ongoing work. By gathering global and inclusive knowledge on water, and by facilitating interdisciplinary collaboration, the overall aim of IHP-WINS is to support UNESCO Members States and other stakeholders involved in water resources management. Additionally, due to its open-access nature, the platform also contributes to closing the gap between North and South, urban and rural areas and high and low income regions in terms of access to knowledge. Finally, the initiative contributes to the follow-up by the UNESCO Members States and the United Nations custodian agencies on the monitoring and implementation of the targets of Sustainable Development Goal 6 (SDG 6) and those of other water related goals.

Continuing work on the reduction of the digital divide between developed and developing countries, UNESCO-IHP launched the HOPE Initiative in June 2013. This Hydro-Free and Open-source Platform of Experts aims to promote the use of Free and Open-Source Software (FOSS) and applications (UNESCO, 2017b). It provides a new approach to research that is more integrative, international and solutions-oriented. HOPE links high-quality focused scientific research to new policy-relevant interdisciplinary efforts for global sustainability based on the use of FOSS. In partnership with 18 universities, centres and other organizations, UNESCO is also collaborating on FREEWAT (FREE and open source tools for WATer resource management project), that is promoting an innovative participatory approach gathering technical staff and relevant stakeholders, including policy and decision makers, to jointly design scenarios for the proper application of conjunctive water policies (FREEWAT, 2017).

Key findings

Accurate information on the trends of countries' water resources is required as a basis for economic and social development, and for maintaining environmental quality. In every sector of economic activity, planning, development and operation require water-related information. With many competing uses and a finite amount of water, water resources need to be managed as effectively as possible, allowing for enough water, of sufficient quality, for everyone including the environment. To make sound decisions, decision-makers and other stakeholders rely increasingly on reliable, accessible data and free water information systems.

Discussion, Conclusions and Recommendations

Evidence based, inclusive decision making and a smarter way to use and share information is greatly needed to address the complex interlinkages within the WEFE nexus and the SDGs. This requires integration of various sources and types of data and modelling to provide sound, actionable scientific information. Cooperation among stakeholders and decision makers from various sectors is also necessary. The examples presented in this paper highlight the critical contribution of filling the data and knowledge gap to achieve a better understanding of the interlinkages that are indispensable for effective decision making. The examples also highlight the importance of ICT, smart water technologies, and modelling in helping to address the need for filling the data gaps and data integration from various sources and types as well as the critical importance of cooperation between different sectors. The role of water information network systems such as WINS allowing for the integration of various data layers, and sharing and exchanging of data and information, is paramount. It is also important to set up and actively use a multi-stakeholder platform to facilitate dialogue and inclusiveness in order to better address issues and themes such as the WEFE nexus and SDG implementation challenges. Open source and free ICT related tools are recommended particularly for developing countries. Finally, building the capacity of both decision makers and technical agencies in charge of collecting, processing and managing data, by equipping them with relevant and easy access tools, is indispensable.

References:

Del Corral, J., Blumenthal, M., Mantilla, G., Ceccato, P., Connor, S. and Thomson, M. (2012). Climate information for public health: the role of the IRI climate data library in an integrated knowledge system Geospatial Health, 6(3), 15.

FREEWAT (2017) Free and Open Source Software Tools for Water Resource Management. Retrieved October 28, 2017, from http://www.freewat.eu/).

Hsu, K., A. Behrangi, B. Iman, and S. Sorooshian (2010). Extreme precipitation estimation using satellite-based PERSIANN-CCS algorithm. Satellite Rainfall Applications for Surface Hydrology, M. Gebremichael and F. Hossain, Eds., Springer, 49–67.

IPCC, 2014: Fifth Assessment Report on climate change.

Liang, X., Lettenmaier, D. P., Wood, E. F. & Burges, S. J. (1994). A simple hydrologically based model of land surface water and energy fluxes for general circulation models. Journal of Geophysical Research, 99(D17), 14415–14428.

Mekonnen and Hoekstra, 2016: Four Billon people facing severe water scarcity, Science Advances 12 Feb 2016:Vol.2, no.2

Sepulcre-Canto, G., S. Horion, A. Singleton, H. Carrao, and J. Vogt. (2012). Development of a Combined Drought Indicator to detect agricultural drought in Europe. Natural Hazards and Earth System Sciences, 12, 3519-3531.

United Nations, Department of Economic and Social Affairs, Population Division, World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352

UNESCO (2017a) Welcome to the Water Information Network System by the International Hydrological Programme of UNESCO. Retrieved October 28, 2017, from http://ihp-wins.unesco.org/).

UNESCO (2017b) HOPE initiative: Hydro Free and Open-source Platform of Experts. Retrieved October 28, 2017, from https://en.unesco.org/hope).

UNESCO/World Water Development Report, 2017: Wastewater: A resource.

Verbist, K., A. Amani, A. Mishra, and B.J. Cisneros. 2016. Strengthening drought risk management and policy: UNESCO International Hydrological Programme's case studies from Africa and Latin America and the Caribbean. Water Policy, 18 (S2) 245-261; DOI: 10.2166/wp.2016.223.

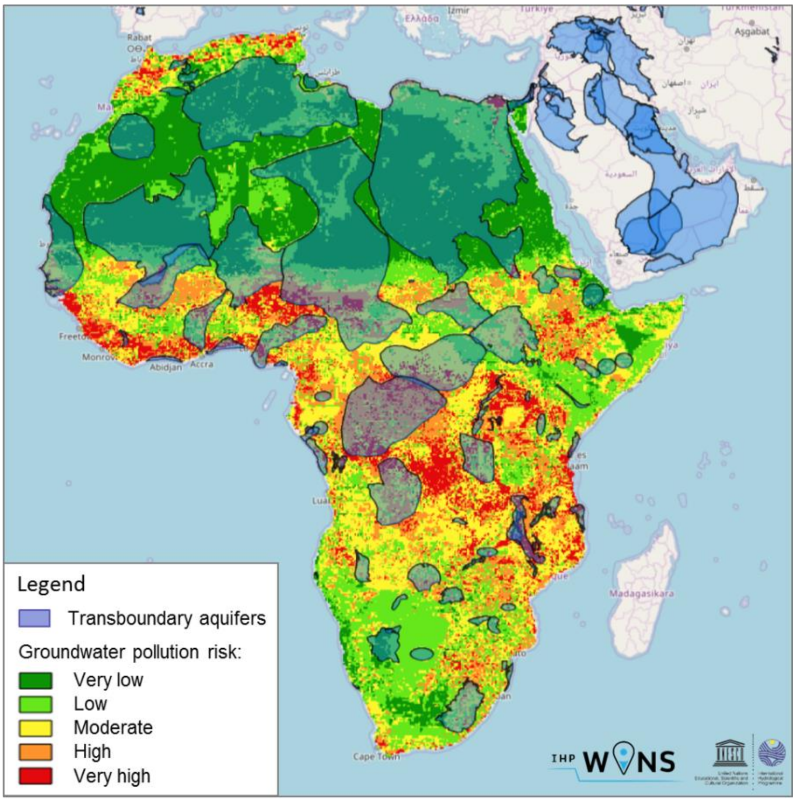

Figure 1. Transboundary aquifers and groundwater pollution risk in Africa (UNESCO-IHP & IGRAC 2015, I. Ouedraogo et al., 2016). © IHP-WINS

Models, methods, and challenges for assessing the interactions between the power and water resources

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ABSTRACT: The operation of hydropower and thermal power plants is linked to the availability and management of water resources, which are in turn used to meet non-energy related needs (e.g. irrigation, navigation, among others). The analysis of these complex linkages is essential for understanding the water-power nexus and supporting the development and implementation of energy and water-related policies. Such analyses are performed by combining two of the models available at the European Commission's Joint Research Centre (JRC) within the WATERFLEX project: the LISFLOOD hydrological rainfall-runoff model and the Dispa-SET power system model. This paper mainly describes the models and methods applied at the JRC as well as the challenges to carry out water-power analyses.

KEYWORDS: Dispa-SET, hydrothermal coordination, LISFLOOD, mid-term planning, water-power nexus

Introduction

The water-energy nexus is attracting growing attention worldwide due to its link to several trending issues such as climate change, population growth and migration patterns (U.S. Department of Energy, 2014). Climate change may affect the availability and variability of water resources whereas population growth and migration patterns may impact on the distribution of water and energy resources. Specifically, the water-energy nexus would have implications in the power system, which has a complex relationship with the water sector, due to 1) the role of hydropower plants, as the most popular clean energy source, to produce hydroelectricity generation, which is characterized by abundant water withdrawals; and 2) the water cooling needs of thermal power plants by using freshwater resources (Behrens et al.,2017). The water-enegy nexus as an integrated system has been analysed in several case studies worldwide, e.g. European Union (Behrens et al.,2017), China (Shang et al., 2016), United States (DeNooyer, 2016), Middle East and North Africa (Siddiqi et al., 2011), to name a few. Several authors have also assessed the water interactions in the power system (see Fernández-Blanco et al., 2017 and references therein). Within this electricity sector context, we briefly summarise the work carried out by the European Commission's Joint Research Centre (JRC) in Sections 2 and 3. We believe that power and water assessments should rely on a hydrothermal coordination model in the mid-term (Fernández-Blanco et al., 2017) to properly account for hydropower management and a unit commitment-based model in the short-term (Conejo et al., 2002) to capture effects of higher temporal resolution. We also point out the main challenges that should be overcomed in order to analyse properly the power and water interdependencies in Section 4. Finally, Section 5 draws some conclusions.

Models overview

The power and water sectors are linked through two models, namely the LISFLOOD hydrological rainfall-runoff model (Burek et al., 2013) and the Dispa-SET power system model [6,10]. The latter is in turn divided into two modules: 1) the Mid-Term

Hydrothermal Coordination (MTHC) model (Fernández-Blanco et al., 2017); and, 2) the Unit Commitment and Dispatch (UCD) model (Hidalgo González et al., 2014).

The LISFLOOD model

The LISFLOOD model developed by the JRC is a GIS-based spatially-distributed hydrological rainfall-runoff model able to simulate hydrological processes at catchment scale driven by the meteorological variables. It is a tool that can be used in large and transnational catchments for a variety of applications, including flood forecasting, and assessing the effects of river regulation measures, land-use change and climate change. It can run using any desired time interval, on any grid size (as little as 100 meters for medium-sized catchments, to 5 km for modelling the whole Europe and up to 0.10 (around 10 km) for global modelling). The model is typically run using a daily time interval to simulate the long-term catchment water balance. Since LISFLOOD has been primarily developed for the simulation of large river basins, small-scale processes are often simulated in a simplified way. Many of those hydrological processes are modelled in different ways, and process descriptions can range between simple empirical 'black box' relations and fully 'physically based' approaches (which are both, numerically complex and computationally demanding). Still, in order to be of any practical use, the model should be computationally efficient to a sufficient degree, especially if it is to be applied on the pan-European scale. Many routines can be found in LISFLOOD and activated on as user-needed basis. LISFLOOD can simulate lakes, reservoirs, and retention polders. For water-power nexus, the reservoir routine is important with reservoirs being simulated as points in the channel network. While the inflow into each reservoir equals the channel flow upstream of the reservoir, the outflow behaviour of those reservoirs is described and constrained by a number of parameters. The interested reader is referred to (Burek et al., 2013) for further information about the structure of LISFLOOD.

The Dispa-SET MTHC model

The mid-term hydrothermal coordination module of Dispa-SET aims to minimise the total generation cost of the power system in the mid-term along the simulation horizon while satisfying technical constraints related to both hydro and thermal units. The typical time horizon ranges from one to several years and the time step could be daily, weekly or monthly. The set of mid-term constraints includes:

- The energy balance sets the energy produced equal to the forecasted energy demand for each period and location. This balance takes also into account the effect of the transmission network by means of a flow-based approach.
- The continuity equation enforces the water balance for each (multipurpose) reservoir in each period and accounts for the reservoir levels, the natural water inflow, the water pumped (if any), and the water released from the reservoir and upstream reservoirs, and/or water demands including irrigation, livestock, industrial or domestic uses. Note that the absolute value of the dual variable or Lagrange multiplier associated with the water balance for each reservoir in each period is defined as the water value (Reneses et al., 2015). These values would provide the right economic signals in the short-term operation of the power system for scheduling hydropower, e.g. in the unit commitment problem.
- The water-energy conversion for hydropower discharges and pumped energy. As explained in (U.S. Department of Energy, 2014), a simple conversion unit approach is adopted. However, more complex approaches (Conejo et al., 2002) could be modelled to mimick accurately the water head effect of hydro reservoirs at expense of computational complexity.
- Minimum and maximum limits on energy generation.
- Bounds on energy flow.
- Ecological, regulatory, or navigational constraints such as the lower and upper limits on reservoir levels or spillage constraints, to name a few.

The mid-term problem can then be formulated as a large-scale linear programming problem by which off-the-shelf software library such as Pyomo (Hart et al., 2012)) can be used in combination with either proprietary or freely available solvers, e.g. GLPK.

The Dispa-SET UCD model

The Dispa-SET UCD model is a more mature module of Dispa-SET which is fully explained in (Hidalgo González et al., 2014). This unit-commitment-based model aims to minimise the system generation costs including variable and fixed production costs of generating units, start-up and shutdown costs, ramp-up- and ramp-down-related costs, and penalizations on some constraints to ensure feasibility. The objective function is also subject to technical constraints ensuring an optimal commitment (on/off statuses of generating units) and dispatch (power productions of generating units). The Dispa-SET UCD model ensures the power balance per period and node as well as the power balance in storage units. The transmission network is represented by a pipeline model, typically used in transport problems. Moreover, other constraints are modelled: generation bounds, power flow capacity limits, ramping rates, minimum up and down times, storage-related constraints, emission limits, curtailment and load shedding limits. Finally, water-related constraints limiting the total water withdrawal of specific thermal power plants or modelling the effect of the power production with the river temperature could be incorporated into the model. Unlike the Dispa-SET MTHC model, this unit-commitment formulation impose integrality constraints for modelling the on/off statuses of generating units. Therefore, this model can be characterized as a large-scale mixed-integer linear programming problem which can be solved by using CPLEX under GAMS.

Modelling framework

The conceptual framework for the joint water and power system models is presented in Figure 1 and model interactions are explained next. LISFLOOD (step 1) is first solved to feed water inflows and water demands into the Dispa-SET model, which would impose constraints on hydropower plants and water-constrained limitations in thermal power plants. Then, Dispa-SET MTHC model (step 2) runs at daily, weekly or monthly time steps during one or several years in order to provide the management of water resources in the mid-term, i.e. the reservoir levels from the reservoirs are passed on to shorterterm problems. Moreover, water values for hydropower sources are an outcome of this model. Note that ideally Dispa-SET MTHC and LISFLOOD should be run iteratively till convergence of the reservoir levels as they are affected both by hydrological flows estimated in step 1 and power plant dispatch decisions decided in the second step. Finally, the Dispa-SET UCD model (step 3) runs at hourly time steps during a target year and the following results can be obtained: 1) the power schedule and dispatch, 2) water-related outcomes (e.g. water withdrawn and consumed by power plants), and 3) economic results (prices and costs).

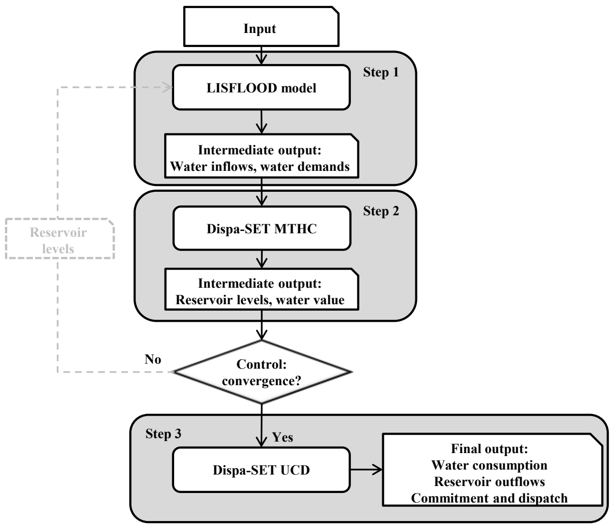

Figure 1. Interactions among the LISFLOOD, Dispa-SET MTHC, and Dispa-SET UCD models.

Challenges in water-constrained power systems

The challenges faced by researchers and practitioners in water-constrained power systems share several aspects regarding scalability, data, and model complexity.

- Scalability: For the sake of model tractability, identification of suitable temporal and spatial scales in both MTHC and UCD problems is highly important. Fine temporal and spatial scale could help identify water stress or excessive water withdrawal periods and locations with a high resolution. However, this could lead to slow convergence when solving large-scale instances. For this reason, we believe that solving the MTHC problem with low temporal and spatial resolution first and then the UCD problem with high resolution represents a good trade-off between scalability and computational complexity.

On the other hand, system boundaries pose challenges from computational and technical perspectives. First, a wide scope with high resolution could lead to slow convergence or even problem intractability, as mentioned above. For assessing water and power linkages, national or continental scopes would be the targets since a global scope would be more suitable for an energy system rather than a power system whereas a local scope would not capture the operation and planning activities of the power system. Second, the power and water sectors are often managed in different jurisdictions, e.g. the power system can be operated on a country-level basis, whereas the water system is managed at catchment level.

- Data: One of the major challenges of analysing the water-power nexus is to collect real, high-resolution, disaggregated data regarding power plant characteristics, water uses and demands, temperature time series and so on. Power system data can be found in 1) national databases which may not contain easy-to-find accessible information; 2) commercial databases such as Platts[20] with third party use policies; and 3) the transparency platform from ENTSO-E[21], which contains aggregated data but only from 2014 onwards (in European countries). Water-related data can be found, e.g. in ICOLD3[22] or GRanD4[23] databases. However, lack of data in critical locations is a common occurrence. Therefore, this time-consuming task could make it difficult to analyse the water-power nexus.
- Model complexity: The trade-off between model complexity and accuracy is an everlasting debate in power systems. This trade-off depends on the questions that researchers or policymakers are addressing. What is the trade-off in a water-power analysis? How accurate the mid-term problem or the unit commitment problem should be? Hydropower modelling is a complicated problem itself due to its inherent complexity, which can be aggravated when it comes to multipurpose hydro reservoirs which are beyond the hydroelectricity generation. Other uses encompass irrigation, navigational or recreational activities, aquaculture, water supply or flood and drought control (EDF-World Water Council, 2015). In addition, water-related constraints on thermal power plants could be considered for a better understanding of the water-power nexus. Apart from those water-related issues, uncertainty characterization is essential in mid-term problems for modelling unpredictable information (water inflows, demand, or renewable profiles). Finally, modelling complexity will be strongly related to data availability.

Conclusions and future work

The water-power nexus could be critical for promoting renewable, water-related or energy efficiency policies. Therefore, policy-driven questions should be taken into consideration when it comes to scalability, geographical coverage, and model complexity. Bearing in mind that data collection could be time consuming, common sense assumptions are deemed necessary at expense of distorted conclusions. At the JRC, future work can be summarised in three main avenues: 1) broader geographical scope (whole Europe and parts of Africa), 2) extension of modelling features (multipurpose reservoirs, water-related constraints on thermal units), and 3) switching from deterministic to stochastic approaches.

[20] https://www.platts.com/about
[21] https://transparency.entsoe.eu/
[22] http://www.icold-cigb.net/GB/icold/icold.asp
[23] http://www.gwsp.org/products/grand-database.html

References:

The Water-Energy Nexus: Challenges and Opportunities. U.S. Department of Energy; 2014.

Behrens P, Vliet MTH Van, Nanninga T, Walsh B, Rodrigues JFD. Climate change and the vulnerability of electricity generation to water stress in the European Union. Nat Energy n.d.;17114:1–7. doi:10.1038/nenergy.2017.114.

Shang Y, Hei P, Lu S, Shang L, Li X, Wei Y, et al. China's energy-water nexus: Assessing water conservation synergies of the total coal consumption cap strategy until 2050. Appl Energy 2016. doi:10.1016/j.apenergy.2016.11.008.

DeNooyer TA, Peschel JM, Zhang Z, Stillwell AS. Integrating water resources and power generation: The energy-water nexus in Illinois. Appl Energy 2016;162:363–71. doi:10.1016/j.apenergy.2015.10.071.

Siddiqi A, Anadon LD. The water – energy nexus in Middle East and North Africa 2011;39:4529–40. doi:10.1016/j.enpol.2011.04.023.

Fernández-Blanco R, Kavvadias K, González IH. Quantifying the water-power linkage on hydrothermal power systems: A Greek case study. Appl Energy 2017;203:240–53. doi:10.1016/j.apenergy.2017.06.013.

Ramos A, Cerisola S, Latorre JM, Bellido R, Perea A, Lopez E. A decision support model for weekly operation of hydrothermal systems by Stochastic Nonlinear Optimization. In: Ehrenmann A, Smeers Y, editors. Stoch. Optim. Methods Financ. Energy, New York: Springer; 2011, p. 143–61. doi:10.1007/978-1-4419-9586-5.

Conejo AJ, Arroyo JM, Contreras J, Villamor FA. Self-scheduling of a hydro producer in a pool-based electricity market. IEEE Trans Power Syst 2002;17:1265–71. doi:10.1109/TPWRS.2002.804951.

Burek P, van der Knijff J, de Roo A. LISFLOOD: Distributed water balance and flood simulation model: Revised user manual. 2013. doi:10.2788/24719.

Hidalgo González I, Sylvain Q, Zucker A. Dispa-SET 2.0: Unit commitment and power dispatch model 2014:1–26. doi:10.2790/399921.

Reneses J, Barquín J, García González J, Centeno J. Water value in electricity markets. Int Trans Electr Energy Syst 2015. doi:10.1002/etep.

Hart WE, Laird C, Watson J-P, Woodruff DL. Pyomo - Optimization modeling in Python. Springer; 2012. doi:10.1007/978-1-46143226-5.

GLPK (GNU Linear Programming Kit) 2016. https://www.gnu.org/software/glpk/.

IBM, IBM ILOG CPLEX Optimisation Studio n.d. https://www-01.ibm.com/software/commerce/optimization/cplex-optimizer/ (accessed August 30, 2017).

General Algebraic Modeling System (GAMS), GAMS Development Corporation n.d. https://www.gams.com/ (accessed August 30, 2017).

Multipurpose water uses of hydropower reservoirs. EDF - World Water Council; 2015.

CGE modelling of Water-Energy-Food Nexus: where do we stand on the water side?

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ABSTRACT: Water is not only crucial for human life and the survival of the ecosystems, but is also essential in many economic activities, first of all agriculture and energy production (i.e., the WEF Nexus). Its unsustainable use and uneven distribution at both global and regional levels are challenging the capacity of water resources to ensure future food security and economic well-being. Understanding the role of water as an economic resource is therefore fundamental, in order to set priorities among alternative economic and non-economic water uses, and defining proper water management and distribution policies. This requires a complex integrated approach, to account for the role of ecosystems in producing and storing water, and a thorough analysis of its links with all sectors in the economy. To this purpose, a Computable General Equilibrium (CGE) model may be the ideal tool, as it analyses the interlinkages between different sectors of the market economy and a portfolio of various resource management policies can be evaluated. Current approaches to account for water resources into these economic models are very useful as they provide a reference framework, yet they suffer from important deficits, which are related to the peculiar characteristic of water resources (i.e., water is a no-market good in most countries), the absence of reliable data and the weak link of CGE models with hydrological models. In this paper, the authors first review the relevant literature on CGE modelling of water resources. A discussion about the main weaknesses follows, and some suggestions on how to improve upon current methodologies are put forward. The authors conclude that a rethinking of the theoretical structure within which water is represented into the CGE models as well as a better integration between economic and hydrological models are among the top priorities to resolve the deficits described.

Introduction

Sustainable use of natural resources is one of the biggest challenges of humanity in the 21st century. Increasing world population, changing dietary habits, human-induced climate change and fast industrialization of developing countries are among the key drivers of increasing stress on natural resources. Unsustainable water use is putting at risk the capacity of water resources to regenerate and ensure food security and economic growth. As most of the world relies on markets for the efficient use and distribution of these resources, a whole-economy framework is thus needed to analyse the sustainable use of natural resources, at the country and global level.

Water is certainly one of the most important natural resources. Water is crucial for human life, for the provision of essential ecosystem services and for many economic activities. For example, agriculture accounts for 70% of global freshwater withdrawals (FAO, 2012); the touristic sector highly depends on the seasonal availability of water (e.g., Deyá, Tortella and Tirado, 2011); and finally, water plays a growing role in energy production (e.g., Bazilian et al., 2011). Unfortunately, water is unevenly distributed across space and time, and in many areas of the world it is under stress by the drivers mentioned above. Thus, an efficient management of water is of paramount importance to provide an adequate supply of water to each region of the world and cope with the challenge of sustainability of human well-being, food security and economic growth, while preserving enough water resources for the ecosystems. Which economic policies and institutional arrangements (e.g. water distribution markets, water pricing policies, etc.) are required to ensure the efficient use and distribution of limited water supply across competing sectors? How much water should be set aside to preserve ecosystems services? This is about setting priorities among alternative economic and non-economic water uses, which requires a complex integrated approach (i.e., coupling economic models with physical and hydrological models).

Understanding the role of water as an economic resource which needs to be managed sustainably requires a thorough analysis of its links with all sectors in the economy. In fact, water problems are defined and studied at river catchment level. Furthermore, a complete understanding of water use cannot ignore the functioning of markets for food and agricultural-related products, as agricultural products are traded internationally. Computable General Equilibrium (CGE) models might thus provide important insights on the issue. CGE models are structural models which rely on a consistent theoretical framework, i.e. general equilibrium theory, which explains the supply, demand and price formation in all sectors of an economy. CGE models are calibrated on databases, i.e. Social Accounting Matrices (SAM), that compile all the key information about an economic system by using System of National Accounting consistent data.

The recent progress in CGE literature, theoretical and applied, allows analysing detailed economic relations among different sectors and all economic agents. Over the past two decades, these models have also been employed to investigate the interactions between economic and natural systems. A number of contributions focus on the use of CGE models to explore issues related to the availability, usage and management of water resources (Berrittella et al., 2007), as well as the links between sustainable water use, food security and energy (Bazilian et al., 2011). The advantage of CGE models in analysing the economics of water is their ability to compare costs and benefits of using water in different sectors of the economy or within agriculture for different crop production systems. CGE models are well capable of analysing the competition on water use between food and energy production systems, and derive important lessons and policy suggestions to better distribute water among alternative uses.

Introduction of water to the CGE models dates back to Berck et al. (1991) and since then became quite popular in the CGE literature (Dudu and Chumi, 2008). Despite the differences in the early attempts to introduce water into the CGE framework, following Berrittella et al*.* (2005), namely the GTAP-Water model, modelling water as a factor of production or intermediate input has become the standard approach in the literature. Most of the effort spent in the literature refined this approach with better representation of the substitution possibilities of water with other factors of production by using different nesting structures (Dixon et al*.*, 2010; Calzadilla et al,. 2011, Osman et al*.*, 2016; Gómez *et al.*, 2004)) or by introducing different irrigation technologies or water types to the models (Calzadilla et al*.,* 2011; Decaluwé et al*.*, 1999; Gomez et al., 2004). These studies have contributed significantly to the literature on the economics of water. However, most of them rely on some key hypotheses and assumptions that limit their ability to properly account for water resources within the economic modelling framework.

One major limitation regards the representation of the production function scheme. The typical way of dealing with production functions in CGE models is through the Constant Elasticity of Substitution (CES) function. In this specification, intermediate production factors (and/or intermediate inputs, like e.g. water) can be substitutes to each other (e.g., the use of less water in exchange for more land), when relative price change due to shocks, according to a given constant elasticity of substitution. The production function can also assume the form of nested CES, where different substitutability between production factors or intermediate is depicted (e.g., if the use of water is a direct substitute of land use, they will enter the same nest of the CES). The CES representation requires a careful exercise by modellers and a good knowledge of the production technologies and (in this context) crop yield response to changes in the use of different inputs, to describe the right substitution possibilities among factors. For example, is water substitutable directly with land or with land and fertilisers or with land and labour? Is it an efficient strategy to increase irrigation when fertilizers adoption is too low? However, this way of modelling production function has some immediate drawbacks. Firstly, the parametrisation issue of the different CES nests is extremely complicated as should rely on robust estimation based on production survey data which are rarely available. Secondly, by definition, elasticities of substitution among factors are constant over time and cannot change endogenously as economic conditions of the productive system evolve. This limits the possibility to model rapidly developing economies or endogenous technological changes able to increase productivity of factors and reduce their use.

Additionally, modelling water in CGE, as in any economic simulation model, has drawbacks directly linked with the specificities of the water market around the world, which have not yet fully addressed. Most of these models adopt market structure which implies perfect competition, zero profit conditions while the water market is more close to what in economics can be defined as a natural monopoly. This has great implication on the price formation mechanism to be associated to this market. Moreover, all factors that enter the production function need to be evaluated in monetary terms, as the calibration of the parameters is based on market transactions data. In fact, most of the water used in agriculture comes freely to farmers from rain or groundwater reservoirs (especially in some African and Middle East countries). As a non-market public good, its cost is not entirely accounted for in the production costs. Water is also a scarce resource, and might rapidly deplete if not employed sustainably. These aspects are especially relevant when employing a CES function, because the marginal productivity of inputs/production factors never goes to zero. This implies that a "zero price" production factor (like water and other natural resources) should be consumed in an infinite amount. All these considerations are rather complicated to be transformed in a simplified representation of the reality which the models are.

Most of the recent studies follow a traditional approach (e.g. Roson and Sartori, 2015; Kahsay et al*.*, 2017; Sartori et al., 2017), where water is not explicitly modelled, but it is assumed it is an implicit/hidden factor of production. Criticisms are raised in the literature, especially on a number of issues regarding: the assumptions about the valuation of water (Cakmak et al., 2008; Hassan and Thurlow, 2011); perfect market assumption for water (Fadali et al*.,* 2012); ignoring the role of water rights, the links to bio-physical (Dudu and Cakmak, 2017) and hydrological phenomena (Nechifor and Winning, 2017; Smajgl, 2006; 2009), as well as climate factors (Young and Ringler, 2010); lack of direct links between investments in irrigation infrastructure and water availability (Ponce et al., 2012); inability to link water issues to poverty especially in the developing country context (Debela and Tamiru, 2016); data issues and weak link to the where water resources come from (Zhao et al, 2008). Nevertheless, a consensus around an alternative approach to describe water issues in a CGE model is still lacking.

To sum up, current approaches are very useful, but suffer from important deficits. These can be solved as better data become available and through a rethinking of the theoretical structure within which the water is represented into the CGE models. In this regard, an improved dialogue and integration between economic and hydrological models, to take into account the role of ecosystems in producing and storing water, is among the top priorities.

How can JRC contribute to the current literature?

State of the Art

The Joint Research Centre of the European Commission is developing a single-country, recursive dynamic CGE model, derived from the STAGE_DEV model (Aragie et al., 2017), to analyse policy scenarios on agricultural economics, food security, fiscal policy and water nexus issues[24] in developing countries. The model has been recently employed to

[24] In the context of the support to African countries in providing evidence-based policy analysis, the JRC is currently testing the use of the single-country CGE model to simulate an expansion of small scale irrigation schemes through an increase in the supply of irrigated land and water in the agricultural activities in Kenya. Kenya is a chronically water-scarce country, where almost 40% of the population lacks access to safe water and more than 70% do not have adequate sanitation. Furthermore, arid and semi-arid land covers 80% of the

simulate an expansion of small scale irrigation schemes through an increase in the supply of irrigated land and water in the agricultural activities in Kenya (Boulanger et al., 2018). The model is calibrated using a reduced form of a Social Accounting Matrix (SAM) that broadly conforms to the UN System of National Accounts (SNA). One key peculiarity of this CGE model is that it is tailored on the economic characteristics of developing countries and incorporates additional behavioural relationships that better account for economic relationships in developing countries. In particular, it improves the representation of the dual roles of semi-subsistent (agricultural) households as non-separable producers and consumers. In a developing country context with a dominating agricultural sector and subsistence production, the focus on a detailed disaggregation of the rural economy in terms of agricultural activities and rural households is essential. Water is among the possible commodities that households either own-produce from their own consumption employing internal labour sources or consume from the market. Additionally, the model improves the representation of structural rigidities in developing economies, including un/underemployment, the use of time for activities outside the "production boundary", e.g., fetching water, introduces a detailed modelling of labour markets and migration, and distinguishes between irrigated and rain-fed agriculture.

Despite the described limitations, CGE models are flexible enough to accommodate water as: a production factor specified at different levels of the agricultural (or other) production nest (Osman et al., 2016; and Luckmann et al., 2014) and/or a commodity consumed (and own-produced) by households (Goodman, 2000; and Gómez et al., 2004). Differently from the current JRC single-country CGE model, some CGE models have introduced water as an intermediate inputs or a production factor specified at different levels of the energy/manufacturing production nest (Hassan & Thurlow, 2011). This last feature turns out to be particularly relevant to cope with the water-food-energy nexus within a CGE modelling framework and to the best of our knowledge only little CGE and non-CGE applications are available in the literature (Bazilian et al., 2011; Ringler et al., 2016; IFPRI, 2017). This is certainly an area whereby it is worth investigating and some ongoing H2020 European research projects are currently focusing on.[25]

Discussion

The improvement of modelling of water in CGE (and other economic) models relies on two main pillars: better data sources and better theoretical treatment of water in the models.

The amount and detail of water-related data available to the modellers are increasing at a geometric pace. Thanks to the enhanced computer power and the efforts made by hydrology modellers, it is possible to obtain very detailed data on the quantity of water available almost in every part of the world, with quite high resolution. Further, there are crop water requirement models that link this data to the yields of main staple crops. However, the information available in these data sets is still far from addressing the needs of the CGE models to account for water resources properly. The discrepancy between available and required information is mostly due to the way water is treated in the CGE models. Apart from data availability, there are conceptual issues. Introducing water as a factor of production requires three key pieces of information to be introduced to the model: (real) volumetric price of water, income generated by water and distribution of this income among different economic agents (i.e. owners of water resources, farmers, land owners, etc.). Treating water as a factor of production relies on the crucial assumption of the existence of a functioning market for water, which is not the case for most countries/regions in the world. In the lack of functioning water

country. Kenya has a very limited irrigation infrastructure which allows irrigation of only 0.3% of the agricultural land and low water availability is one of the causes of the low productivity in Kenyan agriculture. The model shows that agricultural production is highly sensitive to increase in irrigation availability and its increase would be highly beneficial to all agricultural sectors. In terms of food security, this would bring about many advantages in terms of food availability and affordability (general decrease of price) and self-sufficiency of food.

[25] See, for example, www.sim4nexus.eu and www.magic-nexus.eu.

markets, it is virtually impossible to determine the real value of water, income generated by water use and distribution of this income among different economic agents.

In many countries, the ownership of the water resources is not well defined and relies on complicated institutional issues. This brings about quite important issues related to the valuation of water by management authorities or institutions. Moreover, these complicated arrangements in institutional structures also cause ambiguity about the distribution of rent created by water used in agriculture. For example, if water use rights are attached to the land ownership rights, then the value added created by water will be part of the land rent (either paid or imputed). Although it is possible to deduce the information on the value added created by water by comparing the price of irrigated and rain-fed land, this requires the existence of functioning land markets, which is not always the case especially in developing countries. On other occasions, water rights might be owned by users but are transferred to an institution such as a water user association of cooperative. In such cases, the institution that is responsible for the distribution of water among members charges a price for water. However, in most cases these charges are lump-sum payments and are not volumetric. Even when they are volumetric, they generally do not reflect the real value of water which theoretically equals to the marginal contribution of water to the production. These institutions distribute profits to the members by reducing water price. Thus, the difference between the real value of water and the charged price goes to the water users, but are not recorded as income or rent from water. Lastly, the value of water is closely related to the climatic conditions: less water is required for agricultural production under higher rain fall or vice versa. This makes the valuation issues even more complicated.

The above mentioned limitations can be overcome by adapting the modelling framework to the information available in the data. This would require abandoning the approach to model water as a factor of production. Since neither valuation nor the level and distribution of value added created by water are available, it is more appropriate to introduce water indirectly to the production system. One appealing option for this purpose is to link the CGE model to a biophysical model, where water is modelled explicitly with its links to the agricultural production (Figure 1). In such a set-up, key parameters for the CGE model, such as e.g. the change in crop yields and intermediate input use in crop production as water availability changes, can be provided by the biophysical model. The latter does account for the water cycle and thus produces the needed information on the availability of water and its impacts on the technical conditions of agricultural production. The CGE model can then operate without the need to explicitly introduce the "water resources variable" into the model. The main advantage is that there will be no need for the above mentioned unrealistic assumptions. In this case, any value added created by water will be attributed to the irrigated land, which in general does not have any valuation or distribution problem.

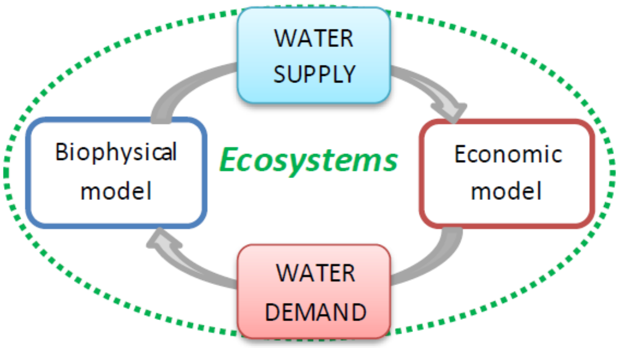

Figure 1. Model linkage in the NEXUS framework

Once the link between biophysical and CGE models is established, a straightforward extension in the CGE model would be the introduction of the irrigation services activity, whose output will be used as an intermediate input by agricultural activities. This would require information on the cost structure of irrigation services activities, which can be obtained from the accounting data of the institutions responsible from the management of water resources in the respective countries. On the other hand, the information that will be received from the biophysical model about the availability of water can be used to adjust the output of this sector by making the CES shifter (i.e. total factor productivity) of this activity a function of the water availability. This way the physical and economic impacts of the changes in water availability would be introduced to the model. Once such an activity is introduced to the CGE model, the economic aspects of water can be easily analysed by using the standard policy tools available in the CGE model.

The above mentioned framework can also be extended to cover energy production by following the same approach. In this setting, the biophysical model would generate information on the allocation of water among agricultural activities and hydro-energy production. This allocation would be a function of the prices of the commodities produced by these activities in the CGE model. For example, if the demand for energy increases as a result of a policy shock, then more water would be allocated to the hydro-energy production, limiting the water available for agricultural activities and causing a decline in the yields of these crops. Then this change would be fed to the CGE model to find a new equilibrium which would imply a change in the relative prices of energy and agricultural products. This iterative process would continue until convergence in the two models is achieved.

Conclusions

Modelling water resources into CGE models is a rather complex endeavour. CGE models are powerful tools to analyse the interlinkages between different sectors through the interaction of economic agents in the markets. However, as there is no market for water in most of the countries or as these markets are incomplete even where they exist, inclusion of water in CGE models requires some unrealistic assumptions, such as treating water as a factor of production, which has implications for income generation and distribution. Hence, keeping water out of CGE models and linking CGE and biophysical models to analyse the water issues instead is an appealing alternative.

References:

Aragie, E., Dudu, H., Ferrari, E., Mainar Causapé, A., McDonald, S., Thierfielder, K., 2017. STAGE_DEV - A variant of the STAGE model for developing countries, EUR 28627 EN, Publications Office of the European Union, Luxembourg. doi:10.2760/90737

Bazilian, M., Rogner, H. Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Müller A., Komor, P., Tol, R.S.J., and Yumkella, K.K. (2011). "Considering the energy, water and food neus: Towards an integrated modelling approach", Energy Policy, 39(12): 7896-7906.

Berck, P., Robinson, S., & Goldman, G. (1991). The use of computable general equilibrium models to assess water policies. In The economics and management of water and drainage in agriculture (pp. 489-509). Springer US.

Berrittella, M., Rehdanz, K., Roson, R., Tol, R.S.J., (2005). The Economic Impact of Water Pricing: A Computable General Equilibrium Analysis, Working Paper FNU-96,Research Unit Sustainability and Global Change Hamburg University and Centre for Marine and Atmospheric Science.

Berrittella, M., Hoekstra A.Y., Rehdanz, K., Roson, R., Tol, R.S.J., (2007). "The Economic Impact of restricted water supply: A Computable General Equilibrium Analysis", Water Research, 41(8): 1799-1813.

Boulanger, P.; Dudu, H.; Ferrari, E.; Mainar Causapé, A.; Balié, J.; Battaglia, L. (2018). Policy options to support the Agriculture Sector Growth and Transformation Strategy in Kenya. A CGE Analysis, *JRC Science for Policy Report* EUR 29231, Publications Office of the European Union, Luxembourg, doi:10.2760/109614.

Calzadilla, A., Rehdanz, K., & Tol, R. S. (2011). The GTAP-W model: Accounting for water use in agriculture Kiel Working Paper No. 1745.

Calzadilla A., Rehdanz, K., Roson, R., Sartori, M., Tol, R.S.J., (2016). "Review of CGE Models of Water Issues", book chapater in The WSPC Reference on Natural Resources and Environmental Policy in the Era of Global Change, vol. 3: 101-123.

Dixon, P.B., M.T. Rimmer and G. Wittwer. 2010. "Modelling the Australian government's buyback scheme with a dynamic multi-regional CGE model." Centre of Policy Studies and the Impact Project, General Paper No. G-186.

Debela G.M., Tamiru S. (2016) Biofuels, Poverty, Food Security and Growth in Ethiopia: A Computable General Equilibrium Microsimulation Analysis. In: Heshmati A. (eds) Poverty and Well-Being in East Africa. Economic Studies in Inequality, Social Exclusion and Well-Being. Springer, Cham.

Deyá Tortella, B. and Tirado, D., (2011). "Hotel water consumption at a seasonal mass torustis destination. The case of the island of Mallorca", Journal of Environmental Management, 92(10): 2568-2579.

Dudu, H., & Chumi, S. Economics of Irrigation Water Management: A Literature Survey with Focus on Partial and General Equilibrium Models. World Bank Policy Research Working Paper Series, 2008, Number 4556. The World Bank. Development Research Group, Sustainable Rural and Urban Development Team.

Fadali, E., Rollins, K., & Stoddard, S. (2012). Determining water values with computable general equilibrium models. Washington, DC: National Academy of Public Administration.

FAO, (2012). Coping with water scarcity. An action framework for agriculture and food security. FAO Water Reports 38. Food and Agriculture |Organization of the united Nations, Rome.

Gomez, C., Tirado, D., Rey-Maquiera, J., (2004). Water Exchanges versus water works: Insights from a computable general equilibrium model for Balaearic Islands, Water Resources Research, 40(10): doi: 10.1029/2004WR003235

IFPRI, (2017). Linking the Economics of Water Energy and Foood: A Nexus Modeling Approach. Egypt SSP Working Paper 04/2017. International Food Policy Research Institute.

Kahsay, T.N., Kuik, O., Brouwer, R., van der Zaag, P., 2017, Clim. Change Econ. 08, 1750004 [30 pages] https://doi.org/10.1142/S201000781750004X

Osman, R., Ferrari, E., & McDonald, S. (2016). Water Scarcity and Irrigation Efficiency in Egypt. Water Economics and Policy, 2(04), 1650009.

Nechifor, N., Winning, M., (2017) Projecting irrigation water requirements across multiple socio-economic development futures – A global CGE assessment, Water Resources and Economics, https://doi.org/10.1016/j.wre.2017.09.003.

Ponce, R., Bosello, F., & Giupponi, C. (2012). Integrating Water Resources into Computable General Equilibrium Models – A Survey. In C. Carraro, Climate Change and Sustainable Development Series.

Ringler, C., Willenbockel, D., Perez, N., Rosegrant, M., Zhu, T. Matthews, N. (2016). "Global linkages among energy, food, and water: an economic assessment", Journal of Environmental Studies and Sciences, 6(1): 161-171.

Sartori, M., Geneletti, D., Schiavo, S., Scolozzi, R., 2017, To What Extent Will Climate and Land-Use Change Affect EU-28 Agriculture? A Computable General Equilibrium Analysis. University Ca' Foscari of Venice, Dept. of Economics Research Paper Series No. 19/WP/2017 .

Zhao, Y., Wang, J. F., Cai, H. J., 2008, Review of CGE models on water resources, Shuikexue Jinzhan/Advances in Water Science 19(5):756-762

Assessments of the water-food-energy-ecosystems nexus in transboundary basins: focus on lessons learned and opportunities for Central Asia

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Introduction

This paper aims at contributing to the reflection promoted by the Joint Research Centre for development of a Position Paper for the European Commission's (EC) Directorate-General for International Cooperation and Development (DG DEVCO) with the stated main objective to "i) frame the context for operationalising the Water-Energy-Food (WEF) Nexus outside EU for development cooperation support and provide recommendations for future projects and initiatives."

Conflicting objectives of different economic sectors regarding water use are commonly a source of tension. Water security is linked to other resource securities – notably food and energy – and environmental security, and these interlinkages need to be taken into account in planning and management for overall sustainability. The interconnectedness of sectorial development goals is evident in Agenda 2030 for Sustainable Development (ICSU, 2017), underlining the need to identify synergies and minimize trade-offs in planning. A "nexus approach" to managing interlinked resources is increasingly recognized as a way to enhance water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance while protecting ecosystems.

Resource security is too commonly inferred to be best achieved through national means when transboundary cooperation and intersectorial coordination at that level may be more effective strategies to that end. Support, investment and partnerships that take into account interconnectedness of resources and sectors are expected to be more effective and more sustainable.

The experience synthesized in the present paper is drawn from the five assessments of the water-food-energy-ecosystems nexus in transboundary river basins[27] under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (signed in Helsinki in 1992) as part of the Convention's Programme of Work 2013-2015 and 2016-2018 (UNECE, 2012 and 2015a). The Nexus approach demonstrated by these assessments invites to consider the effects on resources broadly, not just through e.g. water uses and discharges, but how sectorial policies directly and indirectly influence the dynamics between the resources in focus (water, energy and land/food resources as well as ecosystems) as well as the respective management spheres and where improved sustainability can be achieved through joint action. The basins that were assessed are located in the Caucasus, Central Asia and Southern Europe. These participatory assessments were prepared in close cooperation with the concerned Ministries of the riparian countries sharing the respective transboundary basins. In practice, they involved a study of intersectorial links, trade-offs and benefits in managing water, energy, land and environmental resources, and an accompanying intersectorial transboundary dialogue about the nexus issues and possible solutions, informed by the study (analysis).

[26] The author is responsible for the area of work on the water-food-energy-ecosystems nexus under the UNECE Water Convention. She coordinated the development of the methodology, the basin assessments and serviced the related intergovernmental process. The views expressed in this article are those of the author and do not necessarily represent the views of the United Nations or its Member States.

[27] Information about the basin assessments is available at http://www.unece.org/env/water/nexus.html

Status of applying the nexus concept at the transboundary level and assessment approaches

Giving a review of how the nexus concept is applied in transboundary contexts is outside the scope of this short paper. With somewhat different definitions and scoping, various initiatives involving intersectorial or concurrent multisectorial analysis have been undertaken to study complex interlinkages covering energy, water and food or agriculture or at least some of these sectors (or resources).[28] The paper focuses on the practical experience from the transboundary participatory assessment made under the Water Convention.

The methodology

For the purpose of the assessments, a devoted methodology was designed with the support of expertise representing different sectors, piloted and subsequently applied in river basins and an aquifer selected on the basis of expressions of interest from riparian countries or from transboundary cooperation organizations. The basins differ markedly in size, geography, level of cooperation, characteristics of the economic sectors and by other features. The methodology involves six steps which along with the inputs and outputs of each step is shown in graphical form in Figure 1. For details of the methodology, UNECE (2015b), de Strasser et al. (2016) and, for the governance aspects in particular, UNECE (2017a) can be referred to. The tasks specified for each step are either carried out by analysts in desk studies and analysis (involving quantification with fit-for-purpose tools) or by the authorities and stakeholders during workshops and consultations. The different steps are described in table 1.

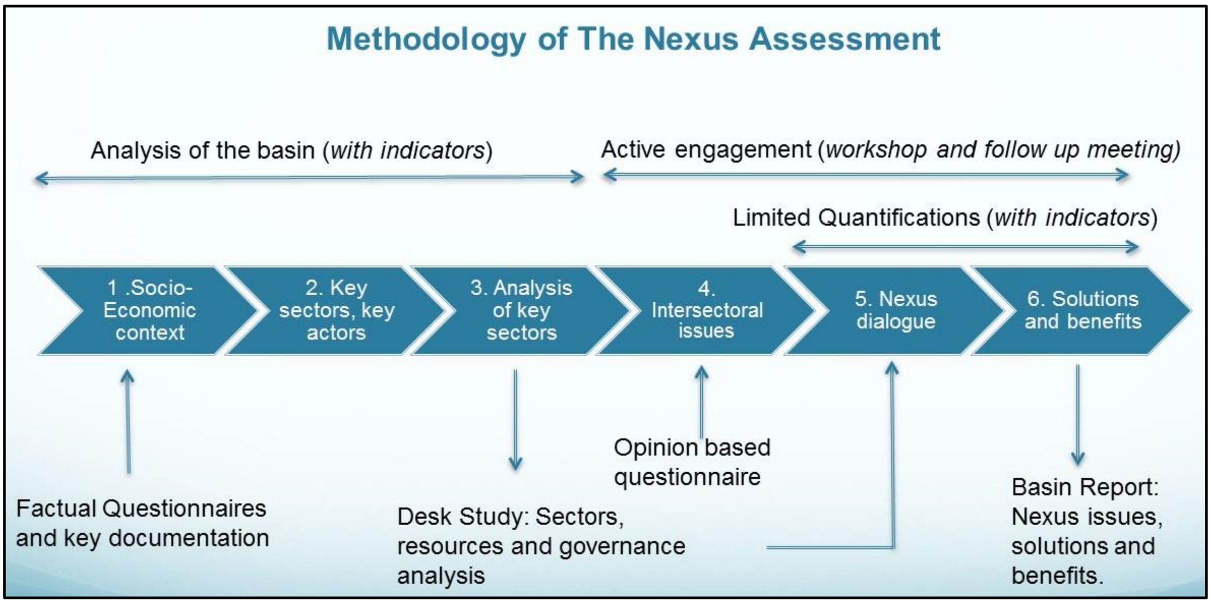

Figure 1. The different stages of and inputs to the nexus assessment methodology developed under the Helsinki Water Convention for application in transboundary basins (de Strasser et al. 2016).

[28] A number of tools and initiatives were presented the global stocktaking Workshop on Assessments of the Water-Food-Energy-Ecosystems Nexus and Response Measures in Transboundary Basins, held at the Palais des Nations, Geneva, 6-7 December 2016. The report of the workshop can be referred to for more information on these (UNECE, 2017a).

Table 1. The six steps of the nexus assessment methodology.

Step and the modality	Inputs and outputs
Step 1 A desk study and an analysis of existing data	The current and if possible projected needs of the population in the basin as well as the national needs that rely on the basin are identified. This is done by looking e.g. at the water, energy and land resources as well as their uses. This develops an understanding of the basins socioeconomic context, its resource base and the governance context.
Step 2 A desk study and an analysis of existing data	The identified needs are associated to sectors and institutions. Hence the key sectors and stakeholders are identified, also to contribute to the process.
Step 3 A desk study and analysis of existing data as well as input from officials and stakeholders during a workshop	The key sectors are analysed applying the Drivers-Pressures-State-Impacts-Response framework. The analysis is further refined in the first transboundary intersectorial workshop.
Step 4 Input from officials and stakeholders during a workshop	In the first workshop, officials and other key stakeholders identify and detail issues between sectors while considering the sectorial strategies and development plans and linkages to other sectors. This includes material presented by experts, officials or stakeholders.
Step 5 Input from stakeholders during the first workshop as well as through a desk study and analysis of additional data	Nexus diagrams about the main interlinkages are reviewed, complemented and validated collectively with the stakeholders (including through group works). It includes the nexus components water, food, energy, ecosystems and the significant linkages identified. Further analysis by experts using additional data refines and details the linkages.
Step 6 With assistance of stakeholders during a workshop as well as by analysis through a desk study and analysis of additional data	Possible solutions to the most pressing intersectorial issues are identified, such as, land use management, cooperation agreements, policy solutions, infrastructure projects or economic instruments. These are discussed in the later workshops.[29]

The Task Force on the Water-Food-Energy-Ecosystems Nexus was established by the Meeting of the Parties to the Water Convention (UNECE, 2012) to guide the work on the nexus assessments and to provide oversight. Because of the key role that the Governments of the countries sharing the basins assessed had in steering the process, the official participation in the process and the various consultations ensured that the assessments reflect the challenges perceived as relevant by the Governments.

Key Findings

Lessons from nexus assessments in transboundary basins

Improvements to management of interlinked water, energy, land and ecosystem resources are not only about financing and technology, but also about mind-sets and behaviours, ways of planning and implementing interventions as well as governance. For

[29] Based on practical experience from the application of the methodology, at least two workshops should be organized in the assessment process, the latter providing for discussion about the findings, either as preliminary or further developed.

identifying the locally relevant nexus issues and for seeking commitment to address them, the following can be highlighted from what has emerged as important[30]:

- A participatory process that seeks to effectively engage all the concerned countries (the basin sharing countries in this case), and all the main sectors and key stakeholders in the process has a particular value for ownership of the conclusions, for integrating local knowledge and for building capacity.
- The need to build on complementary institutional frameworks: Ensuring involvement of the key sectors is crucial and so is selection of the institutional platform(s) used for conducting the assessment and the dialogue. Water management is an important connecting element, but engaging with the energy sector's or other economic frameworks is necessary for promoting awareness and revisiting practices where sectorial policy decisions are taken.

Regarding lessons, Central Asia merits particular attention in this paper, considering the European Commission's engagement in the region[31]. Nevertheless, the findings from the Water Convention's nexus assessment are more generally relevant, demonstrated by, for example, invitation to experience sharing for other regional EC Nexus Dialogues programme supported by the EC and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in the Niger Basin and in Latin America.

Syr Darya Basin

The current situation in the Syr Darya Basin is heavily impacting on the development in the riparian countries (Kazakhstan, Kyrgyzstan, Uzbekistan and Tajikistan) and the basin. Examples of issues that will likely affect the interlinkages with regard to water quality and water quantity are: the lack of a functioning energy market, the fact that water is not valued and priorities of development are different between countries, that there is neither an effective pollution control nor functioning incentives for improving resource efficiency. Important trends are population growth with increased demand for food, water and energy, and increased pressure on natural resources and the environment. Key uncertainties that will affect the impact of these trends are the development of regional co-operation, geopolitics, climate change impact and emergencies (e.g. droughts). The main nexus interlinkages in the Syr Darya Basin, identified jointly with the various ministries and other key stakeholders in the assessment[32], are presented in Figure 2.

Natural resources in the Syr Darya Basin could be developed and used more effectively and with less impact on the environment considering the basin more holistically and capitalizing on the complementarities between the countries. The results of the nexus assessment suggest that adoption of the nexus approach has the potential to improve resource use efficiency and security in the riparian countries. In contrast to national approaches presently employed, cooperation involving all the countries and sectors has significant potential to optimize the use of resources in the basin.

At the same time, applying certain solutions at the country level – including, among others, improvement of efficiency in water and energy use, as well as well-targeted economic and policy instruments – can help gradually build more favourable conditions for transboundary cooperation.

[30] For a more extensive discussion about lessons learned, UNECE (2015b) and de Strasser et al. (2016) can be referred to.

[31] A regional EC Nexus Dialogue programme is carried out in Central Asia with the support of the EC. by https://www.nexus-dialogue-programme.eu/about/nexus-regional-dialogue-programme/

[32] It should be noted that Uzbekistan does not associate itself with the nexus assessment of the Syr Darya.

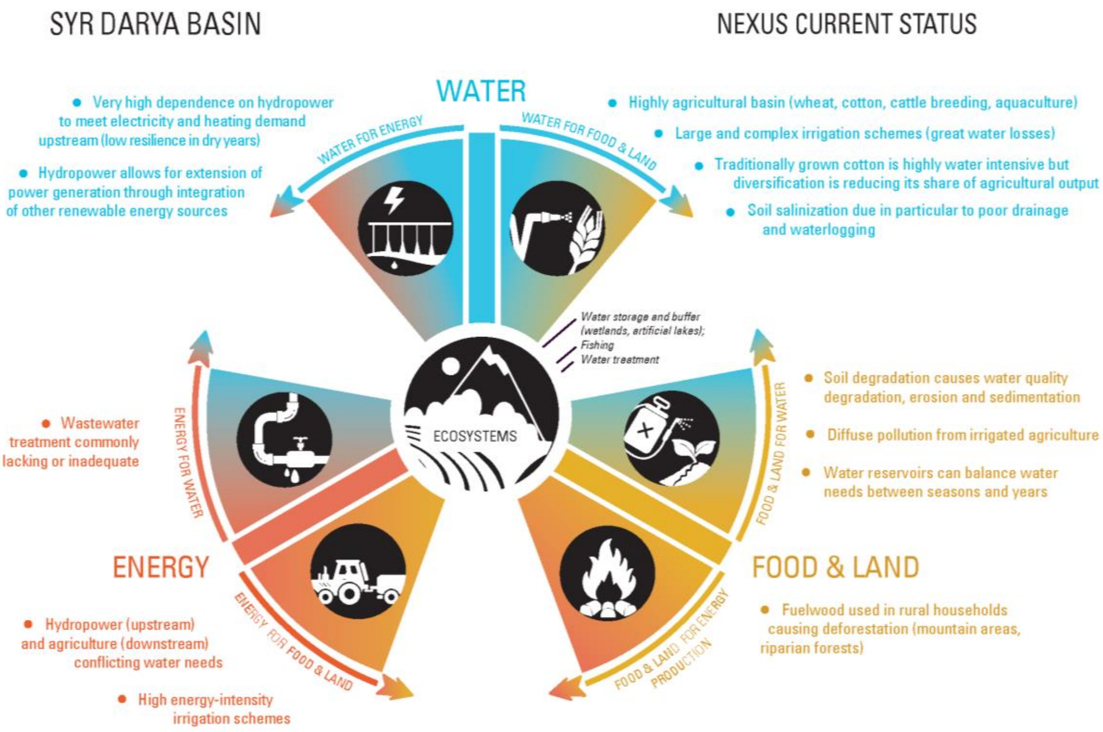

Figure 2. The main nexus interlinkages in the Syr Darya Basin

The solutions proposed in the assessment can be summarized by the following categories (UNECE, 2017b):

- improving energy efficiency, reducing dependency on water for energy (diversification of sources), and rationalizing water use (especially in agriculture);
- developing a well-functioning regional energy market and exploring opportunities for energy-water exchanges between countries, the development of alternative energy sources and improving overall energy efficiency;
- lowering barriers to trading food and agricultural goods, thus promoting their more cost-, water- and energy-efficient production and exchange within the region;
- developing mechanisms to incorporate wider impacts in sector-based policy development, and improving inter-sectorial coordination at the basin level by increasing representation of and consultation with the relevant ministries;
- improving basin-wide monitoring, data verification and exchange, and knowledge-sharing, including joint monitoring (e.g. of water flows and quality) and joint forecasting.

The Syr Darya assessment provides a good information basis for interventions by different actors. A number of more technical and detailed studies have been carried out, referred to in the Syr Darya report (UNECE, 2017b).

Only to mention a few, the following emerged as aspects needing further study in Central Asia:

— Governance across sectors at the national level, as well as the application and outlook for selected intersectorial processes (e.g. Strategic Environmental Assessment (SEA)) in the countries
— Available water resources, saved water, water and land productivity, including a critical descriptive and quantitative analysis of the potential effect of measures in improving efficiency of irrigation and improvement of land reclamation.

— Cooperation opportunities for improving the energy system sustainability, including funding options and mechanisms.[33] The feasibility, costs and benefits of selected nexus solutions prioritized by the countries.[34]

Discussion

Due to the interlinkages between the Sustainable Development Goals (SDGs) on food security (SDG 2), water and sanitation (SDG 6) and sustainable energy (SDG 7), well-targeted measures in economic sectors can have benefits beyond the respective SDGs: As a case in point, increased use of renewable sources of energy and improved energy efficiency will, in most cases, reinforce targets related to water access, scarcity and management by lowering water demands (ICSU, 2017). While wind power is more expensive than hydropower, it could be pursued at selected sites to diversify domestic energy supply and enhance energy security. Indicative calculations made by the Royal Institute of Technology in Stockholm (KTH) for the Syr Darya assessment demonstrate that a combined wind and hydropower programme in Kyrgyzstan and Tajikistan could bring significant water savings (UNECE, 2017b). Agriculture being the main consumptive use of water, more sustainable agricultural practices are key to ensuring meeting a number of water targets under SDG 6, helping to progress towards SDG 2. In addition to introducing and promoting energy and water efficient technologies, development of economic instruments is another means of rationalizing use of these resources. For example, OECD has outlined possibilities for applying such instruments in Kyrgyzstan (OECD 2014).

Central Asia is progressing in gradually introducing principles of international law into national laws and policies, as well as standards and good practices. Related to the environment, the progress is documented in the Environmental Performance Reviews.[35] A recent study shows that, even in introducing the key aspects of IWRM, a lot yet remains to be done by Central Asian countries to make basin level management and participation of different stakeholders well-functioning (UNECE and OECD, 2016). The nexus approach aspires to take integration across sectors even further. Improving policy coherence is a long-term effort, and many EU and UNECE instruments have been developed that are consistent and complementary. They therefore provide a useful reference.

Evidence-based decision-making should be encouraged and supported by improving availability and sharing of relevant information, and facilitating its uptake in policy. Information needs for (quantitative) analysis of the nexus issues across sectors are however high and constraints in availability of or access to data may turn out limiting. For example, availability of up-to-date data on the status of water resources and ecosystems is in many cases not good. Already at the national level, information across sectors is not necessarily easily available. At the transboundary level, information exchange requires improvement, more regularity, continuity, transparency and structure. (UNECE 2011)

Key is to have solid studies informing policy development and decision-making, involving local institutions and local experts, both to transfer knowledge and to integrate in-depth local understanding. However, the conduciveness of official frameworks and processes to consideration of studies varies. The Nexus Dialogue project can be expected to contribute to building capacity and awareness-raising regarding the nexus issues.

The Water Convention's nexus assessments from the Caucasus, the Western Balkans and Southern Europe highlight a number of potentially valuables experiences that are relevant also for Central Asia: Co-optimizing flow regulation (Drina River Basin; UNECE

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[33] The four-country energy system model developed by KTH with an open source tool for the Syr Darya nexus assessment could be used to assess impacts of development, including investments. The precision of related insights could be improved by validation of generation infrastructure information (including for planned projects), as well as detailing of data on electricity trade and capacities, on fuel prices, and transmission and distribution losses.

[34] For a comprehensive list of the proposed nexus solutions UNECE (2017b) can be referred to.

[35] Available from: http://www.unece.org/environmental-policy/environmental-performance-reviews/enveprpublications.html

2017c), improving water use efficiency in agriculture (the Isonzo/Soča Basin) and improving access to modern energy to improve livelihoods with co-benefits for improving the status of water resources and ecosystems through reduced erosion (Alazani/Ganykh River Basin) (UNECE, 2015b).

With the recent positive developments in the relations between the Central Asian countries, the outlook for major projects of transboundary and/or regional significance has also improved. Nevertheless, water remains a subject of conflicting interests. It is positive, though, that the "Joint Communiqué: European Union - Central Asia Foreign Ministers' Meeting "EU and Central Asia: Working for a Safer and More Prosperous Future Together" (Samarkand, 10 November 2017)[36] recognizes that "Continued and expanded dialogue and cooperation contributes to the efficient use of water and energy resources, the protection of the environment and for addressing climate change as well as other cross-border issues."

Conclusions and Recommendations

The EC engagement and support in Central Asia has the potential to assist the region in moving towards more sustainable development of water and related resources. However, a one-off project or even investment programme may have a limited effect in the long term, unless accompanied by assistance to the countries to further develop their legal basis, policies and procedures that can provide for more coordinated and consultative planning and resource management, including for investments, in the long-term. In particular strengthening institutional frameworks that can provide for dialogue, coordination and assessment of impacts would be valuable.

The Syr Darya nexus assessment called for "further analytical, stakeholder engagement and planning work to identify precise governance reforms, policy measures and investment opportunities to address all the challenges and seize any corresponding opportunities". It points at a number of beneficial actions that any further work on the nexus issues in Central Asia can build on. Supporting diversification of energy sources, energy trade and improved energy efficiency, and furthering the on-going transformation of agriculture involving improved efficiency of water use, crop switching and land reform, are examples of areas identified where investment and other measures reduce the demands and dependencies behind the current main trade-offs in the nexus. Facilitating trade of agricultural products and addressing the current regulatory and procedural barriers to trade can support further transformation of the agriculture sector.[37]

There are still significant development needs in the region and many investment projects are therefore still oriented towards expanding supply when some such investments could perhaps be avoided by managing demand. Currently a business case is still commonly lacking for investing into e.g. efficiency in the use of water and energy. For energy efficiency, identification of obstacles to investment in a recent UNECE report is instructive (UNECE, 2017d). Improving efficiency is crucial for progressing towards both SDG 6 and SDG 7. Support can build on and use experiences from efforts towards efficient resource use: Uzbekistan and Kazakhstan have reported investments into water-efficient irrigation (UNECE, 2017b) and in the Kyrgyz Republic, effective irrigation technologies and the outlook for their local application have been investigated (MAM, 2015).

A more enabling environment for investments that considers impacts on the environment and across sectors can be developed. The international financing institutions' procedures and conditions as well as the scope of their investment and related technical assistance programmes also represent relevant factors in moving towards a more sustainable development approach. The EC's cooperation with international financial institutions can

[36] The Foreign Ministers of the Republic of Kazakhstan, Kyrgyz Republic, Republic of Tajikistan, Turkmenistan, Republic of Uzbekistan, the European Union's (EU) High Representative for Foreign Affairs and Security Policy and Vice-President of the European Commission, and the European Commissioner for International Cooperation and Development met on 10 November 2017 in Samarkand, Uzbekistan, for the 13th EU-Central Asia Ministerial Meeting.

[37] Studies of regulatory and procedural barriers in Kazakhstan, Kyrgyzstan and Tajikistan by UNECE Trade Programme:http://www.unece.org/trade/publications.html

help integrate the nexus perspective better into financing. An event organized by the EC through the European Union Technical Assistance Facility (TAF) and UNECE's Sustainable Energy Division hosted on the occasion of the 8th International Forum on Energy for Sustainable Development and Ministerial Conference in June 2017 in Astana, Kazakhstan opened an initial pipeline for identification of renewable energy investment projects. Extending investment discussions to broader groups of stakeholders can lead to wider support and better identification of "nexus" opportunities, including synergies between initiatives. Earlier in a policy cycle, well before implementation of measures (including investments), at the national level, the European Union Water Initiative's National Policy Dialogue provides in four Central Asian countries a platform for inter-ministry coordination in developing strategic documents, policies and pieces legislation (UNECE and OECD, 2016). As an example of institutionalizing a consultative process to assess the effects of policies is Kazakhstan's pilot application of the Strategic Environmental Assessment to the future development options of the national energy system.

Many impacts in the nexus are transmitted through water. As the region's main rivers are transboundary, transboundary impacts (and benefits) of major development projects need to be evaluated. Requirements of financing institutions are influential but the Water Convention and other UNECE instruments are also of support. Some major gaps remain: For example, only with an exception, transboundary procedures related to the Environmental Impact Assessment (EIA) are missing in national legislations of Central Asian countries. Updating of the guidelines for applying the Convention on the EIA in a Transboundary Context in Central Asia, once completed (on-going in 2018) will be a resource for the region, although legal reforms would be needed for a greater effect.

Gradually adopting more cooperative solutions, including planning coordination between the countries, would reduce pressure on shared resources. Developing the institutional frameworks for cooperation is important to that end. It complicates addressing some of the most problematic nexus issues in Central Asia that the frameworks for regional water cooperation do not include the energy sector. At the same time, like the agriculture sector, the energy sector is gradually transforming and modernizing itself – reducing emissions, exploring the potential of renewable energy sources beyond hydropower etc. Decisions affecting the energy mix or about interconnections could potentially offer at least partial solutions to water challenges that are difficult to address by water management alone.

References[38]:

de Strasser, L., Lipponen, A., Howells, M., Stec, S. & Bréthaut, C. (2016). A Methodology to Assess the Water Energy Food Ecosystems Nexus in Transboundary River Basins. Water, 8(2), 59.

ICSU (2017). A Guide to SDG Interactions: From Science to Implementation. Paris: International Council for Science (ICSU).

MAM (2015). Modern irrigation technologies: Recommendations on Implementation in Kyrgyzstan. Ministry of Agriculture and Melioration of the Kyrgyz Republic (MAM), Department of Water Management and Melioration. Bishkek, November 2015. Available from: http://www.unece.org/fileadmin/DAM/env/water/meetings/NPD_meetings/Publications/2015/Study_of_suitable_irrigation_technologies_for_Kyrgyzstan_ENG.pdf

OECD (2014). Reforming Economic Instruments for Water Resources Management in Kyrgyzstan: Proposed Options for Reform. Draft Final report (April 2014).

UNECE (2011). Second Assessment of Transboundary Rivers, Lakes and Groundwaters. New York and Geneva: United Nations.

[38] Most of the documents are available either from http://www.unece.org/env/water/publications/pub.html or at the pages of the respective meetings at http://www.unece.org/environmental-policy/conventions/water/envwatermeetings.html#/

UNECE (2012). Report of the Meeting of the Parties on its seventh session (Rome, 28-30 November 2012), Addendum, Programme of work for 2013–2015 (ECE/MP.WAT/37/Add.1.).

UNECE (2015a). Report of the Meeting of the Parties on its seventh session (Budapest 2015), Addendum, Programme of work for 2016–2018.

UNECE (2015b). Reconciling Resource Uses in Transboundary Basins: Assessment of the Water-Food-Energy-Ecosystems Nexus. New York and Geneva: United Nations.

UNECE (2017a). Revised Governance Methodology for Assessing the Water-Food-Energy-Ecosystems Nexus. Task Force on the Water-Food-Energy-Ecosystems Nexus, Fifth meeting (Geneva, Switzerland, 18 October 2017)

UNECE (2017b). Reconciling resource uses in transboundary basins: assessment of the water-food-energy-ecosystems nexus in the Syr Darya River Basin. New York and Geneva: United Nations.

UNECE (2017c). Assessment of the water-food-energy-ecosystem nexus and benefits of transboundary cooperation in the Drina River Basin. New York and Geneva: United Nations.

UNECE (2017d). Overcoming barriers to investing in energy efficiency. New York and Geneva: United Nations.

UNECE and OECD (2016). Implementation of the Basin Management Principle in Eastern Europe, the Caucasus and Central Asia. European Union Water Initiative National Policy Dialogues Progress Report 2016 (May 2016).

Assessing the WEFE Nexus and finding optimal solutions in the Mékrou transboundary river basin

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ABSTRACT: The Mékrou is a transboundary river basin across Bénin, Burkina Faso, and Niger where the Water-Energy-Food-Ecosystem (WEFE) Nexus should be managed to ensure the sustainable development of this region. The management of the W Park ecosystems, the agriculture (both crop and livestock) production, the relatively poor level of access to basic services (water and energy) are to be improved altogether to alleviate poverty and push for sustainable development. In this project, two components interacted to reach two main objectives: a) define a governance framework to allow to define a strategic and associated investment plan for the Mékrou river basin and b) develop an information system to support this strategic decision making. The institutional component adopted an iterative and participatory bottom-up approach to identify the key priorities of the Mékrou in 2015 and to discuss the strategic framework (CaSSE) options in 2017. From this CaSSE, an action (SDAGE) and an investment plan (PMPI) were discussed by all stakeholders before agreement. In support of the former, the scientific component designed and set up an information system called 'E-water' that integrates tools and analyses related to agricultural production, water resources, the value of the W Park ecosystems, and living conditions. The associated decision support tool is a multi-objective optimization in that it allows to provide optimal solutions according to several competing objectives to the decision maker. This paper will first describe both institutional and scientific processes and their interaction as well as the tools and methods used to encompass the breadth of the WEFE Nexus. The key achievements and examples of the analyses are then detailed before providing lesson learnt and recommendations.

Introduction

The Mékrou River Basin (Figure 1) is a transboundary sub-basin of the Niger River Basin that covers an area of 10,635 km² or about 3% of the total Niger River Basin area. The Mékrou River Basin is shared among Benin (80%), Burkina Faso (10%) and Niger (10%). Agriculture is the key sector of the economy in the three riparian countries, and is also critical for poverty alleviation and food security. The arable land is mainly used for crop production and for raising cattle. The crops are rain-fed and what is produced are cereals (Sorghum, Maize, Rice), Cotton in Benin, Cowpeas and Yam/Cassava. It also exists a small production of legumes. The Mékrou region is subject each year to the "Grande Transhumance" of livestock according to an axis North–South from Nigerien-Burkinabe areas to Beninese areas (DED, 2006). In this configuration, the competition for water resources is mainly between domestic, crop production and livestock demands. In addition, food security within the Mékrou River Basin is neither completely ensured nor homogeneous: 81%

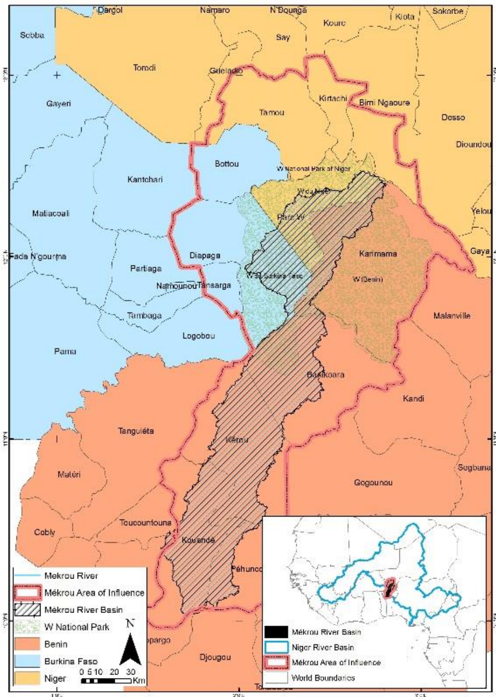

Figure 1. Location of the Mékrou River Basin and Area of

of the surveyed Beninese, 72% of the Burkinabe and only 55% of the Nigerien declared that they could satisfy their family food needs during the last week prior to the 2016 survey. This situation is even less secure when looking back 12 months (2015) as less than 50% of surveyed households declared to have been able to fully cover their family food needs. This insecurity is more acute in Niger and Burkina Faso. The main reason indicated by far was the low harvest following a drought, while 8% had "not enough money" (Markantonis et al., 2017.a).

In addition, there is an environmental water demand to consider, as the Mékrou River Basin includes a very important transboundary national park, the "W Park". The W Park belongs to the W-Arly-Pendjari (WAP) transboundary complex and is known to shelter the largest and most important continuum of terrestrial, semi-aquatic and aquatic ecosystems in the West African savannah (Amahowé et al., 2013). The W Park is emblematic of transitional areas from Sahelian to savanna vegetation in West Africa, which host a high diversity of endangered species of wildlife (Hibert et al., 2004) (Michelot & Ouedraogo, 2009). These ecosystems are unique and provide services to the surrounding population. An environmental water availability is required to maintain them healthy. The local population is well aware of the value of the W Park and the Mékrou River as attested the high importance given to their preservation. The main uses from service of providing water by the Park as an ecosystem according to the surveyed families are: for livestock, for human, for biodiversity and, finally for crop production (Markantonis et al, 2017.a).

With regards to the Energy sector, the access to electricity is very much limited with an average of 20% of the population having access in the Mékrou (Markantonis et al., 2017.a). The main source of energy of the households living in the basin remains wood. Hence, the degradation of the forest, in particular in the upstream part of the river basin, leading to soil erosion processes. This issue was noted by local stakeholders in Benin during consultations in 2015.

From this overview, it appears that Water-Energy-Food-Ecosystems (WEFE) Nexus is a very relevant approach for the Mékrou river basin to define a strategy of sustainable development as well as finding trade-offs between the different uses of resources. With the exception of the fuelwood sourcing issue in the upstream part of the basin, this is despite energy was ranked less of a key issue for national experts and local stakeholders. This consideration was including the plans for the construction of a large electricity dam that were found to be of strong relevance for only one riparian country out of the three. These plans appear to have been replaced by a multi-purpose infrastructure with a hydropower component, the feasibility of which still needs to be assessed.

Methodology

Implementation approach of the information system NEXUS

The general approach adopted in the project of the Mékrou transboundary basin follows a number of steps: a) review, processing and integration of all the data available to assess the socio-economic and biophysical context of the Mékrou; b) identification of the key issues and priorities for development by local stakeholders; c) review of the relevant methods and tools available according to the outputs of the two previous steps; d) further development and adaptation of selected tools/methods with local scientific and technical partners into an easy-to-use module (E-WATER); and finally, e) running of models/analysis to test scenarios of development on the Mékrou river basin as foreseen by the policy makers (i.e. in plans and strategies such as CaSSE and SDAGE[39]). The interaction between science and policy, including by local institutions, is crucial along this process. This is illustrated by the more detailed account of how the approach was implemented in practice as follows.

[39] CaSSE stands for Cadre Stratégique pour la Sécurité en Eaux, SDAGE for Schéma d'Aménagement et de Gestion des Eaux.

The data review required mobilizing the technical services of Meteorology, Hydrology, and Agriculture of the three countries of the Mékrou as well as the W Park management. In addition, two field campaigns were conducted to obtain detailed data from the local population on their living conditions, the access to water resources and their different uses (agriculture, livestock, domestic, ecosystems…etc.) and the role of the park in securing that water supply. This data collection effort was carried out together with a literature review of technical and policy documentation to fill as much as possible data gaps. The main issues at this point were how to treat missing data, the time length of datasets and the low numbers of meteo/hydrological ground stations in the Mékrou.

In parallel with this review, several consultations of key stakeholders (local institutions, village assembly…etc.) in the form of dialogue forums were held in the three countries to discuss and list priorities first at sub-national scale and then at Mékrou river basin (refer to section 3.2). These priorities were thematically grouped as follows: agricultural/crop production, rural development (in particular regarding livestock management), water resources management and allocation between uses, climate variability (precipitation frequency and analysis of heatwaves), ecosystem protection including for tourism in the W Park, and overall socio-economic development in the Mékrou. Based on the data available, a review of the suitable methods and tools was made focusing on what could best fit the priorities identified by the stakeholders. Hereafter the description of the tools selected, their advantages and their application to the Mékrou (Table 1).

Table 1. Description of tools and methods used in E-WATER

Name	**Short description**	**Advantages**	**Reference**
EPIC[40]	The Environmental Policy Integrated Climate (EPIC) model is a field-based cropping system model for assessing the effect of agricultural management practices on crop yield productivity, soil and water quality, and nutrient and pesticide flows and transformations	-Integration with GIS (Pastori et al., 2011) -extensive use in several contexts (Quiao et al., 2018; Van der Velde et al., 2014; Folberth et al., 2012; Wriedt et al., 2009).	(Williams, 1995)
FA	The frequency analysis (FA) of climate variables is a methodology using L-moments, and optionally a regionalization technique to analyse the frequency of extreme weather events, excess or deficit of climate variables, and estimate the time of return of such events.	-accept both remote sensing and ground station data -Cope with low density of ground stations and short climate time series -less sensitive to outliers	(Hosking & Wallis, 1997)
SPI	The Standardized Precipitation Index (SPI-n) is a statistical indicator comparing the total precipitation received at a particular location during a period of *n* months with the long-term rainfall distribution for the same period of time at that location.	-applicable to all climatic regions - easily readable	(McKee 1993, 1995)
Heat Wave Magnitude Index	The Heat Wave Magnitude Index is defined as the maximum magnitude of the heat waves in a year, where heat wave is the period ≥ 3 consecutive days with maximum temperature above the daily threshold for a year reference 30 period.	-possible comparison across regions	(Russo et al. 2014)
SWAT	The Soil and Water Assessment Tool (SWAT) [41] is a process-based, semi-	-flexible structure -cope with resolutions and	(Arnold et al., 1998)

[40] EPIC description available here: https://epicapex.tamu.edu/epic/ last access 20/10/2017.
[41] SWAT documentation: http://swat.tamu.edu/documentation/ last access 13/10/2017

	distributed, basin-scale model. It operates at daily time step and is designed to predict the impact of land use and management on water quantity and quality (water stream flow discharge, flows in the soil, sediments and nutrients cycles) as affected by bio-physical conditions.	quality of input data -well documented model and widely used in many large basins around the world (Gassman et al., 2007, Arnold et al., 2012; Gassman et al., 2014; Malagó et al., 2017) -considers climate scenarios	
MOO	Statistical Multi-Objective Optimisation (MOO) techniques are used to identify combinations, named optimal solutions, according to multiple objectives in a potentially constrained environment.	-multiple and flexible optimal solutions identified (Pastori et al., 2017) - decision makers are directly involved in the selection of the solution	(Cortez, 2014; Pareto, 1971)

Application of selected tools to Mékrou river basin.

A challenge, as often in Africa or the developing world, is the data completeness and availability. This constraint has been overcome by first combining regional data, for instance with ground stations data (for precipitation/discharge) or results from the household survey (for instance in terms of food diet). The combinations of all data sources as well as the selection of appropriate methods are essential steps to ensure the reliability of the database and modelling. In addition, the methods selected are also coping with common low density of ground stations.

In the frame of the Mékrou project, SWAT and EPIC are combined and used to, first, assess climate change impacts on freshwater resources in the river basin using scenario CORDEX AFR-44 RCP 4.5, and; second, generate scenarios according to computed future water demand and land use distribution to ensure crop production and livestock growth under demographic pressure. This is to identify hotspots or stresses in reaching the objectives set at the horizon 2030 by the SDAGE. The socio-economic data, EPIC and SWAT outputs feed then the module of MOO to compute optimal solutions according to defined objectives.

In fact, in the Mékrou, the main objectives are the priorities identified by the stakeholders and are therefore multiple. In the MOO module, the objectives are related to fertilization, irrigation, livestock, revenue from crops production and, food demand. For example, an objective can be increasing the crop production, using fertilization and/or irrigation and/or crop distribution change and livestock. Another objective is to satisfy the domestic water demand (expected to increase by 3-4% per year) while preserving the other water demands. The MOO will identify optimal combination of the parameters that would ensure the objectives.

In the E-WATER, these tools are gathered together to allow a future user to run her/his simulations more easily, and to visualize and export specific results. This is an open source software and tools are themselves freely available (avoiding software license costs).The scientific outputs were used to adjust or refine the CaSSE strategy developed by policy makers during the project. This followed an iterative process between the scientific and policy components (refer to section 3.2).

Key findings

The lesson learnt of the Mékrou project stem from two types of achievements: technical and of policy support.

Technical achievements in terms of WEFE Nexus assessment

As a key issue in the Mékrou, crop production can be simulated according to climate scenarios, distribution of crops (cropland areas) and management practices (mainly irrigation and fertilization). In the below example, the E-Water optimization tool allows to identify optimal strategies to efficiently use land resources combined with increased fertilization and irrigation strategies: optimal crop distribution and fertilization/irrigation plans (which crop, how much and where) can be identified. The 1st scenario is based on the existing agricultural practices, the 2nd one simulates the adoption of more intensive agriculture strategies and the 3rd one is based on the combination of the 2nd scenario and the possibility to change crop land use. The tool is directly addressing the food security and the satisfaction of local needs as one of the first set requirements (constraint) of the optimization. Concretely, for each food crop item, it is possible to estimate the missing quantity required to satisfy local diet demand (food item unfeasibility). In the Mékrou assessment, the total food unfeasibility is reduced by 61% with the 2ndt scenario and by 96% with the 3rd scenario.

Left: distribution of crop groups in the communes as defined for 1st scenario (Cereals dominant in Niger and Burkina Faso; Cotton in Benin). Right: distribution of crop groups for the 3rd scenario (Part of cereals replaced by tubers in Niger; significant reduction of cotton in Benin; increase in vegetables in Benin and Burkina Faso).

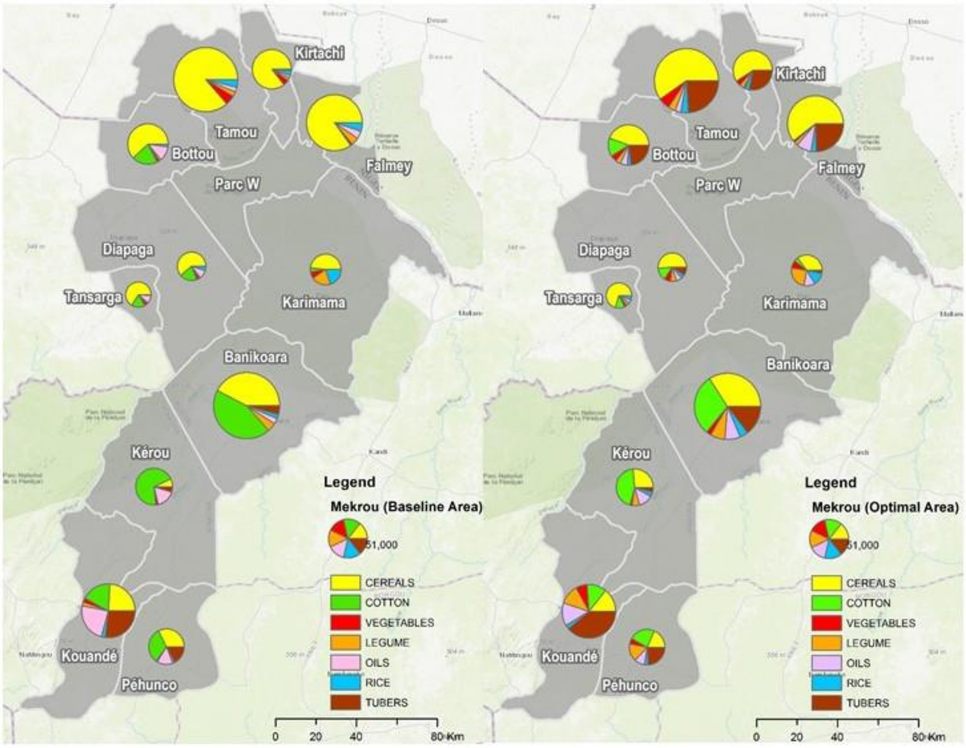

Figure 2. E-water Land use by region for different scenarios.

The food security scenarios include African climate scenarios and can be cross-analysed with time return of extreme events such as precipitation deficits and heatwaves (Markantonis et al., 2017.b).

Another key issue is to ensure the satisfaction of water demands: current and future as set in the SDAGE. Similarly to the agricultural optimization, the e-water allows to find combination of water demands for irrigation, population and livestock according to objectives (i.e., increase the water available for irrigation by 10%) and constraints (i.e., the population water demand is satisfied at 100%), that minimize the exploitation of water resources available. The spatial repartition and the magnitude of the related effort are also computed.

Policy support

As a preliminary remark, the MEKROU project proceeded to a near-WEFE Nexus Assessment of this river basin despite the fact that it was not defined to do so a priori. The need for this arouse from the local dialogues in each of the countries (in 2015-2016) where local stakeholders raised their expressed priorities for the water, agricultural/food, energy and environmental sectors that needed reconciling and optimisation.

To ensure institutional support in this multi-sectorial context, the ministries and their technical services of meteorology, hydrology and agriculture were engaged into the whole process and the development of the E-water module. This systematic involvement has also some advantages in conjunction with the technical activities: a) the application of methods and the results benefit from the local expertise who can detect errors and enrich the analyses or results, b) the ownership of E-water tool is strengthened as it is tested and adapted by these experts, and c) it provides a concrete dialogue space within which stakeholders from several countries can work together on a common product.

The E-Water tool and the scenarios that had been run with it fed the policy process necessary to define a strategic framework for action (SDAGE) at the horizon 2025 for the whole Mékrou river basin. The SDAGE aimed at defining scenarios with priorities and quantifiable objectives for the development of the Mékrou that would be related to: transboundary governance, crop production, livestock, fishing, environmental preservation and conservation, access to water supply and sanitation, water resources management, and industrial/handcraft activities. The definition of the SDAGE resulted in an iterative process that took place between Policy and Science. First, 4 options of development for the Mékrou river basin were defined. These have been simulated within the different models to adjust the figures and assess the feasibility of such scenarios. As an example, the objective of livestock growth was reviewed to a smaller number after estimating the forage (pasture/crop residue) and water required to allow such growth. After a multi-stakeholder dialogue with local representatives from the 3 countries that looked at these scientific inputs, a revised scenario for the basin has been consolidated and adjusted. At this stage, the outputs of regional simulations were also included in the discussion together with inputs from other stakeholders. This has led to the agreement on a joint SDAGE and a related action plan (Plan de Mesures et d'investissements).

Discussions, Conclusions, and recommendations

The Water-Energy-Food-Ecosystems (WEFE) Nexus approach fits a reality of a local population where these four sectors are perceived as important in their daily life. During the project, the local stakeholders raised concerns regarding: i) the management of pressures on resources (water, forests, etc.) for multiple purposes (crop production, livestock breeding, fuelwood for cooking, etc.) in a context of climate change and variability, ii) the preservation of ecosystems in the W Park and, the associated benefits (pool of resources and tourism), iii) the access to basic services and, iv) the management/mitigation of floods and droughts.

One challenge was to integrate these local priorities into the transboundary scale in order to develop a regional development strategy for the river basin while keeping coherent with a national policy frame. The project followed an iterative bottom-up loop in this attempt. In particular, local dialogues with municipalities, user communities, etc. were initially held in each sub-national area. The identification of common issues and main specificities in each sub-area allowed the consolidation of a synthesis on the Mékrou river basin. Several scenarios and development objectives have been defined building up on this synthesis together with the review of the main appropriate strategies of the three Mékrou countries. These scenarios went back to the local level for discussions and were ranked by order of preference, before going through the transboundary dialogue platform for consolidation as Mékrou SDAGE. This method required time and resources for instance because using a not necessarily common consultative framework like the dialogue forums and platform implies more efforts to proceed with the regional synthesis. The regionally agreed SDAGE is a framework of objectives with a main axis for actions that is then detailed by sub-national areas and municipal level, giving the flexibility to address the local specificities identified.

In terms of scientific requirements, the WEFE Nexus assessment demands gathering data in all these different sectors. The main issue encountered in terms of data, as often in the developing world, was the short time series of data and the incomplete series. Methods to cope with this were applied to ensure robustness of the analyses. The combination of multi-source data like remote sensing regional datasets with the few ground station(s) and field campaign results is a robust solution. The E-Water integrates all the tools and analyses applied to the Mékrou river basin into a user-friendly thematic interface.

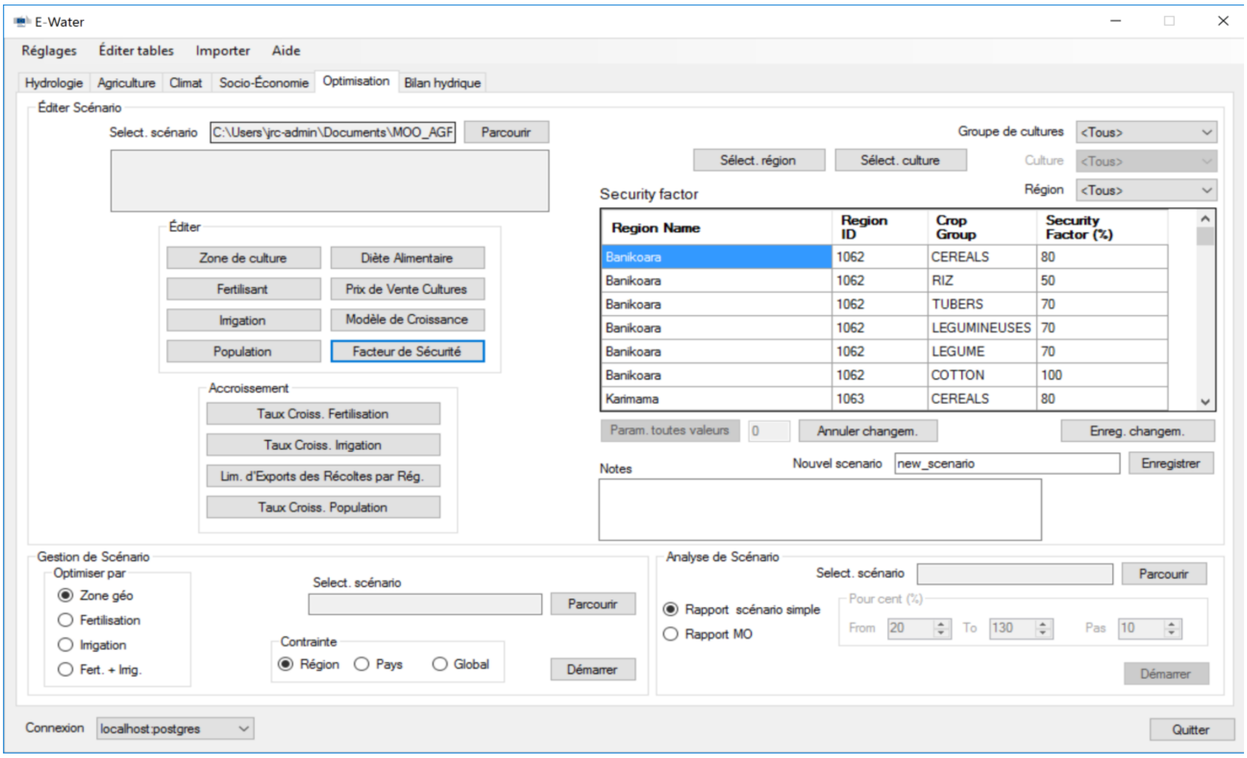

Figure 3. E-water interface – Generation of WEFE NEXUS Scenarios. *HYDROLOGY*: SWAT scenarios; *AGRICULTURE*: Agricultural scenarios; *CLIMATE*: climate variability analyses and maps; *SOCIO-ECONOMIC*: household survey results; *OPTIMIZATION AGRI:* Multi objective optimisation of agriculture production; *OPTIMIZATION WATER:* optimization of water demands vs water availability.

The E-Water open source software was a necessary condition to ensure its use by all stakeholders and the flexibility to replicate them to other river basins. The technical services and scientific experts (i.e. from research institutes or universities) of the three countries were trained and their feedbacks were integrated during the iterative development cycle of the module, thus ensuring its ownership by the local stakeholders.

The following recommendations can be drawn from the Mekrou case:

– Delivering scientifically sound information on a river basin can and should contribute to the dialogue among sectors and countries necessary to address NEXUS assessment and strategy. This can be done through technical workshops with experts from ministries who work in this field on a daily basis. This is important to ensure as much as possible that the technical experts of ministries who participate in the scientific activities are the same. A clear profile of the competences required to actively participate in this type of workshop may help the nomination of the appropriate participant by the relevant ministry.

– The inclusion of appropriate universities and research institutions reinforces the participation of the local expert base and fosters the collaboration between the institutional (i.e., technical service of hydrology or agriculture) and the research side. This inter-sectorial, inter-institutional link developed during a nexus assessment will potentially continue afterwards because people learn to know/trust each other while working on a concrete activity.

– The Information/IT tools have to be open source, to ensure wide use and replicability.

– Developing the information system E-WATER and the strategic planning platform (i.e., SDAGE and PMPI) in parallel with the stakeholders is key in order to ensure maximum synergy. To this effect, the interaction between the two has to be iterative: potential scenarios/objectives of development are tested by available tools. The outputs are then sent back to policy makers and stakeholders to adjust through revision of the scenarios/objectives. The time needed for this interactive process requires should not be neglected.

References:

Agnew C.T., 2000, Using the SPI to Identify Drought in Drought Network News Vol. 12, No. 1, Winter 1999–Spring 2000. Published by the International Drought Information Center and the National Drought Mitigation Center, School of Natural Resources, University of Nebraska – Lincoln.

Amahowé, I.O., L. G. Houessou, S. Ashanti and A. C. Tehou, "Transboundary protected areas management: experiences from W-Arly-Pendjari Parks in West Africa," Parks, vol. 19, no. 2, pp. 95-015, 2013.

Arnold, J.G., Moriasi, D.N., Gassman, P.W., Abbaspour, K.C., White, M.J., Srinivasan, R., Santhi, C., Harmel, R.D., Griensven, A. van, Liew, M.W. Van, Kannan, N., Jha, M.K., 2012. SWAT: Model Use, Calibration, and Validation. Trans. ASABE 55, 1491–1508. doi:10.13031/2013.42256

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment Part I: model dvelopment. J. Am. Water Resour. Assoc. 34, 73–89. doi:10.1111/j.1752-1688.1998.tb05961.x

Cortez, P.Modern Optimization with R.Springer. ISBN 978-3-319-08263-9, 2014.

Deutscher Entwicklungsdienst (DED). 2006. Les conflicts liés à la transhumance transfrontalière entre le Niger, le Burkina Faso et le Benin, 79 pp http://www.peaceresources.net/files/docs/publications/DEDexpert_Transhumanzstudie.pdf , last access the 27th October 2017.

Folberth, C., Gaiser, T., Abbaspour, K.C., Schulin, R., Yang, H., 2012. Regionalization of a large-scale crop growth model for sub-Saharan Africa: Model setup, evaluation, and estimation of maize yields. Agric. Ecosyst. Environ. 151, 21–33. doi:10.1016/j.agee.2012.01.026

Gassman, P.W., Reyes, M.R., Green, C.H., Arnold, J.G., 2007. The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. Trans. ASABE 50, 1211–1250. doi:10.13031/2013.23637

Gassman, P.W., Sadeghi, A.M., Srinivasan, R., 2014. Applications of the SWAT Model Special Section: Overview and Insights. J. Environ. Qual. 43, 1. doi:10.2134/jeq2013.11.0466

Hibert, M. N. De Visscher and S. Alleaume.2004. "The wild ungulate community in the Niger W Regional Park," Antelope survey update (, eds.), pp. 31-35.

Hosking, J. R. M., and Wallis, J. R. (1997). Regional frequency analysis: an approach based on L-moments. Cambridge University Press, Cambridge, U.K.

Malagó, A., Bouraoui, F., Vigiak, O., Grizzetti, B., Pastori, M., 2017. Modelling water and nutrient fluxes in the Danube River Basin with SWAT. Sci. Total Environ. 603, 196–218. doi:10.1016/j.scitotenv.2017.05.242

Markantonis.V, Dondeynaz.C, N'Tcha M'po.Y, Sanon. K, Ameztoy-Aramendi.I, Alhassane.A, Degnide.A.M, Carmona-Moreno. C, 2017.a « Bassin versant de la Mékrou: Enquête sur les ménages. Technical report, Publication Union Européenne, 90 pp.

Markantonis, V., Farinosi, F., Dondeynaz, C., Ameztoy, I., Pastori, M., Marletta, L., Ali, A., Carmona Moreno, C., 2017.b. Assessing floods and droughts in the Mékrou River Basin (West Africa): A combined household survey and climatic trends analysis approach. Nat. Hazards Earth Syst. Sci. Discuss. 1–55. https://doi.org/10.5194/nhess-2017-195)

McKee, T. B., N. J. Doesken, and J. Kleist, 1993: The relationship of drought frequency and duration of time scales. Eighth Conference on Applied Climatology, American Meteorological Society, Jan17-23, 1993, Anaheim CA, pp.179-186.

McKee, T. B., N. J. Doesken, and J. Kleist, 1995: Drought monitoring with multiple time scales. Ninth Conference on Applied Climatology, American Meteorological Society, Jan15-20, 1995, Dallas TX, pp.233-236.

Michelot, A., Ouedraogo, B. "Transboundary Protected Areas: Legal Framework for the W Transboundary Biosphere Reserve (Benin, Burkina Faso, Niger)," in Environmental Policy and Law Paper (EPLP) No. 81, Gland, Switzerland, International Union for Conservation of Nature (IUCN), 2009, pp. 1-33.

Pareto, V., 1971. Manual of Political Economy. Kelley Publ., New York.

Pastori, M., Udías, A., Bouraoui, F., Bidoglio, G., 2017. A Multi-Objective Approach to Evaluate the Economic and Environmental Impacts of Alternative Water and Nutrient Management Strategies in Africa. J. Environ. Informatics 29, 16–28. doi:10.3808/jei.201500313

Pastori, M., Bouraoui, F., Aloe, A., Bidoglio, G., European Commission. Joint Research Centre. Institute for Environment and Sustainability., 2011. GISEPIC AFRICA : a modeling tool for assessing impacts of nutrient and water use in African agriculture (database, model and GIS system development and testing). Publications Office.

Quiao, J., Yu, D., Wu, J., 2018. How do climatic and management factors affect agricultural ecosystem services? A case study in the agro-pastoral transitional zone of northern China. Sci. Total Environ. 613–614, 314–323. doi:10.1016/J.SCITOTENV.2017.08.264

Russo, S., A. Dosio, R. G. Graversen, J. Sillmann, H. Carrao, M. B. Dunbar, A. Singleton, P. Montagna, P. Barbola, and J. V. Vogt (2014), Magnitude of extreme heat waves in present climate and their projection in a warming world, J. Geophys. Res. Atmos., 119, 12,500–12,512, doi:10.1002/2014JD022098.

Van der Velde, M., Folberth, C., Balkovič, J., Ciais, P., Fritz, S., Janssens, I.A., Obersteiner, M., See, L., Skalský, R., Xiong, W., Peñuelas, J., 2014. African crop yield reductions due to increasingly unbalanced Nitrogen and Phosphorus consumption. Glob. Chang. Biol. 20, 1278–1288. doi:10.1111/gcb.12481

Williams, J.R., 1995. The EPIC model In: Computer models of watershed hydrology. Water Resources Publications, Highlands Ranch, CO, USA.

Wriedt, G., Van der Velde, M., Aloe, A., Bouraoui, F.F., der Velde, M., Aloe, A., Bouraoui, F.F., 2009. Estimating irrigation water requirements in Europe. J. Hydrol. 373, 527–544.

Chapter Conclusions and Recommendations

Lessons learned and best practices

28. When designing a Nexus assessment and choosing the methodology for quantification, a number of aspects need to be considered, i.e. data availability, temporal scale and the spatial scale of impacts, stakeholder involvement, impacts on ecosystems at the local, regional and global scale, inequalities in the distribution of impacts on people's well-being, interdisciplinary attributes of experts and tools, and communication needs in translating results to policy makers and people more in general. If there are many such good Nexus tools and methodologies, they are not as general-purpose and transferable as one would desire. That is why focusing on the conceptual, often qualitative, less formal representation of interconnections rather than on how to model them is equally important. Holistic thinking and reductionist modelling can happily go hand in hand.

29. When it comes to data, ground-truthing is critical to address bias for e.g. rainfall estimation from global satellite observations. Uptake by local communities of mobile applications for sharing of real-time rainfall information are helping in that sense through crowd-sourced data. At the local level, tools that support informed decision-making need a good basis of data to be used operationally while improving water management skills. At the same time, sparse data collection networks should keep being reinforced. At the regional level, global hydro-climatic monitoring systems e.g. for drought management or flood forecasting can provide useful and complementary information for decision-making occurring at that level.

30. For comprehensive assessment of synergies and trade-offs among water, energy and food sectors, integrated models are needed to investigate the strength of the interdependency between these three Nexus dimensions and other related SDGs, such as economic growth, poverty, biodiversity, sustainable development, climate change and global security. Integration of different models and methods can tackle the inherent complexity of the Nexus and address its multidisciplinary construct. This allows to perform scenarios analysis to assess sectorial strategies and cumulative impacts of future development goals, which works for decision-making in that it enables the broadest possible evaluation of trade-offs and synergies to result in policy recommendations.

31. In order to best integrate models, it seems desirable to start testing this integration by **selecting the smallest scale at which allocation of resources is at odds with their interconnected nature i.e. a Nexus hotspot**. It is also advisable **not to focus entirely on the technical side of the resource reallocation problem**. Qualitative approaches as well have some use when applied to the Nexus in that they can help map the system with multiple sectors and locate priorities and trade-offs. One such approach is **convergence thinking**, which **engages approaches to problem solving that transcend disciplines and integrate knowledge. This would require creating new collaborations** among multiple disciplines and organizations to implement the Nexus framework. Climate change initiatives are a parallel example and an ongoing opportunity for these multi-sectorial collaborations. Environmental footprint studies are another one.

32. In general, stakeholder buy-in and a demand-driven underpinning are key to both the relevance and the uptake of any Nexus approach. Stakeholder involvement is important to also promote institutional support. Ministries and their related technical services should be actively engaged in the process of model identification and setup, and development of the resulting Decision Support System. This ensures validation of data, methods and outputs by local academic and practitioner experts, ownership of and confidence in the tools, concrete space and opportunity for dialogue, and incorporation of Nexus analysis into the

planning process. Effective involvement of stakeholders can in turn raise interest in funding new data collection, for instance, if dissemination of results leads to a full understanding of the role and benefit of the Decision Support System.

33. Open-source, open-access platforms combining geo-localised data like UNESCO-IHP Water Information Network System (WINS) have been well received in low- and middle-income countries where license costs and governmental authorization may be difficult to overcome or obtain. Governments and other private actors possess many different sources of hydrological information. Sharing this information makes it possible to analyse better the potential for agriculture or hydropower in different regions of the country or of the basin. Near-real-time information on water fluctuations such as drought predictions and other climatic risks are the first kind of data that are being shared on open access platforms due to their potentially direct benefit for e.g. operational farm advice. Open source data, the validity of which should be easily verified, are often seen as a necessary condition to ensure wide use of Nexus tools and replicability of successful experiences in their use for planning purposes at a strategic level by different value-chain actors.

34. As for the creation of an additional institutional framework to existing political processes, **effective collaboration to deal with Nexus issues** is deemed more important to achieve than the establishment of an ad-hoc Nexus body. Collaboration **can be triggered by key issues of the day such as climate change that have led to the formation of soft-type bodies such as national committees.** With the exception of a few countries such as Jordan and Lebanon where issues of water, energy and food security have all become urgent at the same time, adoption of a Nexus approach or framework has not generally been forced. This is despite, at the global level, the Nexus appears to have been considered in SDG implementation, however with little direction as to its practical application.

35. The need for a Nexus approach often stems directly from local stakeholders raising interlinked priorities for the water, agriculture, food energy and environmental sectors during national dialogues convened in different riparian countries and thus the need to reconcile and optimise such objectives. There is perhaps **more value for overarching frameworks such as regional economic commissions, river basin organizations or inter-ministerial committees in a transboundary setting compared to the national context. However, these transboundary organizations may have to undergo institutional fit** for the Nexus. Also, areas of existing conflict or tension may not be the ideal training grounds but then the Nexus can act as a cooperation solution, shifting the problem from a water allocation one to the need to find benefit sharing solutions like power trading.

36. Documentation such as reports, analysis, and briefs from a Nexus assessment in transboundary river basins can substantiate the dialogue among countries and sectors and contribute to capacity building. Additional information that would be valuable to add to such process are in-depth assessments of governance across sectors at the national level as well as a review of how selected inter-sectorial procedures e.g. SEAs are applied or what the perspectives for their use exist in the riparian countries. In these terms, Strategic Environmental Assessments (SEAs) seem to be one of the most suitable frameworks where the Nexus should be addressed.

Knowledge gaps and implementation challenges

37. The currently applied tools are still largely limited to individual sectors and hence not entirely fit for untangling the complex interlinkages of the Nexus, especially beyond the local scale at which initial applications are mostly being tested. In

many instances, this is focused on the economy of a river sub-basin, the resource stocks and flows of which are modelled to assess sector performance in a top-down approach. By contrast, bottom-up approaches tend to quantify the resource footprints of individual products or technological solutions and analyse key processes and technologies crucial to reducing their footprints (see Chapter 3).

38. Limitations exist in either case around the quality and completeness of data and models as we seek vertical and horizontal integration that make them difficult to be validated and therefore used beyond comparison of results. This is why methods and tools with not too much data requirement may be preferred. Results of the bottom-up model can however fill the data gap encountered by top-down model development in a complementary fashion.

39. The technical limitation to sectorial tool integration is also partly rooted in the disciplinary background of model developers, who seldom have the breadth of vision to address interactions in depth. Taking on board all dimensions together is naturally even more complicated. Regardless of the level of computational complexity, data cost constraints should be included in the planning and budgeting for use of such models. For example, primary data sources that are helpful for power system modelling. Time series data of hydropower production are neither publically available nor easily comparable between sites or countries, making it difficult to assess the importance of hydro-climatic variability as a driver of energy production and associated fluctuations.

40. Within the Water-Energy Nexus, studies have primarily focused on calculating the water consumptions of different energy productions. Other more in-depth, “bi-dimensional” Nexus analyses have looked at the impacts of water unavailability on hydropower and thermal power plants. These are typically performed by combining a rainfall-runoff model and a power system model and have already been carried out for regions of strategic interest e.g. water scarce parts of the EU. The analysis of these complex linkages is essential for understanding the water-power nexus and supporting the development and implementation of sound energy and water-related policies. Most of the existing methods and tools for water-energy nexus analysis have been developed to improve understanding before management.[42] Challenges exist in this realm relating to data collection (including due to sensitivity or ownership), degree of model aggregation (including due to system boundaries and different jurisdictions), and computational complexity (including due to hydropower economics, topography and management of multi-purpose reservoirs).

41. Both synergies and trade-offs concern not only monetary values involved in the nexus but also non-monetary values, which are often difficult to measure in market values, such as water, environment and pollution. This makes it difficult to e.g. incorporate water in economic models, to properly examine its role in economic activities, and to study its interaction with other inputs in the production processes. Similar to the input for energy (hydro-power or cooling), data on water availability can also be used to adjust the output of the agricultural sector by making total factor productivity a function of the water availability and introduce the irrigation services activity, whose output will be used as an intermediate input by agricultural activities. These economic models cannot be run at the local or basin level, however, nor can provide a detailed picture of a specific sector or specific commodities.

42. A "common sense" or intuitive decision is normally the outcome of accepted wisdom. Decision Support Systems or tools may help build or corroborate certain practical details of this accepted wisdom, but will never drive (and probably not even influence) the development of wisdom. "Common sense" decisions tend to be conservative, precautionary and no-regret. Taking a common sense/intuitive

[42] https://ideas.repec.org/a/eee/appene/v210y2018icp393-408.html

decision may require acknowledging that models/tools/DSSs are not able to support in addressing the question due to: 1) certain aspects not being considered in the model (e.g. "higher order" biophysical processes or feedback mechanisms), or 2) certain aspects being relevant and recorded in informal knowledge, but not representable in formal knowledge systems/models (e.g. certain societal responses, or crime such as corruption).

43. Training is an essential component where open data show different sources and span disciplines reflecting in little harmonised data-sharing protocols. By contrast, commercial packages can offer longer-term support compared to free software and tools. Also, open source does not automatically equal quality; good, harmonised data is expensive to obtain and not all free-of-charge productions have access to skills and finance to guarantee the adequate level of quality. At the same time, a perception of limited gains and concerns for national security still exist within national governments and sectorial or territorial agencies such as river basin organisations that create a bottleneck hindering significant data exchange which is at the basis for any development of commercial or open access decision support system or tool. Moreover, introducing data sharing as an issue of common interest in the negotiations may assist in building trust and achieving equitable agreements.

44. Strengthening institutional capacity for understanding and consequently acting on the dynamics and interlinkages among sectors at different scales, as per model results, is essential for introducing a Nexus perspective into planning and implementation. This would translate in promotion of mutually reinforcing polices and achievement multiple of goals for a true Nexus uptake and is part of cross-sectorial coordination together with increased dialogue among the key actors from the different Nexus sectors.

Areas of further research and other practical actions

45. Earth system models or integrated assessment models have their place in scientific research (e.g. for exploration, theory development and issue anticipation or tabling), political strategy testing and agenda setting. Going beyond the types of challenges outlined above at the level of model integration, without developing overly complicating integrated models, seems to suggest the need to go beyond models. Being holistic in the way of thinking does not necessarily imply being holistic in coding models. On the contrary, more investment could go in focusing on the conceptual connection of problems, while favouring single-question models that do address these questions as simply as possible.

46. In the example of the Mekrou assessment that looked at the interplay of water availability and crop production with rather loose coupling, the analysis was very much Nexus-informative without being a Nexus model per se. The key is in the **sectorial model output being interpreted as having consideration for its Nexus implications**. Additional drivers that can breach silos are other cross-cutting concrete problems caused by e.g. climate change, population growth and urbanisation. These can be equally used as an opportunity to push sectors to collaborate. The ecosystem services approach is also an attractive approach to help translate the results of Nexus assessments to policy makers and people.

47. **One practical solution to model integration** that keeps domains separate and, consequently, inherently robust **is "soft-linking", "loose coupling" or a "modular approach"**. A key to the Nexus approach is to identify the points at which the resource systems interact and to establish appropriate data exchanges between the modules (e.g. water requirements in the land-use and energy systems but also energy needs for water supply and land use, and land requirements for energy and water infrastructure). The output from one module forms the input for the other two. This type of the multi-model framework is the

most common way of dealing with complex and multiple systems. It is in essence a loose coupling in which the factors in one system are exogenous to the other systems considered. Given its relative simplicity and transparency, this kind of model framework is expected to be more widely applied in the WEF nexus analysis. Despite these advantages, loose coupling approaches have a limitation in considering feedbacks among the individual systems of the Nexus.

48. As an example of the above, Computable General Equilibrium (CGE) models used in macroeconomics are being linked to hydrologic and crop models to get data on water availability and crop response to changes in water supply. Water is thus introduced indirectly into the production system. This economic-hydrologic-biophysical integrated approach allow to take into account physical properties and can moreover account for the role of ecosystems in producing and storing water. It makes it possible to analyse interlinkages across the water-using economic sectors for priority setting among alternative economic and non-economic uses of water.

49. Effective modelling needs to be demand driven and not just an academic or research exercise. To that effect, model users such as policy clients would ideally be educated on what information modelling can actually provide, and tailor questions and expectations to the current modelling reality. They would therefore have sufficient confidence in the model to support its credibility despite or because of its robustness. Equally, it should be possible to be able to disaggregate results and messages in order to facilitate their use and application by different sectors. In better understanding who all the users of the model are, Decision Support Systems could also be used as knowledge management platform to provide relevant information and access to technologies (e.g. via case studies) for the stakeholders in the different sectors. Fora for awareness raising, capacity building, and sharing of experience where to extend national policy dialogues should be equally identified e.g. UNECE's Thematic Working Group on Sustainable Transport, Transit and Connectivity.

50. Some less than obvious interconnections that should be part of the models developed to analyse the Nexus lie **outside production optimisation**. For example, food waste should be accounted for in terms of its water and energy footprint when calculating agriculture potential as this will take up a large share of the annual irrigation demand even if it is not consumed. Likewise, food miles. How far the food needs to be transported is also linked to energy use and GHG emissions. Organic food production for its net positive impact on ecosystems. The use of **virtual water and other environmental footprint methods as a comparative analysis tool** in this context can help better understand better this type of issues.[43] This is a bottom-up application of tools as summarised above that plays an especially important role in the planning and maximisation of those waste recovery opportunities, be it low quality water, heat or biomass.

51. Open data in general has a potential to empower citizens, change how government works, and improve the delivery of public services. **Significant economic value can be unlocked by applying advanced analytics to both open and proprietary knowledge**. It can become an instrument as part of a Nexus approach for breaking down information gaps across industries and sectors, allowing companies and riparian countries to share benchmarks and spread best practices that improve multiple resources securities. **Blended with proprietary data sets, it can propel innovation and help organizations replace traditional and intuitive decision-making approaches with data-driven ones**. But investments in technology and expertise are required to use the data effectively. Equally, open data policies need to be enacted to unlock this finance. Open data can be key to future developments, including commercial, e.g. Software as a Service (SaaS) where web-based tools raise revenues other than

[43] https://www.sciencedirect.com/science/article/pii/S221204161530022X

from licensing. Most important for Nexus implementation, though, is that fit-for-purpose models are kept as simple and transparent as possible through open data.

52. Specific areas for supplementary assessments to build on carried-out analyses of water, energy and land should focus on quantitative descriptions of the potential effect of identified measures for e.g. improving efficiency of irrigation and of land reclamation. This would include **evaluating the costs and benefits of selected Nexus solutions as prioritized by the countries involved in the assessment**. Decoupling of high-energy intensity pumping and irrigation could be achieved by the installation of more efficient and renewable energy-powered pumping systems such as solar, for example. **Existing models could thus be used to also assess the impacts of different Nexus investments and contribute to the definition of bankable Nexus projects**. Facilitation of this operational aspect is for example occurring through UNECE Group of Experts on Renewable Energy at the Ministerial Conference and 8th International Forum on Energy for Sustainable Development.[44]

[44] https://www.unece.org/astana2017.html

Chapter 3. Nexus Governance, Institutions, Cooperation Frameworks, Finance, Investments and Feasibility.

Facilitating WEFE Nexus policies and projects require the appropriate institutional environment. In this context, this chapter presents those governance and institutional settings that can successfully enhance the implementation of WEFE NEXUS projects. The chapter also considers the importance of multi-level stakeholders and public-private partnerships and how participatory approaches influence the application of the WEFE Nexus. Through the different contributions of the NEXUS experts, the chapter also address the key institutions and how can they better cooperate in implementing the WEFE NEXUS projects. It is also important to consider the importance of the civil society and participation of the local societies in the decision-making process and in implementing the projects. Finally, the roles that can be played by diplomacy in the implementation of the WEFE Nexus projects in transboundary basin projects are also addressed. As proposed here, this can be articulated around setting-up cooperation frameworks since early phases to ensure the successful implementation of projects. How can this process be more efficiently facilitated and which are the steps for establishing the cooperation framework are questions to be considered during the early implementation phases and if possible at the level of the identification phase. The cooperation framework should take into account not only the political aspects but also technical ones as data sharing and information at different scales and institutions.

The feasibility and financing of the WEFE Nexus projects are also crucial for deciding upon the investments. Prior to these one, a significant field is to define the criteria for making WEFE Nexus projects part of investment plans. In this context, this chapter defines the conditions and the funding sources for bankable WEFE Nexus projects. Furthermore, it demonstrates the economic benefits induced by applying WEFE Nexus projects towards meeting specific targets of SDGs. The feasibility of WEFE Nexus investments meets and can even benefit from cross-cutting issues such as climate change financing, environmental sustainability and compliance to environmental protection policies.

The sub-themes proposed to guide the roundtable discussions for the topic of this chapter were:

- The requirements for investment-ready Nexus projects with potentially conflicting objectives i.e. financial and economic vs. social and environmental in a portfolio approach to finance;
- The river basin scale as the most appropriate management framework for approaching and implementing the Nexus;
- The advantages of promoting a Nexus approach within the ongoing debates and actions surrounding Climate Change Mitigation and Adaptation;
- The operational aspects of the Nexus as a platform to guide sustainability efforts underpinned by the SDGs.

The Water-Energy-Food Nexus in the Arab Region: Governance and Role of Institutions

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ABSTRACT: Interlinkages between water, energy and food systems in the Arab region are intensifying with time, as the demand for resources increases due to population growth and is exacerbated by changing consumption patterns, low management efficiencies, and the additional impacts of climate change. While these conditions are constraining the ability of existing systems to meet the growing demand in a reliable and affordable manner, the dynamics of the three sectors pose substantial risks for the sustainable development and resource security ambitions of the Arab countries due to their strong and crucial interdependencies. Therefore, it is becoming imperative that policy formulation becomes coordinated among the three sectors. Conventional policy and decision making in 'silos' needs to give way to a nexus approach to reduce trade-offs and build synergies across the three sectors through integrated planning and management, which can only be delivered through appropriate governance and relevant institutions. Currently, the institutional framework governing the elements of the nexus in most of the Arab countries is fragmented and lacks effective coordination mechanisms, which has led to a sectorial approach to policy planning, and consequently fragmented strategies and policies. Some countries have succeeded in presenting different models of "integrated institutions," but their comprehensive and inclusive management of these interlinked priorities still needs support. Enhancing coordination and collaboration mechanisms amongst institutions is key for mainstreaming the WEF nexus approach and not necessarily establishing new institutions.

Introduction

Water, food and energy in the Arab region are strongly and closely interlinked, probably more than in any region of the world. Generally, the region is energy intensive, water scarce, food deficient, and one of the world's most economically and environmentally vulnerable regions to climate change. To make enough food to support a growing population and urbanization, more water and energy are needed; to make water accessible and clean for human consumption demands energy; and producing energy will require water. These interdependencies, termed the "Water-Energy-Food Nexus", are intensifying in the region as demand for water, energy and food increases with population growth, changing consumption patterns, and low management efficiencies in both the supply and demand of these three sectors, and are expected to be further compounded by the impacts of climate change.

These strong interlinkages carry high risks among the three sectors, and the conditions of dwindling natural resources create immense challenges to the countries in this arid region in their attempt to meet the demands of the three sectors. Trying to achieve the security of one of these sectors independently and without due consideration of the trade-offs with the other two sectors will be at the expense of the security of one or two of the components of the nexus, and eventually endangering the security of the sector itself. For example, achieving food security by domestic production without due consideration of the limitations of water resources will not only lead to over-exploitation, quality deterioration, and loss of water resources, but it will also lead eventually to the loss of agricultural productivity, and the deterioration of the agriculture sector itself and the levels of food security.

In other words, adapting a sectorial approach in meeting the demand of these sectors will lead to worsening livelihoods and increasing environmental degradation and thus, potentially, missed opportunities to achieve the SDGs and ultimately negative impacts on human wellbeing. Hence, such a strong interdependency between these three sectors and between them and the environment and climate change calls for a nexus thinking and perspective when addressing the planning and management of these three vital sectors (i.e., an optimization approach rather than maximization); this is an approach that integrates management and governance across sectors, and where conventional policy and decision-making in 'silos' gives way to an approach that reduces trade-offs and builds intelligent synergies across the sectors. Adopting a water-energy-food nexus approach in the Arab countries would provide an opportunity for innovation and learning to minimize security risks and maximize opportunities and enhance resource efficiency and equity. More importantly, it will serve the countries of the region in moving towards achieving the global Sustainable Development Goals (SDGs) and meeting the mandates of a low carbon economy following from their committed Nationally Determined Contributions (NDCs) under the Paris 2015 Climate Change agreement.

Fortunately, this has been well recognized in the region through the "Arab Strategic Framework for Sustainable Development (ASFSD)", adopted by the League of Arab States (LAS) in 2013, aiming to address the key challenges faced by the Arab States in achieving sustainable development during the period 2015-2030. This new development has created unprecedented opportunities for fundamental policy changes in various economic, institutional, technological, and social systems, as well as boosting resource efficiency and productivity by addressing externalities across sectors.

While the usefulness of adopting a nexus approach to achieve the post-2015 sustainable development Agenda (directly SDGs 2, 6 and 7, and indirectly many others) is evident, there are still many questions that need to be addressed on the implementation. Among the most important ones are questions related to mainstreaming the WEF Nexus into institutional and policy frameworks and required capacity development, characterization and research on the WEF nexus to support the implementation of the SDGs.

Harvesting synergies and reducing negative trade-offs across sectors and resources, including efforts to increase cross-resource efficiencies and subsequently to also increase water, energy, and food (and political) security, requires coordination and cooperation across institutions, strategies, policies, and activities. Only a coordinated approach will ensure that efforts in one sector do not cause harm in other sectors but complement each other and generate synergies.

This short paper presents the status and main characteristics of the WEF Nexus in the Arab region, and an overview of the existing institutional framework governing the Nexus elements in the region.

Status of Water, Energy, and Food in the Arab Region

The WEF Nexus in the Arab region is being driven by many natural, demographic, and socio-economic factors that do not only intensify the nexus inter-linkages in the region, but also increase the risks of the nexus components on each other. In the last three decades, most of the countries in the Arab region have experienced rapid population growth and accelerated socio-economic development; the population of the region has doubled from about 170 million inhabitants in 1980 to more than 375 million in 2014 (UNDESA, 2015). This growth is associated with a substantial increase in the demands for water, energy and food. However, the increase is attributed not only to population growth, but also to consumption patterns and low efficiencies in the production, supply, and use of these three vital resources.

The Energy Sector

The energy sector is central to development in the Arab region, making up about 40% of the region's GDP (Fattouh and El Katiri, 2012). The region's fossil fuel engines of growth are driven by the group of high-income, energy-rich economies of the Arabian Gulf; with record prices in recent years, this has translated into a surge of public revenue streams and related development initiatives. With rapid growth in energy-intensive urban/industrial growth, these countries are seeing some of the world's fastest rates of per-capita energy consumption growth, which is resulting in rapid draining of oil and gas reserves of these countries. This has become a top concern in most of these countries given its criticality for future exports revenues and fiscal stability (Khody and Gitonga, 2017).

Meanwhile for the region's energy-import dependent countries, energy challenges are of different type and greater. These countries make up the majority of the Arab countries and host 40% of the region's poor who still lack adequate access to modern energy services (Khoday, 2012). These energy challenges, as well as challenges of other resources, are further exacerbated due to the flow of refugees and forced migrants to these countries (e.g., Jordan and Lebanon). Another challenge facing these countries is the volatility of global energy prices, which has been a drain for public revenues and, coupled with relatively high domestic energy subsidies, is creating major challenges to fiscal sustainability (Sdralevic, *et al*. 2014).

Energy consumption in the region continues to be dominated by fossil fuels. In 2011, the primary energy consumption mix was dominated by oil products (48.5%) and natural gas (50%), with coal (0.7%) playing a minor role and hydro-electricity (0.8%) being the only form of renewable energy to make a measurable impact (AFED, 2013). Current trends and patterns of energy use put the Arab countries' economies among the least efficient ones in global comparisons. Moreover, there has been no decoupling between economic growth and energy demand in the region in the past decade. Growth in energy consumption has been faster than economic growth during the past decade (Figure 1), implying energy is not being used effectively to produce value within the region economies (RECREE 2015).

Fossil fuel subsidies are a contributing factor to the inefficient use of energy. In Arab electricity markets, price subsidies represent one of the major challenges to progress of efficiency measures. Another factor is the prevalence of inefficient electricity infrastructure in most countries of the region. Average Arab electric energy losses in generation, transmission and distribution are 19.4%, which is higher than the world average (8.3%), and much higher than the EU average (5.8%), thus presenting an ample opportunity for achieving energy savings (AFED, 2013).

The Water Sector

The Arab region has an extremely poor supply of water resources with many areas experiencing unpredictable rainfall. Taking population size and growth into consideration, the Arab region is considered one of the world's most water-stressed regions, with continuously decreasing per-capita freshwater availability. The majority of the Arab countries are currently below the water poverty line of 1000 m^3/capita/year, in contrast to a world average of about 7,240 m^3/capita/yr (Figure 2). In 2011, the overall per capita freshwater availability in the Arab region was about 800 m^3/capita/yr. Based on the projected population increase, it is expected that this indicator will continue to decrease to reach about 500 m^3/yr by 2030 when the Arab region population will reach more than 500 million. This means that the whole region will experience absolute water poverty, whereby water will become a major constraint for development impacting the standard of living, health, and the environment (Falkenmark 1989). In addition, precipitation trends are predicted to be decreasing in most of the Arab region while temperature will be increasing (ESCWA, *et al*. 2017). It is expected that by 2030 climate change will have led to a 20% reduction in renewable water resources and more droughts in the region (Doumani 2008), which would further exacerbate the current scarcity situation.

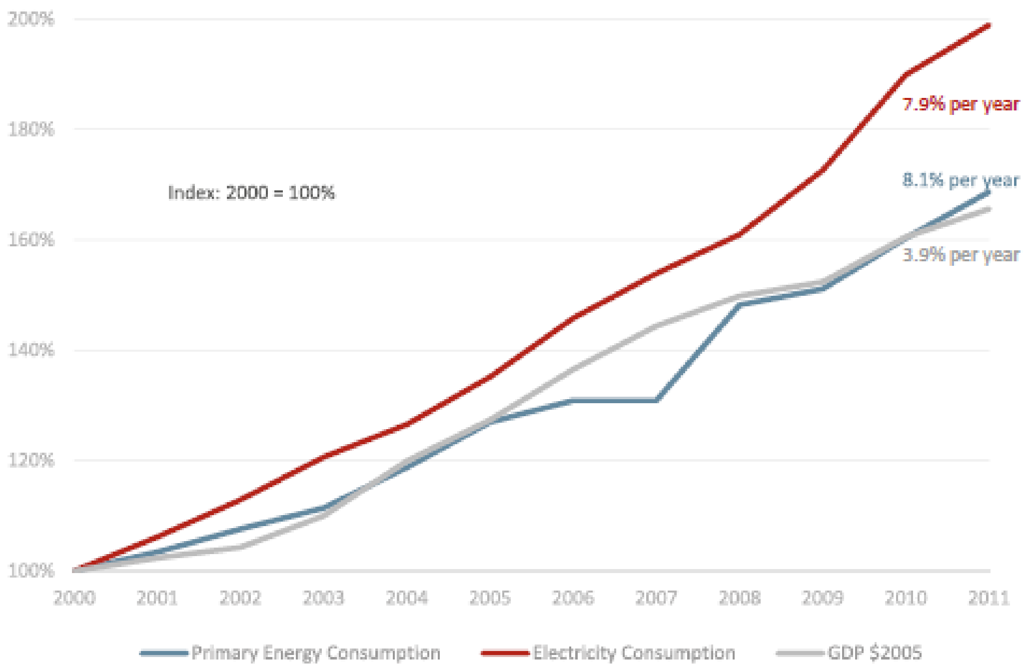


Figure 1. Decoupling of Energy Consumption from Economic Growth in the Arab region, 2000 to 2011 (RECREE, 2015)

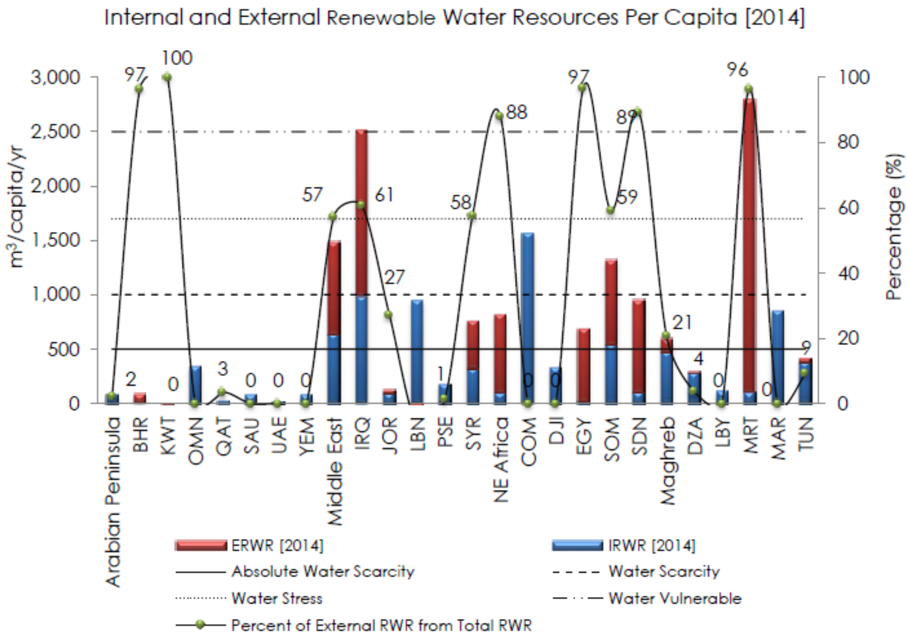


Figure 2. Internal renewable water resources (IRWR) and external renewable water resources (ERWR) in the Arab region (Mohtar *et al*., 2017)[45]

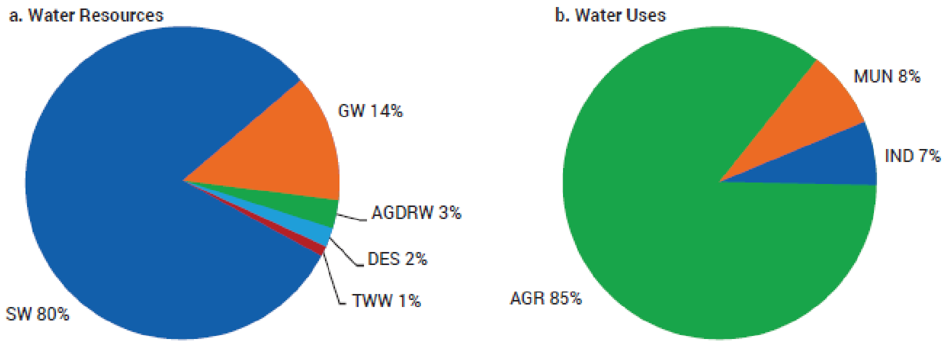
Furthermore, one of the major challenges facing the Arab region is the high overall dependency ratio of the region on shared water resources (i.e., external water resources); more than 60% (about 174 billion m^3/yr of a total of 315 billion m^3/year) of surface water resources originate from outside the Arab region (ESCWA and UNEP, 2015; Figure 2). This issue remains a major concern threatening the region’s stability, food security, and complicates national water resources management and planning. Conventions and agreements on equitable sharing and management of water resources

[45] Internal water resources are those generated within the country, while external water resources are those flowing from outside the country.

have not been signed by riparian countries. In addition, some Arab countries are deprived of their water resources by occupying powers (i.e., Occupied Palestinian Territories, Golan Heights, and Southern Lebanon) which is another major issue in the region and is constraining the development of the population of these countries.

During the past three decades, water demands in all the Arab countries have increased dramatically as a result of increasing population and urbanization growth, improvements in the standard of living, industrial development and efforts to increase food self-sufficiency. The total water use for all sectors in the Arab region increased dramatically from about 190 billion cubic meters (BCM) in the mid-1990s (ACSAD, 1997) to about 255 BCM in 2010 (UNDP, 2013). The majority of water resources in the region are being used for agriculture (85%), while the municipal and the industrial sectors consume about 8% and 7% of the total water use, respectively (UNDP, 2013; Figure 3).

In the municipal sector, in addition to rapid population growth and urbanization, the rapid increase in urban water demands in the region could be explained by many factors, including rise in per-capita consumption, large losses in the supply network, and lack of recycling programs within the sector. In many countries, water efficiency in both the supply side and the demand side is generally very low. On the supply side the physical leakage in the municipal networks could reach more than 40%. Moreover, reuse rates of treated wastewater are at their minimal, representing major lost opportunities under the water scarcity conditions of the region. On the demand side, the per capita water consumption in the domestic sector in many countries ranks amongst the highest in the world (e.g., GCC countries).



(SW: surface water, GW: groundwater, AGDRW: agricultural drainage water, DES: desalinated water, and TWW: treated wastewater; AGR: agricultural sector, MUN: municipal sector, IND: industrial sector)

Figure 3. Water Resources and Water Uses in the Arab Region (UNDP, 2013)

In the face of rising urban demand and the limited supply of conventional water resources, many countries, particularly in the hyper-arid, high-income, energy-exporting countries, such as the Gulf countries, have resorted to desalination. The Arab region leads the world in desalination capacity, where it possesses the majority of the world's desalination capacity; in 2013 total global contracted and online capacity was about 94.5 million cubic meters per day, from which 62.3 million cubic meters per day comes (about 65%) from the GCC countries only (Al Hashemi, *et al.* 2014). Growth in desalination capacity is expected to remain high for the next decade to meet escalating domestic water demand, and the overall share is expected to increase in the region's total water supply as a result of industrialization, accelerated urbanization, population growth and depletion of conventional water resources. However, desalination is an energy- and capital-intensive process, with water production costs depending on energy requirements, technology growth trends, and environmental impact. However, with recent desalination trends showing improvements in desalination technologies, production costs are dropping. The downward trend in the cost of desalinated water indicates that desalination technology might be becoming more viable for poorer countries. Yet, desalination raises energy security concerns and energy consumption creates a larger carbon footprint, although in GCC countries it takes place mostly in thermal-powered co-generation stations that produce both water and electric power, thereby improving energy efficiency and cost effectiveness (IEA-ESTAP and IRENA, 2012). The GCC countries are also increasingly concerned about the threat to marine life and ecosystems posed by the thermal brines discharged from desalination plants (World Bank, 2012).

The Food Sector

In terms of food, most of the Arab countries have made progress in enhancing their food security situation in the past ten years, excluding countries in which there was war or civil conflict. Based on the AOAD Arab food security report (AOAD, 2013), domestic production of food commodities increased considerably and is expected to continue to rise. However, some of the Arab countries have over 30% of the population living in conditions classified as poor, thirteen Arab countries were classified as low on the Global Hunger Index of 2014, and one country was classified as "moderate". Three countries were classified as "serious", while another three were classified as "alarming". Arab countries are unlikely to achieve high ratios of food self-sufficiency; however, they can maintain and improve current ratios (Alzadjali, 2017).

In many Arab countries, agricultural sector performance indicators are very low and agriculture is considered unsustainable due to the continuous deterioration of limited water resources and the limited capacity of arable lands, many having low productivity per unit area. Overall irrigation efficiency is generally low and averages around 45%, while crop productivity is generally low, particularly that of staple cereals, averaging about 1,133 kg/ha in five major cereal producers (Algeria, Iraq, Morocco, Sudan, and Syria), compared to a world average of about 3,619 kg/ha (Sadik, 2014). Moreover, some countries face serious challenges in their objectives to achieve food security locally. These emanate from a backdrop of constraining factors, including aridity, limited cultivable land, scarce water resources and serious implications of climate change. Weak policies, insufficient investment in science and technology and agricultural development have contributed to the impoverished state of agricultural resources and to their inefficient use and low productivity. Population growth, rising demand for food, degradation of natural resources, and conversion of farmland to urban uses pose further challenges to the enhancement of the food security goal in the region.

Moreover, post-harvest losses (PHL) in the region are considered high. It is estimated that the annual losses of grains in Arab countries amounted to about 6.6 million tons in 2012. In addition, loss in imported wheat in some Arab countries translates to about 3.3 million tons due to inefficient import logistics. These national post-harvest losses represent an opportunity cost due to waste of water and energy resources (as well as land and labor resources) used in production (AFED, 2014).

WEF nexus Dynamics and Risks

The complex web of interdependencies between the three sectors and climate variability has manifested itself over the past few years in new and increasingly interconnected crises (the food, energy, and financial crises, together with extreme climate events such as droughts and floods). These crises impacted the Arab population heavily overall and on varying degrees, e.g. hitting the poor the hardest.

The Water–Energy Nexus

Water and energy are critical resource inputs for economic growth. The risks and the impacts the water sector presents to the energy security and the energy sector presents to water security are numerous. However, in the Arab region these risks are more skewed towards the latter case due to the considerable role the energy sector plays in the water value chain in this arid region, especially for the energy-import dependent countries. Energy inputs are spread across the water supply chain. Energy is used in almost every stage of the water cycle: extracting groundwater, feeding desalination plants with its raw sea/brackish waters and producing freshwater, pumping, conveying, and distributing freshwater, collecting wastewater and treatment and reuse. In other words, without energy, mainly in the form of electricity, water availability, delivery systems, and human welfare will not function. It is estimated that in most of the Arab countries, the water cycle demands at least 15% of national electricity consumption and it is continuously on the rise (Khatib, 2010). Moreover, as easily accessible freshwater resources are depleted, the use of energy-intensive technologies, such as desalination or more powerful groundwater pumps, is expected to expand rapidly leading to more energy consumption.

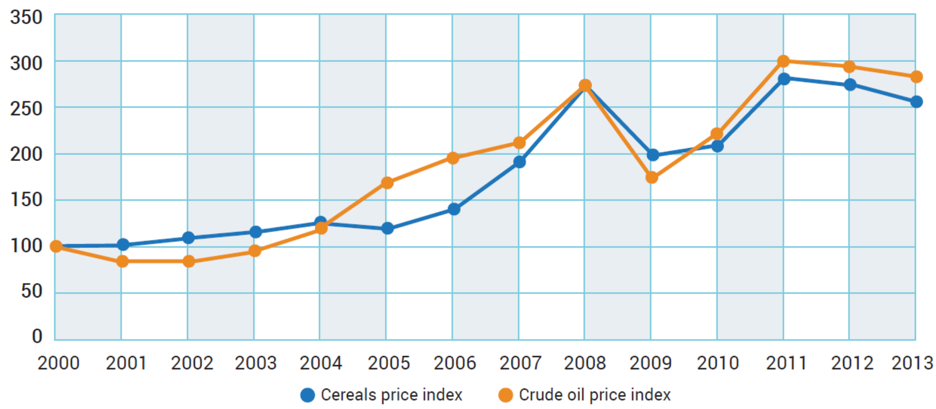
The Water–Food Nexus

The region is already suffering from water scarcity and witnessing intense competition with other sectors, including manufacturing, electricity production, domestic use, and environment. In the face of these competing demands, increasing allocation of water for irrigation will be challenging. Water is a critical input along the different stages of the agri-food supply chain. As the main input in agricultural production, the risks that the water sector presents to food security are considerable and proliferate under the region's arid conditions and sectorial competition. River basins in the Arab region that are critical in the water-food nexus, – such as the Nile, Euphrates and Tigris – are predicted to be "closed basins" (over-allocated), particularly due to energy and agricultural production, and could face challenges from the effects of climate change and lack of regional water agreements.

On the other hand, agricultural practices have substantial impacts on water security for a broader set of stakeholders. Domestic food security is high on the agenda of many Arab countries. In the wake of the 2008 global food crisis, when at least 25 countries imposed export bans or restrictions on food commodities, many food-importing countries realized the grave food security risks that such situations posed. Several Arab countries (e.g., GCC countries) for which food self-sufficiency is very difficult to achieve, began buying or leasing land in relatively water-rich countries, which by itself creates another risk given that many of the recipient countries are home to significant populations of malnourished and are often on the receiving end of food aid.

The Energy–Food Nexus

Agricultural production consumes energy directly in the form of fuels for land preparation and tillage, crop and pasture management, and transportation or electricity supply, and indirectly through the use of energy-intensive inputs, such as fertilizers and pesticides, or energy for manufacturing agricultural machinery. Energy is also needed during processing, distribution, storage, retail and preparation of food products. This makes food security particularly sensitive to the quality and price of energy inputs: in some countries, the price of oil has a rather direct effect on the price of food (Figure 4). Another dimension of the energy–food nexus that is gaining prominence is the impact of the growing share of modern bio-energy in the world's energy mix, which is emerging as a viable renewable energy option for many countries. For example, liquid biofuels produced from straw or wood and biogas from anaerobic digestion of residues would be the most applicable modern bioenergy options in the region as opposed to traditional sources e.g. fuelwood and charcoal.



Source: Based on FAO Food Price Index and BP Statistical Review of World Energy 2014 (Base 2000 = 100)

Figure 4. Links and co-risks of world market prices for energy and food: Oil-cereal price inter-linkages 2003-2013.

The nature of energy supply into the agri-food sector can substantially influence food security. The key risk posed by the energy sector on food security is that the dependence on fossil fuels increases volatility of food prices and affects access to food. This risk is magnified in the region's energy-import dependent countries as fossil fuels continue to provide the majority of the energy inputs for conventional development of the agri-food sector, ranging from electricity and/or diesel for pumping, food processing and storage, to fuel for agro-machinery.

Governance and Institutions in the Arab Region

It is important to note that, in general, there has been weak or lack of real coordination in the Arab region in terms of integrated policies and strategies for water, agricultural land, and energy. In the majority of the Arab countries, the current water-energy-food-climate policy landscape in the region is fragmented and policies have been developed independently of each other. For example, the current low pricing policies for resources in the majority of Arab countries have been promoting unsustainable consumption and production patterns leading to more resource depletion. Low pricing and across-the-board non-targeted subsidies have resulted in domestic over-consumption of resources and the absence of incentives to achieve resources efficiency.

The institutional framework governing the elements of the WEF nexus in most of the Arab countries is fragmented, which has in the past and continues today to delay the comprehensive and inclusive management of these interlinked three priorities. This fragmented institutional framework has led to the sectorial approach to policy planning, and consequently fragmented strategies and policies. This fragmentation is also found within the sector itself (e.g., in some countries more than one authority govern the water[46] and energy[47] sectors). Nevertheless, Arab countries present various models of "integrated institutions;" in the sense one body is responsible for the policy, planning and/or management of two or more sectors/resources[48].

It is increasingly evident that development strategies and national policies can no longer be formulated for individual sectors alone. To ensure proper adoption of WEF nexus, policies and plans must be developed using a multi-stakeholder approach that cuts across the different sectors to address the arising challenges posed by the interdependencies

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[46] one ministry controls water allocation for domestic and industrial use, while another controls irrigation water use, a third ministry sets standards for potable water quality, and a fourth setting quality standards for surface and groundwater.

[47] e.g., energy related ministries responsible of electricity, renewable energy, and petroleum and minerals.

[48] e.g., Ministry of Energy and Water in Lebanon; Ministry of Environment and Water of the UAE responsible for the environment, water resources as well as agriculture, livestock, fisheries, and managing desertification and biodiversity conservation; Morocco combines energy, water and environment under the Ministry of Energy, Mining, Water and the Environment while the Ministry of Agriculture and Fisheries governs the processes of planning water resources and irrigation.

and adequately identify synergies and manage trade-offs. Some Arab countries have a “higher” water commission providing a level of higher decision making than individual sectors. A good example is the Royal Water Commission in Jordan. The Commission, headed by HRH Prince Faisal Bin Al Hussein, invites representatives of the public and private sector to participate in decision-making processes to ensure a coordinated and holistic approach for water management.

Uniting key WEF sectors under the umbrella of one ministry is no guarantee for integrated management and governance. Managing the nexus at the local and national level does not require major institutional restructuring, but rather appropriate changes to protocols, procedures and processes that improve interactions among the relevant ruling entities. The coordination and collaboration mechanisms amongst national institutions are vital elements in applying an integrated approach to resource management. Strong institutions that are better interlinked are means to a nexus approach, and may be more important than additional or new institutions.

For example, many Arab countries have established national cross-sectorial committees for sustainable development[49] and for climate change[50] (Hoff, *et al.* 2017). These committees can be used as key entry points for mainstreaming and implementing the nexus approach by facilitating the integrated implementation of the SDGs and the Nationally Determined Contribution (NDC) of the Paris Agreement.

Conclusion

Even though existing institutions of the Arab world face many challenges to a nexus approach, many opportunities exist that could be tapped into, such as the existing models of integrated institutions and different forms of multi-stakeholders bodies, such as national climate change committees or sustainable development committees could serve as a catalyst to mainstream the nexus approach at all levels of policy development. Governance and institutional structures in the Arab region can be enhanced and strengthened for more effective and integrated resource management by conducting an in-depth evaluation of institutions and the governance system in each Arab country. This would be for better understanding of the weaknesses and gaps that hinder application of a nexus approach, and enhancing coordination and collaboration mechanisms amongst the relevant institutions as a key for mainstreaming the WEF nexus approach, and not necessarily establishing new institutions for the WEF nexus. The ultimate aim is to have institutions that are able to mainstream and implement the WEF nexus approach in policies in the Arab countries in light of the mandates and targets of both the SDGs and the Paris 2015 Climate Change agreement and Arab countries’ NDCs. This is important in order to ensure that the Arab countries will not, in the near future, be sidetracked by crippling resources insecurities on their sustainable development path.

References:

ACSAD (Arab Center for the Study of Arid Zones and Dry Lands) (1997). Water resources and their uses in the Arab world. In: Proceedings of the first Arab symposium on water resources and their uses in the Arab world. Organized by ACSAD, Arab Fund for Economic

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[49] In Jordan, the "Higher National Committee for Sustainable Development (HNCSD)" provides a national platform for dialogue on sustainable development issues, challenges and opportunities towards achieving sustainable development goals in Jordan. The Committee includes representatives from 22 different institutions. It is chaired by the Minister of Planning and International Cooperation (MoPIC) and co-chaired by the Minister of the Environment (MoEnv). It has an Executive Secretariat established in the Sustainable Development Division at MoPIC. In Egypt, the "National Committee to follow up on the implementation of the SDGs" is established under the direct supervision of the Prime Minister and is coordinated by the Ministry of International Cooperation (MIC) in close cooperation with the Ministry of Planning and Administrative Reform (MPAR) and a range of other ministries and councils.

[50] In Egypt, the National Committee for Climate Change is headed by the Ministry of Environment (MOE) and includes representatives from relevant ministries, including ministries of water, energy and agriculture.

and Social Development (AFESD), and Kuwait Fund for Arab Economic Development (KFAED), Kuwait City, Kuwait, 8-10 March, 1997, pp: 25-121 (in Arabic).

Al Hashemi, R., Zarreen, S., Al Raisi, A., Al Marzooqi, FA., Hasan, SW. (2014). A Review of desalination trends in the Gulf Cooperation Council Countries. International Interdisciplinary Journal of Scientific Research, vol. 1: 72-96.

Alzadjali, T.M. (2017). Status of Food Security in the Arab Region. In: Water, Energy, and Food Security Nexus in the Arab Region, Water Security in a New World, pp 43-57, DOI: 10.1007/978-3-319-48408-2_3.

Al-Zubari, W. (2017). Status of Water in the Arab Region. In: Water, Energy, and Food Security Nexus in the Arab Region, Water Security in a New World, pp 1-24, DOI: 10.1007/978-3-319-48408-2_1.

AOAD (2013). Arab food security report. Arab Organization for Agricultural Development, Sudan.

Doumani, F. M. (2008). Climate Change Adaptation in the Water Sector in the Middle East and North Africa Region: A review of main issues. PAP/RAC Workshop, Sardinia, May 19-21.

ESCWA and UNEP (2015). Arab Sustainable Development Report 2015. ESCWA report number E/ESCWA/SDPD/2015/3.

ESCWA *et al.* (2017). Arab Climate Change Assessment Report - Main Report. United Nations Economic and Social Commission for Western Asia (ESCWA), RICCAR (Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-economic Vulnerability in the Arab Region). Beirut, E/ESCWA/SDPD/2017/RICCAR/Report.

Falkenmark, M. (1989). The massive water scarcity now threatening Africa-Why isn't it being addressed. Ambio, 18: 112-118.

Fattouh, B,. and El Katiri, L. (2012). Energy and subsidies in the Arab region. UNDP Arab Human Development Report Research Paper Series, Regional Bureau for Arab States, New York, NY.

Hoff H, Mansour L, Carius A, Kramer A, Abaza H, Al Ouran N, Al-Zubari W, Ulrich A. (2017). Mainstreaming the Water-Energy-Food Security Nexus into Policies and Institutions in the MENA Region: National guidelines on mainstreaming the water-energy-food (WEF) security nexus into policies and institutions in Egypt and Jordan. GIZ, GFA.

IEA-ESTAP (International Energy Agency - Energy Technology Systems Analysis Program) and IRENA (International Renewable Energy Agency) (2012). Water desalination using renewable energy, Technology Brief, No. 112 (March 2012). Available from: www.irena.org/DocumentDownloads/Publications/IRENAETSAP%20Tech%20Brief%20I12%20Water-Desalination.pdf.

Khatib, H. (2010). The Water and Energy Nexus in the Arab Region. Unpublished consultancy report, League of Arab States, Cairo.

Koday, K. (2012). Sustainable development as freedom: energy, environment and the Arab transformation. Poverty in Focus for Inclusive Growth, Vol. 23. International Policy Center, Brasilia.

Mohtar, R. Assi, A. and Daher, B. (2017). Current Water for Food Situational Analysis in the Arab Region and Expected Changes Due to Dynamic Externalities. In: Water, Energy, and Food Security Nexus in the Arab Region, Water Security in a New World, pp 193-208, DOI: 10.1007/978-3-319-48408-2_10.

Sadik, A. (2014). The State of Food Security and Agricultural Resources. In: 2014 Report of the Arab Forum for Environment and Development, Arab Environment 7: Food Security, Challenges and Prospects, Sadik, A., El-Solh, M, and Saab, N. (eds.), pp. 12-43. Arab Forum for Environment and Development (AFED), Beirut.

Sdralevic, C., Sab, R., Zouhar, Y., Albertin, G., (2014). Subsidy reform in the Middle East and North Africa. IMF, Washington, DC.

UNDESA (United Nations Department of Economic and Social Affairs) (2015). World Population Prospects: The 2015 Revision; [http://esa.un.org/unpd/wpp]

UNDP (2013). Water Governance in the Arab Region: Managing Scarcity and Securing the Future. UNDP Regional Bureau of Arab States (RBAS). [Available at: http://www.arabstates.undp.org/content/rbas/en/home/library/huma_development/water-governance-inthe-arab-region.html].

World Bank (2012). Renewable Energy Desalination: An Emerging Solution to Close the Water Gap in the Middle East and North Africa. World Bank, Washington, D.C. [Available from: http://water.worldbank.org/sites/water. worldbank.org/files/publication/water-wpp-Sun-Powered-Desal-Gateway-Meeting-MENAs-Water-Needs_2.pdf].

Defining priority interconnections in Latin America and the Caribbean.

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ABSTRACT: As part of the ECLAC/GIZ WEF nexus dialogue program in LAC, this paper summarizes the report entitled: "The water-energy-food (WEF) nexus in Latin America and the Caribbean (LAC). Planning, legal framework and priority interconnections". Based on a review of the theoretical background to the nexus concept and its current global configuration, we consider the main aspects of the WEF nexus to establish and continue the debate in the LAC region. The paper discusses different nexus features in LAC while identifying the main challenges for implementation, harmonization with the human rights legal framework and national legal priorities for water use. By briefly describing sectorial interactions (water-energy; water-food; food-energy), we identify and discuss those which may prove critical for nexus implementation in the region. The interconnections that should be prioritized include the one between: water for agriculture and food; irrigation modernization and aquifer overexploitation, and biofuels; hydropower, oil and mining; and water supply and sanitation services in cities. Science has provided evidence on the extraordinary importance of these interconnections and priorities, planning and legal frameworks play a key role in integrating and putting them into practice. After summarizing the priority interconnections, we conclude that scant consideration has been given to the nexus approach in a region where it could help transform the current development model of intensive, yet unsustainable use of natural resources.

KEYWORDS: water, energy, food, WEF nexus, planning, LAC

Introduction

Scant consideration has so far been given to the interconnections between the water, energy, and food sectors in Latin American and Caribbean countries, where this nexus has not been incorporated into the design of policies, plans or management of natural resources. The relative abundance of natural resources coupled with a lack of own restrictions on their underdeveloped status and a focus on pressing short-term needs have led to intensive development models. These models, in which the water-energy-food (WEF) nexus is not considered, depend on the exploitation of natural resources that have shown clear signs of environmental unsustainability and social inequality. Conversely, some of the region's characteristics show the potential for appropriate consideration of the nexus in order to improve, such as the relative wealth of these resources associated with a huge potential for future development, weak governance and hardly any capacity to establish and implement public policies, alongside high levels of inequality and dissatisfaction in guaranteeing and realizing human rights.

In this context, this paper seeks to identify the interconnections that can be considered priority or critical for nexus implementation in LAC. This definition is based on the following criteria: i) considering water as a predominant element; ii) impact on the other nexus elements; iii) focus on sectors of economic relevance with development potential and increasing complexity; and iv) realizing and respecting human rights, in particular economic, social and cultural including the right to a healthy environment, as an obligation and priority objective for the region's sustainable development.51 For an

51 These premises with an emphasis on institutional consolidation and guaranteeing economic, social and cultural rights are consistent with risk assessment (WEF, 2016). Unlike other regions that seem more threatened by natural catastrophes, water crises or abrupt variations

interconnection to be a priority or highly relevant, it must be a critical activity for the region or some of its countries and present an opportunity to improve its performance from a nexus viewpoint.

Key Findings

Unlike previous considerations or approaches, the nexus focus allows to examine the multiple interactions of the three elements or sectors to define priorities and avoid harmful or undesired effects, with environmental care and protection always as a prerequisite and a legal constraint. Lack of information, a great regional heterogeneity and weak governance constitute serious obstacles in the identification of priority interconnections for the LAC region. Despite this fact, the abovementioned study on which this note has been based made a considerable effort to synthesize the nexus interactions that might be critical for most of the region's countries.

Out of the activities involving two or more nexus elements, the following have resulted to be a priority for the region:

a) Water-energy: hydropower, hydrocarbons and mining

Most energy production methods require water, although hydroelectricity is the most important method in the region as the main untapped source of power offering most future growth in the majority of South and Central American countries. Large-scale hydropower demonstrates multiple interconnections and excessive dependence on this source in countries such as Colombia, Venezuela and some in Central America for example, but climate change and variability simultaneously threatens water, energy and food security in most countries.

The exploitation of hydrocarbons as fossil fuels and mining for minerals demands variably low to very high quantities of water and energy, which can seriously affect the environment and the quality of water resources. This interconnection is highly relevant throughout almost the entire region, but especially in the Andean countries, Brazil, Mexico, Venezuela and some in Central America. The impacts could become significant when hydraulic fracturing techniques are used. The use of water for energy does not compare with water use for agriculture in quantity (except in arid or semiarid regions), but it is the use that causes the most social unrest due to the displacement of people, its associated consequences and the impact on the quality of water resources.

b) Energy-water: Water abstraction, use and desalination

The largest energy cost in relation to water in the region occurs in the abstraction stages of groundwater, its conveyance and use, which include irrigation. This interconnection must especially consider the level of subsidies granted for extraction, of aquifer exploitation and of inefficiency of the irrigation systems and pumping equipment. The relevance of groundwater for irrigation and the growing dependence on it for development are shared throughout the region, with an emphasis on Central America and Mexico, where it amounts to 65% of the water consumed and in the desert or semi desert areas of Argentina, Brazil, Chile, Bolivia, Mexico and Peru. The increasing overexploitation of aquifers presents interrelations with the three nexus elements by impacting water quantity and quality, removing land from production and increasing the energy costs of extracting it. Currently, energy consumption is not significant in water treatment or seawater desalination, which are confined to isolated areas for highly profitable activities (mainly in Chile, Mexico, Peru and some Caribbean countries).

c) Water-food: Agriculture

The importance of agriculture in LAC must be understood in relation to regional specificities, namely large-scale production and its expansion, mainly for export. This

in energy prices, the concerns of Latin America and the Caribbean are firstly governance failures and secondly profound social instability associated with other economic factors, which come in third place.

type of agriculture has a direct relation with deforestation, single crop growing, the subsequent increase in the risk of diffuse pollution, sedimentation, erosion and flooding, the displacement of local population, and the impact on household based or subsistence agriculture, which is vital for sourcing food in the region. Agriculture is particularly relevant for the region in terms of water consumption and other extra-sectorial considerations such as contribution to gross domestic product and employment forecasts, and because it affects almost all the countries in the region.

d) Water-energy-food: biofuels, pumping, irrigation modernization and urban nexus

A special link occurs between the three nexus elements in the case of biofuel production. Biofuels usually consume water in crop cultivation, are used to produce energy, and can affect food production due to competition for land. Agriculture for bioenergy production, and biofuels in particular, not only share the impacts of large-scale agriculture referred to above, but also have a considerable effect on food availability and price. The development of biofuels is particularly relevant in Argentina, Brazil, Paraguay and, to a lesser extent, Peru, Colombia and Central American countries, such as Costa Rica. A three-way relationship between all the three elements at the same time can also be observed in the agricultural sector in two more cases: when irrigation modernization is involved (which leads to more energy use, more water consumption and, possibly more food production as originally intended) or when policies subsidize electricity through discounted tariffs, thus fostering aquifer overexploitation as a result of increased water abstraction. Finally, the WEF nexus adopts a particular shape in the urban context. Due to regionally very high rates of urban population, with nearly 8 current megalopolis lacking full water supply and sanitation, the interconnection around this kind of services should be also prioritized.

Although this summary did not go into detail, it has synthesized the priority nexus interactions that are crucial for most of the region's countries.

Conclusions and Recommendations

The countries of the region have not yet incorporated the Nexus approach for designing their public policies, planning and management of natural resources. In addition, most of the countries present serious deficiencies in governance systems and lack of reliable information that makes planning, the cornerstone for the implementation of the Nexus approach, very difficult.

In order to prioritize interconnections and avoid conflicts, this planning must be adaptive, multi-scalar, pluri-temporal, inter-sectorial and based on a broad consensus by all political forces, guaranteeing both its immediate feasibility and its permanence over time. Coordinated planning of the three nexus elements can constitute a new impulse to reinforce, integrate and give greater consistency to sectorial processes of territorial, water, energy and environmental planning, at different scales i.e. regional, integrated, national electrical system, local and basin. However, hydrological basin planning will be a preferred instrument for these purposes.

The Nexus approach must include the subsequent and simultaneous satisfaction of the economic, social and cultural rights associated with the three elements as the first objective of nexus policies. This is not only because these human rights are expressly recognized in regional instruments, but also because there cannot be development and an increase in synergies and efficiency or sustainability, which do not have the urgent satisfaction of these minimum vital needs, still pending in many countries, as an immediate objective. This statement connects directly with the idea of water, food and energy security underpinning the nexus approach.

In the current development phase of the region, faced by the challenge of a costly energy transition in a threatening climate change context, the nexus approach can make significant contributions to the adjustment, diversification, adaptation or transformation of development patterns or models that are absolutely natural resource intensive but clearly unsustainable and inequitable from the environmental and the social point of view, respectively.

References:

Altomonte, Hugo y Ricardo Sánchez (2016), *Hacia una nueva gobernanza de los recursos naturales en América Latina y el Caribe,* Comisión Económica para América Latina y el Caribe (CEPAL), LC/G.2679-P, Santiago de Chile.

Babette, Never (2016), "Wastewater systems and energy saving in urban India: governing the Water-Energy-Food Nexus series", *Discussion Paper*, 12/2016, Deutsches Institut für Entwicklungspolitik, Bonn.

Bellfield, Helen (2015), *Water, Energy and Food Security Nexus in Latin America and the Caribbean. Trade-offs, Strategic Priorities and Entry Points*, Global Canopy Programme.

Biggs, Eloise; Eleanor Bruce; Bryan Boruff; John Duncan; Julia Horsley; Natasha Pauli; Kellie McNeill; Andreas Neef; Floris Van Ogtrop; Jayne Curnow; Billy Haworth; Stephanie Duce y Yukihiro Imanari (2015), "Sustainable development and the water-energy-food nexus: a perspective on livelihoods", *Environmental Science & Policy*, volumen 54.

CAF (Corporación Andina de Fomento) (2016), *Informe El Niño en América Latina: ¿Cómo mitigar sus efectos en el sector eléctrico*, CAF.

CEPAL, (2014), *Panorama Social de América Latina 2014*, LC/G.2635-P, Santiago de Chile.

Escobar, Marisa; Francisco Flores López y Victoria Clark (2011), *Planificación de Energía, Agua y Clima para el Desarrollo sin Carbono en Latinoamérica y el Caribe*, Stockholm Environment Institute (SEI).

Falkenmark, Malin y Johan Rockström (2011), "Back to basis on water as constraint for global food production: opportunities and limitations", Alberto Garrido y Helen Ingram (eds.), *Water for food in a changing world*, Routledge, Londres-Nueva York.

Ferro, Gustavo y Emilio Lentini (2015), *Eficiencia energética y regulación económica en los servicios de agua potable y alcantarillado*, Comisión Económica para América Latina y el Caribe (CEPAL), LC/L.3949, Santiago de ChileScott, 2011.

Flavin, Christopher; Milena González; Ana María Majano; Alexander Ochs; María da Rocha y Philipp Tagwerker (2014), *Study on the Development of the Renewable Energy Market in Latin America and the Caribbean*, OVE/WP-02/14, Banco Interamericano de Desarrollo (IDB).

Hoff, Holger (2011), *Understanding the Nexus. Background Paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus*, Stockholm Environment Institute, Estocolmo.

IHA (International Hydropower Association) (2016), *Briefing. 2016 Key trends in hydropower*, Londres.

IRENA (International Renewable Energy Agency) (2015), *Renewable Energy in the Water, Energy & Food Nexus*.

Martín, Liber y Juan Justo (2015), *Análisis, prevención y resolución de conflictos por el agua en América Latina y el Caribe*, Comisión Económica para América Latina y el Caribe (CEPAL), LC/L.3991, Santiago de Chile.

Martin Mateo, Ramón (2008), *La verde energía de la biomasa*, Civitas.

Martínez, Rodrigo y Amalia Palma (2016), *Plan para la seguridad alimentaria, nutrición y erradicación del hambre de la CELAC 2025. Una propuesta para seguimiento y análisis*, Comisión Económica para América Latina y el Caribe (CEPAL), LC/L.4136, Santiago de Chile.

Meza, Francisco; Sebastián Vicuña; Jorge Gironás; David Poblete; Francisco Suárez y Melanie Oertel (2015) "Water-food-energy nexus in Chile: the challenges due to global change in different regional contexts", *Water International*, volumen 40, números 5-6.

Mirzabaev, Alisher; Dawit Guta; Jann Goedecke; Varun Gaur; Jan Börner; Detlef Virchow; Manfred Denich y Joachim von Braun (2015), "Bioenergy, food security and poverty reduction: trade-offs and synergies along the water-energy-food security nexus", *Water International*, volumen 40, números 5-6.

Recalde, Marina Yesica (2016), "The different paths for renewable energies in Latin American Countries: the relevance of the enabling frameworks and the design of instruments", *Wiley Interdisciplinary Reviews: Energy and Environment*, volumen 5, número 3.

Routledge Arroyo, Andrés y Andrea Perdriel (2015), *Gobernanza del gas natural no convencional para el desarrollo sostenible de América Latina y el Caribe: Experiencias generales y tendencias en la Argentina, el Brasil, Colombia y México*, Comisión Económica para América Latina y el Caribe (CEPAL), LC/L.3948, Santiago de Chile

Saulino, Florencia (2011), *Implicaciones del desarrollo de los biocombustibles para la gestión y el aprovechamiento del agua*, Comisión Económica para América Latina y el Caribe (CEPAL), LC/W.445, Santiago de Chile.

Scott, Christopher; Mathew Kurian y James Wescoat (2015), "The Water-Energy-Food Nexus: Enhancing Adaptive Capacity to Complex Global Challenges", Mathew Kurian y Reza Ardakanian (eds.), *Governing the Nexus: Water, Soil and Waste Resources Considering Global Change*, Springer

Vallejo, María Cristina (2013), "Seguridad Energética y Diversificación en América Latina: el Caso de la Hidroenergía", *Revista Retos*, volumen 6.

WEF (World Economic Forum) (2016), *The Global Risks Report 2016. 11th Edition*, Ginebra.

WEF (World Economic Forum) (2011), *Water security: the water-food-energy-climate nexus: the World Economic Forum water initiative*, Washington, D.C.

Willaarts, Bárbara; Alberto Garrido y Ramón Llamas (eds.) (2014), *Water for Food Security and Well-Being in Latin American and the Caribbean*, Earthscan Studies in Water Resource Management.

Water-Energy-Food (WEF) Governance and Institutions in the Southern African Development Community (SADC)

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Background

Water, energy and food resources are vital for human wellbeing, poverty reduction and sustainable development. The Southern African region represents a wide range of resource and climate contexts with varied supplies of water, food and energy. About 60% of the population of the SADC live in rural areas relying on rain-fed agriculture, lacking basic services of clean energy, water and sanitation, yet the region is endowed with vast natural resources. Ensuring water, energy and food security has dominated the development agenda of southern African countries, centred on improving livelihoods, building resilience and regional integration. Increasing demands for water, land and energy resources due to population growth, increasing urbanisation, and increasing economic growth are the major challenge in the region. This challenge is exacerbated by climate change. This is particularly concerning for the SADC region due to dependence on climate sensitive sectors of agriculture and energy, which heavily depend on water resources.

The water-energy-food (WEF) Nexus approach has potential application in the region for ensuring security of water, energy and food; and for bringing resource use efficiency. It provides opportunity to stabilise competing demands and promote regional integration, particularly in the SADC where resources are mostly transboundary. The WEF nexus approach can help to ensure that development of one of the sectors has minimum impacts on the other. Sectorial collaboration is particularly relevant in SADC as watercourses and electricity grids are shared among countries.

This article attempts to review the existing governance and institutions for managing water, energy and food sectors in the SADC region, and identifies potential areas for change in strengthening the WEF nexus governance system of the region.

WEF resource endowments in the SADC region

Water resources significantly vary in distribution, availability and usage across the SADC region. Approximately 75% of the SADC region, most of which in the southern part, is semi-arid to arid receiving less than 650 mm of rainfall per annum. The rest, 25%, which is mostly occupied by northern countries that are closer to the Equator, is classified as sub-humid receiving between 651 and 2 500 mm of rainfall per annum.

According to the SADC (2012), there is an estimated total of 2 300 km3/year of renewable water resources available to the SADC region's population of 260 million people (Aquastat 2011). The level of abstraction is only 44 km3/year or 170 m3/capita/year. Of the 44 km3/year abstracted, 77% is used for irrigation, 18% for domestic purposes while 5% is used by industry (Aquastat 2008).

Seventy percent (70%) of surface water resources are in 15 transboundary river basins (Figure 1-2 and Table 1).

The transboundary nature of the river basins signifies the importance of watercourses in promoting regional integration and development. For example, five SADC countries have water resources dependency ratios of over 50%, that is, they rely on water generated outside their borders to supply more than half of their total water requirements (Malzbender and Earle, 2009).

Although the southern parts are generally drier, the Congo, Zambezi and Orange–Senqu basins have the potential to generate significant regional benefits through water transfer and hydropower generation.

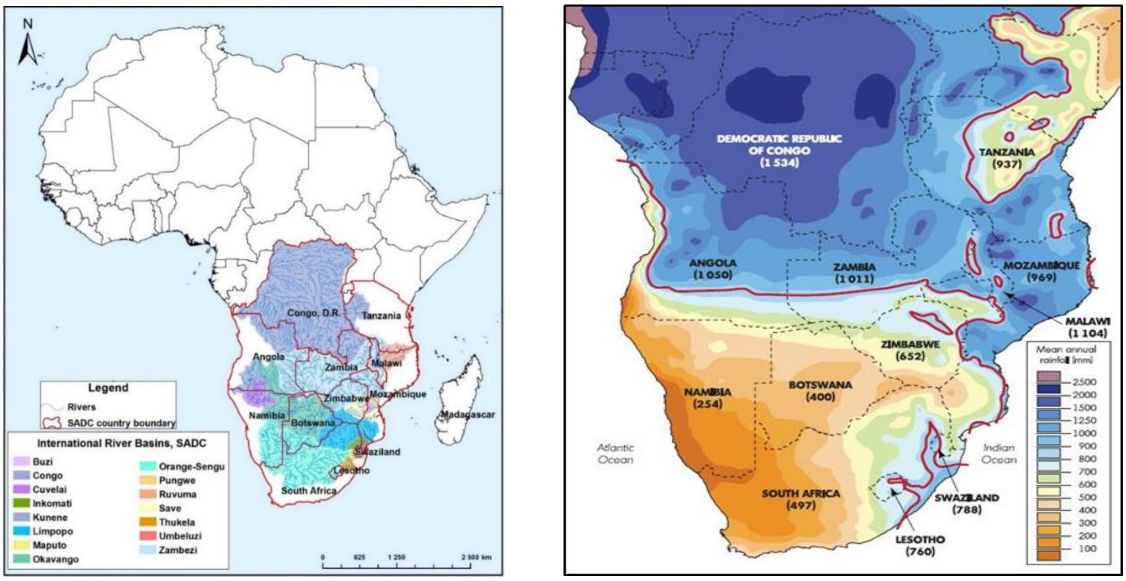

Figure 8. Spatial distribution of mean annual rainfall over southern Africa and International River Basins.
Source: Ashton, 2008

The uneven distribution of resources in the region creates uneven demand pressures on raw materials and natural resources. As a result, demand for water and energy resources is evidently concentrated in the southern parts of the region. In contrast, the northern parts of the region (for example, the Congo and Zambezi river basins) are endowed with the abundant water resources that could sustainably deliver these inputs (The-World-Bank, 2010).

The SADC region is endowed with vast energy resources, although availability varies from country to country. There is huge potential of hydropower generation in Angola, the DRC, Mozambique and Zambia. The region's hydropower potential is estimated at about 150 GW, of which only 12 GW is installed (SADC 2011).The region currently shares power grids whose electricity is generated from shared watercourses. However, biomass remains the most used source of energy as only 24% of the total population and 5% of rural people have access to electricity (Schreiner and Baleta, 2015). Over dependency on biomass energy has contributed to massive deforestation and land degradation in the region.

Demand for energy in the region continues to increase due to population and industrial growth and urbanisation. According to the SADC Regional Infrastructure Development Master Plan (RIDMP) of 2012, assuming an average economic growth rate of 8% per annum, energy demand is expected to increase to more than 77 GW by 2020 and to over 115 GW by 2030, exerting more pressure on water resources (SADC, 2012).

Table 1. SADC transboundary river basins (IRBs) and the riparian states

River Basin	Riparian States	Area (km^2)
Buzi	Mozambique, Zimbabwe.	27,000
Congo	Angola, Democratic Republic of Congo, Tanzania, Zambia	3,800,100
Cuvelai	Angola, Namibia	167,000
Incomati	Mozambique, South Africa, Swaziland	46,740
Kunene	Angola, Namibia	106,560
Limpopo	Botswana, Mozambique, South Africa, Zimbabwe	408,000
Maputo	Mozambique, South Africa, Swaziland	29,970
Nile	Democratic Republic of Congo, Tanzania	3,200,000
Okavango	Angola, Botswana, Namibia	323,192
Orange	Botswana, Lesotho, Namibia, South Africa	1,000,000
Pungwe	Mozambique, Zimbabwe	31,000
Ruvuma	Malawi, Mozambique, Tanzania	152,000
Save	Mozambique, Zimbabwe	115,700
Umbeluzi	Mozambique, Swaziland	10,900
Zambezi	Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, Zimbabwe	1,570,000

Agriculture is the main catalyst for economic development in the SADC as more than 60% of inhabitants depend on it for their livelihoods, providing their subsistence, employment and income. The performance of the agriculture sector, therefore significantly impacts on economic growth, poverty reduction and food security. Despite its importance, performance of the sector has been insufficient to significantly contribute to regional economic growth and address food and nutrition security issues in the region.

Agriculture is mainly rain-fed. There is about 50 million hectares of irrigable land available within the SADC region, of which only 3.4 million hectares (7%) is irrigated (SADC 2011);

The region's plans for increasing agricultural productivity are underpinned on increasing land area under cultivation, and under irrigation. This alludes to land use changes in some cases, and increasing the amount of water withdrawals and associated energy outlays needed for irrigation. Proponents argue that this is feasible given the region's large tracts of underutilised arable land and water resources (dams). On the other hand, there is an argument that much of the land is degraded and may not be suitable for agriculture, and that in some countries such as South Africa, most of the available water is already allocated and with little scope for building new dams.

In summary, considering the uneven distribution of water, energy and land resources in the SADC region and the overall increasing demand for such resources, it becomes evident that a regional WEF nexus approach has potential to increase benefits and reduce risks. There is considerable potential for coordinated infrastructure investment to improve overall use of WEF nexus resources in the SADC.

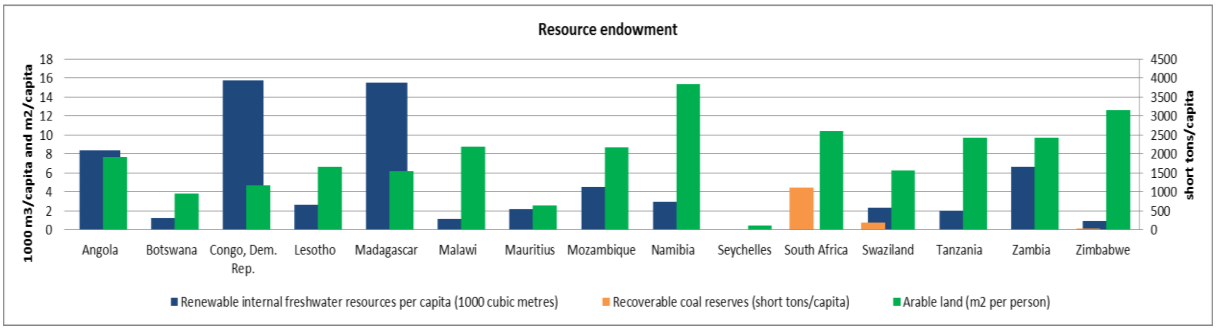

Figure 3. SADC Resource Endowment. Source: SADC 2012 (RIDMP)

WEF nexus related institutions and policies of the SADC

Because of the shared resources and common climatic, cultural and political history, the region has put in place institutions, policies and other frameworks to oversee and direct water, energy and agriculture resources at regional level. However, coordination among the policies and institutions is inadequate.

The SADC Industrialisation Strategy and Roadmap (2015-2063) was approved in April 2015. This framework is aimed at achieving industrial development and has been placed at the core of the developmental integration agenda of SADC. Inherent in this policy is recognition from SADC Member States that industrial development is central to diversification of their economies; development of productive capacity; and the creation of employment in order to reduce poverty and set their economies on a more sustainable growth path. Water, energy and food security are key priority areas for SADC. Integrated water, food and energy planning and promoting regional cooperation are considered a strategy to meet socio-economic security targets, and improve natural resource use efficiencies in the region.

WEF related policies

The SADC region has a number of policies that are related to developing and managing water, energy and land resources.

- The SADC Regional Water Policy was adopted in 2005. The Policy is implemented through a Regional Strategic Action Plan (RSAP), a 5-year Regional Water Programme that aims to achieve an equitable and sustainable utilization of water for social and environmental justice, regional integration and economic benefit for present and future generations. The current RSAP IV (2016-2020) emphasizes the importance of infrastructure development and water resource management for food security in the water-food nexus, and the stronger urgency to take action in the view of climate variability and change. The action plan recognises the role of the nexus in adapting to the challenges posed by population growth and climate change and variability, as well as in optimising resource use in order to achieve regional goals and targets.
- The SADC Protocol on Shared Watercourses (SADC, 2005 (revised)), fosters closer cooperation for judicious, sustainable, and coordinated management, protection and utilization of shared watercourses, and advance SADC's agenda of regional integration and poverty alleviation. As a result, most shared river basins have basin level agreements in place which oversee the day-to-day management of the basins with assistance from the SADC Water Division
- The SADC Protocol on Energy (SADC, 1996), highlights the development and updating of a regional electricity master plan, the development, and utilization of electricity in

an environmentally sound manner, and emphasizing the need for universal access to affordable and quality services

- A Regional Energy Access Strategic Action Plan (REASAP) was approved in 2011, setting broad goals for improving access to modern forms of energy as well as specific policy mechanisms to achieve increased access. However, there is no Regional Strategic Action Plan for Energy that has been officially adopted to-date. A Renewable Energy Strategy and Action Plan (RESAP) was approved in 2016, and a SADC Centre for Renewable Energy and Energy Efficiency (SACREEE) has been established. SADC also has energy cooperation policy and strategy (1996).
- The SADC Regional Agricultural Policy (RAP) (SADC, 2014b) envisages integrated approaches on water resources management and emphasises the importance of improving agriculture performance to meet the food and water security as well as attain sustainable economic development objectives at regional level. The SADC's Regional Agricultural Investment Plan (2017) is derived from the Africa-wide Comprehensive Africa Agricultural Development Programme (CAADP) that promotes the doubling of irrigated area from 3.5% to 7% by 2025. The CAADP (CAADP, 2009) provides a common framework for stimulating and guiding national, regional, and continental initiatives on enhanced agricultural productivity and food security. SADC has a ten years food and nutrition strategy (2015-2025).

WEF nexus related institutions

The regional level institutional structures for managing the water, energy and agriculture sectors are summarized in table 2.

Table 2. Regional level institutional structures for managing the water, energy and agriculture sectors

Sector	**Regional Structures**	**Objectives/mandates**
Food, Agriculture, Natural Resources	Food, Agriculture and Natural Resources (FANR)	▪ Development, coordination and harmonisation of agricultural policies and programmes
Water and Energy	Infrastructure and Services Directorate	▪ Development, coordination and harmonization of Energy, Transport and Communications, Tourism and Water policies, strategies, programmes and projects; ▪ Coordination and promotion of integrated management of trans-boundary water, tourism, transport and communication and energy resources for regional integration and development;
	Water Division SADC-RBOs	▪ To oversee harmonisation of national water use policies, and moderate transboundary issues.
	Southern African Power Pool (SAPP)	▪ enhance regional cooperation in power development and trade, and to provide non-binding regional master plans to guide electricity generation and transmission infrastructure delivery.
	SADC Centre for Renewable Energy and Energy Efficiency (SACREEE)	▪ promote renewable energy and energy efficiency technologies ▪ develop sound policy, regulatory, and legal frameworks, and build capacities

SADC WEF nexus governance and institutional issues

Uncoordinated sectorial plans and targets

The Regional Infrastructure Development Master Plan (RIDMP) (SADC, 2012) sets out the region's infrastructure development targets as shown in the Table below.

Table 2. SADC WEF related targets

Project	Potential	Baseline (2012)	Targeted Plan (2027)
Hydropower	150 GW	12 GW	Increase to 75 GW (50% of potential)
Irrigation	50 M has	3.4 M has	Increase to 10 M has (13% of potential)
Annual Renewable WR	2,300 km^3	14% retained	Increase to 25%
Access to clean water		61%	Increase to 75%
Access to sanitation		39%	Increase to 75%

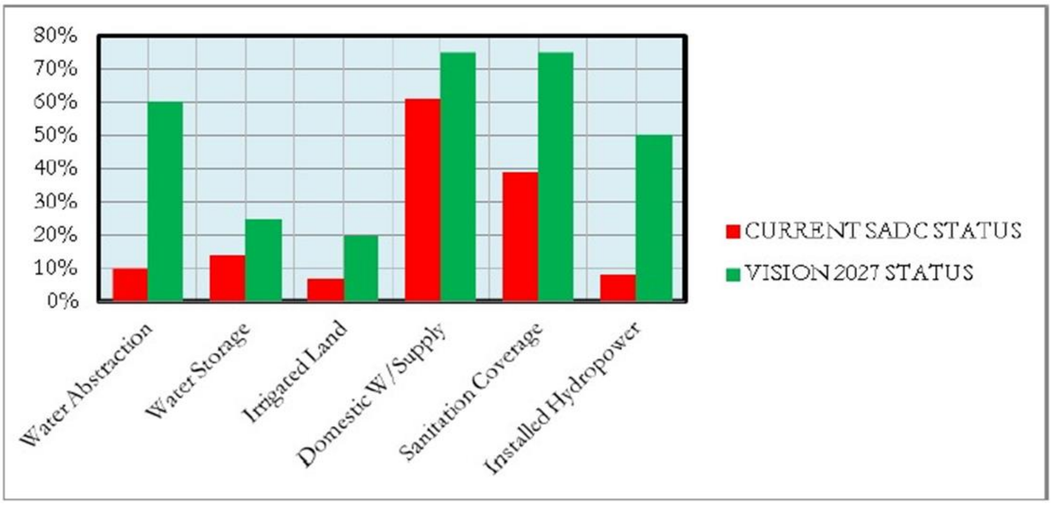

Figure 4. SADC regional infrastructure development targets (2013-2027)

The RIDMP ambitious sectorial targets do not seem to consider the available water, land and energy resources of the region.

Inadequate inter-sectorial dialogues

SADC provided WEF nexus regional platforms, mainly based on the existing SADC multi-stakeholders water dialogues. The 2013 SADC Water Dialogue focused in exploring the WFE Nexus. The discussion was around infrastructure development and strengthening institutions for economic growth. The dialogue recognized the need for integrated planning and implementation of development programs; and recognized that the Nexus approach can provide opportunity for coherent and well planned development and use of water, energy and food resources. Other dialogues include the 2016 SADC Ministerial workshop on energy and water crisis, and the 2017 SADC Water and Energy Ministers Conference. The 2017 SADC multi-stakeholders water dialogue (November 2017) will focus in fostering regional value chains and job creation through the Water-Energy-Food Nexus approaches.

Key issues emerged from the SADC Nexus Dialogues include:

- Enhance sectorial collaboration and joint management in the region

- Promote a nexus thinking at all levels (regional, transboundary and national)
- Anchor Nexus in the sustainable infrastructure development and industrialisation agenda
- Develop an operational framework to drive and guide sectorial collaboration in implementing priority investment projects

Sector-focused policies and institutions with inadequate coordination mechanism

The WEF nexus could lead to more optimal allocation of resources, promotion of inclusive and sustainable regional economic growth. However, this will depend on the availability of support from harmonised WEF institutions and policies.

The water, energy and food policies in the SADC region are sector-focused with limited recognition of the interlinkages between the water-land-energy resources. Similarly, the institutions and governance arrangements are also structured around the sectors without looking at the interlinkages. There is a challenge in shifting from nationally driven agendas to regionally driven agendas due to the transboundary nature of resources that could ensure regional water, energy and food security.

Non-coordinated programs

Programs are more sector-based such as energy sector development, agricultural sector development or water supply service programs. The focus is on attaining sector-specific targets rather than meeting a comprehensive and integrated WEF targets.

The WEF nexus framework for SADC region

Water, energy and food are central to the region's plans for sustainable economic development and transformation. It is in this regard that the WEF nexus offers significant opportunities for a coordinated approach to addressing some of the region's pressing challenges and achieving regional goals. The following specific benefits could be realised through adoption of a WEF nexus approach:

- ***Regional integration***. The WEF nexus provides a meaningful platform for coordinated access, utilisation and beneficiation of shared resources and potential for effective synergies and trade-offs between the WEF nexus components. The WEF nexus also provides an opportunity to harmonise existing institutions and policies and translate them into coordinated balanced strategies that can contribute towards inclusive development, socio-economic security and regional integration.
- ***Sustainable economic development***. The WEF nexus promotes the inseparable link between the use of resources to provide basic and universal rights to food, water and energy security that will promote sustainable and inclusive economic development
- ***Harmonisation of institutions and policies***. Harmonising institutions and policies among the three sectors minimises cross-sectorial conflicts, maximises synergies, mitigates trade-offs, reduces implementation costs and achieves policy objectives through a systems approach. Harmonised polices ensure systematic promotion of mutually reinforcing strategies and instruments and resolve policy conflicts in order to meet the competing demands for resources.
- ***Build resilience***. The WEF nexus approach provides opportunity for increasing regional resilience against climate change impacts and mitigating vulnerabilities through coordinated WEF infrastructure development, improved management of transboundary natural resources, maximising on regional comparative advantages for agricultural production and unlocking more resources for climate proofing through increased efficiencies.
- ***Promote investment in infrastructure development***. The WEF nexus promotes investment.

For the SADC region to reap the benefits of the nexus approach, it needs to establish a regional WEF Nexus Framework. Preliminary level assessment and consultations with stakeholders indicated that the regional framework are represented in Figure 5.

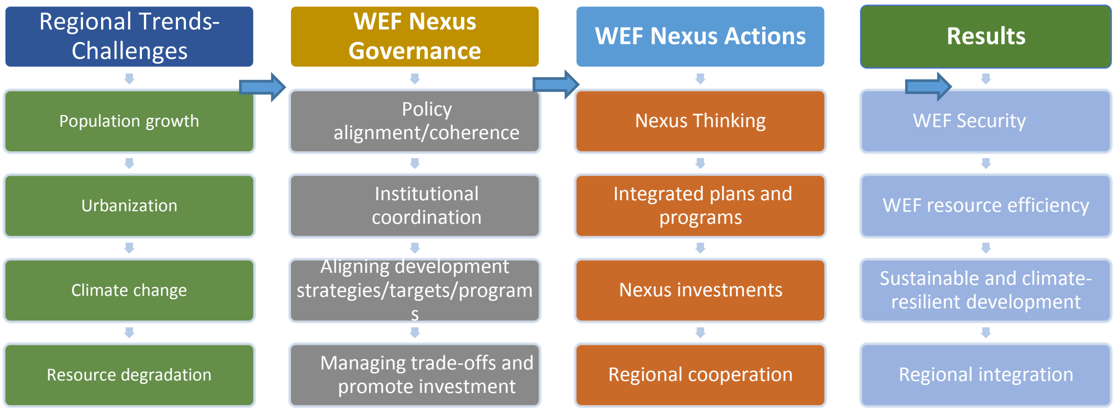

Figure 5. Preliminary level assessment and consultations with stakeholders

Conclusions and recommendations

The SADC region faces water, energy and food insecurity. Climate change projections suggest increased stresses on the WEF sectors, thus challenging future development plans. The WEF nexus approach offers opportunities to effectively achieve sustainable development through cross sectorial collaboration and harmonisation of sectorial policies. Adoption of the WEF nexus approach would be a step forward towards attaining most of the SDGs targets. As the vast and unexploited resources within the region are shared, the WEF nexus presents opportunities for regional integration, coordinated resources development, resilience building and reduction of vulnerabilities and attainment of regional development targets.

The WEF nexus addresses the challenge of sectorial management of resources through the adoption of harmonised institutions and policies, as well as setting targets and indicators to implement and assess resource management for sustainability. In the SADC, the WEF nexus could prove to be valuable by promoting inclusive development and transforming vulnerable communities into resilient communities.

SADC is embracing the WEF Nexus approach providing good political/policy support, opening up dialogues in establishing clear directions and establishing regional framework that will create an enabling environment for Nexus approaches and facilitate nexus investment in the region.

The SADC WEF Nexus Regional Framework is expected to bring about alignment/coherence between the water, energy and food policies; facilitate institutional coordination; align development strategies/targets/programs of the three sectors; and mmanage trade-offs and promote Nexus investments in the region.

References:

AQUASTAT – In http://www.fao.org/nr/water/aquastat/main/index.stm. (Last access 03 January 2019).

Malzbender, D., & Earle, A. (2009). Water resources of SADC: Demands, dependencies, and governance responses. In M. Pressend & T. Othieno (Eds.), Rethinking natural resources in Southern Africa (pp. 85–106). Midrand: Institute for Global Dialogue.

Regional Infrastructure Development Master Plan (RIDMP), August 2012. In https://www.sadc.int/files/7513/5293/3530/Regional_Infrastructure_Development_Master_Plan_Executive_Summary.pdf. (Last access 03 January 2019).

SADC STATISTICS YEARBOOK 2012 in https://www.sadc.int/information-services/sadc-statistics/sadc-statist/ (last access 03 January 2019).

SADC Regional Agricultural Policy (RAP). In http://www.inter-reseaux.org/IMG/pdf/Regional_Agricultural_Policy_SADC.pdf. (Last access 03 January 2019).

SADC Protocol on energy, 1996. In https://www.sadc.int/documents-publications/show/Protocol_on_Energy1996.pdf. (Last access 03 January 2019).

SADC Protocol on Shared Water Courses 2000. In https://www.internationalwaterlaw.org/documents/regionaldocs/Revised-SADC-SharedWatercourse-Protocol-2000.pdf. (Last access 03 January 2019).

SADC regional Water Policy, August 2005. In http://nepadwatercoe.org/wp-content/uploads/Regional_Water_Policy.pdf. (Last access 03 January 2019).

SADC Industrialisation Strategy and Roadmap (2015-2063). 29 April 2015. https://www.ilo.org/wcmsp5/groups/public/---africa/---ro-addis_ababa/---ilo-pretoria/documents/meetingdocument/wcms_391013.pdf. (Last access 03 January 2019).

The Comprehensive Africa Agriculture Development Programme (CAADP), January, 2009. In http://www.resakss.org/sites/default/files/pdfs/comprehensive-africa-agriculture-development-progr-39420.pdf (last access 03 January 2019).

Water-Energy-Food Nexus and Environment in Central Asia

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ABSTRACT: Transboundary river basin systems comprise the backbone of the WEF nexus in Central Asia. In Soviet times, the water-abundant upstream countries provided water for irrigation in summer to downstream countries, and, in exchange, were supplied with energy in winter. Environmental aspects of natural resources management were neglected. The desiccation of the Aral Sea is the most widely known example of the consequences of disregarding environmental impacts. After independence in 1991, the formerly regional approach to water and energy management was replaced by a national approach which led to fragmentation of supply networks and conflicts mainly between upstream and downstream neighbors. This study outlines interventions and technologies for the water, energy, agricultural and environmental sectors at various scales that would be suitable for the introduction of a sustainable regional WEF in Central Asia. In the water sector, designing hydropower systems in upstream countries should consider the release of sufficient water volume for downstream irrigation in summer while the pressure on surface river basins should be mitigated through the increased use of groundwater resources. The energy portfolio in all countries of Central Asia should be diversified through more investment in renewables, and by designing the macroeconomic perspectives of energy policies in the region so as to avoid boom and bust pricing fluctuations on energy commodities. In the agricultural sector, the horticultural and tree cultivation should be prioritized over cotton monoculture. In addition, the rehabilitation of irrigation and drainage systems should be conducted at operational, maintenance and investment costs that are affordable to farming communities. Providing minimum environmental flows in major river networks and the better monitoring of human activities on basin level are prerequisites for an integrated approach of the WEF nexus in Central Asia.

Introduction

Central Asia (CA) is a region where water, energy, food and environment are inextricably linked. This is due to: i) diverse ecosystems ranging from glaciers, high mountain areas, forests, to oasis regions and vast steppes and deserts with associated spatial water resources variability; ii) the structure of the economy, traditionally dominated by agriculture and supported by large-scale hydropower and irrigation schemes and iii) relatively recent geopolitical changes which led to fragmentation of a formerly contiguous region into new nation States separated by international boundaries, creating a new reality and new challenges for managing natural resources, water and energy - in particular.

The upstream countries of Afghanistan, Tajikistan and Kyrgyzstan are located in the mountains of Karakoram, Pamir and Tien Shan, often referred to as "water towers" of CA. Snowfall and glacier melting are important sources of water in an overall dry climate, feeding into a vast river network, which traverses the entire region. The downstream countries of Turkmenistan, Uzbekistan and Kazakhstan are situated on extensive plains, largely converted from grasslands to agricultural lands, which are also endowed with abundant hydrocarbon (coal, oil, gas) resources.

All CA countries, except Afghanistan, were part of the Union of Soviet Socialist Republics (USSR), and have gone through a period of large-scale engineering solutions to water resources development, with a focus on surface water management for irrigation and hydropower. The USSR pursued a policy of regional development with specialization in each region on one product or a small range of products which were distributed through internal exchange mechanisms. This led to monoculture development, e.g. the development of huge cotton plantations in downstream areas, with little concern for the environmental impacts. Upstream countries, where most of the CA river flow is generated, were providing water for irrigation to downstream countries. In exchange, they were supplied with coal and gas for heating and electricity purposes in cold months as well as with agricultural products and especially staple crops.

Intensification of agricultural production, regulation of waterways through dams and other infrastructure and over-abstraction of surface water in the entire CA came at a high price to the environment, resulting in the well-known impacts on the Aral Sea. The fragmentation of the region into several independent states in the late 1990s changed the approach to the Water-Energy Food (WEF) nexus from regional exchange to country-focused policies with each country developing at its own pace and pursuing different development objectives. As a consequence, there were changes in the water use for energy, food and environment which have led to tensions mainly between the upstream and downstream states.

The transboundary nature of water resources in CA remains of paramount significance for the development of the energy, water and agricultural sectors of the region as a whole, creating interdependencies that should, eventually, inspire and strengthen regional cooperation. The objective of this paper is to examine how a sustainable regional WEF nexus approach can emerge in CA in the current and developing geopolitical circumstances, and which appropriate WEF interventions and technologies may best support the development needs of each CA country. Each WEF sector is assessed separately on a regional scale while the natural environment is also acknowledged as a separate component.

State of the art

Transboudary water systems

The two main rivers of the region, the Amu Darya and Syr Darya, are the most important water sources for the livelihoods of about 70 million inhabitants in CA. Both rivers originate in the mountain ranges of the upstream countries. The Amu Darya, the largest river in Central Asia in terms of water volume, is formed by the Panj River on the Tajik-Afghan border and the Vakhsh River in Tajikistan and continues into Uzbekistan and

Turkmenistan before emptying into the Aral Sea. The Syr Darya, which is the longest river in Central Asia, has its source in the Tien Shan Mountains in Kyrgyzstan and flows through the Fergana Valley into Tajikistan and Uzbekistan and then into Kazakhstan where it ultimately discharges into Aral Sea.

Central Asian countries are among the most water intensive economies in the world with a mean water withdrawal per capita at 2,200m yr^{-1} and more than 80% of water used by the downstream countries, mainly for irrigation (Sehring and Diebold, 2012). Irrigated farming in CA was strongly prioritized in Soviet times through the construction of numerous reservoirs, extended supply and drainage networks and large pumping stations. Water management was organized according to "water-use regions" or "irrigation districts", which in some instances were transgressing the republican boundaries (Wegerich et al., 2012). The post-Soviet breakdown has differently impacted each district depending on the facilities, organizational structure and other parameters by avoiding a collapse of the entire agricultural water supply network.

The transboundary irrigation districts ceased to exist after independence in 1991 and administrative boundaries where drawn instead for water resources management on national level. Intensified irrigation practices continue until today although at a slower pace due to the lack of funding for maintenance and operational services (Dukhovny and de Schuetter, 2011).

In the last decade, a river basin management approach was gradually introduced in each of the CA countries in an attempt to improve national water use and allocation plans as per the principles of the European Water Framework Directive (WFD, 2000/60/EC). In particular, the European Union Water Initiative was established in 2002 as transnational, multi-actor partnership to support water governance reforms on the globe (Fritsch et al., 2017). For the region of Eastern Europe, Caucasus and Central Asia, one partnership was established with 12 countries for the improvement of the legal and regulatory water-related frameworks in alignment with WFD, development of River Basins Management Plans (RBMPs) and engagement of stakeholders through National Policy Dialogues (NPDs) and River Basin Councils (RBCs).

For the implementation of the RBMPs, River Basin Organizations (RBOs) have to be established to monitor all activities related to water management on a basin level. Indicatively, the RBMPs have to gather information from local (e.g. WUAs) and centralized institutions (e.g. Ministries), reduce the currently unregulated water withdrawals from rivers, canals, and newly built groundwater wells which are still common practice in rural areas. All CA countries have set up the legal basis for introducing the basin approach while RBMPs have been developed gradually in Kazakhstan, Kyrgyzstan and Uzbekistan over the last 3 years (2014-2017). The legislative documents, mostly acknowledged as Water Codes, emphasize the WEF nexus of each country and the need to harmonize the respective national documentation with that of the neighbouring countries. In practice, the Water Codes dictate how various uses (drinking, agricultural, industrial, environmental) will be regulated and prioritized according to different needs and set the foundations for a comprehensive management of water resources within the country. They also set provisions for water flow requirements of major river systems in respect to international treaties and conventions.

The RBMPs in the upstream countries will be obliged to monitor the construction of big controversial dams such as the Roghun in eastern Tajikistan and Karambata I in north Kyrgyzstan for hydropower production. These large-scale interventions have up until recently created conflicts between the upstream countries and Uzbekistan as the most vocal downstream country. The current and future hydropower developments are presented in Figure 1.

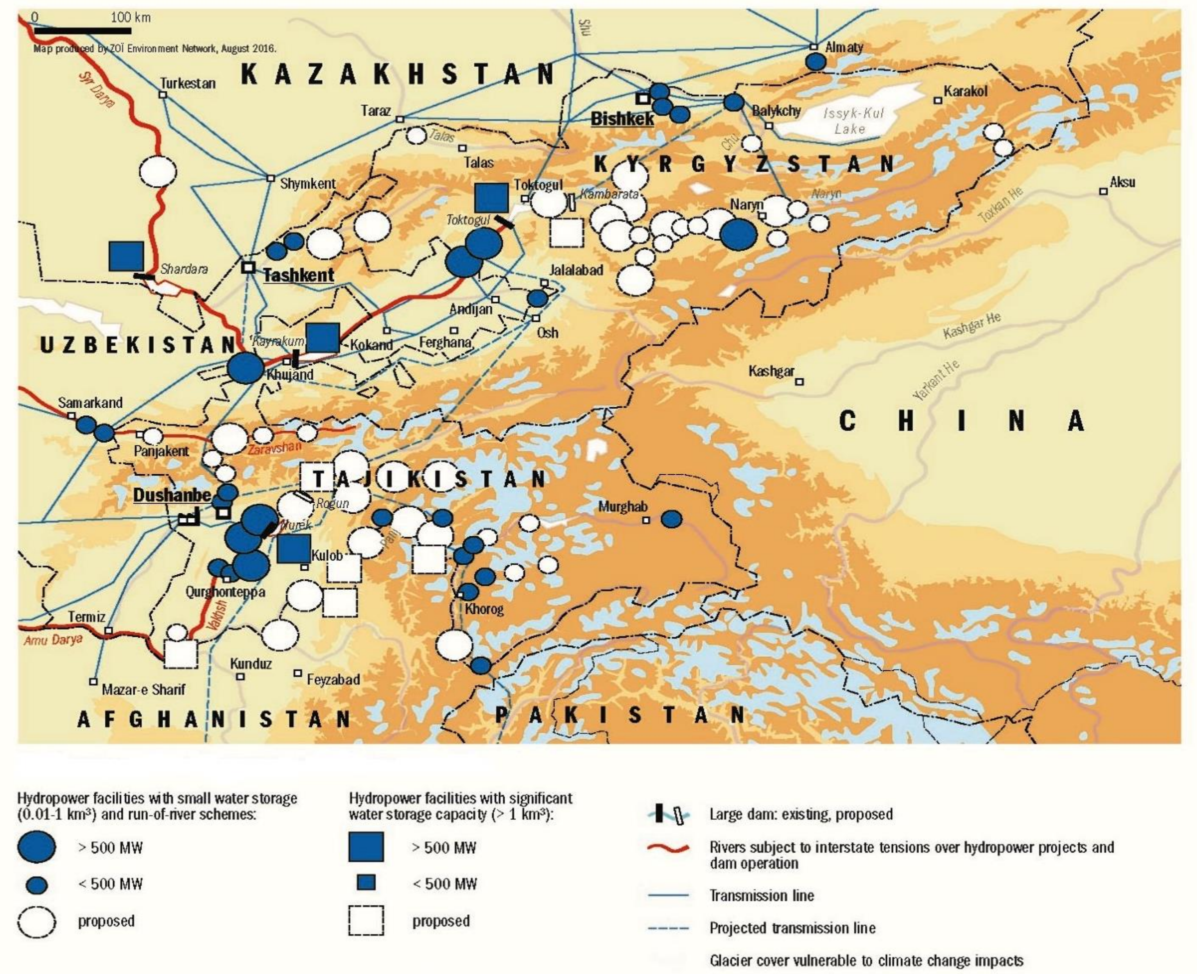

Figure 1. Hydropower developments in Central Asia, with focus on the upstream countries of Kyrgyzstan and Tajikistan, [in page 65, Zoi Environmental Network], 2016. Source: [https://www.osce.org/secretariat/355471]

Tensions in the region have abated somewhat, as a result of feasibility studies (SNC-Lavalin, 2017) that were conducted for both dams, and of Strategic Environmental Assessments (World Bank, 2014) (SEIAs) to evaluate the impact on downstream water volume, but more importantly because of the recent change (2016) in the government of Uzbekistan.

Moreover, investments in technological interventions in oil, gas, coal and uranium mining in the region are slowly increasing in volume (Kazakhstan Green Energy, 2017). The interventions are anticipated to reduce water input and also mitigate the water pollution induced by these activities. Further, international organizations and donors are investing in the rehabilitation of irrigation networks and drinking water supply mainly in rural areas of Tajikistan, Kyrgyzstan and Uzbekistan.

However, there is a notable lack of coordination, monitoring and assessment of these interventions which is mainly due to the overlapping between too many governmental authorities and the differences in prioritizing water resources management by the governments. For instance, Kazakhstan sets a high priority on water management for food production and holds the Ministry of Agriculture responsible for the development and implementation of agricultural policy and water management. Groundwater use remains under the supervision of the Ministry for Investment and Development and the Committee of Geology and Subsoil Use (UNECE, 2017). A similar situation presents itself in Uzbekistan where the Ministry of Agriculture and Water Resources is responsible for surface water resources and the State Committee on Geology and Mineral Resources for ground water. Agriculture also plays a dominant role in downstream Turkmenistan where the Ministry of Agriculture and Water Resources is mainly accountable for efficient agricultural water management.

Kyrgyzstan has attempted to assign greater importance to the water sector by establishing the National Water Council (NWC) in 2005 which has the responsibility to coordinate all the state and private agencies involved with water resources management. In reality, the NWC has remained inactive for many years and the newly introduced basin approach is in substance implemented by the Department of Water Economy and Melioration under the Ministry of Agriculture and Melioration. The clear priority on water for energy use in Tajikistan found expression in the creation of the Ministry of Energy and Water Resources (MEWR)in 2013. While hydropower development is the primary mandate of the Ministry, water for agricultural use is supervised by the Agency of Land Reclamation and Irrigation (ALRI), which is of inferior importance to the Ministry. Coordination of the activities of these authorities by the national RBOs and communication of these RBOs within the framework of a river basin (e.g. Syr Darya) for a more balanced WEF nexus remain a major challenge to be confronted in the CA region.

Energy Sector and trends in national policy frameworks

The CA region looks back on a long history of energy resource abundance (oil, coal and gas in Kazakhstan, gas in Turkmenistan and Uzbekistan, hydroelectric power potential in Kyrgyzstan and Tajikistan). Following the break-up of the Soviet Union in the 1990s, CA countries transited to a decentralized energy production and management system that has been driven by national goals and capacities regarding technological state and advancement, exports, explorations and production (EBRD, 2004). The transition period has been characterized by decaying and dilapidated infrastructure and technology, decoupling transmission and distribution systems and poor energy policies at macroeconomic level. In the last decades, CA countries have aimed at exploiting in full their energy potentials and at developing new transport routes to their major markets, mainly Europe and China. Efforts towards the efficient and sustainable management of energy resources in CA are constrained by regional discrepancies, dependence on Russia, and social, economic and political conflicts. Energy issues in CA are expected to becoming even more critical due to climate change, political unrest, competing international interests in the region, and financial instability.

The main challenges that CA countries are facing today include regional energy market integration, exposure to international boom and busts in commodity prices, technology upgrade and innovation, diversification of export markets and routes, sustainable management of energy resources and conflicting uses of natural resources. To successfully address these challenges necessitates regional cooperation and integration. Macroeconomic insulation to commodity price fluctuations requests the appropriate use of fiscal and macroeconomic tools (such as consumption/deficit/debt rules and Sovereign Wealth Funds)[52]. There is also a need to take steps towards a transition to sustainable and renewable energy. In order to move into this direction, countries need to put into effect legislation on renewable energy and energy efficiency in a way to build endogenous growth. In doing so, there is a need to address the competing energy use mainly of pumped irrigation in a way that considers the linkages between energy, water and food from perceptions of national security, regional stability and economic growth[53].

Also, in developing new transport routes (from West to East or vice versa mainly through China-Kyrgyzstan-Uzbekistan and China-Kyrgyzstan-Tajikistan) CA countries need to consider possible conflicts between countries in the region, their transit position (corridors from Europe to Asia) and their relationship with major trading partners (Russia, EU, China). In terms of financing, CA can benefit from foreign investments, international funding and technical assistance from international organisations and financial institutions. Capitalising on their own resources, countries in the region hold significant assets coming from energy exports (for instance Kazakhstan National Oil Fund

[52] See: Tsani (2013), Tsani et al. (2011), Ahmadov et al (2011), Kalyuzhnova (2011)
[53] See among others Keskinen et al. (2016), Kartayev et al. (2016), Freedman and Neuzil (2016).

holds more than 64 billion US$ while an additional of 61 billion US$ dollars are hold by the Samruk-Kazyna JSC)[54]. Revenues from natural resources can be used to upgrade the existing infrastructure and invest in new technology in such way so as to address the long term challenges CA countries are facing with regards to energy and the WEF nexus.

In terms of regional energy collaboration, water and energy resources were managed during the Soviet period – as noted above - in an integrated and top-down approach. After independence, the unified energy system broke down, and downstream states demanded market prices for their energy fossils. In 1998, Kazakhstan, the Kyrgyz Republic and Uzbekistan signed an ''Agreement on the Use of Water and Energy Resources of the Syr Darya Basin'', later joined by Tajikistan as well. This agreement provided that Kyrgyzstan would discharge water from its reservoirs in summer for the downstream states of Kazakhstan and Uzbekistan, while these would deliver fuel to Kyrgyzstan in winter, so that the country would not need to rely on hydropower. The agreement required annual protocols to define exact discharge times and amounts, as well as the price of energy to be sold to the downstream countries during the summer period and on the transfer prices of coal, gas and electricity. The agreement worked well for some years, but from 2003 on, the parties failed to agree on annual protocols. Efforts were made to deal with this problem, but a lasting solution has not yet been found.

Food security and agriculture

Food and agriculture systems significantly contribute to the Central Asian region's economy and food security. The agricultural sector makes up roughly 15-20% of the national Gross Domestic Product (GDP) for Afghanistan, Kyrgyzstan, Tajikistan, and Uzbekistan while Kazakhstan and Turkmenistan depend less on the agricultural sector (5% and 12%, respectively) due to opportunities in the oil and natural gas industries (Pomfret, 2006). Agriculture provides employment to about 23 million people in CA, most of whom are residing in rural areas. The upstream countries are more engaged in farming activities. For instance, in the least developed countries of Afghanistan and Tajikistan about 79% and 53%, respectively of the entire labour force are mainly occupied in subsistence farming while only 18% of the labour force in Kazakhstan contributes to the agriculture sector, which is dominated by commercial farming. The agricultural sector of CA is mainly consisted of irrigation farming, followed by pastoral and aquaculture/fisheries production. All these activities contribute to local livelihoods and depend on water and energy resources to sustain food production.

Over the 20th century, intensive cotton production dominated the Central Asian economies with pumped (or lift) irrigation as the main driver of intensified cultivation. Today, pumped irrigation occupies nearly half (44%) of the arable land in Tajikistan, about one third (27.4%) in Uzbekistan and a smaller but still noteworthy (16.3%) area in Turkmenistan. Cereals, vegetables and orchard trees have surpassed cotton production since early 2000, especially in Kazakhstan but lately also in Uzbekistan and Tajikistan (Frenken & Food and Agriculture Organization of the United Nations, 2013). However, the transition from intensive and water-demanding monocultures to more diversified production has not provided the anticipated relief on irrigation pressures and freshwater is still being extracted at alarming rates.

In Turkmenistan cultivations suffer from water-stress conditions the most[55] (107%) followed closely by Uzbekistan (100%) then Tajikistan (65%) and Afghanistan (31%). Water appropriation to croplands is also seriously affected by significant irrigation water losses all over CA. For example, only an estimated 30% to 35% of the initially lifted water is delivered to croplands in Tajikistan while the rest is wasted due to inefficient

[54] See: http://www.swfinstitute.org/sovereign-wealth-fund-rankings/

[55] A country is water-stressed if populations withdraw more than 25% of their renewable freshwater resources, 2) approaching physical water scarcity when more than 60% is withdrawn, or 3) facing physical water scarcity when more than 75% withdrawn (IWMI, 2008). Uzbekistan and Turkmenistan are two of the ten countries in the world that withdraw more than 100% of their renewable water resources for irrigation, which means they also withdraw water from groundwater sources.

water use practices and decaying irrigation infrastructures (Abdullaev et al., 2010). The pastoral systems of CA's steppe and mountain landscapes, as well as fisheries/aquaculture in irrigated areas and downstream countries, are also inextricably linked to water resource systems. The availability of water and the type of water sources (e.g. spring, wells) have determined the movement of livestock across the region (Rahimon, 2012). Irrigated water contributes to fodder production for feeding livestock, as well aquaculture production. Freshwater resources are also required to support downstream fishery systems, which are negatively affected by water pollution and shortage due to irrigation, up to the total disappearance of fish in the Aral Sea. On the other hand, in the Northern Aral Sea fishery could be revived thanks to rehabilitation of fish stocks after the construction of the Kok-Aral dike and to water-saving measures along the Syr Darya River, which led to the increase in water volume and quality in this separated part of the Aral Sea (Pala, 2011).

Major challenges to sustain agriculture systems in CA include monitoring and controlling the tremendous water losses in the irrigation sector, financing and facilitating irrigation infrastructure rehabilitation efforts to support agricultural production, promoting energy-efficient solutions for pumped irrigation systems, and providing information and trainings for people engaged in the agriculture sector on water resource use and local-level climate change adaptation strategies that are relevant to food production.

Imminent action should be taken on technical, institutional and policy aspects of making farming economically viable in CA. For example, the decoupling of high energy intensity pumping and irrigation could be achieved by the installation of more efficient and renewable energy pumping systems, such as solar pumping (IRENA, 2016). Local water management institutions like WUAs would greatly benefit from greater authority and recognition from state government agencies, as well as targeted funding to better monitor and assess local level irrigation infrastructures conditions and water use practices. At the policy level, agricultural development objectives in CA should also take into consideration the linkages between irrigation infrastructure rehabilitation efforts and its economic potential for improving the welfare and livelihoods of CA's populations.

Status of the environment in Central Asia

The management of natural resources in Central Asia has continued to pursue the "nexus" approach of Soviet times through integrated management of water, land and energy resources. Based on the belief engineering and technical supremacy over nature, environmental aspects were neglected which entailed vast consequences especially for freshwater resources (Granit et al., 2012). The desiccation of the Aral Sea, 80% of which have turned into desert, has emerged as a symbol of unsustainable water management in the Soviet era. Much of the irrigated land is plagued by salinization, waterlogging and water erosion. The inflow of drainage water is heavily contaminated with nitrates, organic fertilizers and phenol which eventually also pollute surface and groundwater sources. Uranium legacy sites, most of them un-remediated, poorly secured, and often located near Transboundary Rivers and in disaster-prone locations, constitute a continuing threat. In addition, the degradation of wetlands, desertification, land degradation, erosion and increasing landslides, are some of the major environmental challenges to be met nowadays in the CA region. Climate change is bound to increase pressures on the environment and to augment the vulnerability of ecosystems and livelihoods (Alford et al., 2015).

The linkage of the WEF Nexus with the natural environment in CA is heavily pronounced in all three sectors of water, energy and food. The over-abstraction of surface and groundwater has significantly decreased the flow in all major rivers with severe impacts on the fauna and flora mainly in downstream areas. Efforts to replenish aquifers in the Syr Darya and Amu Darya basins have so far met with limited success (Karimov et al., 2010). The outdated irrigation network and the dilapidated drainage systems in many agricultural areas causes soil degradation and salinization problems. Maintenance of such infrastructure is especially precarious in transboundary areas where border demarcation is still in process and willingness to invest is low. Water quality has also deteriorated from insufficient or lacking waste water treatment in domestic and industrial use (Abdullaev and Rakhmatullaev 2016; UNEP, UNDP, UNECE, OSCE, REC and NATO, 2011).

The energy sector also contributes strongly to the degradation of the natural environment in CA. The most noteworthy impact is from pollution by the mining industry in the entire CA region. Gold mining for instance, allegedly contaminates surface waters in eastern Kyrgyzstan while coal mining has caused soil and water contamination by chemicals used in mining processes in all three downstream countries (ZOI, 2013). The regulation of river flows in upstream countries through the construction of cascading reservoirs and large dams has induced erosion and soil degradation which also affects water quality.

The current economic development trends in CA can have mixed impacts on the environment. In agricultural and water drinking supply, recent and ongoing technical investments and institutional reforms have led to some improvement in water use efficiency which can relieve water stress in the entire region. In the energy sector, Kazakhstan, Turkmenistan and Uzbekistan, despite investment programmes for alternative energy sources, still rely heavily on fossil fuels. The development of new hydropower stations remains a priority for Kyrgyzstan and Tajikistan, which produces clean energy but nevertheless has environmental impacts on the river ecosystems.

Of late, the concept of "Green Economy" has gained prominence in Central Asia, most specifically in Kazakhstan, which in 2014 adopted the "Concept for the Transition to a Green Economy". Among others, the concept includes provisions for more sustainable water usage, increase in protected areas and fostering of low-carbon energy. Within the Green Economy framework, both Kazakhstan and Kyrgyzstan have stated the provision of a minimum environmental flow in Syr Darya and the Northern Aral Sea (UNECE 2017). Although the concrete effects of the Green Economy initiatives are still to be seen, they can provide a framework for implementing the nexus approach and link it to issues for which there is political will.

While intersectorial governance and coordination remains a challenge both at national and regional levels, there are some existing arrangements that allow addressing environmental aspects in a nexus approach in CA. The *Interstate Commission for Sustainable Development* (ICSD) was established in 1994 as a sub-body of the International Fund for Saving the Aral Sea (IFAS), which is the only formal organization facilitating cooperation on environmental protection and sustainable development Central Asia. Given this structure, the ICSD is focussed on water-environment linkages and in particular the impacts of agriculture on these. It could, if strengthened, be a good platform to co-ordinate efforts to tackle water-agriculture-environment linkages, while the links to energy, as in the whole IFAS structure, are missing. At national level, all CA countries possess relevant environmental strategies and legal frameworks, and have ratified relevant international agreements. Their implementation and compliance however still faces many challenges.

Key Findings

Following the structure of this paper, the key findings for each sector as well as for the environmental component will be presented in a stepwise manner. The key finding suggests that the transboundary nature of water resources in CA constitutes the major element of the WEF Nexus and most likely also of economic development in the entire region. This is due to geophysical reasons but also partly attributed to the high water, energy and food interdependence of CA during the Soviet period which is still seen up to today. Significant attempts have been made to reduce energy losses in agriculture through the rehabilitation of irrigation systems, changing of monoculture to more economically valuable and less water-demanding crops while the utilization of hydropower potential upstream is meant to be conducted in line with agricultural needs in the downstream counties. On the other hand, lift irrigation schemes which are not so reliable and which are heavily dependent on energy from the grid and old and derelict USSR infrastructure are still in operation in all CA countries. In the downstream countries of Uzbekistan and Tajikistan new large pumping stations are still constructed according to the Soviet model. There is as yet very little usage of groundwater irrigation and also limited research has been on the conjunctive management of surface and groundwater sources (Karimov et al., 2015). Drinking water supply is also still heavily dependent on surface water systems. Studies have shown that the countries of CA, especially the downstream countries, have the potential to use their groundwater reserves more efficiently and relieve the pressure on riverine systems (Karimov et al., 2015). This relief from pressure could also lower the tension over water sources for energy between upstream and downstream countries and encourage a more even allocation of water resources in the region.

In case of the energy sector, the region has to deal with ageing infrastructure, a low technological readiness level, high energy intensity, low energy efficiency, untapped renewable energy potential, poorly functioning regional energy markets, conflicting use of natural resources (consider the case of water for energy and/or agriculture), environmental pollution and ecosystem degradation and a poor legal and institutional framework for regional cooperation, particularly with regards to the exploitation and management of shared resources. Many of these problems are expected to augment as a result of climate change. In the context of regional sustainable development, the transition towards renewable energy should be put at the top of regional cooperation and national energy policy priorities. For a successful and efficient transition towards renewable energy and green growth, a special attention to the WEF nexus should be also paid. The commodity price fluctuations in the last two decades, that coincided with the outbreak of the last economic crisis, and the recent development of alternative energy resources (shale gas in USA) made clear to energy exporters in the region the challenges of managing volatile natural resource revenues. Energy exporters in the region need thus to consider carefully the use of fiscal and macroeconomic tools so as to address similar problems in the future.

The agricultural and food sector in CA is especially dependent on freshwater resources to sustain production. Although commendable water-saving efforts have been made in recent years to move away from water-intensive cotton monoculture crop production to less water-intensive crops, countries in CA remain some of the most water-stressed countries in the world. In addition, melting glaciers and increasing aridity may also affect the future availability of freshwater resources. Under these conditions, it is especially important that WEF policies in the CA region help to develop better monitoring and assessment of water losses, support the rehabilitation of gravity-fed and pumped irrigation infrastructures, identify energy-efficient opportunities for pumped irrigation systems, reconsider their water allocation to agriculture and provide guidance on climate change adaptation strategies that are most relevant to local communities. Local level institutions, such as WUAs, which provide a link between local communities and state government agencies, can play a major role in facilitating these types of agricultural-based WEF policies. However, for these WEF policies to be most effective, it is important for state government agencies in CA to recognize the impactful role that local institutions can have in monitoring irrigation infrastructures conditions and water use practices.

Finally, in terms of the natural environment, Central Asia undeniably faces catastrophic environmental consequences due to the neglect of environmental aspects in earlier (and current) water, food and energy policies. These negative environmental impacts are not only a result of trade-offs between sectors (which also negatively affect interstate relations), but also partly due to the earlier integrated approach (see above). These devastating impacts are not only an environmental concern, but also threatened the quality and availability of resources like freshwater and land, which are crucial for economic development across sectors, be it in agriculture, energy, or industry.

It is therefore essential that any effort to promote the WEF nexus approach in Central Asia takes the environment into account. A water-energy-food-ecosystems/environment nexus approach is needed for development and stability in the region. Implementing a nexus approach to the transboundary management of water, land and energy resources can yield concrete benefits for Central Asia, such as improved water quality and more reliable access to water, improved status of ecosystems and better ecosystem services, reduced greenhouse gas emissions and increased resilience towards disasters and climate change. Such an approach benefits the environment as well as the economies and societies, and would fit into green economy strategies of the countries.

Conclusions and Recommendations

The development of national agricultural and energy resources in CA is strongly dependent on transboundary water sources. The interdependence of CA countries with respect to water underlines the need of a regional WEF nexus framework. However, each country's focus is on national policies and objectives rather than regional perspectives. This is further accentuated by the fact that the various countries occupy different development stages. The development disparities between the individual CA countries are likely to encourage frictions and conflicts over water management which is the pivot of economic development both in upstream and downstream countries.

An enabling precondition for strengthening the nexus-approach in CA is that, given the legacy of the water-food-energy policies of the Soviet Union, integrated approaches were in place to tackle these issues in the region even before the "nexus" term gained prominence. Current examples of different initiatives that tackle water, food and energy issues in an integrated way are the SPECA[56] progamme as well as activities by international funding agencies, development banks and multilateral organizations. Such policies are therefore not entirely new, but can built upon earlier approaches.

At the political level, the nexus concept can provide an opportunity to overcome the deadlock the region faces in transboundary and intersectorial water management. The water discourse is highly politicized in Central Asia. Approaches which directly aim at changing existing water use patterns risk to be faced with mistrust and opposition by ending in the "water trap" (Abdullaev and Rakhmatullaev 2016) notion.

In this context, the nexus-concept has a major advantage opposite other water management approaches on regional level: it is multicentric and therefore can offer alternative, less sensitive pathways to deal with water-related issues in a broader development context. By addressing water challenges in a broader context as one aspect of sustainable development and a nexus approach, can help to achieve a constructive discourse and commonly accepted solutions.

References:

Abdullaev, I., Kazbekov, J., Manthritilake, Herath, & Jumaboev, K. (2010). Water User Groups in Central Asia: Emerging Form of Collective Action in Irrigation Water Management. *Water Resources Management*, 24, 1030.

Abdullaev, I. & Rakhmatullaev, River basin management in Central Asia: evidence from Isfara Basin, Fergana ValleyS. *Environ Earth Sci* (2016) 75: 870. https://doi.org/10.1007/s12665-016-5409-8 Ahmadov, I., Tsani, S. and Aslanli, K. (2011). *Sovereign Wealth Funds as the Emerging Players in the Global Financial Arena: Characteristics, Risks and Governance* in Sovereign Wealth Funds: New Challenges for the Caspian Countries, Public Finance Monitoring Center, Khazar University, Azerbaijan and Revenue Watch Institute NY, USA.

Alfrord D., Kamp., U., and Pan, K. (2015). *Assessment of the role of glaciers in stream flow from the Pamir and Tien Shan mountains*, Report No: ACS12128, The World Bank

Dukhovny, V.A. and de Schuetter, J.L.G. (2011). *Water in Central Asia: Past, Present, Future*; CRC Press: Boca Raton, MA, USA, 2011. European Bank for Reconstruction and Development (EBRD) (2004). *Transition reports*, ISBN: 1 898802 25 4

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[56] The SPECA Working Group on Water, Energy and Environment is a subsidiary body within the governing structure of the UN Special Programme for the Economies of Central Asia.

European Commission, *Water Framework Directive (WFD 2000/60/EC),* http://ec.europa.eu/environment/water/water-framework/index_en.html, (assessed 23/09/17) Freedman, E. and Neuzil, M.(Eds) (2016) *The Environmental Crises in Central Asia: From Steppes to Seas, from Deserts to Glaciers*, 1-196, EarthScan Series, Routledge, 196 p.

Frenken, K., & Food and Agriculture Organization of the United Nations (FAO) (2013). *Irrigation in Central Asia in figures: AQUASTAT survey - 2012*. FAO, Rome.

Fritsch, O., Adelle C., and Benson, D (2017) The EU Water Initiative at 15: origins, processes and assessment, *Water International* Vol. 42, Iss. 4,2017

Granit J., Jägerskog , Andreas Lindström, Gunilla Björklund, Andrew Bullock, Rebecca Löfgren, George de Gooijer & Stuart Pettigrew (2012): Regional Options for Addressing the Water, Energy and Food Nexus in Central Asia and the Aral Sea Basin, *International Journal of Water Resources Development*, 28:3, 419-432, DOI: 10.1080/07900627.2012.68430

International Water Management Institute (IWMI) (2008) *Areas of physical and economic water scarcity*, UNEP/GRID, Arendal Maps and Graphics Library

IRENA (2016). *Solar pumping for irrigation: Improving livelihoods and sustainability, The International Renewable Energy Agency*, Abu Dhabi.

Kazakhstan Green Energy- Water Conservation (2017), https://www.kzgreenenergy.com/water-conservation/ (assessed 19/09/2017)

Kalyuzhnova, Y. (2011). The National Fund of the Republic of Kazakhstan (NFRK): From accumulation to stress-test to global future, *Energy Policy,* 39 (10): 6650-6657.

Karatayev, M., Hall, S., Kalyuzhnova, Y., and Clarke, M. (2016). Renewable energy technology uptake in Kazakhstan: Policy drivers and barriers in a transitional economy, *Renewable and Sustainable Energy Reviews*, Volume 66, Pages 120-136.

Karimov, A., Smakhtin, V., Mavlonov, A. and I. Gracheva, (2010). Water 'banking' in Fergana valley aquifers—A solution to water allocation in the Syrdarya river basin? *Agricultural Water Management*, Volume 97, Issue 10, 2010, Pages 1461-1468

Karimov; A.Kh., Smakhtin, V., Mavlonov, A., Borisov, V., Gracheva, I., Miryusupov F., Akhmedov, A., Anzelm, K., Yakubov S., and A. A. Karimov (2015) Managed Aquifer Recharge: Potential Component of Water Management in the Syrdarya River Basin, *Journal of Hydrologic Engineering*, Volume 20 Issue 3 - March 2015

Keskinen, M., Guillaume, J.H.A., Kattelus, M., Porkka, M., Räsänen, T.A., and Varis, O. (2016) Water-energy-food nexus and the transboundary context: Insights from large Asian rivers, *Water* (Switzerland), Volume 8, Issue 5, 2016, Article number 193

Pala C. (2011), In Northern Aral Sea, Rebound Comes With a Big Catch, *Science ,*Vol. 334, Issue 6054, pp. 303, DOI: 10.1126/science.334.6054.303

Pomfret, R. W. (2006). *The Central Asian economies since independence,* Princeton University Press.

Rahimon R.M. (2012) *Evolution of Land Use in Pastoral Culture in Central Asia with Special Reference to Kyrgyzstan and Kazakhstan*. In: Squires V. (eds) Rangeland Stewardship in Central Asia. Springer, Dordrecht

Sehring, J. and Diebold, A. (2012): *From the Glaciers to the Aral Sea: Water Unites*. Berlin: Trescher Verlag.

SCN-Lavalin, *Feasibility Study for Kambarata HPP-1*, http://www.snclavalin.com/en/projects/feasibility-study-for-kambarata-hpp-1.aspx (assessed 03/08/2017)

Tsani, S. (2013). Natural resources, governance and institutional quality: The role of resource funds. *Resources Policy,* 38(2), 181-195

Tsani, S., Ahmadov, I. and Aslanli, K. (2011). *Governance, Transparency and Accountability in Sovereign Wealth Funds: Remarks on the Assessment, Rankings and Benchmarks to Date,* in Sovereign Wealth Funds: New Challenges for the Caspian Countries, Public Finance Monitoring Center, Khazar University, Azerbaijan and Revenue Watch Institute NY, USA.

Wegerich, K., Kazbekov, J., Lautze, J., Platonov, A. Yakubov, M., (2012) From monocentric ideal to polycentric pragmatism in the Syr Darya: searching for second best approaches, *International Journal of Sustainable Society* 4(1/2):113-130

World Bank, *Assessment Studies for Proposed Rogun Hydropower Project in Tajikistan*, http://www.worldbank.org/en/region/eca/brief/rogun-assessment-studies (assessed 03/08/2017)

UNECE (2017) *Reconciling resource uses in transboundary basins: assessment of the water-food-energy-ecosystems nexus in the Syr Darya River Basin*, Geneva, Palais des Nations CH - 1211 Geneva 10, Switzerland

UNEP, UNDP, UNECE, OSCE, REC and NATO (2011) *Environment and Security in the Amu Darya Basin*, http://www.zaragoza.es/contenidos/medioambiente/onu/1171-eng.pdf (assessed 03/08/2017).

ZOI (2013) Waste & Chemicals in Central Asia: A visual synthesis, https://issuu.com/zoienvironment/docs/waste-chemicals-ca-en (assessed 23/09/2017)

The Water Framework Directive: a tale of rivers and people

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ABSTRACT: The global implementation of Integrated water resources management (IWRM) by 2030 is now enshrined in one of the targets of the Sustainable Development Goals. The European Union has adopted the Water Framework Directive 60/2000/EC, representing in practice the legal instrument of IWRM for the EU Member States. However, many years after its entry into force, the WFD still struggles to achieve its objectives. This contribution elaborates on the current implementation of the WFD to reflect on the reasons for its difficulties. Some difficulties relate to the scientific understanding of river basins as systems, but many others may be rooted in a limited capacity to connect river basin management to the quality of life of people, the well-being and prosperity of communities and the economy as a whole. Using IWRM as a tool for economic growth and community building requires rethinking river basin management, as well as river basin research and assessment: researchers and river basin communities must co-define the questions to address, and find together the responses. Increasingly, managing water requires managing a full array of interconnected aspects. The "Water-Energy-Food-Ecosystems Nexus" approach may make it prominent how a significant part of the appropriate water management goals of IWRM, encapsulated in the WFD, may be achieved by establishing alliances with energy, agriculture and other economic activities, based on the benefits that each one receives from healthy river basins. This prompts policy making to give consideration to the role of business in proposing innovative measures for the river basin management plans to come. At the same time, it calls to step up in the creation of appropriate governance structures and enabling environments, particularly centered on communities, e.g. by harnessing instruments like the "river contracts".

IWRM and the WFD: where are we, and why?

Among the Sustainable Development Goals identified by the United Nations in 2015, Sustainable Development Goal n. 6 "Ensure availability and sustainable management of water and sanitation for all" includes a target (6.5) to apply integrated water resources management (IWRM) globally by 2030. IWRM is defined as "*a process which promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment*" (http://www.gwp.org/en/GWP-CEE/about/why/what-is-iwrm/). It is regarded as largely equivalent to "sustainable management" insofar as it encompasses the environmental, social and economic dimensions of water management.

The Water Framework Directive (WFD: 60/2000/EC) defines the context for IWRM in the European Union. It requires member states to classify the status of their water bodies, set appropriate environmental quality objectives taking into account existing water usages and, based on the analysis of the existing human pressures, design river basin management plans (RBMPs) containing programmes of measures to achieve those objectives. While setting environmental quality objectives for all water bodies, the WFD accepts that existing human activities cannot be discontinued if their broader socioeconomic benefits outweigh the value of restoring the ecological conditions (art. 4(3)). In any case, it requires to achieve conditions that "*reflect, as far as possible, those associated with the closest comparable surface water body type, given the physical conditions which result from the […] modified characteristics of the water body*" (Water

Framework Directive, Annex V No. 1.2.5), implying that, even when human activities affecting the water bodies are to be maintained, significant improvements may still be required.

After the first round of RBMPs, prepared in 2009, the European Commission had already warned on the delays in the achievement of the WFD objectives (EC, 2012). By the deadline of 2015, the periodic implementation assessments conducted at European Union level (EC, 2015) did not highlight univocal evidence that the WFD has radically changed business as usual. On the contrary, the whole process still appears to struggle gearing. Many EU Member States are not yet fully implementing what are considered "basic" measures, e.g. tackling known diffuse pollution and introducing appropriate water pricing, not to speak about more advanced measures to reduce existing pressures beyond compliance with sectorial legislation (EC, 2015). Moreover, the programmes of measures in the first round of RBMPs often appear generic rather than targeting specifically those pressures causing non-achievement of the WFD goals in the water bodies. This suggests that the clear logical connection among status classification, analysis of pressures and design of measures envisioned in the WFD may often be lost. The reasons for these implementation difficulties may include lack of scientific and technical capacity (conceptual understanding of the Directive, inadequate knowledge of river basins), poor river basin governance or lack of financial resources. This in spite of the extensive opportunities existing at the global level for funding, capacity building or technical assistance. The self-interest of the decision makers (and how they respond to the political pressures of different stakeholders) may play an even larger role in causing inefficient allocation of investments and, consequently, implementation of sub-optimal or inefficient measures (Gawel et al., 2016).

However, a more fundamental reason may lie in the insufficient political support enjoyed by the WFD, i.e. the society does not perceive good water bodies' status as a fundamental asset for its wellbeing, security and prosperity. Achieving the objectives of the WFD requires that all existing human activities are reconsidered, and often retrofitted to be compatible with a good ecological potential, when not even a good ecological status, of the water bodies. The *Blueprint to safeguard Europe's water resources* (EC, 2012) acknowledged that the WFD objectives cannot be achieved merely by implementing the existing water legislation, but require "*increased integration of water policy objectives into other policy areas*", including energy, agriculture, transport and disaster management (EC, 2012). This implies deep societal commitment cutting across all economic sectors. Is this realistic in a society that does not consider good status of waters as a necessity?

Sponsors of IWRM

In reality, many sectors of human activity have a clear perception of benefits from waters in good status. Business leaders have made a strong case for IWRM to support the economic performance, and sometimes even to be a necessary precondition, of industrial production with supply chains ramified in water-stressed regions (Waughray, 2012). They acknowledged that water security is so vital to all economic activities, and conflicts on the use of water are so threatening, that the sustainable management of water resources is an imperative for collective action at all levels. From a task for governments pursuing the public interest, IWRM is now evolving more and more as a tool for companies to securitize water as a direct input to operations and across the supply chain, in practically all sectors of the economy. Moreover, IWRM may contribute to set a legal framework minimizing regulatory risks in areas affected by water shortage. Finally, improved efficiency and productivity of water use may bring at the same time competitive and reputational gains. The CEO water mandate (UN Global Compact,2011) provides a framework for corporate water stewardship and engagement with IWRM not just for large conglomerates, but also small and medium enterprises, and engagement seems to be quite widespread and growing (CDP, 2017), although often not yet sufficiently effective (Newborne and Dalton, 2016).

Tourism is another major area of human activity for which good status of water bodies may be critical. Not only are clean waters obviously more attractive than polluted ones, but the hydromorphological conditions of water bodies may be relevant: connected floodplains may be often associated with higher recreational and aesthetic value of river landscapes; channelized streams, contrary to more natural ones, do not offer opportunities for bathing; longitudinal discontinuities are problematic for certain water sports such as kayaking. Commercial and recreational fisheries, both inland and in coastal areas, require productive ecosystems, which normally correlates with good ecological status (McIntyre et al., 2016), and often may support the case for major investments in ecological restoration including dam removal (Headwaters Economics, 2016). Floodplains suitable for outdoor activities and water bodies for swimming enhance the accessibility to physical exercise and pleasant contexts to relax from stress, particularly around large urban areas. This can yield significant savings on healthcare systems, considering the proven benefits that balanced lifestyles have on public health.

Flood management may benefit significantly from rivers in better status. Generally speaking, connected floodplains are acknowledged to be effective in flood attenuation, while reduced channelization and more dynamic exchanges between rivers and floodplains support a number of beneficial ecological processes.

In water supply management, there is an increasing interest by utility companies in developing payment schemes to compensate farmers and other economic activities in drinking water source watersheds for not polluting (e.g. Grolleau et al., 2012), for generally reducing the level of human activity or even for actively supporting water protection. Promising payment schemes are the "water funds", particularly widespread in Latin America (Echevarria et al., 2015). Paying watershed dwellers to protect water resources may at the same time support biodiversity protection, although water resource and biodiversity protection targets are not always fully overlapping (Pagiola et al., 2010).

The above examples on flood management and water supply protection highlight the role of ecosystems as a complement to engineered water infrastructure, and the opportunity of enhancing the "green infrastructure" as an effective investment.

Looming alliances

While many human activities clearly benefit from good status of water bodies, many others seem to have a persisting conflict with the pursuit of environmental quality objectives. Because water supports food and energy security, which are as important as water to human societies, we tend to consider agriculture and renewable energy production as more legitimate competitors of water ecosystems than other human activities.

Agriculture as a sector is traditionally a large water user, as well as a potential responsible for considerable pollution due to nutrients and pesticides. Until now, in many parts of the world agriculture has been granted heavily subsidized access to water. However, more recent trends show that water scarcity and a higher food-consciousness of the public push for water-efficient and low-input agriculture such as organic farming, significantly enhanced by progress in bio-based pest control (van Lenteren et al., 2017). Moreover, not just the quality of agricultural products, but also of the agricultural landscape in itself is increasingly perceived as an asset to put into value in agri-business. Rural tourism is already a significant contributor to farmers' income in many regions of Europe, and the value added of products is often associated to the environmental quality of the production areas.

The case of hydropower is more contentious: existing plants are often typical cases of activities bringing broader benefits to society, including a key contribution to the decarbonisation of the economy, hence they may warrant the affected water bodies certain exemptions when setting environmental objectives. At the same time, dams undergo significant public scrutiny because of their potentially significant ecological impacts. For dam operators, corporate social responsibility actions may be paramount to the sustainability of their business. These include in particular being supportive towards the requests of releasing environmental flows and introducing mitigation measures, such as fish passes, to reduce the disruption of river continuity. New hydropower projects, on the contrary, usually undergo an environmental impact assessment, where the requirements on environmental flows and mitigation measures may be included among the initial design specifications in order to secure chances of approval.

Inland navigation requires significant morphological modifications to water bodies. At the same time, it benefits from availability of instream water. Morphological modifications may cause fish habitat loss, while instream water availability is generally good for fish habitat, although the timing requirements of instream flows for biodiversity may not coincide with those of navigation. This makes navigation an ambivalent allied of the water bodies' ecological status.

Who will lead us into paradise?

Stakeholders from different economic areas are more and more supportive of sustainable water resources management, and ready to positively engage in IWRM. Business leaders may be a powerful actor of change. A long and robust tradition of economic theory, spearheaded by J. A. Schumpeter with his classical "Theory of Economic Development" (Schumpeter, 1934), emphasizes the role of entrepreneurs in finding innovative solutions nurturing progress and well-being for the mankind. An opposite tradition, going back to J.M. Keynes, advocates that governments must play an active role in a market economy. Keynes' view rejects the idea that entrepreneurs can themselves drive society to a common good, just by creating progress through business development: "*This is a fine picture of the great captain of industry, the master-individualist, who serves us in serving himself, just, as any other artist does. Yet this one, in his turn, is becoming a tarnished idol. We grow more doubtful whether it is he who will lead us into paradise by the hand.*" (Keynes, 1926). The views of Keynes and Schumpeter have been opposed in the grand political economy debates of the XX century; now a "Schumpeterian" role of business, bringing forward the wellbeing of society at broad through innovation, is generally regarded as the necessary complement to a "Keynesian" role of the public sector providing orientations for investments and steering of existing markets, if not even for creating markets and enabling a *milieu* for innovative business development (Mazzucato, 2013). This is particularly true when considering IWRM: charting and enacting river basin management plans to generate prosperity and wellbeing while preserving aquatic ecosystems calls on business leaders to change the economic drivers of resource consumption, or at least adapt them taking into account their negative impacts. But it also calls on the governments to create adequate frameworks for action and governance (Polyakov et al., 2017; Schramm et al., 2017). In order for the two roles to interact constructively, attention is increasingly paid to ensuring an "institutional fit" to social and ecological systems (Epstein et al., 2015). Mostert (2017) suggests that a key level is represented by the "community", given by relations of people based on shared values, interests, and willingness to collaborate, corresponding to Tönnies' (1963) concept of *Gemeinschaft* as opposed to *Gesellschaft*. A community of people sharing a common interest for water bodies in as good conditions as possible, acknowledging their dependence on water resources for their security and prosperity, may be postulated to naturally generate broad and long-lasting political support to IWRM. This has analogies with industrial community utopias such as the one of Adriano Olivetti (see e.g. Cadeddu, 2012), visioning a community formed around the productive assets of a territory, to be harnessed for the integral and harmonic development and well-being of society. Empirical evidence (e.g. Serra-Lobet et al., 2016; Flavio et al., 2017; Edelenbos et al., 2017) suggests that well-established communities, and institutions enabling societal engagement, may be more effective in implementing IWRM. In this sense, "community fit", i.e. "*the match between the spatial scale of the relevant community and the scale of the formal institutions and the management issues*" (Mostert, 2017), may be as essential aspect of institutional fit.

Public, experts and decisions

In order to harness the sense of community in IWRM, the involvement of the public may be crucial. While clearly mandated by the WFD, though, the public is often only informed about plans and programmes under IWRM (see e.g. Ker Rault and Jeffrey, 2008). Cases where citizens and organizations from the civil society have had a substantial role in the formation of a river basin management plan are relatively few. Most of the times, the public opinion may exert a pressure on decision makers, but it rarely enters a debate on the environmental quality objectives to adopt, the pressures hampering their achievement and the consequential design of programmes of measures. The whole process of river basin management planning is perceived as largely technocratic, with decisions confined to the remit of specialist scientific professionals. This is necessary when the problems to address can be framed as merely technical, such as designing a wastewater treatment plant with given specifications. However, the supremacy of science advocated e.g. by Collins and Evans, 2002, is now accepted in very limited aspects of decision making. First of all, professionals draw on their disciplines' codes, still largely representing their work as an exercise of applied science resting on a predefined set of accepted methods (albeit increasingly integrated, e.g. with ecology and social sciences alongside engineering or chemistry). But the success of a solution may critically depend on non-technical factors, such as behavioural controls and incentive structures, the appreciation of the expected benefits by stakeholders, and the sense of ownership they are allowed. Formulating and analysing problems only from a professional perspective restricts the possibility to invent creative solutions, which could be instead boosted by harnessing wisdom beyond professional disciplines. Moreover, even decisions in very technical matters should not be regarded as necessarily objective, as the incentive structures in place may bias the professionals' advices. For example, in countries where the payments for engineering design were traditionally determined on the basis of the cost of the designed works, engineers were incentivized to design flood protection structures (e.g. levees) instead of plans to provide more space for flood expansion: the latter would shift costs e.g. on buying riparian land, which would not count in determining the cost of the works.

In most decisions, professionals must *answer* questions of fact; but *posing* questions belongs to politics. It is difficult to ignore the importance of the society in identifying the goals, but also the general river basin management strategies. It is now broadly recognized that not just policy questions, but even research questions in environmental science should be driven by societal needs, and should be co-developed by social and biophysical scientists working closely together with stakeholders and communities. Co-development of scientific knowledge, problem solving and innovation is the "synthetic approach" to research, whereby scientific knowledge acts as the seed of innovation in processes, services and products, at the same time abandoning a technocratic hubris and taking a "bottom up" perspective. It is not uncommon that societal groups undertake their own studies and assessments with the support of their own consultants, scientifically well-prepared advocacy groups, or committed individual scientists. The awareness of the public concerning environmental themes is growing, hence groups and citizens' organizations are in an increasingly dialectic position with respect to specialists (Feyerabend, 1982). As a consequence, the work of the specialists is more and more frequently subject to societal scrutiny. Moreover, scientific exactitude is increasingly challenged by the deep uncertainty under which decisions need to be taken, and scientific robustness seems to become more salient. For instance, the functioning of aquatic ecosystems is complex and difficult to understand. However, for many of the European water bodies not yet achieving the WFD environmental objectives despite many years of planning and management, at least some of the key reasons for failure are well-understood, and often it is possible to identify appropriate and immediately actionable measures. No-regret decision making has been suggested as a suitable approach e.g. for adaptation to climate change (Wilby and Dessai, 2010), and IWRM is a typical context requiring robust decision making (e.g. Yan et al., 2017; Su et al., 2017; Löwe et al., 2017; Trinidade et al., 2017).

The Water-Energy-Food-Ecosystems nexus and the WFD: ideas to move forward

The programmes of measures mandated by the WFD require a political decision on the acceptable trade-offs between human pressures and the status of water bodies. A prominent feature of the WFD is in the focus it puts not on ensuring compliance with standards, but on the identification and pursuit of appropriate water management goals. We have argued that (1) IWRM can be a framework for collaboration among disparate stakeholders, where the "Schumpeterian" role of the business sector is synergetic with the "Keynesian" role of governments; and (2) institutional and community fit can be essential to enable positive relationships between these roles.

Increasingly, managing water requires managing a full array of interconnected aspects. In the last decade, the conceptual framework of the "Water-Energy-Food-Ecosystems Nexus" (https://www.water-energy-food.org/) and a handful of proposals of analytical tools to support its implementation (e.g. Howells et al., 2013) have stimulated many stakeholders to rethink their relations with river basin management, appreciating that water resources status has profound implications on energy and food security, hence social stability and economic prosperity. At the same time, it has helped raising the attention of the energy, agriculture and related industrial sectors on the need of water efficiency and sustainability for the production to not be put in jeopardy. The WFD has proven extremely difficult to implement from a purely "water-centric" perspective, because the ambitious environmental objectives it stipulates cannot be achieved without broad political support. This can be in turn only mobilized if the protection of water bodies can be clearly linked to the wellbeing, prosperity and security of society. Implementing IWRM in the framework of the Nexus may help substantially in this direction. A Nexus perspective makes it prominent how a significant part of the appropriate water management goals of IWRM, encapsulated in the WFD, may be achieved by establishing alliances with energy, agriculture and other economic activities, based on the benefits that each one receives from healthy river basins.

A practical tool to support such alliances may be that of "river contracts" (RCs). These are voluntary agreements, with different levels of legal cogency, signed by a variety of actors in a river basin, where commitments are taken on specific actions relevant to river basin management. These may include land planning provisions by the local authorities, public investment by the governments, private investments and other actions and engagement by specific groups of citizens, economic interest groups, and their organizations. Scaduto (2016) presents an overview and comparison of RCs in Europe and, particularly, France, where they are well-structured in the context of the WFD implementation, and Italy, where RCs have a less formal status. RCs may be mandated to orchestrate the complexity of actions in all sectors that could help achieving the WFD objectives. By creating a coordination framework, RCs may be also a working method for conflict resolution and community fit (or even community building) based on a shared sense of care and stewardship for the river basin and its resources. If communities in a river basin are properly stimulated, the decision making process may be a concrete opportunity to identify common interests in the protection of aquatic ecosystems. RCs may be the elective tool, for instance, to recompose conflicts between hydropower production and freshwater fisheries, angling or water sports, by identifying actions the two sides should undertake to minimize their interferences, e.g. environmental flow releases and mitigation measures for the restoration of river continuity vis-à-vis higher predictability of abstraction permits. RCs may be also the context where investments are coordinated in order to maximize their benefits, e.g. flood defences through natural water retention measures with a nature conservation and/or recreation potential.

Finally, promoting and empowering communities in IWRM may be useful much beyond considerations on the effectiveness of river basin management. In a world plagued by resurgent nationalism and emerging conflicts on ethnical, religious and cultural grounds, the outreach of river basin management could also be much broader than in the water remit, and could constitute a key vehicle of trust building in the spirit of "water diplomacy".

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References:

ECA (European Court of Auditors) Special report no 23/2015: Water quality in the Danube river basin: progress in implementing the water framework directive but still some way to go. https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=35001

Gawel, E., Lehmann, P., Strunz, S., Heuson, C. (2016). Public Choice barriers to efficient climate adaptation – theoretical insights and lessons learned from German flood disasters. Journal of Institutional Economics, 1-27. doi:10.1017/S1744137416000163

Mostert, Erik (2017): River basin management and community: the Great Ouse Basin, 1850–present, International Journal of River Basin Management, DOI: 10.1080/15715124.2017.1339355

McIntyre, Peter B., Catherine A. Reidy Liermann, and Carmen Revenga. Linking freshwater fishery management to global food security and biodiversity conservation. PNAS, November 8, 2016, vol. 113 no. 45, pp 12880–12885. Doi: 10.1073/pnas.1521540113

Headwaters economics, 2016. Dam Removal: Case Studies on the Fiscal, Economic, Social, and Environmental Benefits of Dam Removal. Available online https://headwaterseconomics.org/economic-development/local-studies/dam-removal-case-studies/

Polyakov, Maksym, James Fogarty, Fan Zhang, Ram Pandit, David J. Pannell, The value of restoring urban drains to living streams, In Water Resources and Economics, Volume 17, 2017, Pages 42-55, ISSN 2212-4284, https://doi.org/10.1016/j.wre.2016.03.002.

Edelenbos, Jurian, Arwin Van Buuren, Dik Roth & Madelinde Winnubst (2017) Stakeholder initiatives in flood risk management: exploring the role and impact of bottom-up initiatives in three 'Room for the River' projects in the Netherlands, Journal of Environmental Planning and Management, 60:1, 47-66, DOI: 10.1080/09640568.2016.1140025

Schramm, E., Kerber, H., Trapp, J.H., Zimmermann, M. & Winker, M. (2017). Novel urban water systems in Germany: governance structures to encourage transformation. Urban Water Journal, DOI: 10.1080/1573062X.2017.1293694.

Waughray, D. (editor) Water Security: The Water-Energy-Food-Climate Nexus. Island Press, Washington DC, 272 pp., 2012

UN Global Compact, The CEO water mandate. UN Global Compact Office, New York City, NY 10017, 2011, https://ceowatermandate.org/files/CEO_Water_Mandate.pdf

Flávio, H.M., P. Ferreira, N. Formigo, J.C. Svendsen, Reconciling agriculture and stream restoration in Europe: A review relating to the EU Water Framework Directive, In Science of The Total Environment, 596–597, pp 378-395, 2017, https://doi.org/10.1016/j.scitotenv.2017.04.057.

Grolleau, Gilles , Laura M.J. McCann, Designing watershed programs to pay farmers for water quality services: Case studies of Munich and New York City, In Ecological

Economics, Volume 76, 2012, Pages 87-94, https://doi.org/10.1016/j.ecolecon.2012.02.006.

Serra-Llobet, Anna, Esther Conrad, Kathleen Schaefer, Governing for Integrated Water and Flood Risk Management: Comparing Top-Down and Bottom-Up Approaches in Spain and California. Water 2016, 8(10), 445; doi:10.3390/w8100445

Echavarria, Marta , Paola Zavala, Lorena Coronel, Tamara Montalvo y Luz Maria Aguirre Infraestructura Verde en el Sector de Agua Potable en América Latina y el Caribe: Tendencias, Retos y Oportunidades, 2015. http://fondosdeagua.org/esp/wp-content/uploads/2017/06/infrastructura-verde-en-el-sector-de-agua-potable-en-america-latina-y-el-caribe-espanol.pdf

Pagiola, S., Zhang, W., Colom, A., Can payments for watershed services help finance biodiversity conservation? A spatial analysis of highland Guatemala (2010) Journal of Natural Resources Policy Research, 2 (1), pp. 7-24. DOI: 10.1080/19390450903350812

van Lenteren, Joop C., Karel Bolckmans, Juergen Koehl, Willem J. Ravensberg, Alberto Urbaneja, Biological control using invertebrates and microorganisms: plenty of new opportunities. BioControl, 2017, in press. http://dx.doi.org/10.1007/s10526-017-9801-4

EC, Communication From The Commission To The European Parliament And The Council. The Water Framework Directive and the Floods Directive: Actions towards the 'good status' of EU water and to reduce flood risks, 2015

EC, Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions. A Blueprint to Safeguard Europe's Water Resources , 2012

Keynes, J.M., The end of laissez-faire. Hogarth Press, London, 1926. Version available online at https://www.panarchy.org/keynes/laissezfaire.1926.html

Schumpeter, J.A., The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle. Translated from the 1911 original German, Theorie der wirtschaftlichen Entwicklung. Transaction Books, New Brunswick, New Jersey ,1934.

Epstein, Graham , Jeremy Pittman, Steven M Alexander,Samantha Berdej, Thomas Dyck, Ursula Kreitmair, Kaitlyn J Rathwell, Sergio Villamayor-Tomas, Jessica Vogt, Derek Armitage. Institutional fit and the sustainability of social–ecological systems. Current Opinion in Environmental Sustainability 2015, 14:34–40

Tönnies, F., 1963. Community and society. New York: Harper Torchbooks.

Cadeddu, Davide (2012). Reimagining democracy on the political project of Adriano Olivetti. New York: Springer

Feyerabend, P. (1982). Science in a free society. London: Verso

Collins, H., & Evans, R. (2002). The third wave of science studies: Studies of expertise and experience. Social Studies of Science, 32(2), 235-296. http://dx.doi.org/10.1177/0306312702032002003.

Wilby, R. L., Dessai, S. (2010), Robust adaptation to climate change. Weather, 65: 180–185. doi:10.1002/wea.543

Ker Rault, P.A., Jeffrey, P.J., Deconstructing public participation in the Water Framework Directive: implementation and compliance with the letter or with the spirit of the law? Water and Environment Journal, 22(2008),241-249

Yan, D., Ludwig, F., Huang, H.Q., Werners, S.E., Many-objective robust decision making for water allocation under climate change (2017) Science of the Total Environment, 607-608, pp. 294-303. DOI: 10.1016/j.scitotenv.2017.06.265

Su, H., Zou, R., Jiang, Q., Ye, R., Liang, Z., Ma, W., Chen, Y., Liu, Y. Subjective deep uncertainty and robust decision making for load reduction at the watershed scale (2017)

Huanjing Kexue Xuebao/Acta Scientiae Circumstantiae, 37 (7), pp. 2777-2785. DOI: 10.13671/j.hjkxxb.2016.0466

Löwe, R., Urich, C., Sto. Domingo, N., Mark, O., Deletic, A., Arnbjerg-Nielsen, K. Assessment of urban pluvial flood risk and efficiency of adaptation options through simulations – A new generation of urban planning tools (2017) Journal of Hydrology, 550, pp. 355-367. DOI: 10.1016/j.jhydrol.2017.05.009

Trindade, B.C., Reed, P.M., Herman, J.D., Zeff, H.B., Characklis, G.W. Reducing regional drought vulnerabilities and multi-city robustness conflicts using many-objective optimization under deep uncertainty (2017) Advances in Water Resources, 104, pp. 195-209. DOI: 10.1016/j.advwatres.2017.03.023

Howells, Mark, Sebastian Hermann, Manuel Welsch, Morgan Bazilian, Rebecka Segerström, Thomas Alfstad, Dolf Gielen, Holger Rogner, Guenther Fischer, Harrij van Velthuizen, David Wiberg, Charles Young, R. Alexander Roehrl, Alexander Mueller, Pasquale Steduto, Indoomatee Ramma. Integrated analysis of climate change, land-use, energy and water strategies. Nature Climate Change 3, 621–626 (2013). DOI:10.1038/nclimate1789

Scaduto, M.L., River contracts and integrated water management in Europe. Springer, 2016, 122 pp

CDP Global Water Report. A Turning Tide: Tracking corporate action on water security, 2017. https://www.cdp.net/en/research/global-reports/global-water-report-2017

Mazzucato, M., The Entrepreneurial State: debunking public vs. private sector myths. Anthem Press: London, 2013

UNECE, Policy Guidance Note on the Benefits of Transboundary Water Cooperation. Identification, Assessment and Communication. United Nations: New York and Geneva, 2015. https://www.unece.org/fileadmin/DAM/env/water/publications/WAT_Benefits_of_Transboundary_Cooperation/ECE_MP.WAT_47_PolicyGuidanceNote_BenefitsCooperation_1522750_E_pdf_web.pdf

Newborne, P., and J. Dalton (2016). Water Management and Stewardship: Taking stock of corporate water behaviour. Gland, Switzerland: IUCN and London, UK: ODI. 132pp. https://portals.iucn.org/library/sites/library/files/documents/2016-069.pdf

Blended financing, underpinned by inter-sectorial risk management, enhances the commercial viability of nexus projects: Lessons from the Songwe River Basin Development Programme

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ABSTRACT: This paper demonstrates the efficacy of using blended finance, underpinned by an inter-sectorial risk assessment approach, to improve the financial viability, as well as the environmental and social impacts of water, energy and food related infrastructure and projects. To achieve financial viability, a water, energy and food nexus project needs to address these risks in an integrated manner that does not in effect prioritize one sector over another. The financing mechanisms available to infrastructure projects respond to varying degrees of risk inherent in the project. Blended financing makes use of commercial loans, concessionary loans and grants to cater for the various elements in the projects that carry differing risk levels. An integrated and robust risk management approach allows the blended finance structure to cater holistically to the financing needs of the project without excluding the less commercially viable components in favour of the cash-cows. Nexus projects with well-structured risk mitigation and financing will ultimately yield improved financial, environmental and social returns for the project and community. The Songwe River Basin Development Programme (SRBDP) demonstrates how a nexus approach can address risks and increase a project's viability to attract financing.

Introduction

Assessing the financial viability of water, energy and food related infrastructure and projects, is strongly correlated with risk management and mitigation. A project with a reduced risk profile has a higher chance of attracting financing from both public and private sources. Water, food and energy related infrastructure each present unique risk factors that need to be carefully understood and managed. To achieve financial viability, a water, energy and food nexus project should be assessed taking into consideration the risks and opportunities of each component in an integrated manner. An integrated and robust risk management approach will ultimately yield improved financial, environmental and social returns for the project and community. A look at the Songwe River Basin Development Programme (SRBDP) under development in Tanzania and Malawi demonstrates how a nexus approach can address risks and increase a project's viability to attract financing using the blended financing approach.

Background

Challenges surrounding financial viability are the single most identified reason for the slow pace of infrastructure development in developing economies and a bottleneck to attracting the private capital that is desperately needed to close the global infrastructure gaps and provide services needed by millions of people (Runde, Moser & Neale, 2016). This paper demonstrates the importance of an integrated inter-sectorial risk assessment to improve the financial viability, as well as environmental and social impacts of water, energy and food related infrastructure and projects such as in the approach adopted by the SRBDP.

It is widely understood that the availability of investment resources is not the primary constraint to infrastructure development in developing economies, but rather that investment capital lacks quality projects that are investment ready (Runde, Moser & Neale, 2016). It is project developers and sponsors who are responsible to their constituents to ensure that projects are developed to a financially viable and sustainable state, in contrast commercial debt providers are focused on the risk assessment inherent to the project to engage.

Early development stages of major water, energy, food infrastructure and projects are focused on structuring the project to be financially viable, part of which involves the risk management and risk sharing protocol of the project. The optimum risk-sharing protocol is characterised by assigning project risks to the party best suited to manage the identified risks. Projects with inadequate risk management and risk sharing measures face the challenge of being unable to attract private capital. An integrated risk model that underpins the development of a sustainable project will take into account: the ownership structure; the communities where the project is located; the funding requirements and the project's ability to service the debt; technology, capacity of the infrastructure; environmental analysis; market analysis and contractual and institutional arrangements. The case of the SRBDP provides important insight into how risk management can appropriately be integrated in to complex water, food, energy nexus projects.

The Songwe River Basin Development Programme Case Study

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SDGs foundations of the SRBDP

For nexus infrastructure development to be sustainable, financial structuring must be managed within the constraints of their finite nature and the interdependence of the ecosystem (Weitz, Nilsson & Davis, 2014). Similarly to nexus projects, the Sustainable Development Goals (SDGs) are a set of integrated development goals intentionally designed to support and enhance one another. The SDGs aim to attain goals in one sector with positive or as little impact as possible on other sectors while relying on resource inputs from existing supplies without degrading the resources base and the underlying ecosystems.

Policy development within the water, energy, and food sectors deal with managing rapidly growing demand, finite supplies, and improving resource access for all. Without accounting for nexus related risks and benefits, policies and programmes are less likely to be sustainable (Wakeford, Kelly & Lagrange, 2015). The guiding principle for the nexus approach and the SDGs is providing access to resources in an equitable and efficient manner and to ensure sustainability. The development of a hydro scheme such as that of the SRBDP adopts the nexus approach that links electricity generation through hydropower with irrigation schemes that support commercial and small-scale agricultural processes. New hydro schemes being developed and designed are adopting a more inclusive and sustainable approach to curb negative impact on the ecosystem and improve access for vulnerable and marginalised communities.

Policies that manage water, food, and energy and aim to operationalise the SDGs of Zero Hunger (SDG 2), Clean Water and Sanitation (SDG 6) and Affordable and Clean Energy (SDG 7) cannot be effective and impactful when developed and implemented in isolation. Competition for scarce resources poses a risk to ecosystems and resource security caused by degradation of the ecosystems and irreversible climate change effects. These sectors are inter-dependant, the water sector needs electricity for pumping, likewise, the energy sector needs water for electricity generation, and the food sector is both a consumer and source to energy and water sectors. A holistic policy framework approach can manage these complex relationships nestled amongst rapid population growth, changing economic conditions and climate change (Weitz, Nilsson & Davis, 2014).

In the Figure 1, we see that the SDG targets that underpin the water, energy, and food aim to ensure access to resources, improve efficient management and protection of resources, and provide long-term sustainability.

• Access to affordable, reliable, and modern energy services
• Energy efficiency
• The share of renewable energy in the global energy mix

Energy Security

• Access to safe, nutritious and sufficient food
• Ending malnutrition
• Agricultural productivity
• Sustainable food production systems and resilient agricultural practices
• Genetic diversity of seeds, cultivated plants, farmed and domesticated animals and their related wild species, and access to fair and equitable sharing of the benefits from genetic resources

Food Securitv

• Universal and equitable access to safe and affordable drinking-water
• Water quality, wastewater, recycling, and reuse
• Water-use efficiency, sustainable withdrawals and supplies of freshwater, and reduction of water scarcity
• Integrated water resources management
• Access to sanitation and hygiene
• Protection and restoration of water-related ecosystems

Water Security

Source: *(Weitz, Nilsson & Davis, 2014, 41).*

Figure 1. SDG Goals that address energy, food and water security

The SRBDP is one such project that aims at operationalising the implementation of the SDGs. The project is implemented in a holistic manner with six sub-projects that will address water security, energy security and food security of the Songwe River Basin and surrounding communities. The detailed description of the project components shows the SRBDP addresses food, water and energy security and implementing a nexus project in a tangible manner.

1. Lower Songwe Dam and Hydropower Plant (HPP) Project

The Lower Songwe Dam and Hydropower Plant Project is a multi-purpose dam, located in Ileje District, Tanzania and Chitipa and Karonga Districts, Malawi. The Project, with a capacity of 175MW, is designed to fulfil the following purposes:

- generate hydroelectric power by utilising the head between the water level impounded by the dam and the tailwater level in the river further downstream, at the location of the tailrace outlet;
- protect the downstream reach of the Songwe River from floods particularly for the Lower Songwe Sub-Basin ("floodplain"), by retaining flood waters in the reservoir, and;
- provide irrigation water to the floodplain.

2. Lower Songwe River Tanzania Irrigation and Drainage Scheme

The Lower Songwe River Tanzania (LSRT) Irrigation and Drainage scheme is located in the lower part of the SRB on the left bank of the Songwe River and situated between the Songwe River and the Kiwira River with its upper boundary near the town of Kasumulu just downstream of the Kasumulu Bridge. LSRT, as well as its related project in Tanzania, requires the construction of the Lower Songwe Dam for its water supply. The net irrigation area of LSRT is 3,170 ha.

3. Lower Songwe River Malawi Irrigation and Drainage Scheme

The Lower Songwe River Malawi (LSRM) Irrigation and Drainage scheme is located in the lower part of the SRB on the right bank of the Songwe River and situated between the Songwe River and the main highway from the town of Songwe toward Karonga. LSRM, as well as its related project in Malawi, requires the construction of the Lower Songwe Dam for its water supply. The net irrigation area of LSRM is 3,019 ha.

The area planned for irrigation in both Tanzania and Malawi is currently a rain fed cropping area with the majority of the land under rice cultivation. The rice in this region is a traditional variety which is popular and fetches a good price. This would continue to be the main crop in the wet season, with irrigation being supplemental to the rainfall, and a good portion of it (60%) in the dry season, which will need constant irrigation. The other 40% will be typical upland crops of maize, groundnuts, cassava and market vegetables.

4. Stabilisation of the Lower Songwe River

The project will also stabilise the Lower Songwe, where the meandering and instability of the Lower 39km of the Songwe River is a natural phenomenon exacerbated by the deforestation of the river banks for agriculture and floods also influencing river instability. The river stabilisation, prioritising non-structural bank stability works, is intended to minimise the environmental damage to this important river as well as the costs, in terms of both initial investment and recurrent costs. Through stakeholder consultation, a collaborative approach to the design of the non-structural afforestation component was completed resulting in a set of village-based programmes for planting, maintenance and management of the river stabilisation.

5. Water Supply for Kasumulu and Songwe Towns and Lower Songwe Communities

The project will supply water to the towns of Kasumulu and Songwe and surrounding communities. The scheme is made up of:

- a raw water intake on the feeder canal for the LSRT I&D scheme 13.8 km downstream of the Lower Songwe Dam counter weir;

- a water treatment plant with a design capacity of 10,000 m^3/day with two parallel streams: of capacity 5,000 m^3/day;
- a 3,000 m^3 storage tank to work in combination with the existing tank;
- a distribution network to the Lower Songwe communities totalling 104km of various pipe sizes.

6. Water Related Social Infrastructure

The Water Related Social Infrastructure under the DDIP-SRBDP consists of four elements:

- Fisheries Development;
- Water Supply;
- Tourism Development;
- Rural Electrification;

Discussion and Key Findings

The SRBDP is made up of a diverse set of projects focusing on water resources, power generation, and social infrastructure projects. The projects vary in terms of risk profile and commercial potential. The socially oriented components have limited commercial potential, if any. The projects with revenue generating capacity are the lower dam and associated hydropower plant; and the development of two irrigation schemes on the Songwe River.

To raise external commercial funding, the Lower Songwe Dam and Hydropower Plant (HPP) Project is considered as a standalone project due to the fact that it is able to generate distinct cash flows which can be readily ring-fenced and suitable for a typical project finance structure; i.e. the financing of non-recourse/limited recourse long-term infrastructure where the debt and equity are repaid from the cashflows generated from the services provided by the infrastructure. Central to the project finance structure is the risk mitigation regime that is employed to transfer risk to the parties that can best manage them. The construction risk is addressed through an Engineering, Procurement and Construction (EPC) contract where the contractor undertakes the performance, delay and cost overrun risks by constructing the facility on time, on budget and to specifications. Other risks, such as operating risk are addressed through the Operations and Maintenance (O&M) contract, cashflow risk for the HPP is managed by having a Power Purchase Agreement (PPA) in place that will undertake to buy the power generated at a stated price, eliminating the uncertainty presented by market risk.

As the SRBDP includes not only the development and implementation of the HPP, but an array of projects that aim to develop the basin and address food, water and energy security, the less financially viable projects also need to raise funds that can meet the ensuing risk levels. The nexus approach to the development of the SRBDP lends it to an array of funding options available and is representative of different levels of investor risk preference and appetite for the projects proposed. Two broad funding sources are suitable to implement this project, namely developmental capital, referring to finance provided at concessionary rates and a strong emphasis on the economic and social returns of the project; and commercial capital, where the focus is on earning market related financial returns.

The SRBDP, as a whole, can be financially viable as a viable Public-Private Partnership (PPP) project, if implemented under a blended finance approach that would involve significant concessional debt from Development Finance Institutions and/or Multilateral Development Banks, equity from the two Governments of Malawi and Tanzania, as well as commercial debt and equity from private investors.

The HPP project is financially viable with consistent returns, sufficient net profit, and able to service its debt commitments. The critical factor is structuring the right mix of the various forms of possible financing to ensure that the project generates the right returns to attract private investors.

For the SRBDP's irrigation projects, a mix of grant funding and concessional debt from development finance institutions would meet the capital expenditure needs and a nominal levy to fund the operational and recapitalisation costs of the scheme. The positive economic and social viability of the irrigation schemes enhances the possibility of securing concessional debt finance for the capital cost of the project. The social projects can be funded through grants from donors as these are not commercially based initiatives.

Conclusion

Nexus projects, unlike traditional single sector infrastructure projects, are concerned with the sustainability of not one, but three different major sectors that often have conflicting aspects in implementation. This complicates matters for project sponsors as they must at all times consider the impact of each action on the holistic project and related sectors. To attract financing for nexus projects, robust, integrated risk mitigation systems must be put in place that carefully and clearly address all risk elements presented in the project, to ensure long-term sustainability.

A project's financial viability is based on strengthening a variety of factors, all put in place to mitigate the risks that emanate from implementing an infrastructure project. These factors, include: the capacity and financial strength of the project counterparts, eg, the sponsors, the contractors, the market or off-taker/s; the commercial strength of the business case and the ability for the project to service any debt and returns; and the socio-economic and environmental impacts of the project. A nexus project will deal with a multitude of stakeholders and parties in implementing the project; the effective management of interface risk is also crucial so that implementation is not delayed due to disputes. Clearly defined and communicated roles and responsibilities and associated risks will address this risk. Moreover, a very strong manager will have to be appointed that will manage each party during the implementation.

Nexus projects also address critical areas of socio-economic development, such as access to stable, reliable electricity, access to safe drinking water, building resistance to climate change, agricultural development, and by extension, contributing to poverty alleviation, job creation, improvement of livelihoods and development of small enterprises. Maximising development impacts can improve sustainable financing of nexus projects through the ability to attract financing from varied sources – investment finance from commercial funders and private investors, to grants from donors, as with the case with the SRBDP.

References:

Runde, D., F., Moser, H., & Nealer, E. (2016). Barriers to Bankable Infrastructure: Incentivizing Private Investment to Fill the Global Infrastructure Gap. Centre For Strategic & International Studies

Weitz, N., Nilsson, M., & Davis, M. (2014). A Nexus Approach post the 2015 Agenda: Formulating Integrated Water, Energy and Food SGDs. SAIS Review of International Affairs, 34, 37-50

Wakeford, J., Kelly, C., & Lagrange, S. M. (2014). Mitigating Risks & Vulnerabilities in the Energy-Food-Water Nexus in Developing Countries. Sustainability Institute and School of Public Leadership, Stellenbosch University

Chapter Conclusions and Recommendations

This chapter is at the base of the "EC Position Paper on Water, Energy, Food and Ecosystems (WEFE) Nexus and Sustainable Development goals (SDGs)". This is organised around the conclusions and recommendations of the different thematic chapters with the objective of summarising the experiences coming from the NEXUS experts and the discussions held during the workshop. This chapter is articulated around the lessons learned and best practices coming from the implementation of NEXUS projects in the different geographic areas and topics associated to the NEXUS, the knowledge gaps and implementation challenges identified by the experts to explore areas of further research and other practical actions.

Lessons learned and best practices

53. Accessing finance for the Nexus is underpinned by a project's bankability. Risk management plays an important role in enhancing project bankability. Water, food and energy related infrastructure each present unique risk factors that need to be carefully understood and managed. Furthermore, the individual projects that potentially make up a SDG-pursuing programme for improved access to affordable, reliable, and modern energy services, increased agricultural productivity and universal and equitable access to safe and affordable drinking-water vary in terms of both risk profile and commercial potential. When analysing and looking at investment decisions, usually attention is focused on two parameters: return on investment or simply profitability (i.e. measured investment efficiency) and risk (including in terms of impact on society and the environment). In developing countries, the availability of investment resources is not the primary constraint to infrastructure development, but rather that investment capital lacks quality projects that investment-ready.
54. The socially oriented components of a so-packaged **Nexus programme** have limited commercial potential, if any. However, the whole programme **can become a viable Public-Private Partnership if implemented under a blended finance approach**. For example, the hydropower projects are usually financially viable with consistent returns, sufficient net profit, and able to service their debt commitments. For irrigation projects that would rely on the same infrastructure as hydropower, a mix of grant funding and concessional debt from development finance institutions would meet the capital expenditure needs and a nominal levy to fund the operational and recapitalisation costs of the scheme. The positive economic and social viability of the irrigation schemes enhances the possibility of securing concessional debt finance for the capital cost of the project. The socially relevant infrastructure projects such as roads, schools and hospitals but also river stabilisation, water supply and sanitation, and fishery protection for livelihood enhancement can be funded through grants from donors as these are not commercially based initiatives.
55. On their part, banks and the financial market more in general are increasingly looking into expanding their portfolios of socially responsible, ethical, green or, all in all, sustainable investments. This means going beyond risk management and into green loan origination i.e. supporting businesses and industries with a positive impact on the environment and society. For example, green bonds were created to increase funding by expanding the investor base for climate-friendly projects worldwide. A big part of these green investment opportunities are therefore in clean energy including renewable, but also sustainable land use or clean water, on which Nexus initiatives can intuitively piggyback. The paradigm of this kind of green or sustainable banking and investment is to make Nexus solutions affordable until they outcompete single-sector interventions. This will happen through government financing at cost of capital and private sector

financing being profitable. For that to happen, the size of Nexus solutions markets needs to grow until the private/public sector investment ratio is maximised. Green bonds and loans help bridge that gap in an accelerated way. This is the space where to make the business case for a Nexus approach.

56. Water is a main driver in implementing a Nexus approach. It stands at the centre of the challenges around food security, energy generation, economic development, and climate change. Even when food security is the prevailing goal in a region, water resources and their management or development remain key to achieving it. But this is in the context of competing demands and decreasing infrastructure solutions. From reconciling water availability or quality with existing development goals, there was a need to move to water planning as an integral part of development planning. Responding to pressures on water resources would then shift to responding to broader basin stress and socio-economic pressures. As a result, the River Basin has been promoted by the water (and environment) sectors as the most appropriate management unit. The precondition was that basin plans would need to be aligned with broader economic development and planning objectives. This is perceived as highly relevant in a Nexus perspective, also.

57. **Cities are where local and global resource constraints meet.** Attempts to satisfy the resource demands of growing urban areas and consumers' lifestyles has meant looking ever further afield for supplies – from metropolitan and rural hinterlands, and increasingly at the regional and global level.[57] Resource challenges are further exacerbated by the fast-expanding growth rates and inefficient infrastructure systems of developing cities in several regions of the world. **It follows that the urban environment is an emerging context for also requiring a Nexus approach.** If not demonstrating that the River Basin is not *a priori* the better scale of strategic planning for the Nexus, this highlights the need for connecting multiple scales of analysis and management.

58. Connecting basins with their urban stakeholders means adopting a bottom-up approach to basin management especially involving urban areas through their actions at the catchment level.[58] This offers preliminary lessons for shaping forms of policy and governance which stretch beyond the boundary of the city. Integrated urban planning can also help cities exploit potential synergies of climate change mitigation and adaptation approaches to act on climate change more effectively. What is useful is in the Urban Nexus is the service-oriented approach that has been adopted in the natural infrastructure discourse as well. The provisioning of food, water and energy services in urban areas involves infrastructures and resource flows which are heavily dependent on each other and on the natural environment.

59. Compared to other water management approaches on a regional level, the Nexus concept offers alternative, less sensitive pathways to deal with water-related issues in a broader development context. **In Central Asia, the notion of the Nexus has seen an evolution in the role played by water in the past three decades.** In the 1990's-2000's, the legacy of the Soviet era's water allocation principles led to integrated approaches and regional institutions even prior to the rise to prominence of the Nexus concept, however under the paradigm that water management is exclusively a technical issue. Starting from the 2000's until recently, the region had to seek new arrangements and types of agreements for tackling interplaying water, energy and food issues as water cooperation principles were becoming increasingly contested. With stark upstream-downstream differences in domestic water requirements for hydropower vs. agriculture, water

[57] http://www2.giz.de/wbf/4tDx9kw63gma/UrbanNEXUS_Publication_ICLEI-GIZ_2014_kl.pdf
[58] http://www.iwa-network.org/programs/basins-of-the-future/

had become an economic and political issue. Since 2015, there has been a search for pragmatic and effective solutions to otherwise difficult cooperation dialogues that focus on water as a security issue for all Nexus sectors.

60. The institutional framework governing the elements of the Nexus **in most of the Arab countries** is also fragmented. This has led to "sectorial" approaches to policy planning, and consequently fragmented strategies and policies. Yet, there are some models for integrated institutions with one body responsible for two or more sectors, e.g. the Ministry of Water and Energy in Lebanon or the Ministry of Energy, Mining, Water and Environment in Morocco. **Nexus management does not require major institutional restructuring, but rather appropriate changes to protocols**, procedures and processes that improve interactions among the relevant ruling entities. Strong institutions that are better interlinked may be more important than additional or new institutions.
61. In order to become the prevailing framework **in the Latin America and Caribbean region**, the Nexus approach needs to seriously address regional obstacles and specificities. A few major obstacles already exist for identifying priority interconnections between sectors such as the lack of good quality information, the great diversity of the region, and generally weak governance. Some of the interconnections that should be prioritized in the region are irrigation modernization and aquifer overexploitation, and biofuels; hydropower, oil and mining; and water supply and sanitation services in cities. Whereas science has provided the evidence that these are the important interconnections, planning and legal frameworks play a key role in putting their integrated management into practice. This Nexus planning must be adaptive, multi-scalar, multi-temporal, inter-sectorial and based on a broad consensus by all political forces. Moreover, **the Nexus approach cannot be reduced to technical and efficiency aspects** in the LAC region either. In particular, it cannot be **decoupled from social inequity**. Especially, if seen as a great opportunity to change and revise the current pattern of unsustainable development of the region.

Knowledge gaps and implementation challenges

62. Nexus projects should be assessed taking into consideration the risks and opportunities of each component in an integrated manner, with opportunities being associated to sustainability as a whole (i.e. environmental and social objectives as well as economic). With new criteria like sustainability or development impacts being added to the traditional conflict between risk and return, portfolio selection and resource allocation have become an even more complex undertaking than before. In this context, the application of multi-criteria decision-making methods can be useful. The use of the model would allow decision-makers to decide on their optimal portfolio taking into account their respective preference with regard to return, risk and sustainability. In the event of multiple optimal portfolios, they should decide what projects to finance and execute, e.g. those providing the greatest business value with the acceptable level of sustainability, or those providing the greatest value of sustainability with acceptable level of return.
63. Due to the diversity of objectives of e.g. traditional infrastructure projects and water-related social infrastructure and non-infrastructure (e.g. for flood control and environmental conservation) projects within these optimised portfolios, there is a need to attract financing from varied sources. Investment finance from commercial funders and private investors, development capital from DFIs and grants from donors are all needed in the financing mix. Development Finance Institutions (DFIs) source their capital from national or international development

funds or benefit from government guarantees which ensures their credit-worthiness. The financial support they bring to relatively high-risk projects helps mobilising the involvement of private capital, bringing in such diverse actors as commercial banks, investment funds or private businesses and companies. At the same time, the grant equivalence of that investment needs to be found in the gap between the valuation implied by the terms of the DFI's investment and the value that private investors would put on that enterprise, accounting for risk.

64. Even within DFI's investment, **there is a need to avoid 'cherry picking' of projects**. This might be qualified as the reverse problem of lacking investment-ready quality projects. **A Nexus approach can avoid discriminating on the basis of the best outcome for any one sector**. Nexus projects, unlike traditional single sectors infrastructure projects, are concerned with the sustainability of not one but at least three different major sectors at once despite of the likely conflicting aspects in their implementation. A Nexus approach can also assist in promoting integrated investments in infrastructure that moreover include financing of Health, Education and WASH. Priority social infrastructure are roads, schools and hospitals but investments are also needed e.g. in rural electrification, roads and river crossings, fisheries & fish farming, or promotion of tourism from a socio-economic perspective.
65. From a regulatory framework point of view, the river basin approach is certainly more important as a management condition in certain contexts where it has been adopted like Europe than it might be in the rest of the world. This approach uses a surface water unit as the basis for planning. For this reason, it does not always encapsulates all of the management challenges related to groundwater resources. Groundwater aquifers do not necessarily conform to the same boundaries as surface water resources. Energy also, and power pools in particular that are established to promote energy trade between countries, tends to be regional or national in its organisation as a sector and not tied to river basins. The landscape approach has been proposed to reconcile agriculture, conservation, and other competing land uses. Water is not per se or in all cases a Nexus driver. However, it quickly becomes the stronger one than energy or food in areas of little water as most impacts of an uncoordinated approach to resource management are felt through water in the Nexus.
66. There are also significant data and modelling constraints to analysing three or more elements as an interrelated system (see Theme 2). As a result, even when policies are designed to focus on multiple areas, Nexus analyses often encompass only two resources and two-way interactions such as energy for water or water for energy.
67. With the growing importance of the mining industry in many developing countries, there is a need to better understand the Nexus in the context of mining as well. This is exemplified by certain national ministries that incorporate mining with other natural resources and the environment through its linkages to energy and water. Mining issues are context-specific, as often times in the case of development, but as often come down to water quality and quantity issues downstream of mining sites, competition for access to land for food, markets, production and access to reliable and cost-effective energy.
68. Innovative sources of additional financing for Nexus projects may come from climate funds. Climate change adaptation has a disaster-risk reduction element and climate change mitigation an energy efficiency or energy diversification one. Generally speaking, the global capital is unfamiliar with clean energy solutions. As a result, clean energy finance institutions are few in number. Consumer's demand for this type of Nexus solution is largely uninformed, disaggregated, or blocked by bottlenecks. Moreover, there is an unresolved tension between centralized and

distributed networks as seen for off-grid solutions. Incumbents may even be pricing downwards to thwart clean energy entry. Climate funds for support project developers that are interested in increasing their revenue through carbon finance. The fund would offer loans for Nexus projects at competitive interest rates that can be repaid from the sale of the carbon credits once the projects are operational.

69. Climate Change multi-sectorial approach can be seen as a strategy or a means to an end, i.e. reducing carbon emissions and adapting to the impacts of the unavoidable change, whereas the Nexus multi-sectorial approach is more of a philosophy for better coordinated management. With the Paris Agreement's entry into force, however, the focus has shifted towards its implementation and countries are exploring how to meet the commitments they set out in their Nationally Determined Contributions (NDCs). The operational structures set up by countries to reflect their respective ambitions for reducing emissions, taking into account their domestic circumstances and capabilities, can be an opportunity to foster the Nexus approach. Although not mandatory, most countries are also choosing to include an adaptation component in their NDCs in addition to establishing their mitigation commitments. Care should nonetheless be observed that Climate Change multi-sectorial activities do not monopolise objectives thus 'watering down' Nexus initiatives.
70. **Looking beyond NDCs**, the importance of adaptation is emphasized within the text of the Paris Agreement itself, which includes a call for all countries to engage in national adaptation planning processes. The goals of the National Adaptation Plan (NAP) process are for countries to build resilience to the impacts of climate change through medium- to long-term planning, and to integrate adaptation considerations into all relevant policies and strategies. **There is a potential to leverage NAPs as a process through which developing countries can implement or identify NDC adaptation priorities, and in turn how countries might leverage these commitments to adaptation in support of achieving the SDGs**. Similarly, countries might elect to leverage Nexus initiatives into SDG agendas with set objectives and investment streams that countries already have. This hierarchy of goals and commitments is perhaps why SDGs are the higher order mandate and a preferable channel to mainstream the Nexus to Climate Change per se.

Areas of further research and other practical actions

71. A project's financial viability is based on strengthening a variety of factors. Mitigation of the risks that emanate from implementing the project, especially if an infrastructure project, is a first factor. Blended financing addresses the different levels of commercial risk. Private-Public Partnerships (PPPs) and seed funding are means to this end. At the same time, an integrated risk model will need to be used to underpin the development of such a sustainable project. This would take into account: the ownership structure; the communities where the project is located; the funding requirements and the project's ability to service the debt; technology, capacity of the infrastructure; environmental analysis; market analysis and contractual and institutional arrangements. The **risk management system** so created **can adequately integrate the complexity of water, energy and food projects**, including the risk sharing protocol among the blend of financiers required by the different risk elements.
72. The second factor that needs to be strengthened to increase a project's overall financial viability is to cater for the less commercially viable components. Maximising development impacts can improve sustainable financing of an

infrastructure project. This is why projects need to be designed with the more easily bankable components associated with the less bankable components from the onset. The co-benefit analysis and cost optimisation due to the Nexus approach is how projects are made Nexus projects and how Nexus projects are made fundable. In the current situation where traditional infrastructure-market players e.g. governments and utilities are increasingly looking to private investment to fill the now widely acknowledged global infrastructure funding gap, PPPs can offer a number of benefits when development impacts also need to be maximised. These benefits include a whole-life costing approach that optimizes construction, operation, and maintenance costs, better risk management, and efficient project delivery.

73. In order to catalyse the two factors above, policy commitment and regulatory framework are strong pre-conditions for creating finance opportunities, in particular, for projects with social and environmental components. On the one hand, policy commitment means that financial institutions and governmental agencies should make financing available to local initiatives for e.g. watershed management through decentralized funds and credit schemes that integrate clean and adequate water for all, ecosystem services, livelihoods and economic development. On the other hand, promotion and adoption of e.g. Water Stewardship schemes[59] is an example of both encouragement to, and positive response from, the private sector into Nexus implementation. The same kind of examples should be found for the Energy and Food Sectors. Better definition and prioritization of national clean energy markets would invigorate the supply chain and bring private-sector lending to scale.

74. Regulation can help define the right criteria for Nexus projects, including sustainability criteria, and thus gradually elevate average project quality. But for beneficiary countries to move away from donor-driven agendas, this requires them to have their own (national or regional) agenda and policies in place as well as good regulatory frameworks for projects that are not just 'bankable'. For example, terms of reference that promote by-products of waste management to include recycling, re-use, waste-to-energy conversion and local market possibilities (e.g. wastewater treatment facilities generating biogas). The push for developing and applying such directives should come from comparing the cost of simple waste management to integrated management strategies and estimating financial returns based on reduced capital costs of 'industrial symbiosis'. Use of Big Data and Social Media would also help to create the demand for Nexus solutions and Nexus projects would then be possible to aggregate to build scale.

75. **If not the river basin, the appropriate scale of planning and management for the Nexus seems to be the one where most economic, sectorial interests congregate. In many instances, this would coincide with the sub-basin level** for large rivers such as the Nile, the Amazon, the Niger, etc. but it will need to be determined on a case by case basis. In some cases within regions like SADC, demand for water and energy resources is concentrated in parts of the region that are not the ones endowed with abundant water resources that could sustainably deliver those inputs. In some other cases like LAC, hydropower potential across downstream stretches of tributaries may have to be assessed for trade-offs with upstream land-use change from large-scale export-driven agriculture compounded by climate change. In other parts of Africa e.g. SADC again, overreliance on biomass energy has been the main contribution to deforestation and land degradation.

76. **A multiple hierarchy of scales is needed** anyway. Each scale accounts for a unique assortment of elements, processes and actors and all scales intersect. **The**

[59] http://a4ws.org/

scalar perspective is best suited to understanding how a particular system may differ to that for managing it. **The national scale may be appropriate for target-setting** whilst the farm or municipality or watershed scale may drive the most change. **The landscape scale is important for uniting different needs** including those of ecosystems whilst food security is affected by global issues such as export prices and global energy demand. As an example, the regional scale is particularly important for SADC where watercourses and electricity grids are already shared among countries. This is the context where a regional Nexus operational framework is being developed to drive and guide sectorial collaboration in implementing priority investment projects. This is with a view to anchoring the Nexus in the sustainable infrastructure development and industrialisation agenda.

77. **The implementation of the SDGs, and SDG reporting by UN Member States, must be seen as an opportunity to promote a Nexus approach and vice-versa**. Integrating the SDG indicators and monitoring framework as the background to Nexus activities can help to avoid shortcomings from 'cherry picking' of financial investments as well as ensure a more equitable and politically application of the Nexus approach itself. Conversely, SDGs design promotes multi-sectorial implementation, and the Nexus approach can help make this framework become much more integrated. The key will be to match development cooperation support with country focus that is not on sectors as SDG implementation accelerates.

Chapter 4. Study Findings, Recommendations, Opportunities and the Way Forward.

This chapter highlights the main findings and results of the workshop. It summarizes the most important recommendations for implementing WEFE Nexus projects, demonstrates the opportunities in this field and poses the way forward to more efficient and profitable Nexus projects.

The following recommendations that have emerged from the expert contribution analysis and discussions are to be taken collectively. As with the WEFE Nexus approach that is about the system, the promotion of individual technological solutions and mono-sectorial planning need to be integrated and managed as a whole in a NEXUS approach. Considered individually they are not sufficient to successfully implement the whole system of policies, investments, capacities, and techniques that enable maximisation of synergies and minimisation of trade-offs in land use and spatial planning. They have been here organised around three overarching questions, two more related to science-technology and one more related to policy:

1. Where is the knowledge gap and how can modelling help?
2. What is a Nexus friendly technology as opposed to classic water management?
3. How are decisions made that are part of Nexus governance?

Technical/science area

Filling the knowledge gap

- Water, energy, food and ecosystems (WEFE) sectors play a fundamental role in determining societal health and economic well-being. However, current and expected changes in climate, growth population, and land use/cover changes place these sectors under considerable stress. To cohesively improve policies that target these challenges, there is a need for improved integration of economic decision-making with biophysical models (Kling et al., 2017). This need reflects an increasing demand to better determine cause-effect relationships in these systems. In order to best integrate individual sectorial models, it is advisable to test this integration by selecting the smallest scale at which allocation of resources is at odds with their interconnected nature i.e. a Nexus hotspot. Another practical solution to model integration is "soft-linking" or a "modular approach". It is in essence a "loose coupling" in which the output from one module forms the input for the other two as an exogenous factor to the other systems considered.
- When analysing the WEFE Nexus, it is also key not to focus entirely on the technical side of the resource reallocation problem in order not to lose sight of the environmental and social dimensions of sustainability next to economics. Some less than obvious interconnections that should be part of the integrative models developed to analyse the Nexus lie outside production optimisation. The use of virtual water and other environmental footprint methods as a comparative analysis tool in this context can help better understand issues of e.g. food waste or transport in terms of carbon emissions or biodiversity loss among the environmental impacts along the supply chain and life cycle of a product or activity. There is value in a sectorial model output being considered for its Nexus implications in terms of social equity as well. Qualitative approaches to modelling can be used in that respect to map the system with multiple sectors and potential beneficiaries, and locate priorities and trade-offs.
- Convergence thinking is one such qualitative approach to problem solving that transcends disciplines and integrates knowledge. Adoption would require creating new collaborations among different experts and organizations. Effective collaborations are at the centre of WEFE Nexus implementation. Water managers are being asked to be experts in other sectors to act as bridges between specialists and they will have to be

if they want to continue leading the transition to Nexus practice. Silo breaking then starts with education and academic programmes. In order to support new collaborations, the role and availability of data also remains key. Significant economic value can be unlocked by applying advanced analytics to both open and proprietary knowledge. Blended with proprietary data sets, open source can propel innovation and help organizations replace traditional and intuitive decision-making approaches with multi-sectorial, data-driven ones. Creative solutions are needed to complex Nexus problems and a combination of market-driven efficiency and governed planning principles seems desirable.

- The other key integration for WEFE Nexus implementation after sectors is of scales. The scalar perspective is best suited to understanding how a particular system may differ to that for managing it. The national scale may be appropriate for target-setting. The landscape or city scale is important for uniting different needs. But the ideal scale of planning and management for the Nexus is where most economic, sectorial interests congregate (i.e. the basin or sub-basin scale).

Identifying Nexus friendly technologies

- Sustainable and inclusive intensification and decoupling of resource use and environmental degradation from development can be achieved through technological innovation, recycling and reducing wastage. Technological innovation include desalination based on renewable energy where water is scarce and photovoltaic water pumps where electrification has not occurred (Hoff, 2011). Battery storage systems and/or hybrid technologies such as solar, wind, and fossil fuel combinations can offer flexibility in meeting these water and energy demand of agriculture at times of unavailable supply. There are still technological challenges associated with providing a steady supply but also storage for intermittent use for off-grid solutions. Effective off-grid systems will also require institutional, economic and, to some degree, infrastructural decentralization. Business models and market penetration strategies for these technologies should be explored in more detail to look at potential opportunities beyond cost considerations.
- In multi-use systems, wastes, residues and by-products can be turned into a resource for other products and services. Wastewater-energy integration at treatment facilities and wastewater reuse in agriculture are an example of recycling of water, nutrients and other resources (Hoff, 2011). Making productive use of the nutrient, organic matter, water and energy content of human excreta and wastewater is also known as productive sanitation. The quality of supplied treated wastewater, however, has to reflect the possible uses e.g. for agriculture, domestic or industrial consumption. Consequently, turning solid waste into a resource seems to present fewer health and operational risks than wastewater, e.g. char made from crop residues or other wet agricultural waste like manure, in particular. Also, existing hydraulic infrastructures equipped with photovoltaic panels provide opportunity for additional low-carbon energy generation with minimal or no extra social and environmental costs.

Policy/development cooperation area

- Evaluating the costs and benefits of selected Nexus solutions according to the priorities of the countries involved in a regional or basin Nexus assessment is seen as desirable. Each region with its own specific context, policy reforms need not create further tensions when the Nexus has been recognised as a risk-sharing element. In Central Asia, the notion of the Nexus has seen an evolution in the role played by water in the past three decades. In most Arab countries, Nexus management does not require major institutional restructuring, but rather appropriate changes to protocols. In Latin America, there is agreement that the Nexus approach cannot be reduced to technical and efficiency aspects or decoupled from social inequity. In West and Southern Africa, Nexus support is being injected into reviews of River Basin

Organisations' investment and strategic plans and development of operational frameworks for Regional Economic Communities' proposal processes.

- Existing models could be adapted to also assess the impacts of different Nexus investments and contribute to the definition of bankable Nexus projects. A Nexus programme of projects including socially oriented components can become a viable Public-Private Partnership if implemented under a blended finance approach including investment finance from commercial funders and private investors, development capital from Development Finance Institutions, and grants from donors. There is a need to avoid 'cherry picking' of projects; a Nexus approach would avoid discriminating on the basis of the best outcome for any one sector. Robust risk management system in these Nexus programmes can adequately integrate the complexity of water, energy and food projects. These partnerships developed around a Nexus portfolio are important to reconcile public and private interests.
- In the short- to medium-term, urban area development represents a challenge because of the increasing concentration of population with significant demands on water, food and energy supply. Cities are where local and global resource constraints meet, passing through the river basin for their most pressing needs. Considering the simultaneous pressures that this type of development will have at all scales, the Nexus approach represents a natural framework for key stakeholders to negotiate sustainable scenarios that minimise trade-offs among the different sectors. Joint Ministries e.g. of Energy and Water, and in some instances Mining and Environment as well, and inter-sectorial consultations for large infrastructure projects are a token of the change in the degree with which the Nexus approach has been taken on board and operationalized at the national level. The way these ministries are compartmentalized in the respective departments, however, still speaks to the implementation challenge.
- Effective collaboration to deal with the Nexus is deemed more important to achieve than the establishment of an ad-hoc Nexus body. This can be triggered by key issues of the day such as climate change, which have led to the formation of soft-type bodies such as national committees. There is also more value for overarching frameworks such as regional economic commissions, river basin organizations or inter-ministerial committees in a transboundary setting compared to the national context. However, these transboundary organizations may have to undergo institutional fit.
- The first step in the process of identification and implementation of Nexus projects is the analysis of the benefits of a Nexus approach on the different individual sectors. What is not a Nexus project, for example, is when there is a clear predominance of one sector in making the decisions or where there are limited cascading effects from these decisions i.e. the project is not critical for other sectors. The same applies to the definition of Nexus friendly technologies. Some good fit-for-purpose methodologies already exist to assess impacts across sectors e.g. Strategic Environmental Assessments (SEAs). Where these or equivalent frameworks exist in countries that promote inter-sectorial processes of collaboration from design to decommissioning of engineered and social infrastructure, Nexus projects developed according to these criteria may be rewarded with finance, including international.
- In the context of the UNFCCC, there is a potential to leverage National Adaptation Plans as a process through which developing countries can implement or identify their "nationally determined" adaptation priorities, and in turn how countries might leverage these commitments to adaptation in support of achieving the SDGs. In turn, the implementation of the SDGs, and SDG reporting by UN Member States, must be seen as an opportunity to promote a Nexus approach and vice versa. Effectively a subcomponent or a cross-cutting principle of the 2030 Agenda, the Nexus is perhaps a reminder of the operational needs dictated by action under SDG 2, SDG 5, SDG 6 and beyond. It is undoubted that the water sector can lead the way on Nexus implementation but will not succeed without other sectors sitting at the table.

APPENDIX I. List of Relevant Policy Documents.

There is a wide body of development policy and practise documentation, academic literature, guidance material, ... on the Nexus approaches. This appendix lists 13 reference documents considered relevant by the Editors.

Reference 1	**The New European Consensus on Development "Our World, Our Dignity, Our Future**
Description	Joint Statement 7 June 2017 by the Council and the Representatives of the Governments of the Member States meeting within the Council, the European Parliament and the European Commission. The key document on EU development policy.
Reference 2	Hoff, H. (2011). Understanding the Nexus. Background Paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus. Stockholm Environment Institute, Stockholm.
Description	This paper for the Bonn 2011 Conference presents initial evidence for how a Nexus approach can enhance water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance across sectors. It also underpins policy recommendations, which are detailed in a separate paper
Reference 3	FAO (2014): The Water-Energy-Food Nexus. A new approach in support of food security and sustainable agriculture
Description	The FAO paper detailing how FAO sees the Nexus concept in the light of Food Security in a global context. Introduction to the Nexus concept.
Reference 4	Kougias I., Szabó S., Scarlat N., Monforti F., Banja M., Bódis K., Moner-Girona M., Water-Energy-Food Nexus Interactions Assessment: Renewable energy sources to support water access and quality in West Africa, Luxembourg, European Commission, 2018, EUR 29196 EN, ISBN 978-92-79-84034-0, doi:10.2760/1796.
Description	This JRC Technical Report examines the potential synergistic benefits to energy, water and agricultural production practices in Africa, arising from an appropriate use of clean energy sources.
Reference 5	FAO: Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus in the Context of the Sustainable Energy for All Initiative July 2014
Description	This report proposes a way to carry out a water-energy-food Nexus assessment approach in order to: a) understand the interactions between water, energy and food systems in a given context, and b) evaluate the performance of a technical or policy intervention in this given context. The ultimate goal of the Water-Energy-Food (WEF) Nexus assessment is to inform Nexus-related responses in terms of strategies, policy measures, planning and

	institutional set-up or interventions.
Reference 6	Sustainable Energy Handbook – Module 2.4 – Water-Energy-Food Nexus
Description	This handbook provides a brief overview of DEVCO activities on the water-energy-food Nexus and how this approach will be increasingly used and implemented across a number of thematic units. It is also designed to be a useful summary on the concept itself, with explanation on how it will be operationalised at a global level not only by DEVCO but in conjunction by other EU Member States, international organisations and NGOs.
Reference 7	A Nexus Approach for The SDGs – Interlinkages between the goals and targets
Description	A presentation on interlinkages between and among SDGs – part of SDG TOOLKIT, an initiative co-funded by EU to engage European NGOs at National and European level on the Sustainable Development Goals.
Reference 8	Nexus Message on Water- Energy-Food -Climate through an Urban Lens – Building Integrated Approaches into Implementing the Sustainable Development Goals
Description	Outcome Message from the 2018 Nexus Conference, Water, Food, Energy and Climate, Water Institute at the University of North Carolina at Chapel Hill, North Carolina, USA, April 2018
Reference 9	Introduction to the Water-Energy-Food Security Nexus. 5 June 2018
Description	Training Module 1 "Introduction to the Water-Energy-Food Security Nexus" provides a theoretical introduction to the concept of the Water-Energy-Food (WEF) Security Nexus. The module has been developed by the GIZ Nexus Regional Dialogues Programme in cooperation with the Institute for Technology and Resources Management in the Tropics and Subtropics (ITT) of the Cologne University of Applied Sciences. Co-funded by the EU.
Reference 10	Messages from the Bonn 2011 Conference: The Water, Energy and Food Security Nexus – Solutions for a Green Economy
Description	Summary document setting out the key messages from this landmark conference on Nexus opportunities, principles, and how to make it work.
Reference 11	UNECE, 2015. Reconciling resource uses in transboundary basins: assessment of the water-food-energy-ecosystems Nexus.
Description	This report from UNECE describes the application of the Nexus approach and in particular how to perform the Nexus assessment in a transboundary river

	basin.
Reference 12	UNECE, 2017. Deployment of Renewable Energy: The Water-Energy-Food-Ecosystem Nexus Approach to Support the Sustainable Development Goals
Description	This report focuses on the interaction Nexus but with regards to Renewable energies. It provides good practices from 3 cases studies in South-eastern Europe and central Asia.
Reference 13	Angel Udias, Marco Pastori, Céline Dondeynaz, Cesar Carmona-Moreno , Abdou Ali , Luigi Cattaneo, Javier Cano. A decision support tool to enhance agricultural growth in the Mékrou river basin (West Africa)
Description	The paper describes an operational decision support system to help local managers assessing the WEFE NEXUS. The e-NEXUS has been applied in the transboundary MEKROU River Basin shared by Benin, Burkina Faso and Niger. The e-NEXUS has accompanied policy makers as part of the MEKROU's Strategic Development Plan by cross-checking development scenarios.

APPENDIX II. List of NEXUS Experts.

This document is the result of collaborative work that began in January 2018 during a meeting of international NEXUS experts in Brussels. The Editors want to thank all the experts, those who participated since the beginning and those who joined us along the way. They understand that their work is not just about synthesising information, but also about making scientific and technical knowledge available to contribute to more sustainable development and, ultimately, to help create a better world.

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