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The Climate Change Crisis in the Eastern Mediterranean and in Cyprus in the Context of the Water-Energy-Nexus

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Introduction

The region comprising the Eastern Mediterranean and the Middle East (the EMME Region; Figure 1) is known for its water scarcity at present and throughout its history. For instance, Jordan's water supply represents one of the world's most vulnerable. Its demand significantly outstrips the supply from aquifers, surface rivers, lakes and other sources. To cope with dwindling supply, water is being pumped at an unsustainable rate from all of its groundwater sources, including fossil water reservoirs. This notwithstanding, water resources per person are less than 60 m^3 per year in Jordan, lying far below the international water poverty line. Thus, without sufficient additional supply, the threat to water security in the country continues to increase (*Whitman*, 2019).

Figure 1: The countries of the EMME region considered here

Climate change and falling precipitation rates exacerbate the challenges not only for Jordan, but also for many of the EMME countries. Cyprus, with a mean annual precipitation rate of 463 millimeters as the only natural source of water and an annual renewable internal freshwater resource of 656 m^3 per capita is one of Europe's most water-stressed nations. The total annual water withdrawal exceeds the total annual renewable water resources in Cyprus by a factor of appr. 28. Such a stark imbalance is not only observed in Cyprus and Jordan, it is shared in 10 of the 17 EMME countries, implying an ongoing overexploitation of available resources in these countries.

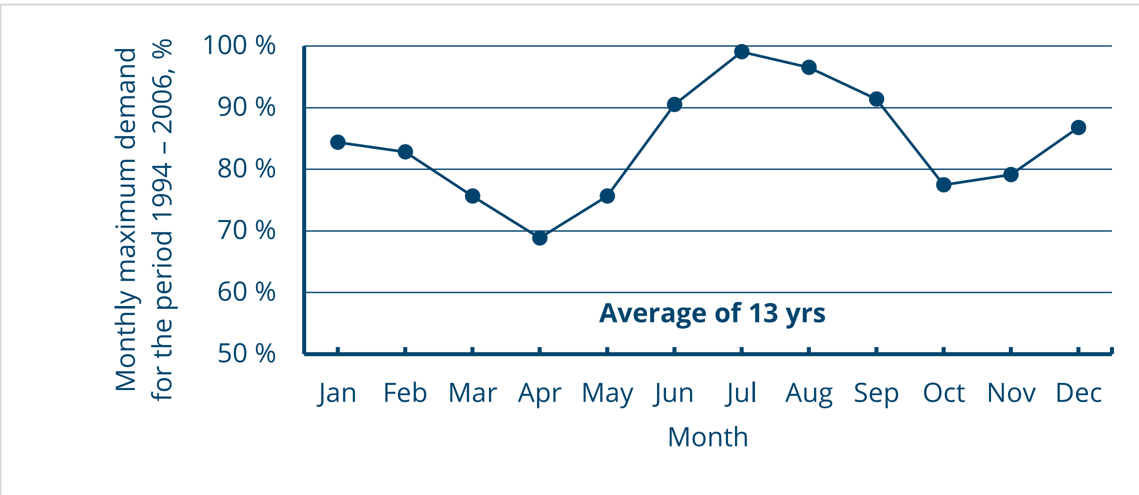
One of the remedies to maintain freshwater supply to the countries' citizens has been to employ the desalination of brackish and seawater. While enabling a reliable source of drinking water, desalination has been known to be extremely energy intensive. This technology thus represents but one of the numerous linkages and interdependencies between energy and water, which have been considered through the Water-Energy-Nexus (WEN) concept (see, e.g., *Lange*, 2019).

Before taking a closer look at the WEN, we will briefly examine various conditions in the EMME region, with a focus on Cyprus and will consider their current water and energy security in light of ongoing changes in climate conditions. Following a brief review of the WEN, we will look at some innovative technological solutions to address water and energy security, in general, and in the EMME countries, in particular.

Major Conditions in the EMME Region

The Mediterranean and the EMME region are considered "climate change hot spots", which have experienced warming rates almost two times faster than the global rate during the past four decades (*Giorgi*, 2006; *Zittis et al.*, 2022). In fact, Mediterranean temperatures have diverted from global mean temperatures by about 0,5° since about 1980 (*Cramer et al.*, 2018). In order to explore future changes in climate conditions, regional climate models (RCM), based on the results of global climate modeling have been employed (see, e.g., *Hadjinicolaou et al.*, 2011; *Lelieveld et al.*, 2012). Outcomes of RCM modeling imply that temperature changes in the summer months are uniformly higher than those for the winter months (compared to a 1961–1990 control period) and that late-century increases in temperature (3.5–7°C for 2070–2099) are significantly higher than for the mid-century period (3–5°C for 2040–2069). In addition, models also imply a significant increase in the number of heat waves (i.e., a prolonged period of more than five hot days and warm nights) compared to the recent past. Maximum daily temperatures will rise from about 46°C to almost 50°C at the middle to the end of the century, resp. (*Lelieveld et al.*, 2016). This will not only have adverse consequences for local communities, but will also lead to a significant electricity demand for space cooling to enable comfortable indoor conditions, particularly in urban settings. Such developments are reflected, e.g., in the mean monthly electricity demands for Cyprus, which clearly indicate maximal need during the summer months (Figure 2a). The sharp rise in annual electricity demand since the mid-1980s in Cyprus is due to an increasing use of electrical appliances, particularly air conditioners (Figure 2b), which was followed by a slight decrease starting in 2005.

a)



b)

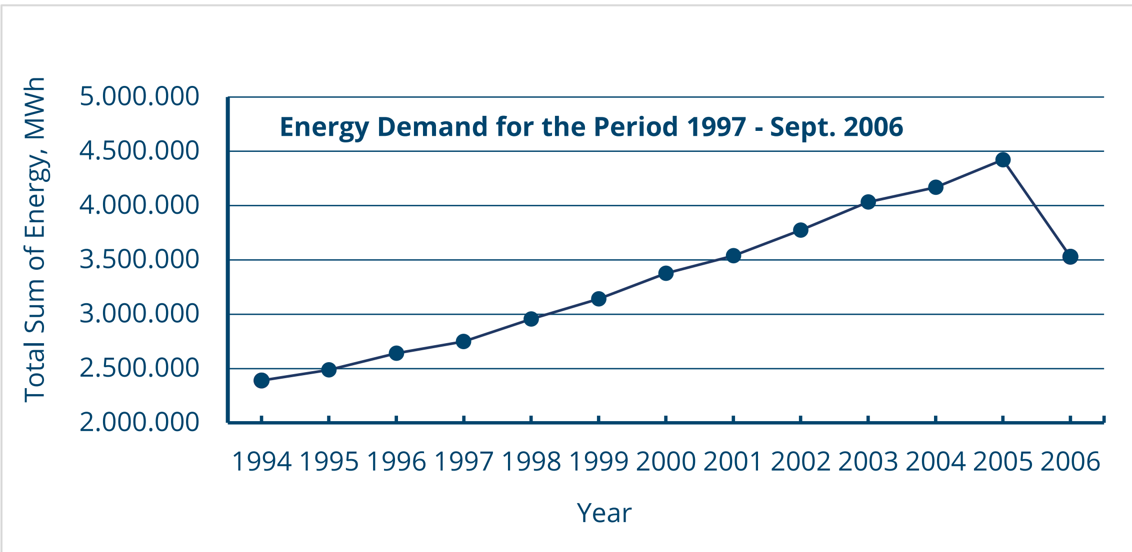


Figure 2: a) Monthly mean electricity demand in Cyprus for 1994 to 2006; b) Total electricity demand in Cyprus for 1997 to 2006; source: Cyprus Transmission System Operator

Model projections of future changes in precipitation in the EMME region, while characterized by higher uncertainties, indicate an overall trend of decreasing precipitation over most of the Middle East and North Africa region (MENA region), which is consistent with global climate model results and other regional climate modeling (see, e.g., Figure 5 in *Lange*, 2019). This implies a significantly longer dry season for most EMME countries than at present, substantial reductions in surface and subsurface water availability, directly affecting river flow, and soil water reservoirs, to name but a few of the consequences. Moreover, a reduction in available water resources, below the 500 m^3 per capita/year threshold in several EMME countries, is also expected.

For Cyprus, RCM results indicate an overall reduction in precipitation of 7% in mainland and coastal regions and by 2% in mountainous terrains by the mid-21st century (*Hadjinicolaou et al.*, 2011). While this may not sound overly dramatic, it significantly affects the recharge of surface reservoirs and dams, which represent the main source of irrigation water for agriculture. In order to ensure sufficient drinking water to its citizens, Cyprus has significantly enlarged its desalination capacity resulting in freshwater production reaching or even exceeding demand. As mentioned before though, this implies a sizeable need for electricity underlining the links between water and energy security.

The Water-Energy-Nexus

The relationships between water and energy in the context of the WEN have been described for the MENA region including the EMME region in numerous publications (for a brief review, see *Lange*, 2019). This is usually pursued by describing the interrelationships between water and energy through an assessment of the role of water in the energy sector and conversely that of energy in the water sector.

In the water sector energy, is needed for several purposes, including:

- The already mentioned desalination of brackish and seawater;
- conveyance and pumping in distribution networks;
- water treatment prior to consumption;
- water pumping through the distribution networks;
- wastewater treatment to make water available for secondary uses;
- and for the constructing, operating, and maintaining of water supply facilities.

Water use by the energy sector comprise a number of important activities, particularly:

- the extraction and refinement of natural resources; more specifically the use of water in mining and quarrying operations and in oil and gas exploitation;
- in hydrocarbon extraction and refining;
- for the cooling of conventional power plants, including nuclear power plants;
- and in addition, for the operation of hydroelectric power plants.

The Water-Energy-Nexus in the EMME Region

The observed increase in water and energy demand in the EMME region over the recent past is caused by various factors and circumstances including:

- the overall economic development in some of the EMME countries;
- the significant population growth and a continuous increase in urbanization in the region;
- the general change in lifestyles and shifting consumption patterns;
- inefficiencies in the use of resources that result from technical and managerial inadequacies

- and energy and water subsidies in several countries of the region, which discourage the careful use of these scarce resources.

When considering major measures aimed to satisfy the rising energy demand, we will briefly look separately at the energy and water sector and will subsequently consider some of the interrelationships/interdependencies between these commodities.

Measures in the Energy Sector

In order to satisfy the rising energy demand (space cooling, desalination), conventional measures include the construction of new conventional, hydrocarbon-burning power plants to enhance the electricity generation capacities in the Middle East. Current planning calls for a more than doubling of the overall capacity of conventional power plants by the Gulf Cooperation Council (GCC). This implies a rise in capacity by 294 GW between 2014 to 2040 from a current level of 285 GW in 2014 (*International Energy Agency*, 2016). Such drastic measures do not only require substantial capital investments. Conventional electricity generation also implies significant environmental impacts, including a rise in greenhouse gas emissions and a substantial demand for water (see above). Given the overall setting of the EMME and countries of the Gulf Cooperation Council (GCC countries), the utilization of renewable energy sources, most notably solar power appears as a much more meaningful alternative. This will also result in significantly reduced water demand for power production (*Fink*, 2018).

Measures in the Water Sector

It has been estimated that the total unmet annual water demand in the MENA region will rise to about 200 km^3 in the foreseeable future (*World Bank*, 2012). This is at least partly explained by the expected increase in population and an increasing urbanization, as mentioned before. The rise in food demand will have to be addressed through enhanced agricultural productivity by utilizing an increasing degree in irrigated agriculture. This will elevate demand for water in the already largest water-consuming sector for most of the EMME countries. It has been shown that the energy requirements for pressurized irrigation amounts to 1,56 kW/ha at a pumping energy efficiency of 58% (*Rodríguez Díaz et al.*, 2011). In order to avoid a continued overexploitation of stressed groundwater reservoirs and to ensure sufficient irrigation water, alternative water sources will have to be employed and/or water use efficiency in irrigated agriculture will have to be improved.

In addition, water needs in oil and gas exploiting countries, e.g., in Iraq, Iran, Egypt, and Saudi Arabia will likely increase due to a growing demand for hydrocarbon-based fuels. A higher degree of recycling through wastewater processing and the use of recycled water may somewhat relax the burden on available water resources.

Interrelationships/Interdependencies in the Water and Energy Sectors

As mentioned before, in light of the increasing demand in potable water, many countries have adopted unsustainable practices of water withdrawal by overexploiting existing aquifers and surface water reservoirs or by utilizing precious fossil water. However, given the limitation of such measures, many countries employ seawater desalination as remedy. Since desalination is highly energy demanding, the price for the resultant freshwater is closely linked to local/national electricity prices and remain unaffordable for many consumers without substantial government subsidies. The overall energy demand in Reverse Osmosis (RO) plants, the most widely used desalination technology (*Lange*, 2013), has been estimated to amount to 3.7 kWh_e/m^3 of potable water (*Semiat*, 2008). However, GCC countries primarily rely on thermal desalination technologies, which are even more energy demanding. This implies the need for additional power generating facilities. This, in turn though, implies the need for copious amounts of cooling water. In order to satisfy the rising water demand, it has been estimated that a 40% increase in power generation will be needed in Middle Eastern countries by 2050 (*Fink*, 2018).

WEN: Mitigation and Adaptation

Background/Rationale

In order to address water and energy security in the context of the WEN, well-conceived and scientifically based mitigation and adaptation measures will be needed. Enhanced mitigation through significant reductions in CO_2 emissions appears particularly relevant in the case of Iran and Saudi Arabia, which rank seventh and eighth in the list of carbon-emitting countries worldwide (*CARBOUN*, 2015). While subscribing to the Paris Agreement of the U.N. Framework Convention on Climate Change (UNFCCC) in 2015 (*Dagnet et al.*, 2016), the implementation of effective greenhouse gas reduction policies still remains elusive in many of the EMME countries (*Griffiths*, 2017).

However, the conspicuous signs of climate change impacts in the region and the prospects of continued adverse consequences of these changes call for enhanced efforts to specify effective adaptation strategies and measures in the EMME countries. In the following, I will provide some examples of such strategies in the water – and energy sectors and will briefly discuss their applicability in the region.

The Water Sector

Since agriculture represents the main consumer of water in most of the EMME countries, addressing appropriate water saving measures in agricultural practices is particularly relevant. This includes shifts from water intensive to draught tolerant crops, rainwater harvesting for irrigation and reforestation of marginal, abandoned agricultural lands, and advanced irrigation technologies (for more details, see, e.g., *Lange*, 2019).

Another important field is the protection and careful management of existing water reservoirs, which comprises the monitoring of existing groundwater aquifers for quality and quantity and careful planning of their use, the artificial recharge of groundwater resources by reservoirs and check dams and the recharge of groundwater in severely depleted aquifers by tertiary-treated sewage water, to name but a few.

Given the enhanced water need in urban settings, but also observing environmental water requirements calls for measures including an analysis of environmental flow requirements and options, an improved rainfall-runoff management and stormwater use in urban settings and the upgraded leakage detection in urban water distribution systems (for more details, see, e.g., *Lange*, 2019).

While some of these measures have been or are being implemented in a number of EMME countries, a more holistic assessment of activities needed to advance adaptation (and mitigation) in the water sector, remains largely forthcoming.

Energy Sector

In light of the aforementioned rising energy needs, on the one hand, and the largely insufficient mitigation measures in most EMME countries, on the other, the deployment of renewable energies in combination with enhanced energy efficiency provides significant opportunities to reduce greenhouse gas emissions. Given the rich endowment of renewable energy resources, particularly of solar and wind energy (see, e.g., *IRENA*, 2016; *Nematollahi et al.*, 2016) represents a strategy to not only reduce greenhouse gas emissions, but to also increase energy security in the EMME region. However, the intermittency of both sources requires innovative solutions in order to avoid or minimize the need for conventional backup for periods when solar and wind energies are not sufficient to satisfy demand, which will be addressed below.

Innovative Solutions for the Eastern Mediterranean

Energy Storage[1]

One of the strategies to avoid intermittency-related energy shortages consists in the employment of energy storage devices. **Electrical storage devices** include the following storage classes:

I. Electrical storage
II. Mechanical storage
III. Electrochemical storage

The latter consist of accumulators with internal memories and of conventional batteries including lead-, nickel-cadmium and, lithium-ion batteries. In addition, there are accumulators with external storage, comprising gas storage devices (electrolyzer and fuel cell/turbine), storage with liquid active masses (e.g. Vanadium redox system) and primary batteries with external regeneration (e.g. Zn-Air devices). Each of these technologies has specific advantages and disadvantages with regard to costs and gravity-energy density, which have to be considered in relation to existing circumstances. Hydrogen storage systems with electrolyzer and fuel cells exemplify an important chemical energy storage technology. Pumped storage plants, representing mechanical storage devices may be employed if appropriate geographical and hydrological conditions exist.

Producing electricity through conventional turbines that rely on **heat storage devices** represents an alternative method to deal with intermittency-related energy shortages. The direct storage of heat in synthetic oil, heat transfer fluid (HFT) and molten salt as storage medium has been studied and used in the energy industry since the 1980s. In addition, new storage concepts based on concrete and phase change materials have been examined.

Hybrid Renewable Energy System and Storage Unit

Utilizing various forms of renewable energy in a hybrid renewable energy system in combination with energy storage devices (i.e., electrical and/or heat storage) offers new and innovative ways to enable the continuous provision of electricity. The former may include constant (e.g., geothermal, biogas) as well as intermittent sources ((agri-) solar, wind) of renewables. The schematic in Figure 3 presents a hypothetical, "idealized" system, comprising a maximum number of components for the Hybrid Renewables System and the Multi-Storage Unit. Box 1 and Box 2 in the former are linked to agricultural activities and other renewable sources, respectively. Box 1 and Box 2 in the latter stand for electricity and heat storage devices, respectively.

Such a hybrid system will require substantial innovative efforts in integrating the different energy and storage devices, but could indeed pave the way for completely autonomous energy provision without conventional backup sources.

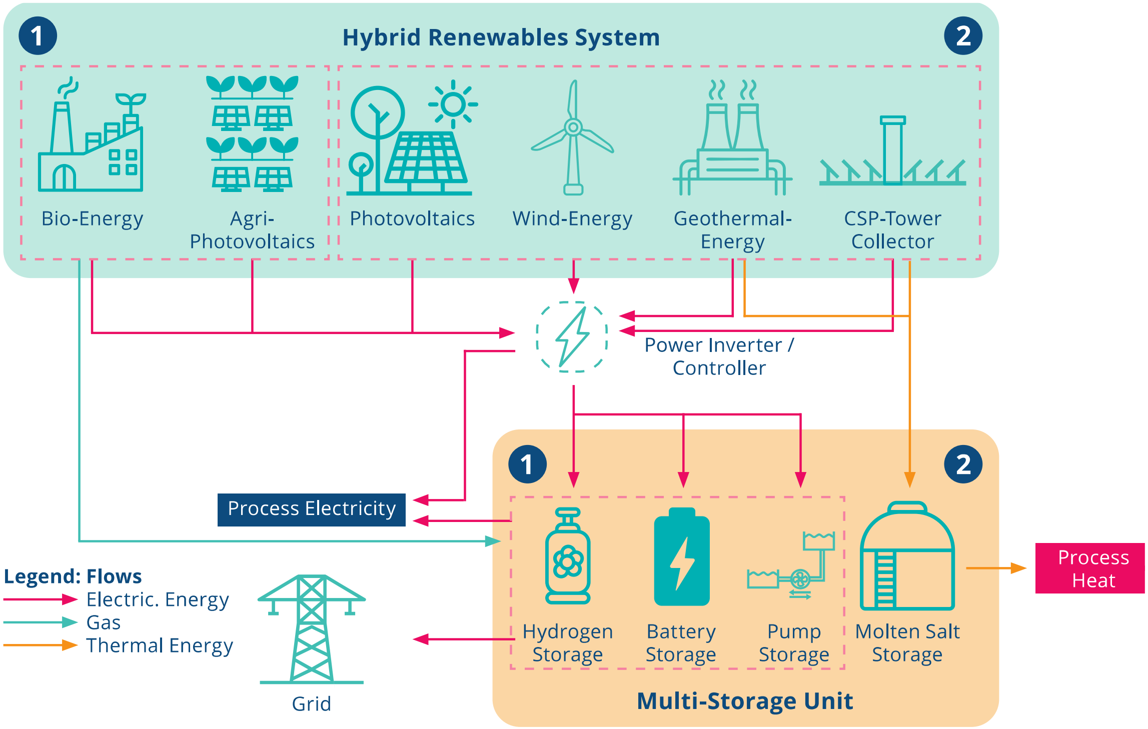


Figure 3: Schematic representation of a hypothetical hybrid renewable system in combination with various storage devices

Combined Production of Electricity and Desalinated Seawater in a Storage Plant

The employment of Concentrated Solar Energy (CSP) in combination with thermal energy storage units, offers an additional opportunity. Such plants can also readily utilize alternative fuels/renewables in hybrid operation, thereby avoiding the problem of intermittency of solar and wind energies (see above) and have been described as storage plants (for more details, see *Trieb and Thess*, 2020).

However, the particularly attractive opportunity of storage plants lies in the fact that they enable the simultaneous generation of both electricity and water. This is accomplished through the utilization of stored heat for operating a conventional steam generator, on the one hand, and stored heat in combination of remaining heat energy contained in the steam exiting the generator in, e.g., multi-effect desalination units to desalinate sea- or brackish water (for more details, see *Lange*, 2013,2019). The Cyprus Institute in Nicosia, Cyprus has pioneered such a plant in its PROTEAS experimental facility in southern Cyprus (*Papanicolas*, 2010).

Conclusions

Climate change and falling precipitation rates exacerbate the challenges to water and energy security in the EMME region. Cyprus represents one of Europe's most water-stressed nations. Desalination as one of the remedies to maintain freshwater supply to the countries' citizens is known to be extremely energy intensive. Thus, desalination represents one of the numerous linkages and interdependencies between energy and water, which should be considered holistically through the Water-Energy-Nexus (WEN) concept (see, e.g., *Lange*, 2019).

Ongoing and future changes in climate exacerbate the threats to water and energy security in the EMME region. Increasing frequencies and durations of heat waves, particularly in urban settings require rising electricity for space cooling, while decreasing precipitation and add pressure on water availability for agriculture and human consumption. The growing energy demand for advanced irrigation technologies and alternative water sources such as seawater desalination underline the need to employ a WEN concept to tackle these challenges.

To avoid continued warming in the EMME region as a result of continued increasing atmospheric greenhouse gas concentrations, as well as to minimize adverse impacts of climate change, specifically with regard to water and energy security, well-conceived and scientifically based mitigation and adaptation measures in the context of the WEN are required. Various options of such measures for the water and energy sector have been identified (see above and, e.g., *Lange*, 2019). Given the interdependencies between the water and energy sector, the reliable and economically as well as the technically feasible provision of electricity represents an urgent necessity for countries in the region.

Of particular importance in that regard and in light of the favorable conditions in the EMME region, the use of renewable energy sources, specifically solar and wind energy appears to be most advisable. Given the intermittency with regard to the latter, the need for electricity and thermal storage devices to reduce the need for conventional energy backups is pertinent. In addition, the utilization of various renewable energy sources in an innovative integrated renewables hybrid system adds to enhance the capacity for the continuous provision of electricity and minimizes the need of conventional energy sources. The employment of specific renewables as well as of particular storage units depends on the local conditions. Utilizing Concentrated Solar Energy (CSP) as well as possibly other renewables in combination with thermal energy storage units, offers the unique opportunity to co-generate electricity and freshwater through thermal desalination in an integrated storage plant. Thus, such plants address the need for electricity and water in a single unit, thereby reducing the risks to water and energy security in the region.

While the Cyprus Institute in Nicosia, Cyprus has pioneered such a technological concept in an experimental plant, we are convinced that this may provide a model for other countries in the EMME region, as well. A particular advantage is the near-independence of water and energy provision from a well-developed electricity grid and a water distribution network, i.e., in remote, isolated rural communities. Such conditions are typical for many parts of the EMME region.

The Eastern Mediterranean and Middle East Climate Change Initiative of the Cyprus government (https://emme-cci.org/) represents a first step towards finding common solutions to ensure sustainable water and energy security in the countries of the EMME region in light of ongoing and future climate change.

About the Author

Prof. Dr. Manfred A. Lange currently serves as Professor at the Energy, Environment and Water Research Center (EEWRC) of the Cyprus Institute and as Director of the Future Earth MENA Regional Center (FEMREC). He is on the Steering Committee of the Mediterranean Experts on Climate and Environmental Change (MedECC) and a member of the Facilitation Team for the Future Earth Water-Energy-Food Nexus Knowledge Action Network (Nexus-KAN). In prior positions, among others, he acted as Founding Director of the EEWRC, Acting Vice-President for Research at the Cyprus Institute, Director of the University of Münster's Center for Environmental Research as well as Professor in Geophysics at the Westfälische-Wilhelms-Universität Münster, Germany. His main research interests include the assessment of climate change impacts with a focus on water- and energy security, renewable energy sources and energy- and water use efficiency in the built environment.

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Endnotes

[1] The following is no more than a brief and incomplete presentation of some of the available technologies

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