PREFACE

Water-energy-food NEXUS is central to sustainable development in MENA Region. Demand for these domains is increasing, driven with a rising global population, changing diets, rapid urbanization and economic growth. Agriculture is considered to be the largest consumer of the world's freshwater resources, and more than one-quarter of the energy consumed globally is spent on food production and supply. The linkages between these essential domains require an appropriately integrated approach to ensuring water and food security, sustainable agriculture, and energy provision worldwide.

Water is a finite resource having to serve exponentially more people and usages, and so ensuring that everyone has access to a reliable supply and sustainable progress. As water resources become more stretched, the energy and food sectors' dependence on water means that decision-makers are now increasingly focusing on water resources management, ecosystem protection, and water supply and sanitation as part of their policy and practice for sustainable developments goals. In addition, there will be need for development of less water-intensive renewable energy, such as hydropower and wind power, before it makes a significant impact on water demand. As a result, food production and energy generation can intersect at many points. By identifying these intersections, it will be the solution for both sectors to capture and to optimize plans by capturing the common cutting point of each other.

Approximately 10% of the earth's population in MENA Region is forced to rely on polluted water sources for basic needs. As climate change and some demographic trends will increase, the stress on available water sources and the urgency of providing clean water to people in rural areas will become more acute. This proceedings book discusses advances in several new technologies that are enabling clean, safe, and sustainable water supplies to remote and rural areas in MENA. It will also take a look at the water-energy-food nexus from an international perspective, considering the evolving water needs of an increasingly decentralized grid. Furthermore, different innovation techniques displayed in this proceedings book on energy, water and food sectors deal with the question, how (i) to achieve climate change mitigation and adaptation, (ii) to understand how combined water-energy systems might behave under future conditions, (iii) to attain a strategic vision to enhance water, food and energy system resilience, and (iv) to improve water resources efficiency. Additionally, the different papers focusing on emerging approaches for the MENA Region are based on current researches that suggest adaptation actions for cost-effective risk reduction without investments of policy, management, and financial resources. Many strategies will involve high capital costs, but social acceptance of some alternatives may be limited.

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ROLE OF DAMS IN WATER-ENERGY-FOOD NEXUS

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Abstract

Water is essential for life and sustainable socio-economic development. It is an essential element for the eradication of poverty and hunger. Population growth, industrialization, urbanization and rising affluence in the 20th Century resulted in a substantial increase in water consumption. While the world's population grew three fold, water use increased six fold during the same period. The demand on water resources will continue to increase. Contrary to the general perception, Turkey is among the countries that is or will be under water stress. In recent decades, Turkey has made a lot of works in development of water resources for irrigation, hydropower generation, flood control, and other purposes. The building of dams and reservoirs has enabled to save the water from its brief seasons of rainfall to use throughout the year for irrigation, energy, drinking water and sanitation. Water storage facilities are needed to benefit from existing water resources. By the year 2018, 596 dams are under operation and 83 dams under construction in Turkey. Irrigation areas are also planned to increase from 5.6 million hectare to 8.5 million hectare in 2040. In this study, water resources of Turkey and regulation studies of surface water are discussed. The usage of dams for generating energy and as irrigation facilities are given in detail.

1 Introduction

Water is the most essential matter for life and a precious resource, which is getting steadily scarcer. More than half of the world population will be living with water shortage within next 50 years because of a worldwide water crissis. Moreover, a substantial increase of water consumption has been resulted by population growth, industrialization and urbanization all over the world. Water resources and sustainable water resources management are very important for satisfying basic human needs, promoting social and economic development in general, and conserving the ecosytem for the future. All countries should develope their water infrastructures and water plans to use their water resources more efficently [1]. Turkey is anticipated to become a water-stressed country by 2030 with its growing population, rapid urbanization and industrialization. Taken into account that Turkey's water is not always at the right place at the right time in order to meet present and anticipated future needs, efficient water mangement systems should be planned in a very short time. Turkey has made substantial investments in water resources development for domestic use, irrigation, flood control and power generation. The dams and reservoirs built for controlling water have enabled Turkey to save water from its brief seasons of rainfall to use throughout the year for various purposes, for energy and agriculture in particular.

In this study, the water resources of Turkey and regulation measures of surface water are discussed. The usage of dams for generating energy and as irrigation facilities are given in detail.

2 Water Availability in Turkey

The availability of water per capita per year in Turkey is only about one fifth of that of water rich countries. It is, therefore, imperative that Turkey should improve per capita water availability in order to enhance the quality of people life. Therefore, in recent decades, Turkey has made great efforts in water resources development for domestic use, irrigation, power generation, flood control, and other purposes. Owing to considerable variation observed in the run-off in terms of seasons, years and regions, it is absolutely necessary to have water storage on the rivers in Turkey. This ensures access to water, when it is necessary [2]. In Turkey, State Hydraulic Works (DSI) is in charge with single and multiple utilization of surface and ground waters and prevention of soil erosion and flood damages. For that reason, DSI is empowered to plan, to design, to construct and to operate dams, hydroelectric power plants, domestic water and irrigation schemes. Hydro-electric power is the largest source of renewable electricity in the world. The importance of renewable energy sources increases day by day. It is generally accepted that it will be the most important energy source of the 21st century as it reduces technical and other cost factors in obtaining renewable energy [3].

3 Water Resources Development in Turkey

3.1 Water Resources In Turkey

All water resources in Turkey are thoroughly measured and evaluated through the hydrological and meteorological network extended all over the country [2]. Due to the fact that Turkey's water is not always distributed evenly in terms of time and place to meet the needs, the country faces water shortage. Turkey is divided into 25 river basins as seen in Figure 1, which correspond with hydrological features. Their specifications are given in Table 1 [4, 5]. Among these river basins, the Euphrates -Tigris river basin is very important because of the Southern Eastern Anatolia Project (GAP), which is Turkey's largest project for power generation, irrigation and regional development. When the GAP is once completed, energy capacity will rise to 27 billion KWh/a, and 1.82 million ha of agricultural land will be irrigated by 19 Hydro-Electrical Power Plants (HEPPs) and 22 dams.

There are more than 120 natural lakes and almost 1,160 dam reservoirs in Turkey. The average annual runoff is approximately 186 BCM/a (billon cubic meter per year) [5]. The average annual precipitation in Turkey is approximately 643 mm/a, which corresponds to an average volume of 501 BCM of water. 274 BCM of this volume is returned to the atmosphere through evapo-trans-piration from soil, water surfaces and plants, 69 BCM of which feed groundwater, and 158 BCM flow through streams to the lakes and ponds in closed basins. 28 of 69 BCM of water feeding the groundwater and rejoining the surface water through springs. There is also an average of 7 BCM of water coming from neighboring countries annually. Thus, Turkey's surface water potential is almost 193 BCM [2, 6].

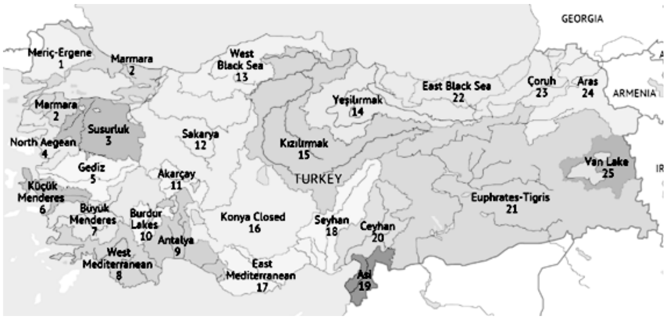

Figure 1: River Basins of Turkey

Table 1: Specifications of River Basins in Turkey

No	Name of Basins	Area (km^2)	Average Annual Run-off (km^3)	Theoretical HEPP Potential (GWh/yr)	River Basin's Total Potential
1	Meric-Ergene	14,560	1.33	1.00	0.2
2	Marmara	24,100	8.33	5.18	1.2
3	Susurluk	22,399	5.43	10.5	2.4
4	North Aegean	10,003	2.,9	2.88	0.7
5	Gediz	18,000	1.95	3.92	0.9
6	Kücük Menderes	6,907	1.19	1.38	0.3
7	Büyük Menderes	24,976	3.03	6.26	1.4
8	West Med Sea	20,953	8.93	13.6	3.2
9	Antalya	19,577	11.1	23.0	5.3
10	Burdur Lakes	6,374	0.5	0.89	0.2
11	Akarcay	7,605	0.49	0.54	0.1
12	Sakarya	58,160	6.4	11.3	2.6
13	West Black Sea	29,598	9.93	17.9	4.2
14	Yesilırmak	36,114	5.8	18.6	4.3
15	Kızılırmak	78,180	6.48	19.6	4.5
16	Konya Closed Basin	53,850	4.52	1.22	0.3
18	Seyhan	20,450	8.01	20.9	4.8
17	East Med Sea	22,048	11.1	27.5	6.4
19	Asi	7,796	1.17	4.9	1.1
20	Ceyhan	21,952	7.18	22.2	5,1
21	Euphrates-Tigris	184,918	52.9	133	30,7
22	Doğu Karadeniz	24,077	14.9	48.7	11.3
23	Coruh	19,872	6.30	22.6	5.2
24	Aras	27,548	4.63	13.1	3.0
25	Van Lake	19,405	2.39	2.6	0.6
Total		779,452	187	433	100

Considering that the 41 BCM of average annual precipitation feeds the groundwater, the total renewable water potential of Turkey is estimated to 234 BCM/a. However, on the basis of today's technical and economic conditions, average consumeable surface water potential is 98 BCM. If the 14.7 BCM groundwater potential is added to this amount, average consumable surface and groundwater resources are 112 BCM/a, of which 44 BCM can be used in the country [6]. Where it is not appropriate or economic to use surface water, irrigation water demand is covered by groundwater. Groundwater reserve is 14.7 BCM in Turkey, and 13.6 BCM/a is allocated to use.

3.2 Dams

Even though the freshwater resources are unevenly distributed, demand for water is steadily increasing throughout the world. During the past three centuries, the amount of water withdrawn from freshwater sources has increased by factor 35, whereas world population by a factor of 8 [7]. Building of dams, which provide regular water from reservoir, is vital part of civilizations evolved in major rivers. In early times, dams were built for flood control, water supply, irrigation and navigation. Dams have been built to generate power and electricity since the industrial revolution.

In Turkey, dams are important for the country's socio-economic development. Sustainable water management includes not only the planning or minimizing of adverse environmental effects, but also satisfying and reconciling water needs for human activities [2, 5]. Seasonal variations and climate irregularities in flow like floods and droughts cause problems at catastrophic proportions. Water storage facilities enable to benefit from existing water resources, which are not regular in terms of time and space. In Turkey, the modern era of dam building began 1954 with the foundation of DSI, whose primary duty was to provide water and power for development of the country. Subsequent legislation and establishment of regional administrations contributed to dam development throughout the second half of the 20th Century. The dam building era reached a peak in the 1980s.

3.2.1 Dams for Energy Generation

The world's annual energy needs are rapidly increasing in parallel with the population growth. Developing countries will soon be the world's largest markets for energy. Their total energy consumption today is only half of the rich countries, and their per capita energy consumption a mere one-tenth of what it is in the rich countries, but it is expected to increase by the course of economic growth. This projection assumes significant improvements in energy efficiency. Although increasing this magnitude, per capita energy consumption in the developing countries would still be relatively low, allowing for population growth, it would be less than one-fourth of per capita energy consumption in the industrial countries today [7].

Hydraulic energy is a type of energy that has been used all over the world for many years. It provides clean water as well as "clean energy". Obtaining 90% of the total national electricity from HEPPs in 24 countries in the world shows its importance clearly. The total installed capacity has grown from 2005 to 2015 by 39%, with an average growth rate of nearly 4% per year. The rise has been concentrated in emerging markets, where hydropower offers not only clean energy, but also provides water services and energy security, and facilitates regional cooperation and economic development. The drivers for the upsurge in hydropower development include the increased demand for electricity, energy storage, flexibility of generation, freshwater management, and mitigation and adaptation solutions along with climate change. HEPPs have the lowest value, when compared with other types of energy generation by means of operation costs, the longest operating life span and the highest yield. Hydroelectric energy is a strategic energy source, as it is renewable and can be continuously produced along with the world's water cycle [8]. There is a tremendous untapped potential for new HEPPs in the world.

Table 2: Hydroelectric Power Potential of the World

Region	**Hydroelectric Power Potential (TWh/yr)**	**Technical and Economical Hydroelectric Power Potential (TWh/yr)**
Africa	1,665	1,000
Asia	6,800	3,600
Australia	270	105
Europe	1,225	800
Northern America	1,500	1,100
Southern America	2,600	2,300
Total	14,060	8,905
Turkey	216	158
Turkey's share in the world (%)	1.54	1.77

As can be seen from Table 2, which is prepared according to DSI data, the world's technically feasible potential of hydroelectricity is 14,060 TWh/yr, and presently economically feasible hydro-electric power potential is 8,905 TWh/yr. Asia has the largest share of global hydropower potential, followed by South America, Africa and North America [9].

Turkey has 1.54 % of the world's hydroelectric power potential, while having 1.77% of the technical and economic hydroelectric power potential. These values are variable and depend on the energy prices and the developing technologies [10].

Approximately 20% of the electricity consumption of the world has been supplied by hydroelectric power plants. Some of the world's co-operative organizations and leading countries in hydropower generation are shown in Figure 2. As can be seen therein, Asia is at the leading continent in hydro-power consumption, and Northern America including Canada shows important improvements in hydroelectric power generation during the recent years and ranks in fourth. Turkey has almost 1% of the world's hydropower electric consumption. World's hydroelectric power generation rose to 5 million tones oil equivalents (mtoe) [11].

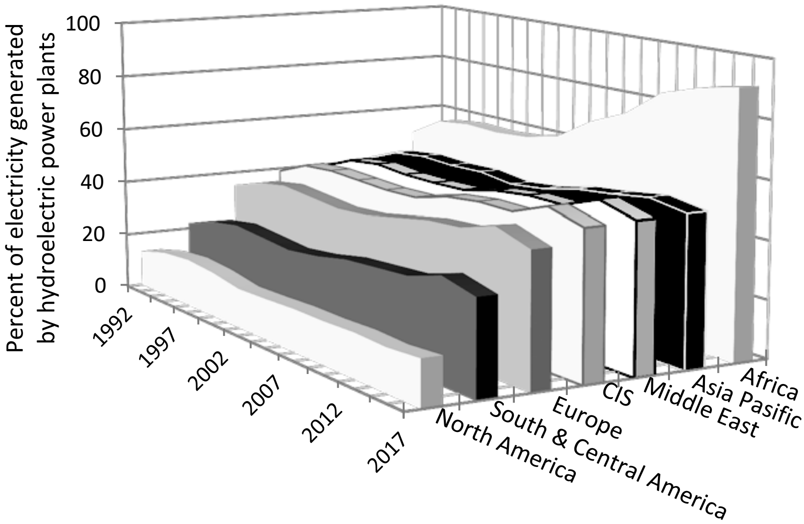

Figure 2: Hydroelectric power consumption of the world [12]

The gross hydroelectric energy potential of Turkey is 433 billion kWh/a as a function of topography and hydrology [12]. It corresponds approximately to 59% of the total hydroelectric energy potential of Turkey. Turkey has 596 HEPP in operation with an installed capacity of 26,819 MW. Allocation of hydroelectric energy potential according to river basins are also shown in the last two columns of Table 1. The largest share belongs to Euphrates-Tigris Basin with 30.7%. East Mediterranean, Antalya and Coruh Basins follow it with 6.4%, 5.3% and 5.1%, respectively.

Table 3: The highest dams constructed for HEPP in Turkey and their specifications

Name	Height (m)	Aim	Type	Dam Concrete Volume (km^3)	Reservoir Capacity (hm^3)	Energy Capacity (MW)	Installed Capacity (MWh/yr)
Yusufeli*	275	Energy	Concrete arch dam	2,350	2,130	540	1,827
Deriner	249			273	1,973	670	2,118
Ermenek	218			3,500	4,580	306	1,047
Berke	201			735	427	510	1,700
Karakaya	173			2,000	9,580	1,800	7,500
Oymapınar	185			676	300	540	1,620
Gökçekaya	158			650	910	278	400

**Under construction*

Table 3 is prepared in order to show some of Turkey's highest dams and their specifications, which were built for generating energy. Yusufeli Dam, which is under construction, will be the 3rd highest dam of the world having the height of 275 m in the category of double-curvature arch dams when it is completed. Deriner Dam is 6th highest in the world and 3rd highest in Europe with its height, and the highest dam of Turkey. Ermenek and Berke were listed in the "the highest 30 dams of the world list" in their construction years.

3.2.1.1 Deriner Dam

Deriner Dam the highest dam in Turkey with a height of 249 m. The double-curvature concrete arch dam is located on the Coruh River near Artvin province in the north-eastern part of Turkey. The powerhouse has four units, with an overall capacity of 670 MW, and 2013 the powerhouse generated 2.12 GWh electricity.

The electrical energy generated by this HEPP will be about 6% of the total energy provision in Turkey, when all turbines are under operation, and water demand of 750,000 people will be provided with its 1,970 million m^3 water storage. Figure 3 shows two images of the Deriner Dam.

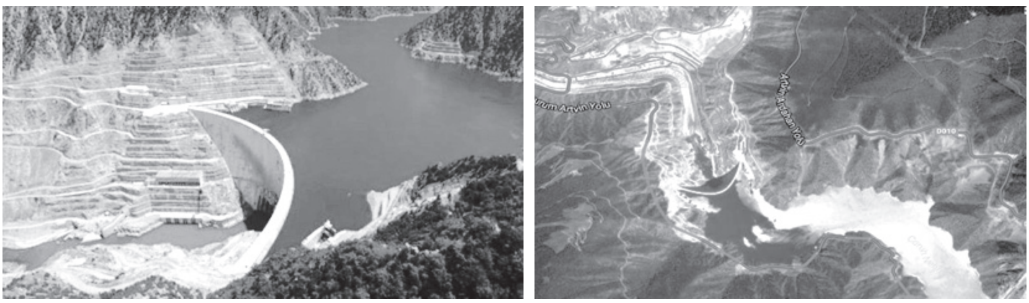

Figure 3: Images of Deriner Dam *(Source: Google Map)*

3.2.2 Dams for Irrigation

Dams are crucial to Turkey's agricultural production, allowing even in dry regions to produce great variety of crops through irrigation, which is the most common use of dams. Among the dams constructed for single-purpose, 48% of them are for irrigation, 17% for electricity generation, 13% for water supply, 10% for flood control, 5% for recreation and less than 1% for navigation and fishing [13].

Dams have always played a key role in human's development since the third millennium BC, when the first great civilizations evolved along the major rivers. Initially, only small dams were built for water supply and for irrigation. According to a study of the World Commission on Dams (WCD), half of the world's large dams were built exclusively or primarily for irrigation, and an estimated 30-40% of the 271 million ha of irrigated land worldwide rely on dams. Dams are estimated to contribute 12-16% of world food production. About 1 billion people depend on food produced by reservoir related irrigation. There is no alternative of how this food could have been produced by other means. Most of the dam projects not only have the objective of economic benefits, but they also address the overall socio-economic development of the people at the region. The major irrigation projects, which are dependent on dam construction, often help prevent the migration of rural people to the cities, while giving them a higher standard of living in their native areas [6]. Turkey's important dams constructed for irrigation purposes are listed in Table 4.

Table 4: Turkey's important dams constructed for irrigation purposes

Name	Operation year	River	Aim	Reservoir volume (hm^3)	Reservoir area (km^2)	Irrigation area (ha)
Seyhan	1956	Seyhan	I+F+E	1,200	67.8	174,000
Almus	1966	Yesilırmak	I+F+E	950	31.3	21,350
Kesikkopru	1966	Kızılırmak	I+E	95	6.5	11,860
Suat Uğurlu	1981	Yesilırmak	I+E	182	9.7	83,312
Arpacay	1983	Arpacay	I	525	41.8	40,420
Ataturk	1992	Euphrates	I+E	48,700	817	1,430,000
Demirozu	2003	Lori	I	62,6	5.68	14,586

I = Irrigation; F = Flood Control; E = Energy Generation

Water scarcity affects many countries worldwide. Thousands of dams have still to be built to store water and to make it available during the first half of this century on a worldwide basis especially in the developing countries. In Turkey, 34 BCM of total exploitable water potential was consumed for irrigation in 2008. According to future projections, the share of irrigation use will decrease from 74% in 2008 to 64% by 2023. Figure 4 shows the sectorial variations of irrigational areas in Turkey. From 2011 to 2023, while private irrigation areas out of the total irrigation areas are decreasing from 18% to 6%, the irrigational areas of State Hydraulic Works (DSI) are increasing from 60% to 76%.

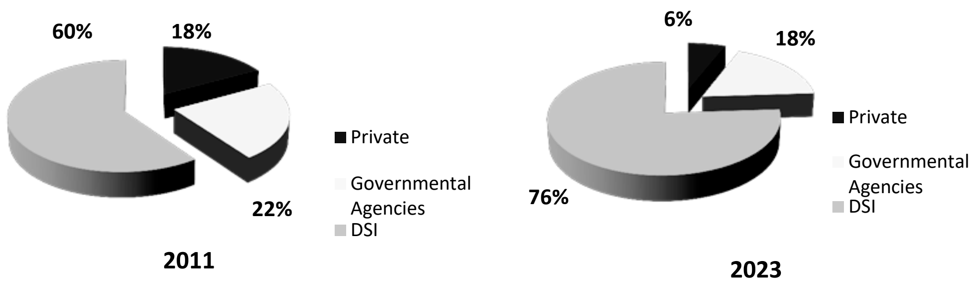

Figure 4: Sectorial variation of irrigational activities in Turkey between 2011 and 2023

3.2.2.1 Atatürk Dam

The first dam built during the republic era in Turkey was the Cubuk-I Dam, the main purpose of which is to meet the domestic water requirement of the capital city Ankara. No serious activities in dam construction were observed until the end of Second World War except for a few small dams built for irrigation purposes. The largest multi-purpose dam constructed in Turkey is Atatürk Dam (Figure 5). Comparing with the reservoir capacity, Atatürk Dam is 8,600 fold larger than Cubuk-I Dam [14].

Figure 5: Atatürk Dam and its project area (Source: *Google Map)*

The Atatürk Dam was constructed on the Euphrates River in 1980s as the central component of a large-scale regional development project for the South-Eastern Anatolia Region, known as GAP. Since the first development plan for the region was presented in 1970, the objectives for regional development have changed significantly. The Atatürk Dam project in the semi-arid south-east region is an example of a large multipurpose dam project that has been implemented as part of a large-scale regional development plan. The Atatürk Dam is the most important component of GAP. It was constructed on the mainstream of the Euphrates River between 1983 and 1990, primarily for irrigation and hydropower generation [15]. The Atatürk Dam has an important role to play in the development process anticipated for the region. Also, it constitutes a significant national energy source with the greatest power generation capacity of all hydropower dams in Turkey [16].

The dam has a height of 169 m and a total storage capacity of 48.7 million m^3, which makes it the 20th largest reservoir in the world [7]. One of the main goals of this project has been to transform the region into a base for agricultural exports. Irrigation is expected to increase crop yields and to promote diversification, thus contributing to increase the economic activities and the development of agro-industries and other agricultural activities.

Sanliurfa is the province with the highest agricultural output in the region (mostly in Harran) with the Ataturk Dam and irrigation projects playing a major role. Agricultural yield increased from