Raising Adaptive Capacity to Climate Change in the Energy and Food Sectors of Egypt

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Abstract

Climate change will likely impact food security globally, regionally, and locally. Climate change can disrupt food availability, reduce access to food, and affect food quality. Accordingly, the impacts of climate change on the agricultural sector reflect food security and pose a serious threat to sustainable development. Furthermore, the total energy demand of Egypt is marked by an exponential growth of electricity demand, at a pace much faster than that of GDP, primary energy consumption, and population mainly due to a doubling up of the consumption of Egypt. The expected development of the industrial sector, the accelerated access to electricity, and the improvement of standards of living (directly connected with the consumption of the residential sector) are the reasons for these consumption upsurges. The different components of climatic change such as projected increases in temperatures, changes in precipitation patterns, changes in extreme weather events, and reductions in water availability may all result in reduced agricultural productivity and may cause energy consumption upsurges. The main problem with climatic change and climatic variability in all parts of the Mediterranean Basin is that systematic climate observation programs are, at present, inadequate to permit reliable assessment, quantification, and prediction of climatic conditions and their impacts. More accurate assessments of regional climate variability and change and their related environmental and socio-economic impacts are highly needed.

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1. Introduction

Egypt as a part of the Mediterranean Basin possesses a rich heritage of observational records of climate, However, many of these records are not readily accessible or are stored in perishable paper formats in publications and archives according to El-Shinnawy et al., (2010), (Mahmoud, M.A. (2017)) and Hereher, M.E. (2015).The direct repercussions on food security stem from alterations in water availability, soil traits, and crop output. Detrimental effects on soil quality can arise due to the reduction of soil organic matter, diminished fertility, decreased water retention, and soil-related issues like structural degradation, crusting, erosion, and salinization.As far as energy sector is concerned, in 2006, the electricity consumption of the Egypt and south Mediterranean countries accounted for 26% of the total electricity consumption of the Mediterranean basin (Anthoff et al., (2007). This figure is likely to reach 40% by 2025. Turkey and Egypt account for about 60% of the total electricity production of the south Mediterranean countries according to Amelung et al., (2004). The average annual electricity consumption per capita is 3.8 times lower in Egypt than in the Northern Mediterranean Countries (NMCs); this ratio is likely to shrink to 2.3 by 2025. In Egypt, the fossil energies used to produce electricity accounted for over a third of primary energy (34%) in 2006. The choice of sectors depends on the natural resources available in the countries (gas in Algeria and Egypt; coal in Israel, Turkey, and Morocco). Over the past 35 years, a salient fact has been the penetration of natural gas which accounted, in 2006, for 50% of the sources of energy used to produce electricity, as against 3% in 1971. The oil share in electricity production has reported a reverse trend: passing from 56% in 1971 to 17% in 2006. Coal, which accounted for 10% in 1971, rose to 20% in 2006. For the time frame 2025, coal is likely to account for 31% of fossil fuels for electricity (as against 23% in 2006) and gas for 64% (as against 55% in 2006). The nuclear option is under construction in Egypt; it is likely to emerge in the energy mix within the time frame of 2025. It ensues from these evolutions that CO_2 emissions due to the electricity sector have grown tenfold (x 10) between 1971 and 2006. By 2025, these emissions are likely to grow more than twofold concerning their level of 2006 in Egypt.

Accordingly,the overall objective of this paper is, to bring together the main components of climatic data, agricultural data, and energy data to remedy deficiencies in systematic climate observation programs in Egypt to ensure that the information produced by them meets the needs of decision-makers and other users, as well as defining the optimum strategies to mitigate and/or adapt to the negative effects of global climate on the exponential demand of food and energy in Egypt whereas energy and food security are located at the heart of the climate change issue according to Lange (2020), Med ECC (2020) and Birdlife International (2017). Knowledge of the long-term behavior of climate over past decades and centuries is essential to understanding climatic variability, planning for adaptation to future climatic variations, and the calibration of global and regional climate models,according to BirdLife International (2017), Al Amar Consulting Group (2015), EEAA (2008), EEAA (2015a) and El-Amier, et al., (2017).Climate change impacts on the agricultural sector include production (in terms of quantity and quality), species types, environment, and land use changes according to Granjon, L. (2016). The integration of all these confounding components represents the main challenge for Egypt.

1.1. Data Sources and Methodology

This study utilizes the IMPACT model, an international model system comprised of interconnected models. Data about food production and energy sectors were obtained from the primary authorities, namely the Ministry of Agriculture and the Ministry of Electricity, with appropriate permissions. These data were input into the IMPACT model to assess the impact of climate change on both sectors quantitatively. The results of the climate change analysis were integrated into an integrated biophysical and economic model to better understand the likely consequences of temperature and rainfall changes on Egypt's agricultural and energy sectors. The main components of this methodology include climate models, crop models, and water models. These modules are integrated into the IMPACT multimarket model, while others are coded as separate modules interconnected through information flows. Climate change data and results encompass analyses from paleoclimatology studies and proxies. This paper outlines one scenario, termed the baseline scenario, to evaluate the impact of climate change. This scenario serves as a framework to comprehend how varying economic conditions could influence responses to climate change and its effects. However, future research is likely to consider multiple scenarios, enabling researchers to better understand potential future trajectories and formulate strategies accordingly. These scenarios may vary in factors such as economic growth, policy responses, technological advancements, and international cooperation, all of which can significantly impact the ability to mitigate and adapt to climate change.

2. Results and discussion

2.1. Egypt’s Sources of GHG emissions

The GHG inventory estimated that the total GHG emissions of Egypt in 1990 were equal to 116.608 mtCO2 equivalent using the 1995 Global Warming Potential (GWP) of the IPCC, while the net emissions were equal to 106.708 mtCO_2 eq. as GHG sinks represented 9.9 mt. the energy sector is the main source of GHG emissions having 71% of total emissions, Donlon et al., (2012).

2.2. Climate change impacted on the food security sector in Egypt

The agricultural yield is positively affected by rainfall but negatively impacted by CO2 emissions. The latter are positively related to temperatures, which leads over time to aggravate the warming climate phenomenon (Fig.1). The results further show that GDP per capita indirectly lowers agricultural yield through its effects on CO2 emissions. Therefore, promoting renewable energy to reduce CO2 emissions provides the best option to fight climate change and reach food security in Egypt, ERM/Environics (2015). Agricultural and fishing yields are expected to drop (as a result of the accumulated conditions related to temperature, rainfall, the state of the soil, and the behavior of animal and plant species. In a drier and hotter climate, crops will require increased water supply. It can also be presumed that if fish populations change (through species migration and/or changes to the food chain) to the benefit of species of sub-tropical origin, consequently, this will significantly influence the value and quantity of catches.

2.2.1. Predicted Change in agricultural Yield due to climatic change in Egypt

The negative impacts of climatic change on the agricultural yield of Egypt have been analyzed using one of the worldwide models (IMPACT); by Robinson et al. (2015) IMPACT model is a partial equilibrium model that employs a framework of supply and demand equations to examine food demand, production, pricing, income, trade dynamics, and population metrics at both national and regional levels. It consists of 159 countries, 154 basins, and 62 agricultural commodities markets. Using the IMPACT model, it was possible to find out the quantitative relationships between the negative impacts of climatic change and food sectors as shown in Table 1. Three major biophysical yield stressors have negatively impacted and reduced crop production because of climatic change. These three biophysical yield stressors are 1. Heat stress 2.Water stress and 3.Salinity stress and Fig.1. Climate change will affect crop production indirectly by increasing crop water requirements. Climate change could increase summer crops' water requirements by 16%; on the other hand, decrease winter crop requirements by 2% by the year 2050 as indicated in Fig.1 as well as Table 1 **(El-Mowelhi,1998).**

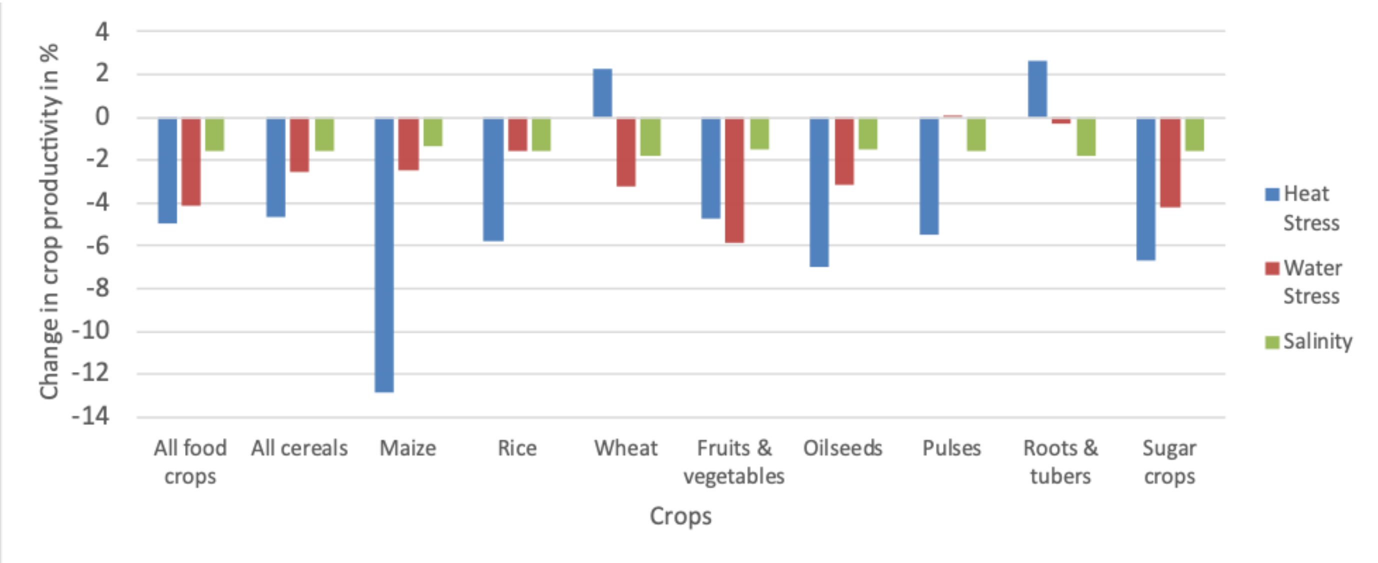

Fig.1. Changes in Agricultural productivity due to biophysical impacts of climatic change in Egypt (originated from the present author).

Commodity	Heat Stress	Water Stress	Salinity	Cumulative Effects	Egypt	Rest of World
% Change from a no climate change scenario						
All food crops	-4.94	-4.14	-1.55	-10.29	-6.17	-5.24
All cereals	-4.66	-2.57	-1.59	-8.59	-10.36	-7.74
Maize	-12.86	-2.46	-1.36	-16.16	-19.54	-17.66
Rice	-5.81	-1.59	-1.58	-8.78	-8.53	-5.61
Wheat	2.27	-3.25	-1.78	-2.81	-0.56	0.82
Fruits & vegetables	-4.73	-5.88	-1.48	-11.66	-8.28	-1.95
Oilseeds	-6.98	-3.18	-1.53	-6.92	-12.08	-6.69
Pulses	-5.46	0.04	-1.57	0.47	-9.98	0.01
Roots & tubers	2.61	-0.29	-1.79	-11.96	3.56	-4.58
Sugar crops	-6.66	-4.19	-1.56		-13.28	-10.39

Table 1. Changes in Agricultural productivity due to biophysical impacts of climatic change in Egypt (Robinson et al. 2015).

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2.2.2. High temperature will increase evapotranspiration

From a national perspective, some studies examined the anticipated effect of climate change in Egypt was projected that the average temperature level would increase by approximately 1.4 and 2.5 °C by 2050 and 2100, respectively (Fig.2) (Agrawala et al. 2004). Moreover, the substantial rise in greenhouse gases, particularly CO2, leads to alterations in rainfall patterns. Consequently, Egypt, being among the nations directly or indirectly impacted by severe climate change, experiences profound effects on its agriculture. Several studies have illustrated the potential effects of climate change on some field crops such as **Jones et al., (1998); Jackson et al. (1988); El-Shaer et al. (1997), and Marsafawy (2007) (Figs 1 and 2).** Moreover, these studies highlighted the effect of climate change on crop yields by 2050 compared to the status quo; it is projected that rice yield would fall by 11%, soybean by 28%, maize by 19%, barley by 20%, and sunflower by 27%, however, the cotton yield would increase by 10%. Simultaneously, it is also projected that water consumption will increase by 8%, 16%, and 12% for maize, rice, and sunflower, respectively, by the year 2050 (**ElMarsafawy & El-Samanody 2009**). The surge in irrigation water demand is a direct result of elevated temperatures leading to heightened evaporation rates (Agrawala et al., 2004). Moreover, a large share of agricultural land may become unusable due to immersion or saltwater intrusion landfall from the Nile Delta (**Alkire & Santos 2010**)

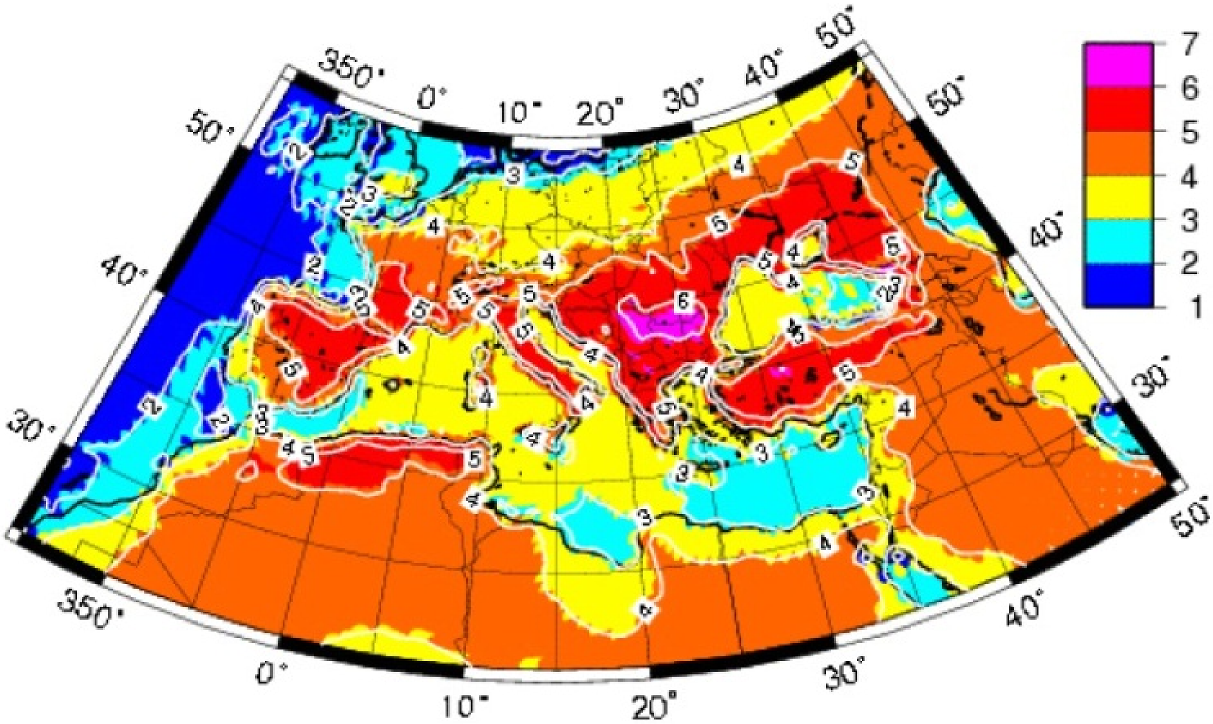

Fig.2. Annual mean variation of air temperatures in summer (°C) – 2070-2099 vs 1961-1990.Source: Somot et al., 2007

2.2.3. Earlier crop growing and lesser production

As per Bruinsma (2017), the country falls under the classification of a low-income country (LIFDC) and has encountered economic decline, leading to elevated levels of poverty, unemployment, and food insecurity. The agriculture sector accounted for 11.5% of the gross domestic product (GDP) in 2017, while simultaneously providing livelihoods for up to 30% of the population, and the agricultural cropland occupied 3.4 million hectares (a small strip along the banks of the Nile River). The agriculture sector in Egypt is irrigated agriculture-based (around 90% of Egypt's agricultural production is irrigated), and the 1 World Bank Database; Model Nile provides about 95% of the total Egyptian water uses (**Agrawala et al. 2004).** Furthermore, the country's ability to sustain its population of one hundred million people, with fifty-six million residing in rural areas, is supported by agricultural production and imports. Egypt produced only 60% of its food and 40% of its crop consumption (**Abutaleb et al. 2018**). There are millions of tons of losses in grain production as can be seen in Fig.3. A further scrutiny of Fig.3 reveals that losses in grain production in Egypt are directly due to climatic change expressed in terms of a rise in sea level which has negatively affected soil salinity and in particular coastal lands.

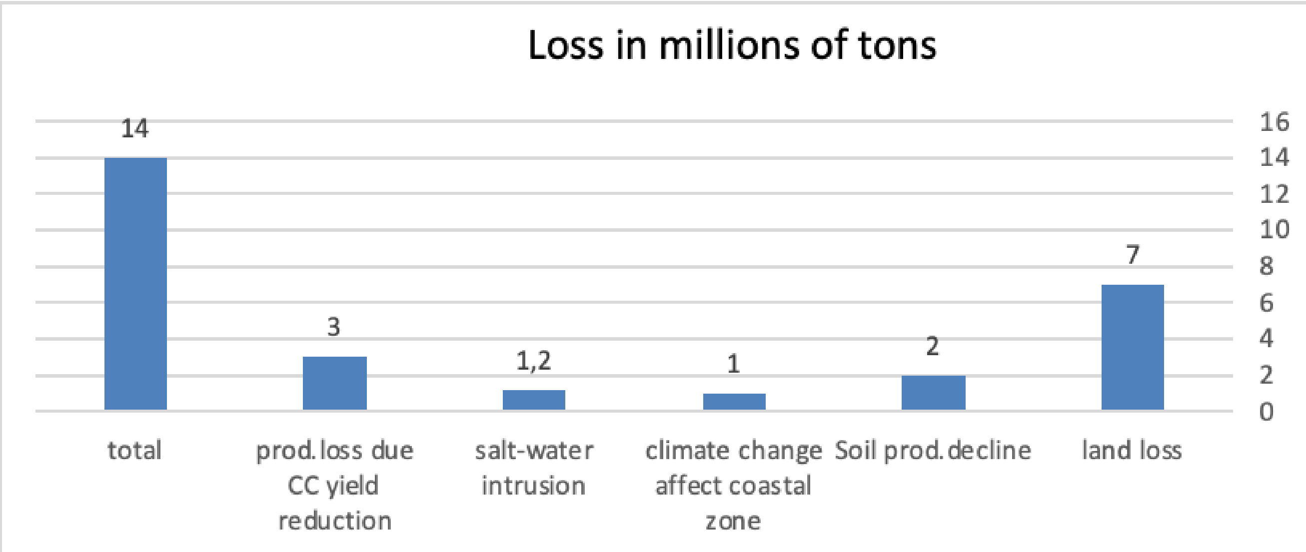

Fig.3. Loss in millions of tons of grain due to climatic change (originated from the present author)

2.2.4. Rise in Sea level and soil degradation

Rising sea levels will have the highest impacts on groundwater resources in coastal aquifers, Environics (2016). First, the shoreline will become more exposed and become land (depending on the topography of the area); (**Sefelnasr et. al,2014**). The impact of sea level rise and seawater intrusion into the body of the delta is impacting the productivity of the land, turning the land into saline soil that makes it hard for farmers to deal with (Fig.4) and (Fig.5). Farms and fisheries along the two Nile branches, Rosetta in the west and Damietta in the east help feed the country and provide products for export. However, due to climate change and increased soil salinity, the earth has become less responsive to their normal crops and many have had to shift to fruit trees as they are more resistant to the changes. All of that is increasingly threatened by climate change and rising seas.

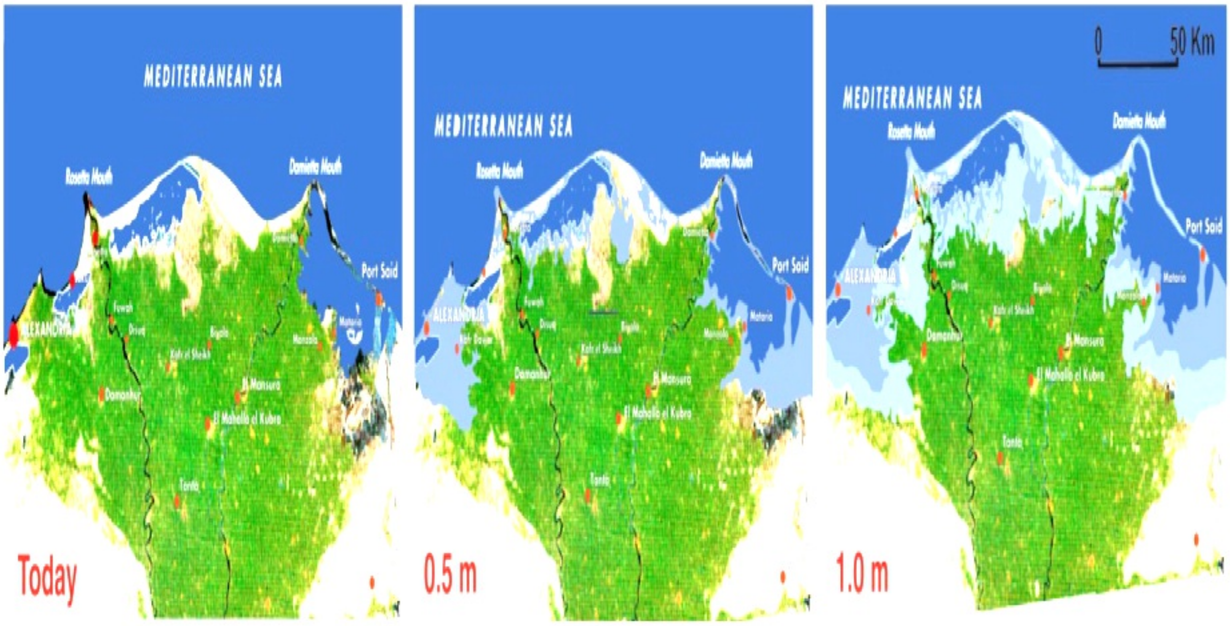

Fig.4. Nile Delta, the potential impact of sea level rise (Source: UNEP/GRID – Arendal Maps and Graphics Library).

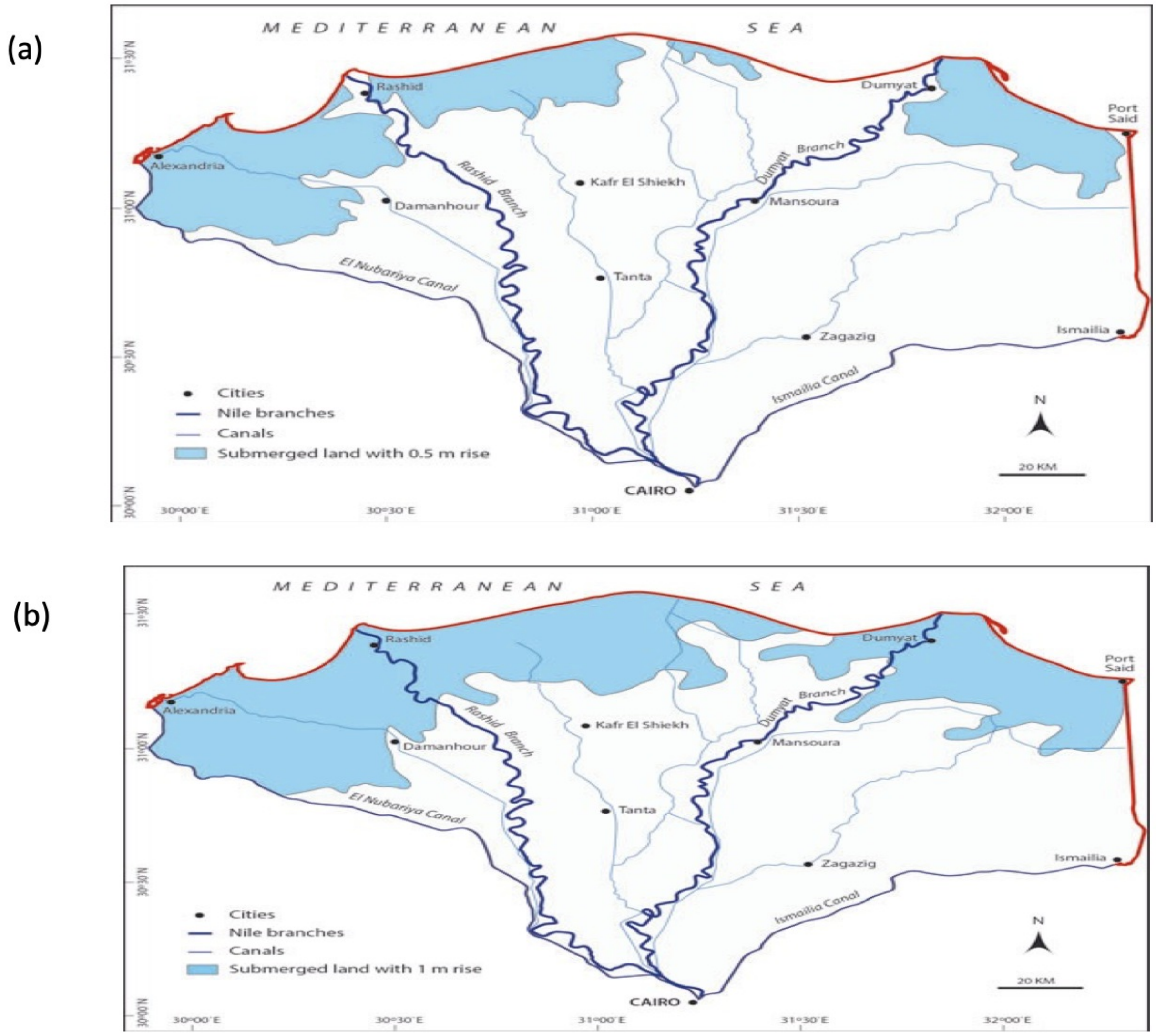

Fig.5. (a) Submerged land in the coastal zone under the condition of 0.5m seawater rise. (b) Submerged land in the coastal zone under the condition of 1.0m seawater rise. (Seflelnasr et al.,2014).

The following elements have been noticed and presented in Fig.5 and Fig.6.

1- An increase in air temperature in the range of 2.2 C° to 5.1 C° for Egypt as well as the countries of Southern Europe and the Mediterranean region over the period 2080 – 2099 concerning the period 1980 – 2020 (**IPCC 2007**, scenario A1B);

2- A significant decrease in rainfall, ranging between -4 and -27 d % for the countries of Southern Europe and the Mediterranean region (Table 2);

3- Increase in drought periods manifested by a high frequency of days during which the temperature would exceed 30 °C (**Giannakopoulos et al. 2005**). Extreme events, such as heat waves, droughts, or floods, are likely to be more frequent and violent.

4- An increase in the sea level which, according to some specific studies, could be around 35 cm up to the end of the century.

Table 2. Change in rainfall patterns for selected climatic stations in the Nile Delta

Station	Beheira	Kafr Al-Sheikh	Dakahlia	Damietta	Port Said
Annual mean	330 mm	300 mm	280 mm	320 mm	125 mm
Wet Season (Mean monthly)	53 mm	41.6 mm	50 mm	50 mm	18 mm
Dry Season (Mean monthly)	2mm	2mm	2mm	2 mm	2 mm

2.3. Climatic Change and Energy-Based Issues

The energy production sector is the industrial activity most physically affected by the effects of climate change. One consequence of increased hydric stress coupled with the increased frequency of extreme climatic events would be a drop in hydroelectric potential and the cooling potential of thermal plants (reduced yield). The probable increase in the number of extreme events would entail re-scaling or modification (e.g.: dams designed for much higher peak flows than is currently the case. The expected growth of energy consumption in Egypt is considerable for the time frame 2025, which is connected, above all, with the development of electricity production. This growth could, nevertheless, be slowed down by difficulties related to the financing of infrastructures. One of the major constraints, for Egypt and Turkey, is connected with the investments necessary for the new plants (+120 GW by 2020) which have been estimated by OME, based on the costs of January 2008, as about 110 billion Euros (Fig.6). To this, there must also be added the investments related to coal ports and natural gas production and transport infrastructures, which are equally considerable; this explains, among other reasons, the predilection for projects of gas combines cycle plants (+60 GW), which are less costly and easier to construct than coal-fired plants, for instance. This represents a reduction by 50 to 71 Mt of CO2 for the time frame 2025 thanks to the gas penetration projected in the various countries. These reduction rates are calculated concerning the current level of total emissions in Egypt. This represents (Egypt plus countries in the southern Mediterranean Sea Basin) 26 to 37 Mt of CO2 for the time frame 2025. These reduction rates are calculated concerning the total emissions of 709 Mt of CO_2.

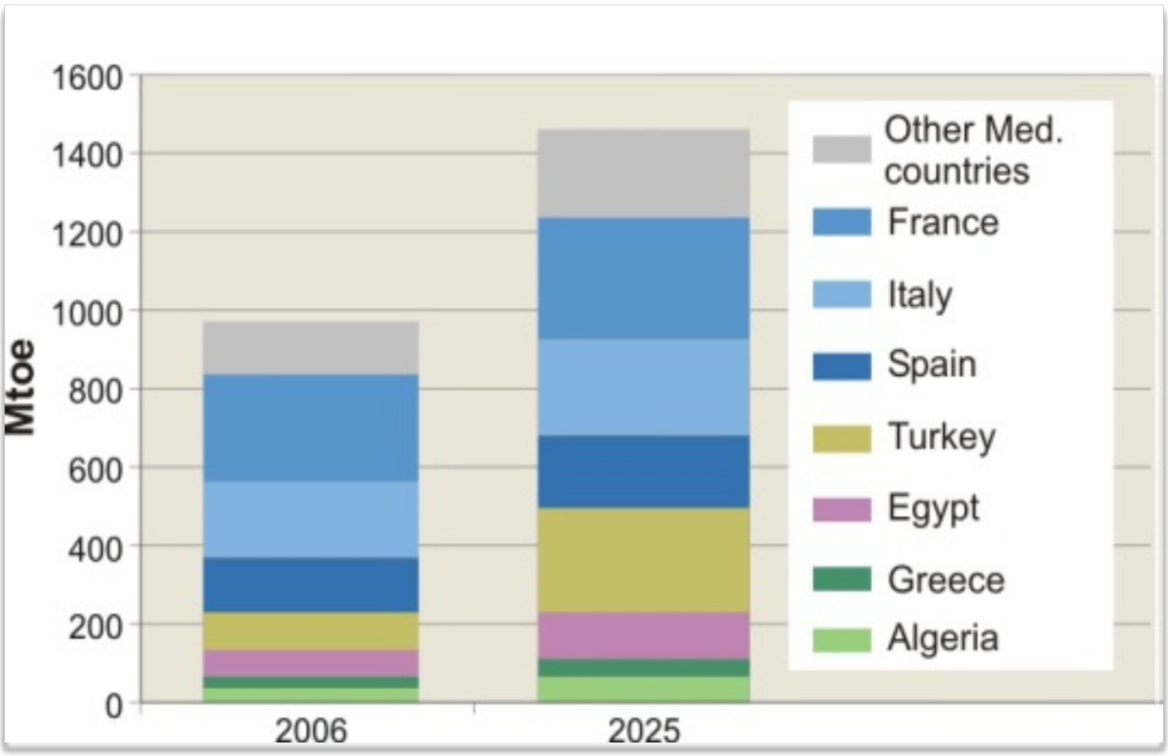

Fig.6. The seven main energy consumers in the Mediterranean

2.3.1. Analysis of energy consumption pattern in Egypt

According to the latest estimates in BP's 2021 Statistical Review of World Energy, the most consumed fuels in Egypt were petroleum and other liquids (36%) and natural gas (57%) in 2020 (EIA,2022). Renewable energy and coal accounted for 6% and 1%, respectively, of the country's total consumption for the same year (Fig. 7). Coal is primarily used in Egypt's industrial sector.

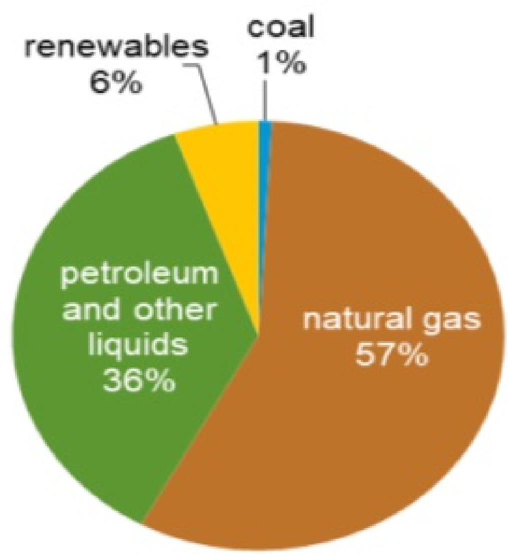

Fig.7. Primary energy consumption in Egypt, 2020 (originated from the present author)

The per capita electricity consumption for Egypt grew on average by 5% per year since 1980/81, as it increased from 380 KWh/capita in 1980/81 to 1225 KWh/capita in 2004/05 (Ministry of Electricity,2). Although the per capita electricity consumption in 2004/05 is still below the world average (2330 KWh/capita), the annual growth rate is more than 3 times the world annual average growth rate (1.6%). The future annual growth rate is expected to have an average value of 5.7% based on energy demand. The growth rate is assumed to follow the following changes: For the period 2005/06 to 2010/11: 6.6% per year. For the period 2010/11 to 2020/21: 5.8% per year. However, due to the present political instability, this foregoing planned growth was not maintained. For the period 2020/21 to 2029/30: 5.2% per year. It should be important to mention that during the last 25 years, electricity consumption has increased by an annual average growth rate of about 6.7% while the Gross Domestic Product (GDP) has increased by a lower annual average value of 4.5%. This would be attributed to current electricity consumption behavioral practices which are characterized by relatively low efficiency of electric energy usage (high electric energy intensity). It is expected that the situation will be improved through anticipated electricity tariff reform and market liberalization (Fig.7).

2.3.2. Oil products and natural gas consumption

Egypt is the third-largest natural gas producer in Africa, following Algeria and Nigeria. Egypt operates the Suez Canal and the Suez-Mediterranean (SUMED) Pipeline, which are important transportation infrastructures in international energy markets (EIA,2022). During the period 1980 – 2006, the total oil and gas consumption increased annually by about 4.8% from 15.6 **m**illion **t**ons of **o**il **e**quivalent (**mtoe**) to 52 mtoe. The oil and gas consumed for electricity generation has increased from 4 mtoe to 21 mtoe with a growth rate of 6.6% annually, while the oil and gas consumption for other sectors increased from 11.6 mtoe to 31 mtoe with an annual average increase of 4%. Domestic gas consumption is dominated by the power sector at 60% for the year 2005/06, followed by the fertilizer industry, petrochemicals, and other industrial sectors. Natural gas for power generation is expected to decline to about 50% of local gas demand by 2029/30. Gas exports were equivalent to 25% of Egypt's local gas demand in 2005/06, but are expected to peak at about 60% in 2012/13, eventually reducing to about 35% by 2029/30. As natural gas is becoming increasingly important to the economy of Egypt, particularly with the growing potential for exports, moving towards cost-based pricing of gas is becoming increasingly important (Fig.8).

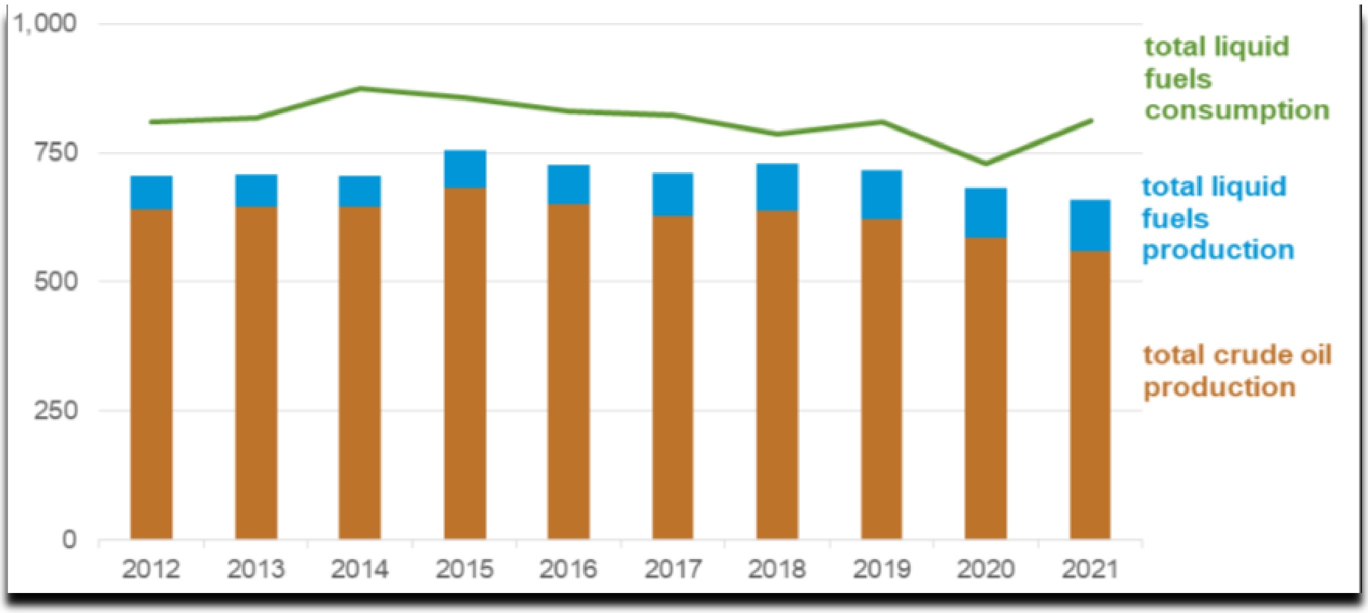

Fig.8. Total annual liquid fuels production and consumption in Egypt (originated from the present author based on data from 2012-2021, thousands of barrels per day (EIA,2022).

As a result, the government of Egypt (GOE) is planning to assess to determine the cost of gas and has requested the World Bank's assistance to do so. The objective of the study will be to calculate the economic cost of natural gas for domestic customers at certain off-take points from the network, including at power stations. The study objective has been modified later to include a strategy for energy pricing and should be completed by the end of 2008 and will provide important input to the GOE's long-term energy pricing policy and strategy including sensitivity analysis of gas price changes impact on the long run marginal cost of electricity (Fig.8).

3. Recommendations and Conclusions

Ultimately, the impacts of climate change on Egypt, and course, on the Mediterranean environment, can be summarized as relating particularly to water, via a change of its cycle due to a rise in evaporation and a decrease in rainfall. This water problem will be of crucial importance to the issue of sustainable development in Egypt and its surroundings; Soil, via the acceleration of already existing desertification phenomena; Land and marine biological diversity (animal and plant), via a displacement northwards and in altitude of certain species, extinction of less mobile or more climate-sensitive species, and emergence of new species; These impacts will exacerbate already existing pressures on the natural environment connected with anthropogenic activities. Climate change will have impacts particularly on: agriculture and fishery reduction of yields (heat waves, water scarcity), coastal areas, and infrastructures as can be observed for the Nile Delta (significant exposure to the action of waves, coastal storms, and other extreme weather events, rise in sea level), human health (heat waves), the energy sector (water needs for power plants, hydropower and increased consumption). Long-term, high-quality, reliable instrumental climate records are indispensable for undertaking robust and consistent studies to better understand, detect, predict, and respond to global climate variability and change. Although Egypt has a very long and rich monitoring history in the atmospheric and surface domains, the climate data heritage is largely under-exploited.

The current state of affairs is hindering the region's ability to make precise evaluations of the regional climate's fluctuations and alterations, as well as their corresponding environmental and socio-economic consequences. It is also making it difficult to determine the most effective approaches for mitigating and/or adapting to the adverse effects of global climate change in Egypt and its neighboring areas.

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