AMERICAN UNIVERSITY OF BEIRUT

INVESTIGATING WATER INFRASTRUCTURE MITIGATION MECHANISMS TO REDUCE IMPACTS ON CLIMATE CHANGE: THE CASE OF EL-AZZOUNIEH DAM. (LEBANON)

by
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AN ABSTRACT OF THE THESIS OF

Jad Jari for Master of Urban Planning and Policy
Major: Urban Planning and Policy

Title: Investigating water infrastructure mitigation mechanisms to reduce impacts on climate change: The case of El-Azzounieh dam (Lebanon)

Water infrastructure impacts on climate change are increasing with the shortage of resources all over the world. Dams are considered a major contributor to these impacts. Taking El Azzounieh dam (Lebanon) as a case study, this thesis investigates mitigation mechanisms to be introduced to dam design to reduce dams' impacts on climate change, especially given several dam projects are due to be established in Lebanon under the CEDRE umbrella. To acquire a better understanding of dam strategies, the thesis also explores the water policy in Lebanon.

The thesis proposes an assessment approach to evaluate dams' impacts on climate, through which a set of policy and technical solutions are suggested in order to mitigate dams' impacts on climate.

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ACRONYMS

CEDRE:	Economic Conference for Development through Reforms with the Private sector
MoEW:	Ministry of Energy and Water
IPCC:	Intergovernmental Panel on Climate Change
NWSS:	National Water Sector Strategy
MoE:	Ministry of Environment
HCPP:	High Council for Privatization and PPP
EIA:	Environmental Impact Assessment
CDR:	Council for Development and Reconstruction
UNEP:	United Nations Environment Program

CHAPTER I

INTRODUCTION

1.1 Problem Statement

Water scarcity problem is rising with the increasing environmental issues around the world (Gosling and Arnell, 2013). Mismanagement of water resources along with uncontrolled rapid urbanization is making the problem more critical (Vairavamoorthy et al, 2008). In Lebanon, the problem exists as well due to the lack of implementing a comprehensive management plan to meet future risks on the water sector (El-Fadel et al, 2010). In fact, decision making of the water sector is centralized within the MoEW (Ministry of Energy and Water) whereas the four regional water establishments (Beirut and Mount Lebanon Water Establishment– Head office in Beirut, North Lebanon Water Establishment – Head office in Tripoli, Bekaa Water Establishment– Head Office in Zahle and South Lebanon Water Establishment– Head office in Sidon (Saida)) are responsible for tariffs and service provision (MoEW, 2010). Also, in terms of climate change, the main cause of increase releases of greenhouse gases is human activities (IPCC, 2014), and this impacts the water sector negatively. Accordingly, it would be important to consider climate change vis-à-vis water infrastructure.

The challenges of the water sector in Lebanon are addressed by the NWSS (National Water Sector Strategy) initiated in 2010 by the MoEW (MoEW, 2010). Several alternatives are presented to tackle water scarcity, however, dam projects seem to be the most advocated due to their efficient storage volume capacity and the sustainability of their supply in comparison to running surface water or groundwater.[1]

Moreover, in April 2018, the CEDRE (Economic Conference for Development through Reforms with the Private sector) conference aimed to boost the Lebanese economy through infrastructure investments up to 11$ Billion USD to adapt for the major demographic changes and challenges in the country resultant of the Syrian crisis in 2012 and the increasing flux of migration (Irish and Pennetier, 2018). The conference held in Paris on April 6, 2018, is in support of Lebanon's development and reforms in order to strengthen the Lebanese economy through a comprehensive plan of reforms and infrastructure investments.[2]

Among those investments, several dam projects are proposed over the four water establishments on a national scale[3]. From a climate perspective, the challenge facing such projects is the adaptation to climate change in terms of extreme variations in precipitations and rainfall patterns (Leavesley, 1994). In fact, infrastructure is typically designed following hydrological and meteorological data from the previous 10 to 20 years[4]. Hence, our current designed infrastructure would be vulnerable to the upcoming fluctuations in weather from the changes in climate. Besides the infrastructure and management

[1] NWSS- http://www.databank.com.lb/docs/National%20Water%20Sector%20Strategy%202010-2020.pdf
[2] CEDRE opening address by the Minister for Europe and Foreign Affairs, Jean-Yves Le Diran- https://www.diplomatie.gouv.fr/IMG/pdf/cedre_discours_du_ministre_en_cle8a64f3.pdf
[3] CEDRE capital investment- http://www.cdr.gov.lb/study/cedre/cedrelist.pdf
[4] United States Department of the Interior, Bureau of Reclamation. (1973). Design of small dams. Washington, D.C

shortcomings in the Lebanese water sector, climate change will increase the shortage of water and the stress on groundwater exploitation.[5]

Such changes will cause the deterioration of infrastructure on both structural and operational dimensions. Also, literature shows that some infrastructure projects such as dam reservoirs would impact climate negatively by the emissions of greenhouse gases (Prairie, 2018). Accordingly, while designing and implementing dam projects, both adaptation and mitigation mechanisms should be adopted to limit the impact.

1.2 Justification of Case Study

While the vulnerability of the water sector facing climate change is increasing and CEDRE projects aim to boost the infrastructure in Lebanon, it is important to study the potential proposed dam projects under CEDRE.[6] Moreover, CEDRE advocates for "sustainable" projects[7] to meet the United Nations sustainable development goals to which Lebanon has adhered[8]. Given the negative impacts from dam on climate, and the scope of this thesis, I chose one of those projects. My research for this thesis was conducted as part of an internship at the UNDP climate change unit in the MoE in Beirut, Lebanon. In order to study one of the dams proposed by CEDRE, we need to analyze its EIA (Environmental Impact Assessment); the process of evaluating the environmental impacts of a proposed project and the potential alternatives or solutions. In fact, following the environmental legal

[5] Lebanon third national communication to the UNFCCC- http://climatechange.moe.gov.lb/viewfile.aspx?id=239
[6] CEDRE capital investment- http://www.cdr.gov.lb/study/cedre/cedrelist.pdf
[7] CEDRE joint statement, article 10- https://www.diplomatie.gouv.fr/IMG/pdf/cedre_statement-en-_final_ang_cle8179fb.pdf
[8] UNDP sustainable development goals- https://www.lb.undp.org/content/lebanon/en/home/sustainable-development-goals.html

framework of the MoE developed since 1993, funding bodies require from the Lebanese government to conduct an EIA for proposed projects (El-Fadel et al., 2000).

Only three dams proposed have detailed descriptions published by the HCPP (High Council for Privatization and PPP). The most vulnerable water establishment in terms of scarcity and shortage of provision is the north water establishment.[9] Moreover, this establishment has the highest number of proposed dam projects compared to its size.[10] Accordingly, my first choice was El-Bared dam, the largest among the proposed dams by CEDRE. However, the EIA scoping report was not yet developed for this project. I thus chose El-Azzounieh dam because of its size in terms of water storage, provision capacity and the availability of its EIA. Moreover, the site location is important due to its classification as a protected natural site in the NPMSP (National Physical Master Plan of the Lebanese Territory).[11] Thus, the project is not only critical for the impact on climate but also on the surrounding natural sites of the area.

1.3 Research Question and Objectives

How do dam projects impact climate and what are the possible mitigation mechanisms to be integrated in the EIA to reduce this impact?

The first objective of this research is to identify the processes developed in dam reservoirs that will contribute to the increase of greenhouse gases emissions rate and have

[9]NWSS- http://www.databank.com.lb/docs/National%20Water%20Sector%20Strategy%202010-2020.pdf, p. 8
[10] NWSS- http://www.databank.com.lb/docs/National%20Water%20Sector%20Strategy%202010-2020.pdf, p. 51-13 potential dams in the north water establishment
[11] National Physical Master Plan of the Lebanese Territory, p. 15- http://www.cdr.gov.lb/study/sdatl/English/NPMPLT.PDF

future negative impact on the climate. The second objective is to quantify the processes to include them as tangible criteria in the EIA. In fact, from a climate change perspective, current EIA processes do not take into consideration weather fluctuations/changes, and therefore the need to mainstream climate change into the process is important. Taking one type of water infrastructure projects as a pilot would contribute to the already developed guidelines by the UNDP climate change unit on how to integrate climate change in the general EIA for all projects.[12]

1.4 Methodology

I use available research and quantitative methods of analysis based on data related to greenhouse gases emissions and the environment status in El-Azzounieh, in order to assess the dam's impacts on climate.

My research was conducted during my internship at the UNDP climate change unit. I started by collecting data regarding the Azzounieh dam project design and Beirut Mount Lebanon water establishment. This allowed me to get more familiar with the structure of the sector in general and with the policies defining it. In parallel, I investigated climate change assessment methods developed and provided by the IPCC. This facilitated the exploration of several policies and technical alternatives that would fit the case study in consideration and other established water infrastructure projects in Lebanon. I focused on the eutrophication process, which is the degradation of the water quality due to the increase in phosphorus and nitrogen in the lack of proper circulation in artificial reservoirs and the

[12] UNDP general guidelines for integrating climate change in EIA- http://climatechange.moe.gov.lb/viewfile.aspx?id=219

greenhouse gases emissions (Yang et al., 2008). I chose these two factors to be able to calculate the predicted emissions of greenhouse gases in the atmosphere that would impact the climate[13]. Adding such quantitative indicators in the EIA of dam projects would help assess the potential negative impacts on climate and determine future mitigation processes to adopt.

1.5 Research Significance

This thesis contributes to the study of dam impacts on climate and the importance of integrating the climate change component in the EIA to predict such impacts. This would allow a better assessment of the projects to be established. Addressing climate change in the EIA of water infrastructure projects will thus allow the implementation of efficient projects to tackle the challenges of the water sector. In this research, I will present an overview of the visions and strategies in the water sector that justifies the emphasis on dam projects in Lebanon to argue that among different types of water infrastructure projects, EIAs for dams are critical to address in terms of climate change. However, the limitations of this study are the lack of available hydrological and meteorological data about the different areas in Lebanon. This limits the accurate assessment to find the most important indicators among others in reservoirs impacting climate. In fact, if the evaluation of climatic trends is more accurate it would reduce the uncertainties in design; however, such investigation is outside the scope of this thesis. Also, accurate data could lead to further climate change prediction. Methodologies developed by the IPCC[14] for instance, allow the

[13] Global climate change NASA- https://climate.nasa.gov/faq/19/what-is-the-greenhouse-effect/
[14] IPCC TIER methodology-
https://www.ipcc.ch/site/assets/uploads/2019/05/01_2019rf_OverviewChapter.pdf

calculation of greenhouse gases emission rates of reservoirs in a more detailed way based on the morphometry[15], operation and site location, which is not possible in our case.

1.6 Thesis Structure

The first chapter of this thesis is an overview of the literature review concerning climate change in Lebanon and its impacts, dam structure and operation vulnerability to climate change and the impacts from dams; emissions of greenhouse gases from reservoirs on climate. Literature about the Lebanese water sector is also presented in order to understand the dam implementation policies.

In chapter 2, I explore the EIA legal and administrative process in Lebanon and the possibility to integrate the climate change component. Also, I explore the limitations of the Lebanese EIA. In chapter 3, I develop the methodology I followed for this research. I explain the UNDP guidelines to integrate climate change in the EIA and the criteria I focus on for the assessment of the case study. In chapter 4, I present the case study (El-Azzounieh dam) and the background of the proposed project. Also, I show that based on the criteria of assessment the Azzounieh dam project would impact climate change due to the high risk of eutrophication and thus emissions of greenhouse gases. I concluded with the necessity to include tangible factors in the scoping level of the EIA to measure concretely the potential risks on climate. Moreover, I suggest that furthermore detailed criteria can be taken into consideration as well but such step requires accurate data that we lack in Lebanon.

[15] Explanation in methodology section

CHAPTER II

DAM RELATIONSHIP TO CLIMATE AND LEBANESE WATER SECTOR

The literature review presented in this chapter focuses on; climate change in Lebanon, dam vulnerability to climate and dam impacts on climate. Also, it presents an overview of the EIA process and its methodology within the concerned institutions in Lebanon.

2.1 Climate Change in Lebanon

Climate change is experienced through the major changes in the measures of climate components such as temperature and rainfall over a certain period of time. According to the World Meteorological Organization (WMO), the radical changes in climate in the 20th century are due to anthropogenic activities that built up an excessive amount of greenhouse gases in the atmosphere (Turner, 2012). The comprehensive assessment of the IPCC argues that the causes are the increasing use of energy and expansion of the economy without proper environmental considerations (IPCC, 2014). In the case of Lebanon, climate change is observed in the varying conditions of water shortage that is caused by the urban development level and the hydrodynamic responses affected by snowmelt and precipitation trends.[16] The lack of sustainable strategies, monitoring, and adaptation or mitigation policies aggravates the condition even more in Lebanon.

[16] NWSS- http://www.databank.com.lb/docs/National%20Water%20Sector%20Strategy%202010-2020.pdf p. 25

The predicted increase in temperature will result in a decrease in snow level that will impact negatively Lebanon's water supply (Doummar et al, 2018). A reduction of the total volume of water by 6-8% is predicted if no measures are taking into consideration[17]. These values are based on an increase in temperature of 1°C. However, the current increase worldwide is around 3.2°C while the Paris Agreement target is for 1.5°C to 2.0°C[18]. Accordingly, the reduction of water volume would be much higher beyond the predicted ones if the Lebanese government does not tackle to problem of greenhouse gases emissions.

		Beirut	*Zahle*	*Daher*	*Cedars*
Prcp (%)	DJF	-7,95	-23,50	-0,99	-1,82
	MAM	-8,60	35,50	-0,38	-15,50
	JJA	-26,80	-84,20	-39,00	-49,80
	SON	-8,87	23,80	14,10	12,60
T_{max} (degrees C)	DJF	1,08	1,23	1,92	1,77
	MAM	0,87	1,14	1,53	1,28
	JJA	2,15	2,14	2,28	2,13
	SON	1,48	1,64	1,67	1,70
T_{min} (degrees C)	DJF	1,22	1,28	1,63	1,27
	MAM	0,90	1,09	1,36	1,06
	JJA	2,13	2,36	2,46	2,24
	SON	1,83	2,08	1,96	1,98

Figure 1 Changes in temperature (Tmax, Tmin) and precipitation (Prcp %) over Beirut, Zahle, Daher and Cedars from the PRECIS model for winter (DJF), spring (MAM), summer (JJA) and autumn (SON), 2025-2044-source: Farajalla et al. (2014)

[17] UNDP Water: Climate Change Lebanon- http://climatechange.moe.gov.lb/Publication.aspx?pageid=35
[18] Emissions Gap Report warns about missing Paris Agreement targets- https://public.wmo.int/en/media/news/emissions-gap-report-warns-about-missing-paris-agreement-targets

The consequences of climate change on the water sector in Lebanon are the following[19]:

“Increase in forest fires leading to; decrease in ground cover, increase in erosion and decrease in infiltration”; damaging the ecosystem and high risk of failure on infrastructure.

“Reduction in surface and groundwater quality, higher temperatures that will reduce dissolved oxygen levels”, this will change the patterns of rainfall leading to higher risks of flood and reduction of lake levels.

“Sea level rise leading to intrusion of seawater into coastal aquifers and interference with sewage and storm water[20] sea outfalls/networks in coastal areas.” This will lead to the degradation of groundwater quality and eventually on the supply network of the drinking water.

Climate change impacts on the water sector go beyond the risk on water as resource. Without adaptation or mitigation strategies, the degradation of the quality of water resources will impact the urban system as well. The consequences described above show a risk of erosion, seawater intrusion and degradation of groundwater with a shortage of freshwater in aquifers that are directly linked to urban areas.

Also, climate change in Lebanon is critical to the economy. According to a study conducted by the UNDP in collaboration with the MoE in 2015, the lack of proper management of climate change adaptation and mitigation strategies will impose additional costs across all segments of Lebanon’s economy and society. The shortage of water supply in different

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[19] Adaptation of the water sector to climate change- https://www.riob.org/en/node/3464
[20] Water that originates from rain, including snow and ice melt.

sectors will impose an increase from 21 USD in 2020 to 1,200 USD in 2080 in the cost on households and businesses to compensate for the shortage.[21]

Moreover, if the Lebanese authorities do not take into consideration the impacts of climate change, under high greenhouse gases emissions rate, the annual economic cost on Lebanon would be 3,600 MU$ at the end of 2020.[22] This cost would lead to a reduction in the GDP of 17,600 MU$[23]. The study presents three projections scenarios on the economic cost in Lebanon based on the rate of emissions of greenhouse gases.

The first one represents the current situation in Lebanon with high emissions on the IPCC standards, while the second one is a projection of the cost on the economy if Lebanon's emissions follow the IPCC lowest standards. The third one is a comparison between the first two scenarios to assess the potential savings on the economy if Lebanon reduces emissions of greenhouse gases. Results are shown in Figure 2:

[21] Economic Costs to Lebanon from Climate Change: A First Look- http://climatechange.moe.gov.lb/viewfile.aspx?id=228
[22] Ibid 20
[23] Ibid 20

	2020	2040	2080
A. Potential costs if global emissions follow the IPCC's highest-emissions scenario (current trends)			
Total cost (millions)	USD 21,200	USD 80,700	USD 1,009,700
Average per household	USD 16,400	USD 57,300	USD 721,900
Government's share (millions)	USD 6,800	USD 25,800	USD 322,000
B. Potential costs if global emissions follow the IPCC's lowest-emissions scenario			
Total cost (millions)	USD 15,200	USD 30,800	USD 91,300
Average per household	USD 11,700	USD 21,900	USD 65,200
Government's share (millions)	USD 4,800	USD 9,800	USD 29,100
C. Potential savings from reducing global emissions to the lowest-emissions scenario			
Potential savings (millions)	USD 6,000	USD 49,900	USD 918,400
Potential savings (percentage)	28	62	91

Figure 2 Present value of economic costs that global GHG emissions in 2020, 2040, and 2080 would impose on-source: MoE (2015)

The MoE and UNDP projections in 2015 show an alarming situation in Lebanon. Climate change is impacting natural resources as well as the economy. Accordingly, future water projects are very critical in Lebanon in terms of climate change and any development should take into consideration the potential risks on climate and the vulnerability towards climate as well.

2.2 Dam Vulnerability to Climate Change

I will first discuss the risks of failure related to the structure of dam and later the risks of failures related to the operation system.

2.2.1 Impact of Climate Change on the Failure of Dam Structure

Dams and reservoirs are acknowledged to have numerous beneficial purposes: Electricity production, water storage for irrigation, industry-human consumption, flood control, and navigation and recreation. Climate is putting dam structure under risk and the most important aspect to take into consideration is the longevity of the structure to make its operation efficient (Lamperiere, 2013). The obstacle in that sense is to choose the right type of dams for the targeted purpose. This decision is an empirical process that relies on technical study and the opinions of experts based on previous experiences because a specific methodology of choice is not documented in the literature (Emiroglu, 2008). The material used in the construction is of great importance because it might influence the operation of the dam to meet its purpose whether it is for water supply, electricity production, or flood control and navigation.

Choosing the right material for construction might reduce the risk of failure from different natural causes. The constraints related to the purpose, construction, and material of the dam developed further into new approaches and methodologies for dam construction. For example, Cemented Material Dam (CMD) is considered environmentally friendly, more economical and safer for the dam and the area downstream (Jia et al., 2016). The study argues as well that optimizing the dam structure can be reached by using a different type of material for different parts of the structure. Also, symmetrical or trapezoidal structural shapes are not always necessary if the correct material in construction is used.

However, these technologies in construction will not always eliminate the risks of failure. Such innovations will help in improving the efficiency of the dam to meet its purpose. A recent example is the failure of the main reinforced concrete slab of the Toddbrook reservoir in the UK due to the increase of the level of water that caused erosion in the structure steel bars[24].

2.2.2 Climate Impact on Dam Operation

Dam reservoir assessment focuses on the evaporation rate related directly to the efficiency of the dam operation, its site and construction, and the environment within its area.

Fekih, M and Saighi, M (2012) provide a detailed methodology to estimate the evaporation rate from dam reservoirs in Algeria. The study uses the energy budget equation to calculate the evaporation rates from an open water body. According to the study, the main method to estimate evaporation rate is based on the use of pan and proportionality.[25] Introducing the equation of the energy budget proved efficient in the case study. In fact, the method is important in the areas where the input climatic variables are not available (Fekih and Saighi, 2012). Hassan, A et al. (2018) research on the Lake Nasser in Egypt estimates the monthly evaporation rates using Remote Sensing (RS) and Geographic Information System (GIS) techniques. The methodology followed proved efficiency and effectiveness in the monthly calculation. Several data are required to conduct the modeling. For instance, data from meteorological stations installed to monitor lake meteorology is needed in order to calculate the evaporation rate using Harbeck equation.[26] The data provided consists of the lake coefficient (mass transfer coefficient), wind speed at a specific height above water

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[24] Collapse of Toddbrook reservoir, UK- http://theconversation.com/whaley-bridge-dam-collapse-is-a-wake-up-call-concrete-infrastructure-will-not-last-forever-without-care-121423

[25] Evaporation is measured daily as the depth of water evaporates from the pan.

[26] Harbeck equation relates evaporation to several meteorological factors (wind speed, saturation and vapor pressure)

surface, the saturated vapor pressure of air at water surface temperature and the actual vapor pressure of air at the same height (Hassan et al., 2018).

Evaporation is one of the largest water losses from dams due to the large surface area exposure to sun in the reservoirs. In Lebanon for example, the estimated evaporation rate is around 50% of the total precipitation (Farhat, 2018). The study conducted by Behrouzi (2017) on Karaj dam lake, Iran provides several methodologies to estimate evaporation losses taking into consideration cost and accuracy. These different methods have several advantages and disadvantages. The factors affecting evaporation are governed by the environment (wind and solar radiation) and intrinsic factors related to the water's thermal properties and impurities. Therefore, some methods are effective for a daily base estimation and others are used for a long-term or yearly estimation depending on the resolution of the climatic data. Thus, as the study showed, combinational methods are the most efficient to satisfy both feasibility and accuracy. However, for different climate zones, the optimal model may be different. Thus, in terms of climate change, it would be critical to use outdated and low-resolution data for the estimation of evaporation. This latter component of the water balance is hence not the priority for the dam assessment itself; it is rather the mitigation process that can be implemented to reduce the environmental and intrinsic factors resulting from it (Behrouzi and Chini, 2017).

Even with the advancement of methodologies used to estimate the evaporation rate of reservoirs in the aim of optimizing the design and the type of dam and its reservoir, the assessment of the impact of climate change on the water budget remains challenging due to the uncertainty in the design baseline data.

2.2.3 Climate Change Impacts on Dam Safety

Dam structure safety and operation are questionable when it comes to future climate changes because its design depends on historical weather data. Accordingly, with the global climate change, design criteria would be inaccurate due to the changes in precipitation patterns and other fluctuating intensities of weather events (Baecher, 2015). Floods in that sense are critical to the safety of dams and their operation. Chernet, H. (2013) study examines flood frequency development due to climate change and its possible effects on Aurland[27] hydropower dam. The study elaborates first on the historical patterns used in conducting the assessment of the design. Second, climate models and scenarios were developed to estimate the anticipated future changes from previously recorded data. Analysis of the future flood pattern may incur possible damages in the spillway of the dam structure that is essential for its operation. The modeling was developed on a seasonal basis to project different scenarios and the results showed the necessity of increasing the design flood safety. Uncontrollable situations of future flood systems can be mitigated by well-functioning dam management based on early warning systems such as runoff forecasting and detailed information about possible magnitudes of the inflowing water (Chernet, 2013).

2.2.4 Challenges in Dam Structures Located in Karst Areas

Dam sites and reservoirs are very critical to the functioning of the dam. Karst rocks prone to dissolution, such as limestone, are presented as one of the most inefficient formations to host dams (Vick and Bromwell, 1989). Formations such as limestone and

[27] Aurland lies 200 kilometers from the west coast of Norway.

dolomite are characterized by a high degree of seepage and leakage problems below the dam site and reservoir because of intense fracturing and dissolved fissures very characteristic of these aquifers. The problem is related to the geographical and geological factors that would create karstic cavities in random forms and orientations at different depths. For this reason, design of dams on karstic limestone is very critical and needs in-depth detailed engineering geological investigations (Erguvanli, 1979). Engineering literature argues that potential risk of reservoir failure in karst formation exists always. Uncertainties always remain with the high random distribution of dissolution failures.

Therefore, additional measurements should be taken into consideration to assess properly the adequacy of the dam site before construction. The most frequent technical difficulties are water leakage at dam sites and from reservoirs and breaching by water and mud during tunneling and other underground excavations. The investigation methods in karst formation are essential a priori of the dam site choice (Milanovic, 2011). A good geological map and detailed hydrogeological data are necessary for dam and reservoir construction in any geological environment. The most common methods applied in dam construction in karst are specific hydrogeology/hydrology, tracer tests, geomorphological analysis, specific geophysical investigations, speleology and dissolution tests in the case of evaporates (Milanovic, 2011).

Failures are under three forms:

1. Concentrated leakage during the first filling of the reservoir
2. Slow and constant erosion of the natural fills from joints and caverns
3. Collapses in reservoirs with seepage after many years of operation

Even if the risk of failure always exists, several engineering prevention solutions are developed such as leakage prevention in karst based on surface treatment in order to reduce water losses and underground treatment to modify curtains by increasing its length or depth (Milanovic, 2011). Understanding the hydrogeology of karst sites is also important for future climate changes and overexploitation of water resources in the area. Climate changes such as drought together with overexploitation of surface water and groundwater have reduced river discharge in most rivers. Such recent negative development imposes challenges for dam site selection that is based on past and outdated hydrological conditions, especially concerning river discharge, without enough knowledge about the changing groundwater conditions (Rezaei et al., 2017).

Karstic formation is incompatible with the dam structure and functioning. Moreover, the cost of deeper investigation and engineering solutions for the prevention of failure is high in terms of time and budget.

Risks of failure	Climate change impacts
Variations in local floods	Heavy rainfall patterns
Decrease/increase reservoir water levels	Precipitation variability, changes in water demands
Gate performance	Changes in temperature causing stresses and deformations
Internal erosion	Drier soils, water level fluctuations

Figure 3 Summary of main dam failure caused by climate change-source: Fluixa-Sanmarting et al. (2018).

2.3 Dam Contribution to Climate Change

Beside the risk of dam failures with the fluctuating patterns of extreme weather events, dams impact the environment negatively and increase the future climate changes risks.

The impact on climate is translated into the amount of greenhouse gases trapped in the atmosphere due to the construction of the dam or its operation. I will focus first on the general impact of dam on the environment and next I will elaborate on the process of eutrophication in reservoirs and the predictions of greenhouse gases emissions. The emissions from upstream will affect the ecosystem surrounding the dam and its reservoir as bypassing downstream to the structure. In fact, such emissions are marginal in normal conditions but increase with the presence of the dam reservoir. This contribution would increase the impact on the climate as well.

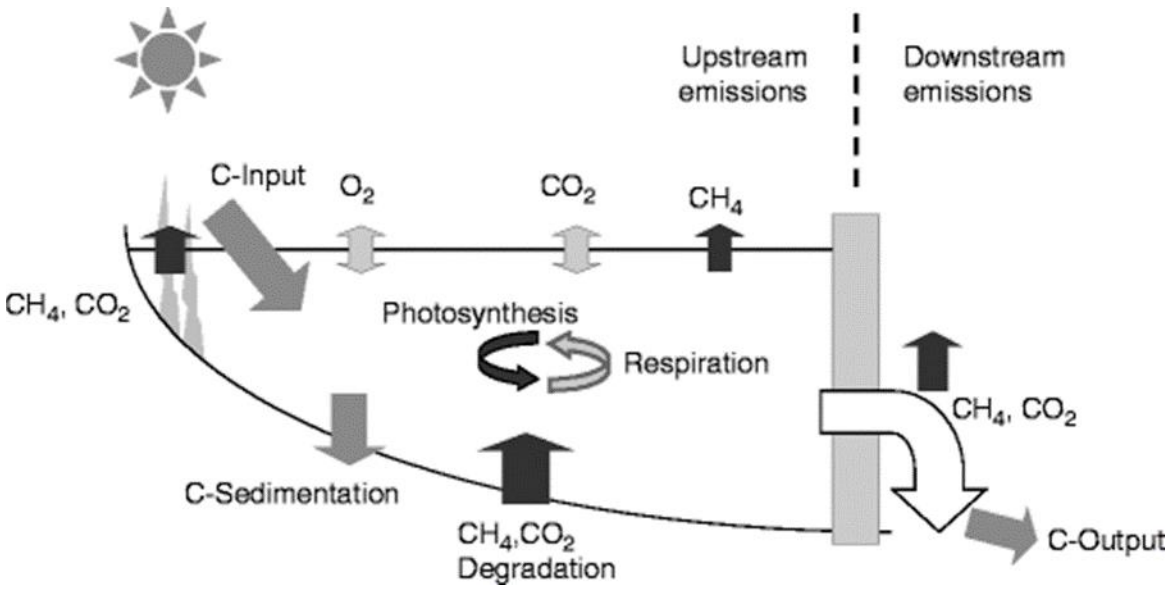

Figure 4 Major gas fluxes in a reservoir- source: Varis O. et al. (2012).

2.3.1 Impact of Dams on the Regional Water Quality

In his research Gyasi, S. (2018), explains that dam affects the surrounding water quality. The study demonstrated that generally, inhabitants “near to the dam” communities perceived the construction of the Bui Power Project on Black Volta river, Ghana has degraded their drinking water quality as well as their health. In addition to related studies on water quality, several experts argue for the removal of dams. Such decisions are based on reviewing the ways that dams may damage river ecosystem, examining criteria used to classify dams and describing how these criteria are of limited value in evaluating the environmental effects of dams (Poff and Hart, 2002). For such a reason, the assessment of the dam structure beside the design and construction should be examined as a whole entity, studying all details from the operation phase. It is crucial to articulate assessment criteria that would reduce the ambiguity of the design choice, in order to obtain sustainable development. Different priority levels are presented through the literature. Following this, in analyzing or predicting the processes impacting climate in reservoirs, such as eutrophication, we should take into consideration the surrounding activities in the location of the dam. Fertilizers and agricultural waste are two main human activities that catalyze the process of eutrophication in surrounding water bodies (Zhou et al., 2019).

2.3.2 Impact of Dams on Global Climate

Dam structure and operation can have significant impacts on the carbon cycle and climate system due to the damming of rivers. Maarava, T et al. (2017) argue that the effect is not only on the scale of the surrounding of the dam, it goes further to the global carbon cycle and thus impacting directly the global climate. The analysis of the organic carbon traveling down rivers based on physical parameters such as water flow and reservoir sizes showed that ongoing dam construction impedes the transport of nutrients such as phosphorus and nitrogen through river networks. The changes in nutrient flow have global impacts on the quality of water delivered to wetlands, lakes, floodplains and coastal marine areas downstream (Maarava et al., 2017).

2.3.3 Impact of Dams on Micro-climate

Besides the impact on the carbon cycle, experts argue that dams have an impact on precipitation patterns. Several factors are considered a catalyst for precipitation, one common is the capacity of vertical profile of temperature[28] and humidity to contain atmospheric instabilities[29] (Reid, 2009). Evaporation in the reservoirs of dams would catalyze this process and thus induce variability and fluctuation in precipitation patterns. In that sense, studying the micro-climate of the site location is necessary because it has a potential impact on the climate as well. Also, according to Shahin (2003), the area surrounding a dam would impact nature by changes in the microclimate due to water leakage. When water is exposed to sunlight, and due to its high heat capacity, it changes energy balance[30]. The impacts go beyond just the changes in temperature; changes in air moisture percentage and the topography of the region as well are two important contributors to the influence on microclimate (Tahmiscioglu et al, 2007). These impacts exist due to the functioning of the dam itself as an artificial reservoir for water storage.

2.3.4 Eutrophication and Impact on Climate

Based on Carlson and Simpson criteria of water quality (1996), trophic state assessment is based on the amount of biological activity in water body. TSI (trophic state index) is rated on a scale from zero to one hundred and it classifies the quality of water as follows:

[28] Averaging atmospheric temperatures over all latitudes and across an entire year

[29] Atmospheric instabilities- the amount of energy a given mass of air- indicator of atmospheric instability, which makes it very valuable in predicting severe weather (Reid, 2009)

[30] Energy balance and microclimate- https://www.cambridge.org/core/books/microclimate-and-local-climate/energy-balance/D90F6B2F9D84C38EA533E99FF759A9AA

TSI values	TrophicStatus	Attributes
< 30	Oligotrophic	Clear water, oxygen throughout the year in the hypolimnion
30-40	Oligotrophic	A lake will still exhibit oligotrophy, but some shallower lakes will become anoxic during the summer
40- 50	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
50-60	Eutrophic	Lower boundary of classical eutrophy: Decreased transparency, warm-water fisheries only
60-70	Eutrophic	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems
70-80	Eutrophic	Heavy algal blooms possible throughout the summer, often hypereutrophic
>80	Eutrophic	Algal scum, summer fish kills, few macrophytes

Figure 5 Carlson's trophic state index- Source: Prasad et al. (2012)

Oligotrophic is the state of water body that has low productivity; low amount of nutrient content and thus clean water is present with high drinking quality.

Mesotrophic is the state of water body with intermediate level of productivity; they present a medium level of nutrients. Water quality is classified as healthy and drinkable.

Eutrophic is the state of water body with high biological activity. The water body is dominated by aquatic plants due to the abundance of nitrogen and phosphorus. Water quality is considered deteriorated and not drinkable.

The problem of eutrophication starts when we have a lack of proper flow circulation in the water body. Reservoirs are considered artificial water bodies where flow circulation can be minimal. Under such conditions and with human activities in agriculture using fertilizers and detergents or combustion of fossil fuels, nutrients for algae increase in the water body (Chakraborty et al, 2017). The main two are nitrogen and phosphorus (Yang et al., 2008). The uncontrolled and rapid growth of algae would prevent sunlight penetration. This phenomenon will reduce the capacity of the ecosystem to produce photosynthesis. Moreover, algae growth will consume a large amount of oxygen from water. Anoxic (oxygen-free) environment is created in the water body and will develop anaerobic organisms; capable of living without oxygen, the death of the ecosystem starts (Yang et al., 2018). Besides the formation of harmful substances such as nitrosamines that cause degradation and death of human cells, the literature argues that eutrophication in reservoirs is a main cause for the increase emission rates of greenhouse gases (Beaulieu et al., 2019).

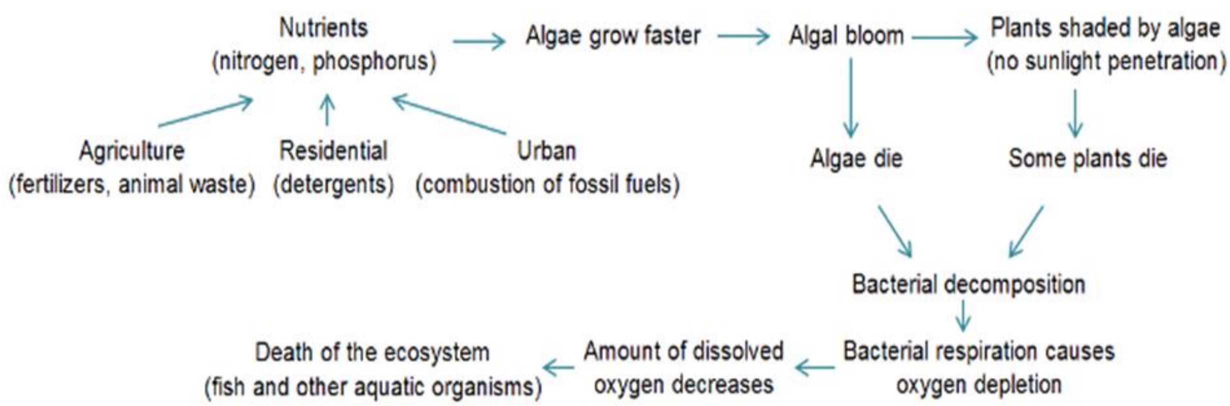

Figure 6 Eutrophication process in reservoirs and lakes- source: Knockaert, C. (2019)

2.4 Climate Change Challenges in Lebanon

In the case of Lebanon, the risks from dams are even more critical due to the lack of proper information and data necessary to mitigate the impacts.

Karam, F. (2002) discusses the status of climate change in Lebanon, the available monitoring strategies and the risk of uncertainty and data shortage. In order to make predictions of climate change, the methodology followed is based on calculating the effects of all the key processes operating in the climate system. The core component of the mathematical model developed for this assessment is the rainfall analysis. The study shows that in Lebanon we need risk assessment tools to anticipate the changes in climate and current water policies will not respond properly to climate change in the lack of projection scenarios to predict the weather patterns (Karam, 2002).

In the case of Lebanon, investments are in favor of building new dams. Even though the EIA process provides strategies to mitigate the effects of dams on the environment, it lacks tangible evidence to predict accurately the potential risks on the surrounding.

As Lima, I et al. (2007) argued, even with available potential engineering technologies such as recovering methane emissions and to fit the standards of the Kyoto Protocol, countries should consider such strategies as mitigation procedures for already existing projects and not the solution for building new dams. With the lack of such technologies, Lebanon’s dam policies are considered inefficient towards climate change.

After examining the impacts of the dam structure and operation on the environment, a new approach of understanding water management is essential to be developed. Existing dams are at high risk of failure and their lifespan is questionable due to the climatic changes. Besides the structural failure explained before, climate change will increase evaporation rates from reservoirs and thus the dam will fail eventually to meet its purpose with the lack of needed volume storage capacity.

The main impact is due to the changes in the carbon cycle in the surrounding of the dam and the global climate as well as changes in the precipitation patterns from the other. These two phenomena in parallel with the emissions from reservoirs are considered catalysts in climate changes. Moreover, the literature argues that these risks would increase further in countries that lack information and correct data for future projection scenarios.

Based on the literature and the case studies examined in this section:

- Climate change phenomenon is critical in Lebanon. Two factors are to consider: the data collection methods for climate projection scenarios and the proper assessment to be conducted. Projected scenarios can be found on the national scale and not on a particular area.
- Climate increases the risk of dam structural and operational failure.
- Impact from dam on the surrounding ecosystem and on climate is more critical to take into consideration. In fact, reservoirs, as discussed, will always catalyze the increase in emissions of greenhouse gases. Even in the presence of technologies to develop a more resilient dam structure, climate changes will maintain. Thus, tackling the impacts of dam projects on climate is more efficient.

An overview of the Lebanese water sector governance is essential to understand the procedure of implementation of dam projects in order to be able to identify mitigation mechanisms.

I will introduce the National Water Sector Strategy launched in 2010 by the Ministry of Energy and Water in order to explain the reason behind the choice of dams. Also, I will elaborate on the governance of the water sector in general to understand the process of implementation of such projects and the related stakeholders. These two mentioned sections are essential to understand the current investments of the CEDRE plan in the water sector and the chosen case study of Azzounieh dam.

2.5 The National Water Sector Strategy (NWSS) Vision

The strategy launched in 2010 by the MoEW aims to regulate the water sector in Lebanon to adjust the existing problems of scarcity and resources management and to adapt for future risks on water. It was developed by the MoEW in collaboration with national stakeholders and international donors for the implementation of the proposed projects and strategies. According to the MoEW (2010), the main goal is to boost the water sector infrastructure and develop proper management through technical and policy recommendations:

- Infrastructure initiatives such as optimization of surface water resources, artificial groundwater recharge, and increase surface storage by proposing 13 potential dam projects.
- Management initiatives by improving the operation of institutions under law 221/2000[31]

The NWSS aims for six main outcomes (MoEW, 2010):

1. Improved, sustainable and affordable water supply

[31] Lebanese law on the organization of the water sector- https://www.pseau.org/outils/ouvrages/mwe_law_no_221_date_29_05_2000_and_its_amendments_2000.pdf

2. Sustainable water resources management and allocations to priority use
3. Putting wastewater on a sustainable footing and protecting the environment
4. Profitable and sustainable irrigated agriculture
5. Strengthened sector capacity for oversight and reform implementation
6. Improved efficiency of public investment

Among the proposed strategies, the implementation of dam projects seems to be the priority of the MoEW.

2.5.1 Why the Focus on Dam Projects?

<u>Dams and political power</u>

According to McCully (2001), the ideology behind dam building was always an attempt of governments to show their adversarial and dominating relation to the environment. These practices belong to the classical political strategies to dominate and control nations. McCully elaborates on the idea by using the term “discipline nature” as a mean of governments to prove their political and hegemonic legitimacy. Hence, dam projects are not only water projects to serve the needs of the population, rather they are a political tool to control and symbolize the power of state in extracting resources and dominating the environment. The logic behind this political strategy is based on the understanding that natural resources belong to the state and it has the authority to fully exploit them for the progress of the population.

The history of this practice is rooted in the history of humankind and its relationship to water. Wittfogel (1981) argues that despotic governments in oriental societies needed to control water for irrigation and flood control and that this ancient practice exists in recent societies such as the communist regimes of the 20th century and the advocacy for water control through large infrastructure projects while they are not hydraulic societies. Looking at the political history of water in the Middle East and linking it to the argument given by Wittfogel, we can see the emphasis on the need to control water resources with the NWSS policies in 2010.

In Lebanon, the strategies to implement dam and the policies behind the investment is purely political. According to Riachi and Ghiotti (2013), loans provided by international donors, especially the World Bank would give politicians and decision-makers access to control land and water resources. The provided control creates a monopoly over decision making in the water sector and thus alternative solutions such as artificial recharge of groundwater will not be applied even if they are mentioned in the NWSS because such solutions do not open possibilities for land proclamation and resources control.

The following political strategies give also control over the population. The fact that large infrastructure is implemented without proper assessment rather than effective solutions is a practice mode of clientelist policy (Makdisi, 2007). Based on that dam projects will always be the target of decision-makers, yet an effective assessment in the design and implementation phases taking into consideration environmental issues is necessary.

Dominant discourse and neoliberalism: The cases of scarcity and IWRM (Integrated Water Resources Management)

The history of water control in the 20th century evolved to introduce the IWRM in the later 1960s (Allan, 2003). The IWRM aims for the correct use of water resources to serve the demands and needs of the people in order to maximize economic and social welfare[32]. However, IWRM seems to be a political process based on concepts that may fail to target people's needs. In that sense, Molle (2008) argues that three concepts are essential to understand to assess the impact of IWRM strategy: The Nirvana concept, natural phenomena narratives and government icons.

Nirvana concept is the ideal need developed in population and the goal needed to reach. Governments develop the target goal and the necessary need to reach it without taking into consideration the concrete aspect of the water sector. In Lebanon, IWRM evolved from the correct perception that water management has been fragmented while interventions in water sector are taking place without adequate consideration of impacts on groundwater exploitation and hydrological leakages. This first concept is thus a mean to obscure the political nature of natural resources management in order to facilitate the legitimization of certain political groups' agendas. This is translated by the unequal division of roles in the water sector. While the MoEW is responsible for general decision making, the water establishments have minimal responsibility of exploitation.

The second concept is the narratives that are used to give interpretation for a specific natural phenomenon. Governments tend to correlate negative components together to establish the needed synthesis without focusing of the real complexities of the problem. In that sense, the first example we can relate to is the correlation of water deficiency in Lebanon and the need to construct dams to increase the storage volume to be provided

[32] UNDESA (United Nations Department of Economic and Social Affairs)- https://www.un.org/waterforlifedecade/iwrm.shtml

while obscuring the real causes of deficiency, the controversy of dam structure in karstic formation and the costs behind such projects.

The third concept is the icons and models provided by governments to people. They are considered the successful outcomes of certain policies for reforms and development. Such models are approved by experts and related institutions. In Lebanon, such models are the reforms implemented in the water sector under the 221 law in 2001 and the NWSS in 2010 by the MoEW. The main conception in the country is that these two “models” should have been completely successful without the current ongoing political constraints on the national and regional scale without putting the two models under a concrete scientific assessment.

Gerlak, A and Mukhtarov, F (2013) argue that the focus on the technocratic solutions in the IWRM created a stalemate manifested in less research on the subject of water and scarcer attention of policymakers. It is true that IWRM advocates for the integration of various aspects of water management under multiple levels of governance, however, this shift from territoriality to neo-liberal approaches in management develop a greater role for the private sector and a more complex political process that makes implementation difficult. Climate change and dam projects could illustrate such cases because of the different institutions involved in the process. MoEW is for the dam constructions proposed under the CEDRE conference while several international and national actors are asking for consideration of the climate issue.

2.6 Water Sector Challenges in Lebanon

Compared to the rest of the MENA region, Lebanon is considered one of the richest countries in terms of water resources. Yet, the literature shows a clear inefficiency in water delivery due to the mismanagement of this sector. The national supply of fresh water that can be accessible to the citizens in Lebanon is very sufficient and can meet all the needs and requests of water. However, the service provision is inadequate on several levels (UNDP, 2016).

The water supply network coverage in Lebanon varies from 62% to 87% along the different regions in the country.[33] Taking into consideration the quality of the network, the maintenance, and the spatial distribution, this amount is reduced to 50%.[34] Losses vary between leakage and pipes quality. This is one of the main reasons that most of the households are dependent on private water suppliers. Also, we have a high deficit during summer because of an increase in saltwater intrusion in the coastal zones. This is due to the semi-arid climate in summer in Lebanon and its karstic characteristic (The World Bank, 2010).

The condition of the network and the quality of water are alarming in Lebanon, yet the question to be addressed revolves always around the political will of the government for rehabilitation. In fact, the World Bank estimates that the total cost for the water sector mismanagement in Lebanon is around 2.8% of the annual GDP (World Bank, 2010).

[33] NWSS- http://www.databank.com.lb/docs/National%20Water%20Sector%20Strategy%202010-2020.pdf, p.8
[34] Republic of Lebanon Water Sector: Public Expenditure Review. World Bank (2010)- http://documents.worldbank.org/curated/en/965931468265767738/pdf/520241LB0ESW0B110Disclosed0July0141.pdf

Hence, the key point lays in the decision-making in this sector and not in the effectiveness of the government in rehabilitating the network. The analysis of the network distribution and the quality of water is sufficient to understand that the problem of water distribution in Lebanon goes beyond the technical framework, politics of the management of this sector is the root concern that enables us to recognize the flaws and later on discuss equitable solutions.

Projections calculated for the coming ten years prove that the water demand will increase beyond the potential capacity. The net water balance will reach around 3,500 MCM/year in 2030 while the exploitable water level will remain constant on 2,000 MCM/year until 2030 (UNESCWA 2012). The analysis for this phenomenon concludes that the cause is both technical and political. The weak supply system is due to the deteriorated infrastructure such as the old unmaintained pipelines and the quality of water. Also, financial obstacles are aggravating the case with the lack of proper management of the water sector. Accordingly, personal private initiatives are being taken by the Lebanese population and this led to further problems in the sector creating unregulated private sources for water supply. Examples on the issue are the excessive number of illegal wells over the Lebanese territory extracting over 176 MCM/year of water[35].

2.7 Water Management under Law 221/2000

Beyond the challenges on the technical level of the water sector in Lebanon, the sector faces a lack of proper management.

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[35] State of environment report. MoE (2011)- http://www.undp.org.lb/communication/publications/downloads/SOER_en.pdf

The water sector legislation and main stakeholders' structure follow the law 221/2000[36]. The main changes are the reorganization of the already existing 22 water bodies into four regional water establishments (WE)[37]:

1. Beirut and Mount Lebanon Water Establishment– Head office in Beirut.
2. North Lebanon Water Establishment – Head office in Tripoli.
3. Bekaa Water Establishment – Head Office in Zahle.
4. South Lebanon Water Establishment – Head office in Sidon (Saida).

And giving the MoEW a key role in the management of the sector. The management of the sector is divided into three levels: National, regional and local.

On the national level, the MoEW is responsible for the supervision of the water establishments, designing, building and implementing large water infrastructures and assess the status of water resources on a national scale. The CDR channels international funding for water projects and mobilizes financing and implementing projects either from the MoF or from international funds (IFI, 2015). As for the MoE, it controls pollution and regulates activities that impact the environment and evaluate the EIA. The decision making of implementation is thus centralized between the MoEW and the CDR while the MoE has only a passive role limited to advising.

[36] Organization of the water sector law-http://www.ebml.gov.lb/english/Organization-of-the-Water-Sector
[37] NWSS-http://www.databank.com.lb/docs/National%20Water%20Sector%20Strategy%202010-2020.pdf, Article 2 and 3

On the regional level, the four WE plan and distribute water resources within their geographical areas, maintain water networks, monitor the quality of water and recommend tariffs.[38]

On the local level, municipalities manage sanitation projects and sewage disposal facilities, control pollution and conduct minor maintenance/rehabilitation within their geographical areas (Kerkezian and Farhat, 2015).

	Description of responsibilities	MoEW	WEs	MoA	MoE	MoPH	MoIM	LRA	CDR	MoI
Policy-making	• Definition of sector policy, institutional roles and structures • Enactment of legislation and regulation • Development of investment and subsidy policy	💧								
Planning and Implementation	• Establishment of long-term consolidated planning for water, irrigation and waste water • Evaluation of infrastructure and investment requirement • Water rationalization • Design, construction and operation of major water infrastructures • Funding and execution of investment programs	💧	💧	💧		💧		💧	💧	
Conservation and Resource Management	• Allocation of resources across regions, e.g., water reuse • Identification and promotion of water conservation campaigns	💧		💧	💧			💧		
Regulation and Enforcement	• Issuance of regulations • Enforcement of regulations and standards for cost recovery, service quality, water quality, and consumer relation	💧				💧	💧			💧
Operation and Distribution	• Billing and collection of tariffs • Maintenance and renewal of infrastructure		💧					💧		
Waste Water Treatment	• Operate, maintain and renew sanitation infrastructure		💧							
Control and Monitoring	• Management of all information including data collection, analysis and reporting • Implementation of service quality and contingency planning	💧								

Figure 7 Roles and Responsibilities of the Different Governmental Stakeholders in the Water Sector-source: Kerkezian and Farhat (2015)

[38] NWSS-http://www.databank.com.lb/docs/National%20Water%20Sector%20Strategy%202010-2020.pdf,Article 4

CHAPTER III

THE EIA: DEFINITION AND CRITICAL ASSESSMENT WITH REGARD TO DAM'S IMPACT ON CLIMATE CHANGE

Based on the previous chapter, the implementation of dam projects in Lebanon is centralized between the MoEW and the CDR. Also, the funding for such projects is directly channeled between the CDR and international donors. However, a necessary step for dam projects implementation is the EIA, evaluated by the MoE. Dam reservoirs impact climate and this should be addressed in the EIA.

This chapter will define the general EIA, the Lebanese EIA and explore the different possible strategies to integrate climate change component in the process.

3.1 General EIA Definition and Procedure

An Environmental Impact Assessment (EIA), is both an administrative procedure and a technical study, prior to the completion of a project. It is defined as a "planning process used to predict, analyze and interpret significant environmental effects of a proposal"[39]. According to Caldwell (1988), the EIA is a tool that was developed under environmental policies to protect the public and the environment from potential risks of implemented projects. Following this, the development policy of the EIA worldwide was

[39] "Environmental Impact Assessment as a tool for environmental management" by Shukla. S-From *Geomorphology and Environmental Sustainability* pp. 239

based on planning theory, technology and risk assessment and objectives related to environment sustainability.

Thus, the effectiveness of the EIA system is assessed in the influence of decision-making to change the environmental management conditions. Based on that, EIA should be a long term strategy to reduce the implementation of projects which have significant impacts on the environment in order to mitigate risks as well as future monitoring and mitigation costs.

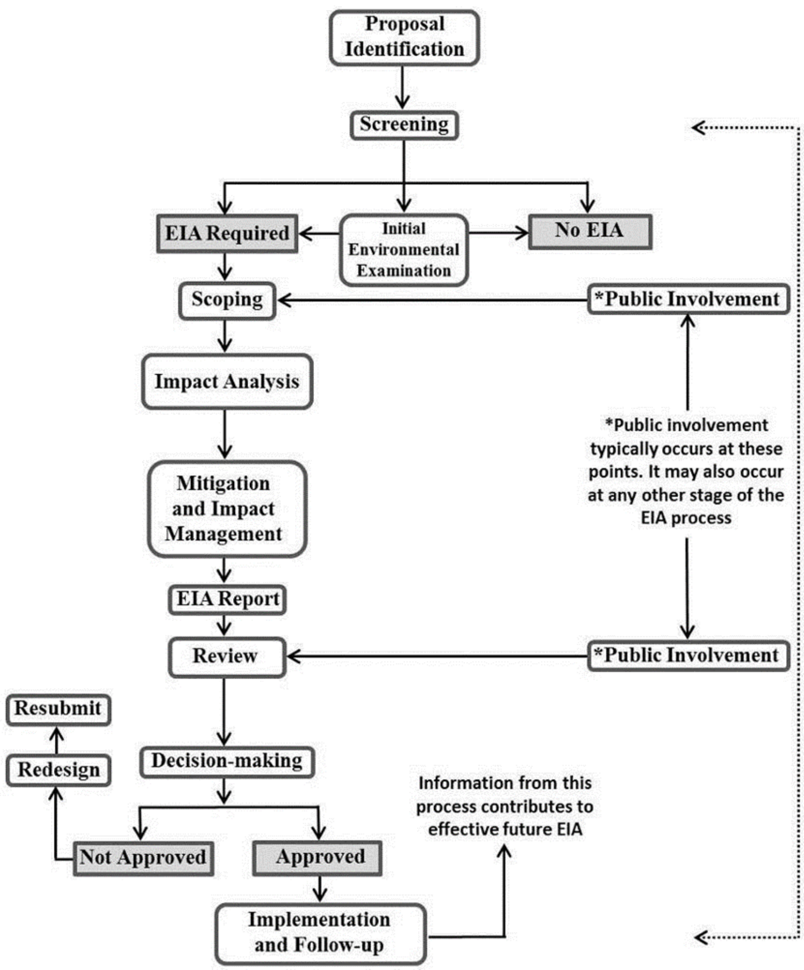

Figure 8 Generalized EIA Process Flowchart-source: UNEP (2002)

The steps of an EIA consists of the following:

The concerned authority identifies the proposal of the project to be implemented. This step is called screening; the initial environmental examination that either requests EIA or not.

In case an EIA is required, a scoping step is necessary. It is the first framework of the EIA that will be conducted at each stage later on and describes the future EIA detailed requirements. Public involvement is required at this stage for approval on the steps.

Impact analysis is then done in order to evaluate the socio-economic and environmental potential impacts of the proposed project and identify alternatives. Following this, mitigation measures should be defined to reduce those impacts.

Impact management is the next step to prepare the strategies for addressing mitigation measures and other risks (failures/natural disasters).

The EIA report is prepared based on all the previous steps; it is a comprehensive document that contains all key components. This step also involves public participation in order to review and approve the EIA points.

The final step is reviewing and licensing from the designated authority again. It is a step to determine whether the project should get final approval or not. If there is rejection, the EIA report should be revised again or amended (steps might include a change in design or location).

3.2 Climate Change Integration in the EIA

According to the IPCC report synthesis (2014), mankind's activities influence climate is critical and studies reflect the highest amount of greenhouse gases emissions in history during the last half-century. Based on this evaluation, it is necessary for policymakers to address the climate issue to adapt to the changes happening and to mitigate future risks and impacts on the climate. Thus, the integration of climate change as main component in the EIA process became a necessity for future development projects. Two international bodies introduced the role of impact assessment in international climate change agreements: The United Nations Framework on Climate Change Convention (UNFCCC)[40] and the Kyoto Protocol (Sok et al., 2011).

The first addresses the issue from a global scale in the sense that all contracting parties; i.e. countries and international bodies accepting the climate change synthesis of the IPCC should hold responsibilities to minimize the effects on all sectors through adaptation mechanisms and mitigation processes.

The second targets in detail each contracting party based on the status of each one. Some parties shall strive to implement policies and measures to minimize the effects of climate change for example and others shall focus on the reduction of emissions from projects that contributes to climate change.

Worldwide, there is six general key approaches for addressing climate change using regulations and guidelines specific to each phase of the EIA system (Sok et al, 2011): Regulations for screening issues related to climate change, guidelines that should be considered during the scoping stage, guidelines for prediction and evaluation methods including adaptation and mitigation processes, guidelines for public participation in

[40] European Commission. (2013). Guidance on Integrating Climate Change and Biodiversity into Environmental Impact Assessment. https://ec.europa.eu/environment/eia/pdf/EIA%20Guidance.pdf

environmental assessment, criteria for approval for the different stakeholders involved in the project, regulations for the implementation and follow-up phases that will enhance monitoring and enforcing climate change mitigation and adaptation measures.

3.2.1 Obstacles for Integrating Climate Change in EIA

Problems facing the integration of climate change as a main component in the EIA process varies from one country to the other, however, some obstacles are common.

The slow progress of integrating climate change in EIA is reflected in the limited number of governments that actually adjusted their regulatory framework compared to the number of government willing to move towards it (Agrawala et al., 2011).

The first obstacle for integration is the precautionary principle and scientific uncertainty. The process of EIA is built on several cumulative scientific data and thus it is not designed to support sudden changes or unpredictable events (Gao, 2017). Accordingly, governments that lack the correct and necessary amount of data related to climate change are incapable to integrate climate change as a main component in the EIA. By doing this, related institutions and stakeholders will be forced to readjust the EIA regularly to adapt finally through an empirical approach to the missing climate data. Furthermore, data collection also needs institutional capacity and a dynamic decision-making process that would impact the implementation of EIA due to the required re-amendments.

The second obstacle is the mitigation and adaptation aspects to be established under the EIA (Hands and Hudson, 2016). Accuracy in the choice of mitigation and adaptation processes is required due to the uncertain impact of certain regulatory activities. EIA is designed to evaluate and prevent future possible risks on the environment. From a climate change perspective, methods and mechanisms chosen for a certain risk may focus on one aspect of climate change more than the other. In that case, governments with climate component in the EIA process tend to prioritize the potential risks for different cases to be able to choose the correct mitigation and adaptation methods.

3.3 Lebanese EIA Law and Scheme

The Lebanese EIA legislation is based on the following laws and decrees[41]:

- Law No. 216 on April 2nd, 1993; the establishment of the MoE
- Law No. 690 on August 26, 2005; defining the role and organizing the structure of the MoE
- Law No. 444 on August 8, 2002; under the environment protection, the cost of reviewing the EIA study and the initial environmental examination
- Decree No. 2275 on June 15, 2009; organizing the different units of the MoE and defining their role
- Decree No. 8633 on August 8, 2012; project classification and the need for EIA (initial environmental examination step)

The Lebanese EIA follow the same procedure as the general one.[42] The MoE after registering and screening the application of the proposed project, within 15 days decide if the projects need EIA or not. The owner of the project then does EIA scoping report and

[41] Fundamentals of Environmental Impact Assessment- http://www.undp.org.lb/stores/profiles/vacatt/1465.pdf
[42] Ibid 38

registered at the MoE. If the decision of the ministry is negative, the owner shall prepare a new EIA scoping report. If there is approval, the owner shall prepare the EIA report based on the components delivered in the scoping and submitted back to a technical EIA unit in the MoE for approval. Upon approval, the owner is held responsible for the proper implementation according to the EIA. Informing public concerned stakeholders shall be done in the scoping step and again in the EIA report step.

3.3.1 Limitations of the Lebanese EIA with Regard to Dams and Climate Change

Several limitations exist in the current EIA procedure in Lebanon. Increased bureaucracy and overlap of duties between the institutions decrease the efficiency of the process. In fact, EIA does not replace the authorities/institutions that give permits and licenses (El-Fadel et al., 2000). In the case of dam projects, the decision making for implementation is centralized within the MoEW. For instance, the EIA of Bisri dam emphasizes seismic risk, risk of damaging the ecosystem and climate change, however, the implementation is ongoing without proper environmental management plan to reduce these risks or take into consideration alternatives[43]. The overlap of duties between institutions create as well a week law enforcement from the MoE on the correct implementation or not of the EIA. Even though penalties exist for not following environmental management plans that would reduce the risks[44], however, projects such as Bisri dam are still being implemented. Also, the amendments of the EIA are not flexible due to the dependency on

[43] Greater Beirut water supply augmentation project environmental and social impact assessment by CDR- http://documents.worldbank.org/curated/en/182961468054232421/pdf/E45760P12518400Box385237B00PUBLIC0.pdf
[44] Law No. 444/2002-Chapter 6, article 58- http://www.legallaw.ul.edu.lb/LawArticles.aspx?LawArticleID=986313&LawId=244662&language=ar

international donors for project implementation (El-Fadel et al., 2000). Thus, the procedure of integrating climate change component in the EIA would take lots of procedures and legal frameworks to address, mainly because the main priority of international donors is tackling scarcity before raising the concerns about climate change.[45]

[45] Dublin statement on water and sustainable development - http://www.wmo.int/pages/prog/hwrp/documents/english/icwedece.html

CHAPTER IV

METHODOLOGY

Based on the literature review done previously, future dam projects impact the climate through different processes happening within the reservoir. Even if law enforcement is weak in Lebanon, the integration of climate change component in the EIA is considered a major step to implement properly dam projects without raising future impacts on the climate.

The CEDRE conference resulted in 11 BU$ investments for infrastructure projects in Lebanon. Among the total budget, 10.8 BU$ are loans from international donors and countries.[46] The largest loan (4BU$)[47] is from the World Bank, the pioneer of the IWRM (Integrated Water Resources Management) program in the World. The World Bank assisted the Lebanese Ministry of Energy and Water in reviewing the country's ten year National Strategic Plan for Water starting 2000 (MoEW, 2010). Drawing on a multi-stakeholder process, it also helped launch the preparation of a national IWRM plan within the Lebanese reconstruction process[48]. Among 266 projects to be implemented from the CEDRE investments, 124 are water and irrigation projects[49] which is around half of the projects (46.6%).

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[46] Reuters- https://www.reuters.com/article/us-lebanon-economy-france/lebanon-wins-pledges-exceeding-11-billion-in-paris-idUSKCN1HD0UU
[47] Ibid 43
[48] Global water partnership- https://www.gwp.org/en/About/more/news/News-and-Activities/News-and-Activities-GWP-Mediterranean/Contributing-to-IWRM-and-WSS-plans-in-Lebanon-and-Egypt/
[49] CEDRE capital investment- http://www.cdr.gov.lb/study/cedre/cedrelist.pdf

Among the water and irrigation projects, we have 32 dam related projects and around 18 new dams to be designed and constructed.[50] In the joint statement of CEDRE signed on the 6th of April 2018, the human and financial resources are allocated to the High Council for Privatization and Partnership.[51] The council was established in 2000 under the 228 law for privatization and assumed private-public partnership (PPPs) functions in 2017 under law 48.[52] Among the dams' projects, the council published in March 2018 the launching of (HCPP, 2018):

- El Bared Dam
- Ain Dara-Azzounieh Dam
- Maaser el Chouf Dam

The joint statement of CEDRE prioritized the Lebanese government's vision of "Increasing the level of public and private investment" and the only article addressing an eco-friendly vision was article 10: "Private investment in a sustainable way".[53] Also, claiming that "the implementation of water code is crucial".[54] The article does not address the climate change problem in Lebanon, a "sustainable way" is a very vague terminology that does not imply any consideration for the necessity of climate change adaptation in the infrastructure

[50] Ibid 46
[51] CEDRE joint statement, article 9- https://www.diplomatie.gouv.fr/IMG/pdf/cedre_statement-en-_final_ang_cle8179fb.pdf
[52] Water governance in Lebanon- https://www.gwp.org/globalassets/global/gwp-governance-microsite/materials-and-resources/lebanon-report-en---final.pdf
[53] CEDRE joint statement, - https://www.diplomatie.gouv.fr/IMG/pdf/cedre_statement-en-_final_ang_cle8179fb.pdf
[54] Ibid 50

projects to be implemented. Moreover, the listed dam projects do not address the issue as well in the description.

4.1 UNDP Guidelines Regarding Climate Change

In September 2014, the UNDP climate change unit in Lebanon developed general guidelines for all sectors on how to integrate climate change in the EIA. The following overview is necessary to determine what factors I will work on.

The strategy is to raise key considerations and key questions related to climate change impacts and processes in the different steps of the EIA process. The different steps are screening, scoping, data collection and assessment, and decisions/recommendations.[55]

In the screening step, experts must determine if climate change should be taking into consideration or not in the EIA process based on the nature of the project, its lifetime and climate-related parameters that might be raised; **"would implementing the project be likely to have significant effects on climate change?"**

In the scoping step, climate change is considered in relation to design criteria, ecology, physical factors, socio-economic issues, cumulative issues associated with climate changes for the lifetime of the project and predictions of uncertainties. At this stage, the components to tackle are identified following the question **"what climate variables and elements of the project need to be assessed?"**

[55] Guidelines on integrating climate change into environmental impact assessments- http://climatechange.moe.gov.lb/viewfile.aspx?id=219

For dam projects, and following the literature, mitigation should be prioritized over adaption because their impact on climate is more significant than their vulnerability to climate change. Following the guidelines of the UNDP, the main concerns I chose for dam projects are related to direct greenhouse gases emissions. The key questions at the screening and scoping level are the following:

1. Will the proposed project emit carbon dioxide (CO_2), nitrous oxide (N_2O) or methane (CH_4) or any other greenhouse gases part of the UNFCCC[56]?
2. Does the proposed project entail any land use, land-use change or forestry activities (e.g., deforestation) that may lead to increased emissions?

The above key questions are related to the direct emission of greenhouse gases. However, they should be addressed taking into consideration the timeline of the project. The changes in the surrounding area as in the land-use and human activities can vary the rate of emissions over the life span of the dam. Thus, even if the preliminary assessment of the proposed project shows low emission rate in accordance with the international standards, these questions should be raised at different times during the operation of the dam.

The next step to focus on is identifying the indicators to work on is data sources. The general guidelines provide options such as; regional climate change projections and project-specific climate change modeling. Both are perfect to predict the emissions of greenhouse gases from dams however, the accurate meteorological and hydrological data in Lebanon is limited. For instance, the IPCC developed methodologies to predict the future emissions of

[56] European Commission. (2013). Guidance on Integrating Climate Change and Biodiversity into Environmental Impact Assessment. https://ec.europa.eu/environment/eia/pdf/EIA%20Guidance.pdf

greenhouse gases in the phase of construction of any project and its lifetime.[57] Such methodology to follow and include in the EIA in Lebanon seems not effective due to the lack of data.

Finally, the guidelines focus on main issues to take into consideration in data collection and the EIA process; "**trends in key indicators over time"** (are the processes impacting climate continuing or might change in the life span of the project?), "**thresholds/limits"** (the EIA may determine whether a certain process is already at its maximum as an alarming criteria to stop the project) and "**key areas that may be particularly adversely affected by the processes"** (protected/classified areas).

As for the recommendations articulated, mitigation measures can be the "**consideration of construction materials that reduce emissions"** or "**planning possible carbon off-set measures"** such as tree planting.

Dam reservoirs impact the climate through emissions of greenhouse gases. Eutrophication is the process responsible for such emissions and it follows the lifetime of reservoirs.

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[57] IPCC TIER methodology-
https://www.ipcc.ch/site/assets/uploads/2019/05/01_2019rf_OverviewChapter.pdf

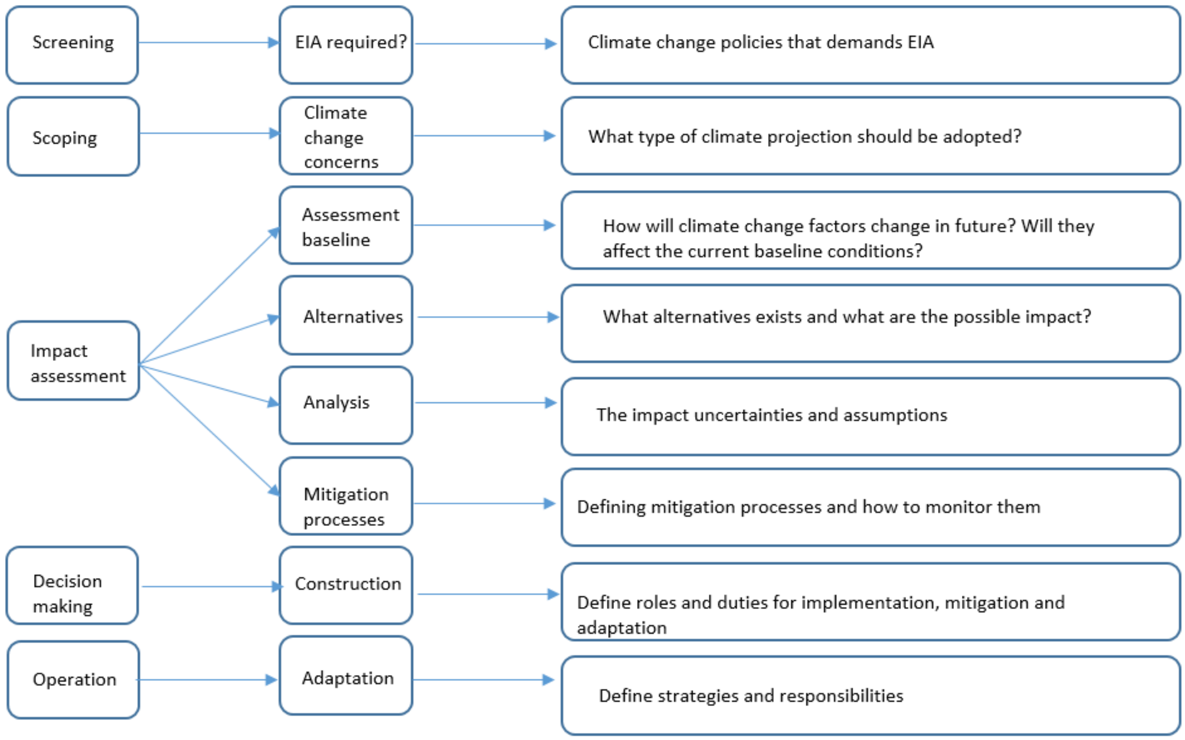

Figure 9 Scheme of UNDP guidelines for the integration of climate change in EIA-source: UNDP climate change unit Beirut, Lebanon.

4.2 Criteria to Assess Water Quality in Reservoirs

Based on Carlson's guidelines (1996), indicators on each criterion to be as follow:

TSI	Chl	P	SD	Trophic Class
< 30—40	0—2.6	0—12	> 8—4	Oligotrophic
40—50	2.6—20	12—24	4—2	Mesotrophic
50—70	20—56	24—96	2—0.5	Eutrophic
70—100+	56—155+	96—384+	0.5— < 0.25	Hypereutrophic

Figure 10 Carlson's water eutrophication guidelines (1996)

- Chlorophyll A is the photosynthetic pigment that causes the green color in algae and plants. The concentration of chlorophyll a present in the water is directly related to the amount of algae living in the water.
- Phosphorus is an essential element for plant life, but when there is too much of it in water, it can speed up eutrophication (Bennett et al, 2001)
- A Secchi disk is an 8-inch (20 cm) disk with alternating black and white quadrants. It is lowered into the water of a lake until it can no longer be seen by the observer. This depth of disappearance, called the Secchi depth, is a measure of the transparency of the water. Transparency can be affected by the color of the water, algae, and suspended sediments. Transparency decreases as color, suspended sediments, or algal abundance increases.

4.3 Eutrophication Numerical Modeling

Sperling (2013), argues that the morphometry of reservoirs is linked to the water quality and thus to the eutrophication process. One of the most significant morphometric parameters for describing and predicting the functioning of the aquatic environment is the relative depth. Morphometry of lakes and reservoirs is the physical features related to the shape and dimensions. The morphometry of a reservoir affects its temperature and the circulation flow of water.

Although several mathematical models were developed to link all morphometric features to the development of eutrophication, we will focus here on the study of Sperling to give an example of criteria linked to the reservoir structure itself and prediction of eutrophication. Already developed mathematical models can be applied as well to predict the process.

The study focuses on the relative depth of reservoir (percentage relationship between the maximum depth of the reservoir and its area), through the following equation:

$$Z_r = 50 * Z_{max} * \frac{\sqrt{\pi}}{\sqrt{A_o}}$$

Z_r: relative depth of reservoir

Z_{max}: maximum depth of reservoir

A_0: Area of the reservoir

The study on 700 water bodies either natural lakes or reservoirs in Brazil showed a positive correlation between the relative depth and eutrophication process. The development of eutrophication is closely related to the circulation pattern of the lake or reservoir. Aquatic systems with high relative depth are not able to circulate completely which indicates that the oxygen supply to the bottom of the reservoir is not adequate. Most water bodies have a relative depth less or equal to 2%.

4.4 Numerical Prediction of Greenhouse Gases Emission

Modeling for greenhouse gases emissions from surface of water are also available in relationship to the characteristics of the reservoir. Pighini et al. (2018) developed a mathematical model to measure the near-surface dissolved concentrations of CH_4 and CO_2 from 40 lakes in Alpine areas to estimate the potential of emissions.

Comparing the results to the average dissolved amount of these gases in water surface, the study concludes that the lakes chosen act as a sources of greenhouse gases to the atmosphere and thus contribute in the climate change process. The mathematical model developed calculates the concentration of the gases through a logarithmic formula as follows:

$$\log(CH_4 + 1) = -0.22 + 1.02 * \log(\text{Temperature} + 1) - 0.52 * \log(\text{Depth} + 1).$$

$$\log(CO_2 + 1) = 2.37 - 3.52 * \log(DO + 1) - 0.81 * \log(\text{Elevation} + 1).$$

DO: Dissolved Oxygen [0-100%]; high level (close to 100%) indicates good water quality.

The model can be applied to our case study to predict the amount of greenhouse gases emission from the future reservoir if the baseline data is sufficient. Average CH_4 and CO_2 surface dissolved concentrations amounted to 1.10±1.30 and 36.23±31.15 µmol L^{-1}, respectively.

CHAPTER V

CASE STUDY ANALYSIS

5.1 Dam Location and Site

El-Azzounieh dam is among the dam projects listed by the NWSS under CEDRE investments. It is located on the Damour river between the two localities of Ain Dara and El-Azzounieh. An agreement done between the Ministry of Energy and Water - Directorate General of Water Resources and Electricity jointly with GICOME - Antoine SALAMÉ & Associates Sarl to conduct design studies.

The Azzounieh dam is planned to be located in the El-Azzounieh valley south-west of Ain Dara village at an altitude of 1,050 meters. The current basin of El-Aazzounieh is cultivated on its major part by fruit trees where several water sources ensure the irrigation of these lands. The current access to the dam site is the Mdeirej - Ain Dara road. Moreover, the current road to the locality of Bmahray allows access to the downstream area of the dam. The dam to be constructed will be in between two water springs: Safa and Barouk. A major risk facing the springs in the area is that gauging stations do not provide accurate measurements of the discharge flow. Moreover, measurements are done usually in the wet season and this value does not represent the annual average discharge.[58] Taking this fact into consideration the location of the dam seems to be critical to meet its purpose of supply for the Aley area.

[58] Assessment of groundwater resources of Lebanon-UNDP (2014)

Also, the area of Ain Dara has a protected forest of Cedars that is at risk from such construction. Conservation of the forest is based on the government decision No. 127/1 in 1991.[59]

[59] State of environment report. MoE (2011)-
http://www.undp.org.lb/communication/publications/downloads/SOER_en.pdf

Figure 11 Location of El-Azzounieh dam-source: http://www.lebanonclean.org/contact-us.html

5.2 Objectives

The dam aims to collect water from rainwater and snow melting runoff, and existing water bodies in the watershed with an average storage capacity in a normal year of around 4.1 million m^3. The dam is expected to reduce the drinking and irrigation water deficit in Aley (will supply 86 towns in Aley by gravity and driven pressure conveyance systems), enforce the sustainable development of the area and improve as well the infrastructural services of the region.

Moreover, the dam will eliminate the need to drilling groundwater wells. The project involves the construction of the dam and its reservoir and different project components mainly water conveyance systems (potable water and irrigation water networks including new water tanks) and if need a water treatment plant for making water potable before distribution.

5.3 Related Institutions

The major authorities and institutions that are involved in this project include:

- The Municipality of Aley
- Kaem Makamiyet Aley
- The Municipality of Ain Dara, the Mayor of Azzounieh and the Mokhtar of Bmehray
- The Ministry of Environment (MoE)
- The Ministry of Energy and Water (MoEW)
- Directorate General of Water Resources and Electricity

- The Council for Development and Reconstruction (CDR)
- The Ministry of Public Health (MoPH)

Also, public participation of the community representatives of the area was in form of consultations to provide information about the project and ensure that the views expressed are taken into account at the scoping stage of the EIA. Among the attendees, political figures such as mayors and heads of municipalities and citizen representatives. Information about the project and the objectives were given by consultants and representatives of the listed above ministries, while concerns and opinions were taken into consideration form other attendees. The dynamics and the role of all the concerned stakeholders are beyond the scope of my analysis, however, they are presented in detail in the scoping report[60].

5.4 Dam Type and Specifications

The planned dam is an earth fill dam (46m high and 300m long). The body of the dam will be constructed for its two downstream and upstream parts of limestone refills that are present onsite. A watertight barrier formed of a tightly packed volcanic tuff core with plastic concrete wall will be built inside the body of the dam.

The dam aims to collect water from rainwater and snow melting runoff, and existing water bodies in the watershed with an average storage capacity in a normal year of around 4.1 million m^3.

The area of the proposed reservoir will be around 280,000 m^2. The water levels in reservoir are expected to reach a maximum of 1,102 meters above sea level. Water will be mainly

[60] Scoping EIA report of Azzounieh dam project

collected from rainwater and snow melting runoff. Consequently, the average storage capacity of the dam’s reservoir in a normal year will be around 4.1 million m^3.

Dam and Reservoir Characteristics	
Highest water level	1,102 masl
Reservoir Catchment Area	28 ha
Rainfall per year	1,250
Normal capacity of the reservoir	4. 1 Mm^3
Type of Dam	Embankment dam (volcanic tuff core with plastic concrete wall)
Crest length	300 m
Crest width	10 m
Height	46 m
Maximum height (Highest attitude above ground)	53 m
Upstream slope	2H/1V
Downstream slope	2H/1V
Embankment materials	735,000 m^3
Flood spillway	350 m^3/sec

Figure 12 El-Azzounieh dam reservoir characteristics-source: Scoping EIA report

Earth fill dams are most likely to be vulnerable to climate change: increased erosion, more extreme fluctuations in water levels, changes in vegetation and prolonged drying during hot weather could combine to exploit existing weaknesses that may exist in the dam design or construction (Li et al, 2018). The form of non-erodible structures (concrete, masonry, etc.) is unlikely to be particularly vulnerable to climate change, but there are exceptions, particularly at dams where existing climatic variation is known to cause problems associated with cracking or joint movement. Overflow structures and spillways may also be vulnerable due to increasing frequency and size of flows and catchment impacts that might increase debris and vegetation.

5.5 The Impact from Earth Fill Dam Reservoirs

Literature associates the major impacts of dams on climate to the hydropower dams due to the thermal and turbine operations in these structures. However, earth fill dams are as well contributing in the impact on climate through the emissions of greenhouse gases in the atmosphere (Prairie et al, 2018). The emissions are outcomes of the change in landscape and in the ecosystem, the evolution and chemical changes in the reservoir and the hydrological changes that happen after the construction of the dam. Blocking rivers would create an unnatural stagnant lake that will most probably deteriorate the ecosystem. The excess water is pushed onto the banks (higher edges of the dam reservoir) which are often covered in plant life. These plants are then in lack of oxygen and die. Bacteria in water will decompose these plants and this will contribute to the creation of carbon dioxide and methane. The generation of methane is considered more harmful to the atmosphere because methane is more potent than carbon dioxide (IPCC, 2014). Aquatic surfaces have a major contribution in the processing of the carbon cycle in the atmosphere (IPCC, 2013). Accordingly, artificial reservoirs will destabilize the already existing natural carbon footprints; the amount of carbon dioxide released. From a climate perspective, assessing the anthropogenic impact of reservoir greenhouse gases emissions should account only for the net changes in greenhouse gases fluxes to the atmosphere resulting from the landscape transformation of a river into a reservoir. However, as mentioned the chemical evolutions in the reservoirs are well contributing to the process.

Although natural water bodies contribute to the carbon cycle, dam reservoirs are not similar. The establishment of dam would produce changes in carbon cycling because of the mixture of greenhouse gases sources with already existing ones and new ones that are not part of the natural ecosystem of the area.

5.6 Scoping and EIA Analysis

Besides the description of the project, the scoping report provides a description of the environmental baseline of the project and the potential environmental impacts. In the section concerning meteorological and climate data, the report claims that data climate "will be investigated and collected in shape of a statistical distribution of weather conditions over a period of time". As literature proves, climate change is represented by the random and extreme changes in weather patterns. Thus, the baseline assessment is not efficient because the data used might change over the lifetime of the project.

The scoping report has several problems to address while taking into consideration climate change:

Based on law 115/2019 on the rectification of the Paris Agreement, there is a national obligation on Lebanon to reduce emissions of greenhouse gases. The EIA of the project claims that the dam may induce the generation of greenhouse gases without developing an appropriate environmental management plan to mitigate the risk.

The solutions proposed by the EIA are either the do-nothing scenario or the future water management strategies such as groundwater exploitation, the use of treated wastewater and the reduction of non-revenue water losses. These solutions do not target the process of eutrophication directly and thus won't eliminate the emissions of greenhouse gases. Such propositions would regulate the operation of the dam on a short term basis and would increase the cost of maintenance and monitoring.

There is no appropriate study and indications during the operation life of the dam to assess the emission rates of greenhouse gases and thus the necessity of mitigation processes.

Table to answer the questions in order according to the tangible indicators chosen:

Key issues to address in scoping level	**Scoping based on the two chosen indicators**
"Would implementing the project be likely to have significant effects on climate change?"	High risk of eutrophication and damaging the surrounding ecosystem.
"What climate variables and elements of the project need to be assessed?"	Dimensions of the dam and site location.
"Will the proposed project emit carbon dioxide (CO_2), nitrous oxide (N_2O) or methane (CH_4) or any other greenhouse gases part of the UNFCCC?"	Risk of CO_2, N_2O and CH_4 emissions.
"Does the proposed project entail any land use, land-use change or forestry activities (e.g., deforestation) that may lead to increased emissions?"	Deforestation of the surrounding area for dam construction site accessibility and logistics.

Key issues to address in scoping level	**Scoping based on the two chosen indicators**
"**Trends in key indicators over time"**	Degradation of the protected area according to the National Physical Master Plan of the Lebanese Territory.
"**Thresholds/limits"**	The current report does not provide tangible thresholds or limits
"**Key areas that may be particularly adversely affected by the processes"**	Protected area in risk
"Consideration of construction materials that reduce emissions"	The current scoping report does not present such alternatives
"**Planning possible carbon off-set measures"**	Not available

Figure 13 Integration of climate change component elements

5.7 Calculations

Morphometry of reservoirs along with mathematical modeling of the potential emissions of greenhouse gases from fits the criteria of integration of climate change into the EIA and answers the relevant questions raised in the general guidelines of the UNDP climate change unit.

The main step to raise the two factors is the scoping of the EIA process. It should be addressed in the process of screening and initial environmental examination. Accordingly, if these questions are not answered properly, the process of EIA should be reviewed for approval.

Based on the numerical prediction of eutrophication mentioned earlier, and using the following equation of the relative depth:

The Azzounieh dam is an earth fill dam, its mean depth is around 80% of its maximum depth (Chapman, 1992). Based on the scoping report, the maximum depth of the dam is 52m and thus the mean depth is 41.6m.

Using the equation of the relative depth, Azzounieh dam has a relative depth of 6.96% which is considered very high and this predicts a high risk of eutrophication. Moreover, even if the literature argues that healthy water bodies have a maximum relative depth of 2%, this threshold should take into consideration other surrounding factors as well. Human activities generating agricultural waste and detergents, for example, will catalyze the process of eutrophication and thus the increase of greenhouse gases emissions. Thus, following this equation for prediction should include a limit below 2% depending on the surrounding activities of the dam.

Based on the maximum relative depth in reservoirs, the Azzounieh dam should have a maximum height of 15m. However, with such design criteria, the storage volume would not be efficient to meet the objectives of the dam. The height proposed in the design is 46m, thus the new storage volume would be approximately the third of the proposed one (4.1 Mm^3).

Following the table presented in the previous chapter, the current scoping report of the Azzounieh dam does not include climate change components. Having a numerical indicator to predict eutrophication answers the threshold to be respected in the UNDP guidelines.

For the prediction of future CO_2 emissions based on the mathematical log model equation, a lack of data concerning the average dissolved oxygen of lakes in the area was a constraint to conduct the calculation for the case study. However, according to Houri and El Jeblawi (2007), the water temperature in the Damour river is around 25^{o}C and thus calculations for the prediction of future CH_4 are possible. Based on the mathematical log model, the average dissolved CH_4 in the water would be 1.28 μmol L^{-1} which is in the average range (1.10±1.30 μmol L^{-1}). With a high risk of eutrophication, this average emission prediction could increase and change over the life span of the dam.

Although the eutrophication process occurs as lakes age through geological time scale[61]; which is beyond human life activity, however, the establishment of artificial reservoirs shows different correlations. According to Wurtsbaugh et al., (2019), the fact that artificial reservoirs limit the proper circulation of water along with human activities surrounding the dam will increase the rate of eutrophication. The study over five years in the USA and Europe indicates that water bodies with limited circulation present a higher level of nitrogen and phosphorus; the main nutrients for algae and the main cause for the start of the process of eutrophication. Therefore, even if the natural process of eutrophication is beyond the life span of any dam structure, literature and case studies show rapid progress of eutrophication that needs to be controlled.

[61] Lake eutrophication- https://www.des.nh.gov/organization/commissioner/pip/factsheets/bb/documents/bb-3.pdf

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

Climate change is affecting water resources all over the world with changes in precipitation patterns, rainfall rates, and extreme weather conditions. In Lebanon, this is observed in the shortage of water resources. Moreover, this problem is increasing with the challenges facing the water sector management. Under the NWSS and CEDRE investments, water infrastructure projects are planned to be implemented to face these obstacles. However, the literature review shows that dam projects impact more the climate and if the implementation does not follow a proper assessment the effect is even more critical. In order to address the issue, an overview of the water sector management shows that the EIA is the tool to focus on. Even if the role of the MoE in the water sector is practically minimized for advising and the implementation of projects is centralized between the MoEW and the CDR, integrating climate change in the EIA would be the first step to mitigate the emissions of greenhouse gases and thus limit the negative impacts on the climate.

This thesis has discussed the addressed challenges of integrating climate change in the EIA assessment. In the first chapter, a literature review on climate change situation in Lebanon and the problems facing the water sector was developed to understand the impact of dam reservoirs on climate. In the second chapter, I presented an assessment of the EIA procedure regarding the environmental evaluation of dam projects to be able to develop the right methodology of integrating climate change in the procedure. I based my approach on the UNDP climate change unit guidelines and focused on the scoping step of the EIA to include tangible numerical indicators to predict eutrophication and greenhouse gases emission rates. The investigation of these guidelines shows that key relevant questions should be addressed not only at the screening level but also throughout the life of the project. In fact, potential future changes in the surrounding human activities and in the operation of the dam itself can be a catalyst for the impact. Following the investigation of these guidelines and the general Lebanese EIA framework, I chose to focus on the scoping step because it is the initial step for approval or not of the EIA by the MoE. The case study of the Azzounieh dam according to its scoping and EIA report will face challenges of eutrophication and the changes of the ecosystem in the surrounding such as deforestation for construction will increase the process as well. Defining tangible indicators to measure eutrophication is necessary in that sense to predict the rate of the process before construction. Results of morphometric analysis of the dam showed a high risk of eutrophication, even without considering the catalysts from the surrounding site location. Accordingly, recommendations would be to include numerical indicators and standards in the EIA at the scoping level to be respected as well throughout all the process of the EIA. The Azzounieh dam EIA should include for that sake more efficient mitigation scenarios. The literature on dam impacts on climate shows that such mitigations include changing in the design (eco-friendly material for construction) or changing in the site location to reduce deforestation.

The main findings are the rapid rate of the eutrophication process in the Azzounieh dam and the lack of proper environmental management plan to reduce the impact on climate throughout the life span of the project. Also, morphometric elements such as relative depth are a tool to rethink the design of the dam for better storage capacity.

The integration of climate change in the EIA is essential for future infrastructure projects as well. In fact, CEDRE investments advocate for the boost of infrastructure through sustainable projects and this includes the climate component. Also, institutional reforms are requested[62] and decentralization of decision making in the water sector would be an initial step for this.

Addressing climate change in EIA is also beneficial from an economic basis. The cost of monitoring and rehabilitation of water infrastructure is increasing due to the negligence of the climate component. Implementing projects without an accurate assessment of risks is observed (Bisri or Jannah dam) and the cost of construction, monitoring and reparation are increasing. The implication of water-related projects also impacts the general economy of the country. Such effects on the economy in parallel with the rise of climate change pushed several countries to abandon dam projects as a solution for water supply, flood management and energy production[63].

Integrating climate change in the EIA is essential to reduce the future impacts on climate but also reduces the risks on the operation of dams. Through providing detailed predictions, a more accurate design can be implemented for more adequate water storage. Such analysis and the potential dam detailed design should be essential in the EIA at the scoping level to

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[62] CEDRE joint statement, article 7- https://www.diplomatie.gouv.fr/IMG/pdf/cedre_statement-en-_final_ang_cle8179fb.pdf

[63] American Rivers and International Rivers Network- https://www.internationalrivers.org/sites/default/files/attached-files/beyonddams.intro_.overview.pdf

make the procedure more efficient in terms of decision making. Also, this would allow developing accurate mitigation and environmental management plans later on.

The choice of the two numerical indicators was based on the available literature and data. However, morphometric analysis of reservoirs and lakes goes beyond just the relative depth. For instance, the literature argues for research about different factors such as the volume, the area, retention time and watershed criteria to be included in mathematical modeling for accurate predictions of emissions.

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