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WATER-FOOD-ENERGY NEXUS: A MULTI-CRITERIA DECISION EVALUATION OF POLICY INSTRUMENTS IN THE LITANY RIVER BASIN

by

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AN ABSTRACT OF THE THESIS OF

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Title: Water-Food-Energy Nexus: A Multi-criteria Decision Evaluation of Policy Instruments on the Litan River Basin

In order to investigate the decision making process currently taking place inside a Water-Energy-Food Nexus framework, a study was carried to evaluate policy instrument on the Litany River Basin. The MCDA method has been proposed in order to combine qualitative and quantitative data. This is particularly important in a developing country context where data availability is a major concern. Eleven policy instruments concerning the agriculture sector were ranked in order of importance under five sensitivity analysis evaluations. The first sensitivity analysis puts forward the Cost criteria and the CDR WWTPs were ranked first. The second puts forward the Energy criteria and modern irrigation techniques were ranked first. The third puts forward the Water criteria under which again the WWTPs were ranked first. When the Food criteria were amplified the Water storage option was ranked first. And finally, when the Social criteria were amplified the modern irrigation techniques were also ranked first. The proposed Nexus framework proved to be valuable for decision makers, it offers a system thinking approach where the WEF nexus resources are interconnected. The tool proves to be most valuable if centralised planning agency is created, where decisions about policy implementations take into consideration institutional dialogue, resources tradeoffs and synergies and social and security concerns.

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ABBREVIATIONS

AHP	Analytical Hierarchy Process
CDM	Camp Dresser and McKee
CDR	Committee for Development and Reconstruction
CLEW	The Climate, Land, Energy and Water
EDL	Electricity du Liban
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GHG	Green House Gases
GWh	Giga Watt hours
ha	Hectares
LCA	Life Cycle Analysis
LEAP	Long Range Energy Alternatives Planning
LRA	Litany River Authority
MAUT	Multi-Attribute Utility Theory
MCDA	Multi-Criteria Decision Analysis
MCM	Million Cubic Meters
MESSAGE	Model of Energy Supply Strategy Alternatives and their General Environmental Impacts
MoEW	Ministry of Energy and Water
MW	Mega Watt
PODIUM	Global Policy Dialogue Model
SMART	Simple Multi Attribute Rating Technique
WEF	Water Energy Food
WEAP	Water Evaluation and Planning system
WWTP	Waste Water Treatment Plants
UN	United Nations

CHAPTER 1

INTRODUCTION

1.1. Background

Water, energy and food have rapidly growing demands and different regional availability. The challenge is to solve a set of complex interrelated problems that are directly related to areas of water, energy and food (WEF). (Bazilian et al. 2011) In fact, there are many areas where tradeoffs and synergies between the three resources are readily identifiable. Globally, there are billion of people without access in quality or quantity of the three resources. Additionally, the three resources have deep security issues as they are fundamental to the functioning of society hence require explicit identification and treatment of their related risks. Recent research show that there has been little work focusing on how to support decision making at the water-energy-food nexus as there are few experts in all three areas. (Bazilian et al. 2011) Inter-disciplinary researcher is therefore fundamental as the three resources are closely interlinked and cannot be dealt with in isolation. In this regards, a multi criteria decision evaluation will be preformed during the course of this study to understand the complex relationship between food, energy and water and to assess a series of policy instruments that could potentially be implemented according to a set of diverse criteria.

Lebanon has always enjoyed relatively more water resources than its neighbouring countries, this is attributed to its topography that allows high rates of precipitation over its territory. (Lebanon, 2014) The country has 17 main rivers, about 2000 springs and nearly 50,650 wells. However water is distributed unevenly among regions, between seasons and sometimes difficult to harness due to steep slopes. Additionally, the use of water resources in Lebanon is approaching unsustainable levels. Drought occurrence has been frequent over the last 40 years with incidents getting closer in time. (Del Sarto 2014) In 2014, the annual rainfall level hit one of the lowest points on record, by January the average rainfall in Beirut was recorded at 237.8 mm compared to a 440 mm normally, in Central Bekaa the average was 128 mm compared to 435 mm in previous years (Del Sarto 2014). During the summer of 2014 Lebanese citizens had to relied on different adaptation measures and/or new water sources for their water demand. The current situation could be considered a preview of what it is in store for Lebanon under a climate change scenario.

Water is not the only resource under stress, energy in Lebanon faces similar difficulties. The formal sector is unable to meet the growing energy demand. Most of the energy for electricity in Lebanon is produced by Electricity du Liban (EDL). The government monopoly, controls the formal power sector and operates six thermal power plants with a net installed capacity of 2,040 MW. (Osseiran 2014) EDL also relies on hydroelectric power plants stationed on Lebanon's main rivers. Notably though, most of the installed hydropower plants (199 MW of the 282 MW) are located on the Litany river. (MoEW 2014) However EDL is unable to meet the growing electricity demands, the remaining production is either imported from neighbouring countries or produced locally by privately owned diesel generators. In result, the informal sector has been growing steadily since the last decade owning a market share of approximately 30% of the electricity produced in Lebanon.This trend forces the Lebanese citizens to pay a double electricity bill; one for EDL and the other for the private neighbourhood generator. To add misfortune to the situation the Lebanese electricity system is heavily subsidised and the governmental monopoly has been running on a deficit for many years making it unable to invest in new power plants and meet the growing demand.

The agriculture sector benefits from subsidised electricity in the sense that it makes the cost in accessing water relatively cheap. However these kind of policies like many other form of subsidies encourage unsustainable irrigation methods and groundwater pumping and consequently have strong impacts on underground aquifers. Moreover the agricultural sector in Lebanon has been undergoing diminished productivity for many years which has recently been aggravated by the

Syrian conflict. Effectively, bilateral agricultural trade with Syria and in transit trade through Syria has considerably dropped. Syrian products were cheaper as a result of being heavily subsidised by the Syrian government. Lebanese farmers reported that their production costs have increased as they have been forced to buy more expensive Lebanese or imported agricultural inputs (FAO 2015).

The access to these fundamental resources will be further aggravated by a broad range of factors including population growth, lack of effective resource management , economic development, uncontrolled exploitation of groundwater resources and urbanisation. These transformational trends are increasingly putting food, energy and water under substantial pressure and are contributing to the lack of support for societal development and the provision of necessary service. (Flammini et al. 2014)

1.2. Thesis Objective

To put matters into perspective, system thinking is often not easily translated into governmental policy making especially in Lebanon where it seems that there is little to no coordination between government bodies, even inside the same ministries (Osseiran 2015). This calls for an influential interdisciplinary approach that engages environmental concerns, the access of quality services and the prevention of negative consequences that range from social to economic to security concerns. Furthermore the proposed solution needs to engage stakeholders participation in all stages of the decision making process in order to ensure high quality assessment and response. (Flammini et al. 2014)

This study acknowledges that assessments aimed at informing decision makers in terms of strategy, planning, institutional reforms and policy interventions need to be tailored to local conditions. In this regard, this study will develop a WEF nexus assessment tool and test it on Litany River Basin in Lebanon. The Litany river represents an interesting case for the water food energy nexus, it accounts for 70% hydroelectric power being produced, it supplies a large area within the

Lebanese territory with water for irrigation and the basin is a large source of water for domestic use (Doummar et al. 2008)

Moreover, in the 1950's a plan was brought forward to implement major infrastructure work around the river, the plan sought to store water using a series of lakes, dams and canals. (Assaf et al. 2008) This plan was not fully implemented but recent initiatives have been made to revive it. The challenge of this thesis is to question the decision making process currently taking places in the Lebanese government concerning the Litany river's resource exploitation. The aim is to engage as many stakeholders in the decision making process and to incorporate system thinking into public resource planning.

The study will evaluate several policy options that can potentially be implemented on the Litany River Basin. A Multi-Criteria decision evaluation will be performed comparing these policy options under a set of criteria related to cost, energy, water, food and social. The results will be assessed and clear recommendations for policy implementation and institutional reforms will be suggested.

CHAPTER 2

LITERATURE REVIEW

2.1. WEF Nexus

There are many areas where interactions of the WEF nexus are readily identifiable. Interactions take place within the context of external global drivers, such as demographic change, urbanisation, industrial development, agricultural modernisation, international and regional trade, markets and prices, technological advancements, diversification of diets, and climate change as well as more site-specific internal drivers, like governance structures and processes, vested interests, cultural and societal beliefs and behaviours. (Flammini et al. 2014)

For instance in the power sector, thermal power plants use large amounts of water for cooling. (Macknick et al. 2011). Hydro power plants use significant quantities of land and interfere with existing water flows, sediment load, nutrient flows and water quality.(Flammini et al. 2014) Additionally a considerable amount of water is lost due to evaporation (Torcellini et al. 2003). Significant quantities of water are also required for other energy processing activities, such as refining oil products or manufacturing synthetic fuels.

In the water sector, energy is used in transportation, treatment, and distribution. About 7% of commercial energy production is used globally for managing the world's freshwater supply. (Bazilian et al. 2011) The energy is consumed to extract, purify and distribute water and after use energy is required for treating and recycling water.

In the agriculture sector 60-80% percent of total global freshwater withdrawals is for irrigation, making it the largest user of water. (REN12 2015) In arid developing countries, irrigation can account for as much as 90% of total water use. At the same time, the food production sector and its supply chain consume about 30% of total global energy (FAO 2011). It is noteworthy to mention

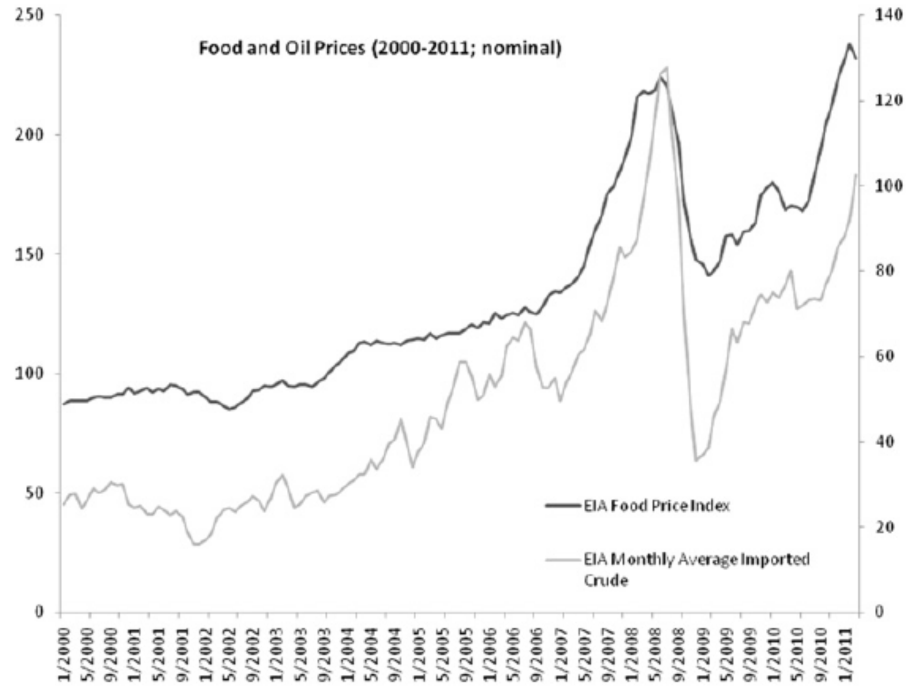

Fig 2.1 Food (primary x-axis) and oil prices(secondary x-axis) 2000–2010(FAO and EIA nominal data)

that most of the recent increase in food-related energy use occur in the post-harvest stages (Canning 2010). Energy is required to produce, transport and distribute food as well as to extract, pump, lift, collect, transport and treat water. This is best manifested in the close relationship between food prices and oil price indexes. (**Fig 2.1**) Petroleum has a significant importance in food production through fuel inputs (such as transport and cooling facilities) and products (such as fertilisers). Food products can also be inputs for energy production, biofuels generate 1.8% of the global electricity produced (REN12 2015) however policies that aim at promoting biofuels as an alternative to fossil fuels often neglect impacts on: deforestation, biodiversity, water, energy, food prices, lifecycle emissions and land use change.

2.2 WEF Areas of Interaction

In this section we will examine areas with distinguishable system boundaries for the WEF nexus, these include but are not limited to:

- Energy access and deforestation

- Biofuels from energy crops (and unconventional oil and gas) production
- Powered irrigation and food security
- Hydropower
- Water desalination for agriculture
- Resource efficient food production
- Bioenergy from degraded land

Energy access and deforestation are major issues especially in sub-saharan Africa. In Uganda, electrification rate is 9% that leaves 91% of the population without access to electricity. 93% of the energy needs of the country is supplied by wood which results in deforestation and in turn impacts the water system. The lack of electricity access slows development and, often, causes low-productivity agricultural methods. (Biswas et al. 2001) Nexus thinking needs to be deployed in such circumstances. A pilot project called the Sahara Desert Projects has been launched with the initial focus on Nexus thinking implementation in Jordan and Qatar. The project aims at making electricity generation from concentrated solar power more efficient, revegetate desert lands by growing high value crops in the desert inside saltwater-cooled greenhouses. The project will also produce freshwater for irrigation or drinking from a desalination plant, safely manage brine and harvest useful compounds from the resulting salt. (Flammini et al. 2014; Ansari et al. 2015)

Irrigation and food security is another important area where the nexus resources are directly in interlinked. The interrelation of energy, irrigation and food security has become alarmingly noticeable in many countries around the world. A well known and documented case study is the Punjab area in India, it has only 1.5% of India's land but its output of rice and wheat accounts for 11% of rice and 17% of wheat that the government purchases and distributes to feed more than 400 million Indians. (Flammini et al. 2014) The surface water resources has become increasingly scarce due to population growth in the last 50 years. In result, to meet the ever-growing demand for agriculture, industry and the population, farmers have been pumping aquifers faster than they can be replenished. The over pumping of groundwater is also directly related to the energy subsidies provided by the government to the farmer, which encourages intensive agriculture and consequent impact on underground aquifers. One option involves the use of distributed photovoltaic powered water pumps that can introduce better pricing signals. Under appropriate conditions, PV irrigation systems are becoming utilised in this area to great success. In Kenya, the Sunflower Pump was first developed in 2004, it is an effective and a simple renewable-powered irrigation device, which uses concentrated solar energy to produce steam that run a small steam engine and pump water. Small-scale irrigation systems based on renewable energy could provide a viable alternative to exhaustive manual pumping and environmentally polluting fossil fuel powered generators. An added benefit of the solar pump is that it frees children and women from the time consuming task of manually pumping and carrying water. It can also spur employment since the sunflower pump can be serviced locally. The key risk of such projects is that groundwater pumping has proved to be difficult to regulate and in the long run may have negative consequences for local and global food production. Another example is South Africa, the country has been a net importer of food from 1985 to 2008 but due to population growth and decrease in agricultural productivity it has become a net importer. Planned electricity tariff increase (31% from 2009 to 2010) affect most significantly the agriculture sector, switching to rain fed agriculture may endanger food security especially in drought periods. (South African Government 2008). It has become abundantly clear that each nexus related problem is presenting different challenges to policy makers when it comes to providing citizens with sustainable energy, food or water.

Another area where the three resources interact is hydropower generation. Hydropower meets 16.6% of the world's electricity needs bringing total global capacity to approximately 1,055 GW and has been one of the main driving forces behind the construction of 45,000 large dams worldwide (REN12 2015). Hydroelectric dams provide access to modern electricity and when associated with storage in reservoirs, contribute to the stability of the electric system by providing flexibility of dispatch and grid services. However large scale and small scale hydropower infrastructure may significantly alter the timing of stream flows as the timing of water releases is generally governed by the demand curve for electricity. The quality of water is also affected, particularly downstream where aquatic and wetland ecosystems may be negatively impacted if social and environmental impacts are not considered in the management. Large-scale water infrastructure projects may have synergetic impacts on downstream uses, including irrigation, in-stream uses, and supporting ecosystems. (Flammini et al. 2014)

A typical case of such conflict is found in Central Asia, where the Kyrgyz Republic needs to release water in the winter time to generate electricity, while Uzbekistan and South Kazakhstan need water in the summer for the irrigation schemes (World Bank 2004). Jordan presents another interesting case. The country relies on the limited water from the Jordan River and a few other river systems. Energy is needed for lifting, moving, and treating surface water, especially from the Jordan Valley. Energy imports come at significant cost, both financially and also from a foreign policy perspective (Scott et al. 2003). Energy and water pricing is another major issue. Even prior to the recent increases in energy prices, it is estimated that Jordan used 25% of its electricity, primarily generated from oil imports, to manage its limited water resources (McCornick et al. 2008).

By highlighting these interdependencies, the Nexus concept corroborates the need to view water, energy and food not as being separate, but as being complex and inextricably entwined. This, in turn, allows for more integrated and cost effective policy-making, planning, implementation, monitoring and evaluation related to the different Nexus areas of interaction. At the same time, a nexus approach to policy-making helps to reflect the broad range of views and expertise involved throughout the process, promoting dialogue between different sectors, seeing solutions to open challenges as collective efforts.

2.3 WEF Nexus Methodologies

It is clear that the interactions are both significant in scale and complexity. Creating a framework capable of abstracting these issues at appropriate levels for decision-making is a crucial step. The design of such a framework will need to be informed by detailed understanding of specific areas where the WEF nexus is apparent. (Bazilian et al. 2011) The next section will discuss some of the methodologies that are currently being used in assisting decision making within a Nexus context.

In 2011, the Bonn Nexus Conference was a milestone moment where the international community and several governments acknowledged that policies regarding water, food and energy cannot be dealt with in isolation. Most of the focus since the Bonn Conference has been on the better understanding of the inter-relations between water, food and energy policies and how these can be addressed in policy development and implementation. Since then many attempts have been made to come up with an integrated nexus methodology. At present there is no universally recognised methodology for nexus analysis which brings together both quantitative analysis and qualitative reasoning in relation to the environmental impacts of the three resources. Decision makers need improved tools in order to be better informed about trade-offs and synergies between different development and management choices, and need help with identifying options to sustainably manage the food, energy and water resources.

Rogner 2009 notes, "...most water, energy and land-use planning, decision and policy making occurs in separate and disconnected institutional entities." Likewise, the analytical tools used to support decision-making are equally fragmented (Brazilian, 2011). The MESSAGE[1],

[1] MESSAGE (Model of Energy Supply Strategy Alternatives and their General Environmental Impacts) is a systems engineering optimisation model, which can be used for medium to long term energy system planning, energy policy analysis and scenario development. The model provides a framework for representing an energy system with its internal interdependencies (IIASA (International Institute for Applied Systems Analysis), 2001).

MARKAL[2] and LEAP[3] models are most commonly used for energy system analysis. Water system planning rely on the Water Evaluation and Planning system (WEAP)[4] and water scarcity and food security planning rely on the Global Policy Dialogue Model (PODIUM)[5]. However there are some newly established tools that attempts to tackle the nexus methodology that encompass all three nexus resources. The Climate, Land, Energy and Water (CLEW)[6] is a modelling framework that was recently applied on the islands of the Mauritius to assess national energy security and GHG policy mitigation. Namely, the substitution of imported gasoline with domestic ethanol produced from sugar cane. Another case that is worth mentioning is the Life Cycle Assessment (LCA) model developed for food production profiles that delivers a degree of self-sufficiency for Qatar. Most recently the Food and Agriculture Organisation developed a methodology entitled FAO Nexus methodology that uses data that is available only on a national level and cannot be applied when the reference system is local. These and other models, lack the methodological components required to conduct an integrated policy assessment in a developing country policy context and were dismissed for the following reasons.

First of all, some of the aforementioned tools focus on one resource and ignore the interconnections with other resources and for this reason were not considered for the purpose of this research. Second, these tools offer a strategic long term evaluations and are not beneficial for direct policy implementation. Third, the process of examining each methodology is time consuming, the methodology needs to be thoroughly examined to ensure that the data requirements are available for each case study. Additionally the softwares used for the nexus methodology are costly so investing

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[2] Market Allocation (MARKAL) model of the ETSAP implementing agreement of the International Energy Agency (ETSAP (Energy Technologies Systems Analysis Program), 2011).

[3] Long Range Energy Alternatives Planning (LEAP) model of the Stockholm Environmental Institute (SEI (Stockhom Environment Institute), 2011).

[4] The WEAP energy model is maintained and supported by the Stockholm Environmental Institute: http://www.seib.org/software/weap.html.

[5] The Podium model is maintained and supported by the International Water Management Institute http://podium.iwmi.org/podium/.

[6] A case studies using the rapidly developing CLEWS framework can be found in Rogner et al. (submitted)

in them requires adequate research. Fourth, some of these tools are not apt to fulfil the interdisciplinary requirements of a nexus methodology. They focus on the environment aspects and ignore the economic and social concerns that needs to be taken into consideration. In fact, interdisciplinary approaches allows greater flexibility and robustness in systematically exploring different ways of framing and interrogating the focal problems. (Stirling 2015) They facilitates more radical interactions between different styles of knowledge, fostering potentially transformative solutions. Indeed, insights and capabilities from various kinds non specialist – local communities, target groups, farmers, social movements, street level bureaucrats or many different kinds of practitioner can greatly improve the development of nexus-related understandings. (Stirling 2015) Finally , different studies show that increasing the level of stakeholder engagement is crucial to ensure high quality assessment and response. Most of the tools examined lack stakeholders engagement as an initial component in their setup. The development of a multi-criteria decision analysis (MCDA) is a response to these shortcomings and will be discussed in detail in the next section.

2.4. Multi-Criteria Decision analysis

MCDA is a tool developed to help decision makers handle complex decision making issues. It is mostly used to resolve operational research problems with a finite number of decision options among which decision makers have to evaluate and rank based on the weights assigned to a finite number of evaluation criteria. (Figueira et al. 2005; Kabir et al. 2013). The total number of papers that use one of the MCDA methods have increased from single digit numbers in the early 90's to hundreds in the late 2000's. (Huang et al. 2011) Researchers adopted this method by taking into account the opinions of local community groups and other stakeholders and have integrated these opinions in the decision process. (Huang et al. 2011) Naturally, applications that require strategy development, stakeholder engagement, and integrated environmental assessment are more dominant, which is only natural due to the interdisciplinary aspect of environmental problems. Environmental decisions are often complex and draw upon multidisciplinary knowledge which include natural science, physical science, social sciences, politics, and ethics. (Huang et al. 2011)

MCDA has been applied to a variety of applications in the past, ranging from sustainability assessment of domestic hot water technologies, waste management, energy system planning, among many others. There are many studies that have used MCDA in resources management and planning evaluations.

In energy planning Diakoulaki et.al 2007 carried out a study on the greek electricity system, proposing four scenarios to satisfy demand in 2010. Dimitrijevic et.al 2012 also turned to an MCDA when they assessed the sustainability of three different scenarios of new renewable sources for Bosnia and Herzegovina. Ribeiro et al. 2013 designed and used an MCDA tool to support the sustainability assessment of different power options for Portugal for 2020.

In water resource planning, Silva et al. 2010 carried out a group decision making model that uses MCDA to support watershed committees in Brazil. Bouchard et.al used MCDA for the selection of small drinking water treatment system. Trojan et.al 2012 also turned to MCDA to prioritise the alternatives for the maintenance of water distribution networks.

In agricultural planning the use of MCDA is less common however Riesgo etl.al 2006 and Bartolini etc.al 2006 evaluated different scenarios in irrigation policy planning. It is evident that the Multi-Criteria Decision Analysis has been applied on all three of the Nexus resources and is suitable in evaluation policy options on the Litany river basin.

However to what concerns the purpose of the current study, the evaluation of policy interventions inside the WEF nexus, the MCDA has not been applied. Nonetheless the method is a clear fit for system thinking evaluations and stakeholder engagement at all stages of the decision making process. The method offers a high degree of flexibility and can be tailored to local conditions. This applies particularly when the reference system is different from the national level, for which more data is usually available. MCDA is, in fact, exemplary for combining qualitative and quantitative data which becomes particularly useful in developing countries where data availability is a major constraint.

CHAPTER 3

METHODOLOGIES AND MATERIALS

3.1 The Proposed Framework

3.1.1 Multi-Attribute Theory Method

The current paper will adopt a combination of three multi-attribute theory methods: Analytical Hierarchy Process (AHP), Simple Multi Attribute Rating Technique (SMART) and Multi-Attribute-Utility-Theory (MAUT). The proposed methodology shown in **figure 3.1** used a combination of the three methods. This is sought to fulfil better the requirement of a comprehensive and simple tool for the quantitative evaluation of individual instruments. (Konidari 2007) The framework offers ranking of different alternatives (for this paper the policy interventions) using multiple and conflicting criteria. MCDA is particularly appealing to researchers working with decision makers due to their simplicity both in concept and computation. (Jia et al. 1998; Chang and Yeh 2001; Duarte and Reis 2006; Butler et al. 2007) None of the three methods alone was considered convenient for this particular evaluation due to the following reasons. MAUT and SMART requires less effort by decision makers, but their procedure for determining weight coefficients is not convenient considering the complicated framework. The total number of pairwise comparisons becomes manageable by restricting the use of AHP only to the determination of weight coefficients for criteria/sub-criteria.(Saaty 2008). This is generally thought to be simple, and can be flexible when multiple stakeholders are involved (Huang et al. 2011).

The additive multi-attribute model provides a single value for the overall performance of each instrument against multiple criteria. The value is produced using:

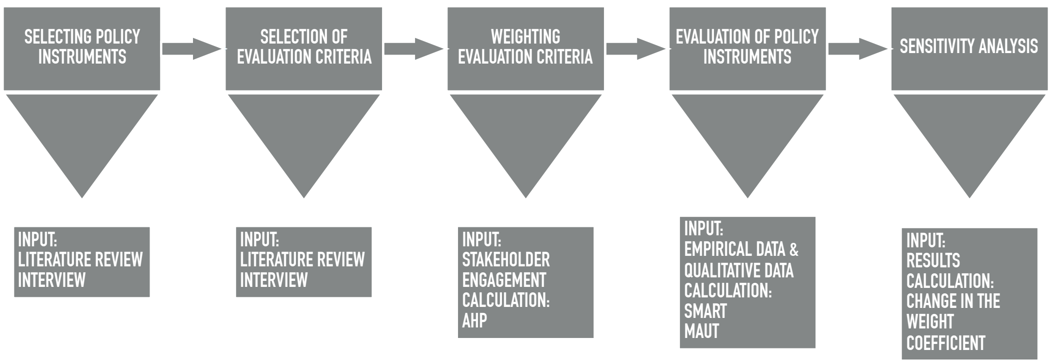
- value= $\Sigma(wiSij)$, (1)

where for each j instrument, value is measured as the weighted sum of performances *Sij* for this instrument on each of the i criteria, weighted by their relative importance *wi* reflecting the criterion importance. The value serves as an index (Kim et al. 1998) for the evaluated aggregate performance of the instrument. The greater the value, the more preferred the instrument is.

SMART is used to normalise the observed values, it provides an ordinal scale with a worst case equal to zero and best case equal to 100. The value is produced using the following equation:

- 100*(-Observed Value+Worst Value)/(-Best Value + worst Value),

Figure 3.1. The Proposed Framework, a step-by-step methodology



AHP allows a systematic approach (step-by-step) for the determination of the significance of criteria/sub-criteria, the existence of trade-offs between the criteria and contributes to the better understanding of the complicated framework. It allows potential users to assess progressively the relationship between criteria/ sub-criteria.

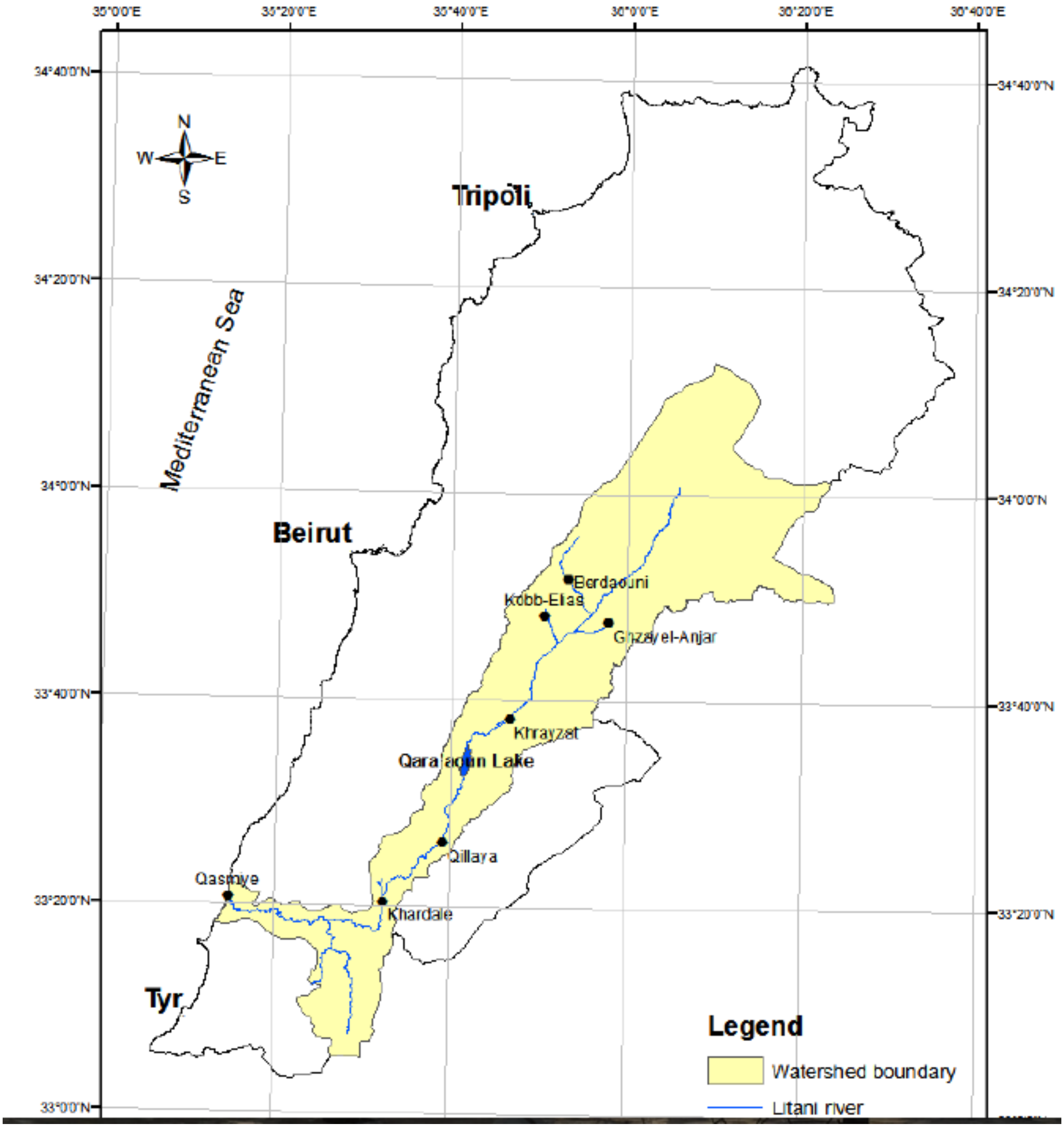
Users of MAUT, SMART or AHP realise better the most agreeable policy intervention and their weaknesses by observing the final values that reflect aggregate performances. It reduces complexity of elicitation procedures (Kim et al. 2001). It has minimum value loss compared to other aggregation functions (Chang and Yeh 2001). It provides more robust outcomes under sensitivity analysis (SA) compared to other aggregation functions (Kumar and Alappat 2005).

3.2 Case Study

3.2.1 The Litany River Basin

There are many areas where tradeoffs and synergies between the food, energy and water resources are apparent within the Litany River Basin. The Litany River (**Fig. 3.2**) is the largest Lebanese river. It is the country's most important water resource. It has a length of about 172 km and a basin area of about 2180 km2 (which is equivalent to about 21% of the Lebanese territory), occupied by about 400 000 people (Shaban 2014). The Litany River originates from the middle part of the Bekaa plain, flows 140 km in southerly and westerly direction to meet the Mediterranean 70 km south of Beirut (LRA, 2004). The construction of a major hydroelectric system in the 1950s taps the 800-m head between the river site at Qaraoun and the Mediterranean. The project involved the construction of Qaraoun dam and diverts the Litany River through a system of tunnels and ponds to empty its water into the Mediterranean further north from its natural mouth (LRA, 2004). The Qaraoun reservoir is the largest Lebanese artificial reservoir with area of about 12 km2 and water capacity of about 220 million m^3. More than 50% of this volume is lost by evapotranspiration, and the remaining amount feeds the existing springs and groundwater reservoirs as well as the drainage system in the river basin.

Figure 3.2 The Litany River Basin



As a major water source, the Litany River has the utmost concern for the decision makers in Lebanon, because of its principal role in water supply to the areas within (and even out of) the basin limits. The water from the river is also conveyed to Al-Awali River, a coastal river (south to Beirut), in order to use the running water for hydropower generation, as well as for different irrigation purposes, and consequently another project has been assigned to supply water from Al-Awali River to Beirut district. (LRA, 2004). The success of the water development schemes hinge to a large extent on the reliability of the water resources, which are subject to natural variability and uncertainty possibly influenced by a longer term climatic change.

According to the FAO, the agriculture sector in Lebanon (including crops, livestock, fisheries and forestry production) represents, on average, about 6.4% of the country's annual Gross Domestic Product (GDP) (from 2001 to 2010). Agricultural value added per square is higher in Lebanon than in many nearby countries, reflecting a higher intensity of production and greater focus on high value crops (fruits and vegetables). Although agriculture represents a small portion of Lebanon's service-oriented economy, it is a major source of livelihoods for its population. Indeed, approximately (20-25)% of Lebanon's active population is involved in the agriculture sector, including full-time and part-time workers as well as seasonal family labour (FAO 2015).

Furthermore Lebanese households tend to spend a significant amount of their household income on food. Indeed, on average, a quarter (24%) of their income is spent on food. Additionally Lebanon relies heavily on food imports, especially from Syria. However recent drop in its food production in the neighbouring country and the security situation has been restraining all transportation through the country, threatening food imports into Lebanon. The current situation calls for better crop management, training of farmers to introduce their products in local and international markets and a larger focus on basic crops like cereals to decrease reliance on food imports.

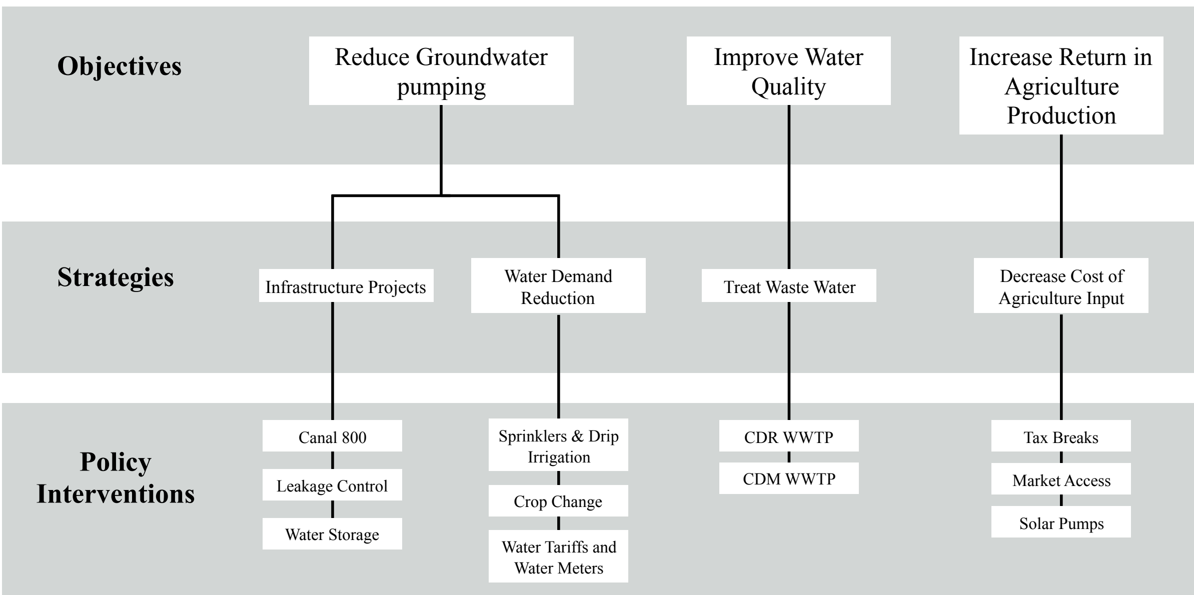
Lebanese farmers have been suffering lately from a decrease of their agriculture yield. The main reason behind this decrees is the reduction in accessible natural resources, mainly water. Specifically, 58% of crop yield decreases have been linked to this reduction, while only 20% could be traced back to a higher cost of agricultural inputs. (FAO 2015) The access to water have been gravely affected by precipitation shortage of the last two years, some rivers and wells have run dry, and that most of the remaining water bodies have become polluted or have been infiltrated by salt water, especially on coastal areas. The lack of water means that farmers now need to purchase water for irrigation, therefore increasing their agricultural production costs. It becomes apparent that a system thinking approach is needed to resolve such pressing issues. The food sector situation in

Lebanon will only get worse without meaningful policy interventions. Lebanon will have to rely on more food imports and households would consequently have less access to quality food resources as their prices surge. The government should work towards having a self-reliant food system in which food is produced, processed, and controlled locally as much as possible; a food system where sources are multiple and varied; and where community members are involved in the decision-making process.

3.2.2 Selection of Policy Instruments

Three policy objectives have been considered for the Litany River basin case study, the strategies tackle the agricultural sector while taking into consideration the interaction that comes into play with the WEF Nexus. The first objective focuses on reducing groundwater exploitation by

Figure 3.3 Litany River Policy Options



the agricultural sector. The second objective tackles the deteriorating water quality of the river. And lastly the third objective aims at reducing the cost of agricultural production. For each objective to be achieved several strategies have been suggested. For reducing groundwater pumping two strategies have been considered. The first is focuses on implementing new infrastructure projects (Canal 800, reducing leakage and water storage). The second targets better management of water resources by implementing three demand reduction policy options (Irrigation Techniques, Crop Change and Water Tariffs). For the purpose of improving the river's water quality only one strategy was considered. It deals with the waste water being dumped in the river, it suggests building new waste water plants on the Litany 's basin. Lastly for reducing the cost of agricultural production, the strategy considered aims at reducing cost of agricultural input relying on three government interventions (Tax breaks, Market access for farmers and solar pumping). The policy interventions are shown in **figure 3.3**.

3.2.2.1 Reduce Pumping of Ground Water Resources in Agriculture Sector

Groundwater resources are being heavily exploited when water from other sources become scarce. The estimated number of unlicensed private wells according to "The assessment of groundwater resources of Lebanon" (Lebanon MoEW 2014) is between (55,000 to 60,000) three times higher than the number of licensed private wells which is approximately 20,537. The situation is more worrisome in the Litany basin since the percentage of farms relying on groundwater resources is 23.21% compared to 15.86% the national average **(table 3.1, 3.2)**. These wells are being used for irrigation purposes mostly, and would therefore have higher extraction rates. A command and control options to prevent illegal exploitation of groundwater resources is clearly ineffective, another way to prevent further exploitation is better management of surface water in Lebanon. Groundwater is considered a strategic resource due to its usually high quality and perennial availability. (Kinzelbach 2003) However groundwater resources are facing continued stress especially in dry years where water from other sources becomes scares and farmers and domestic users increase pumping activity. One way to better manage groundwater resources is investing in infrastructure project that steer water usage from groundwater towards surface water.

Table 3.1 Litany River Basin Water Resources in Agricultural sector

Source of Water	Farms	Percentage
Litany River	22339	24.12%
Ground Water (Wells)	21491	23.21%
Water Storage, Distribution	19965	21.56%
None	28813	31.11%
Total	92608	100.00%

Table 3.2 Lebanon Water Resources in Agricultural sector

Source of Water	Farms	Percentage
River	201888	35.78%
Ground Water (Wells)	88463	15.68%
Water Storage, Distribution	121056	21.46%
None	152805	27.08%
Total	564212	100.00%

3.2.2.1.1. Infrastructure Projects

In 2012, the LRA was able to revive plans to divert approximately half of the water volume from Qaraoun Lake for irrigation and municipal water supply to the southern and interior parts of the country (Marjeyoun area). A $400 million construction project is currently underway. The **Canal 800** water carrier is set to transfer up to 110 million cubic meters (MCM) per year from Qaraoun Lake to the south of the country 90 MCM of which will be purposed for irrigation and 20 MCM for water supply. The water for irrigation will create 15,000 hectares of new irrigated land. However on the down side, the implementation of the canal 800 project diverts water usage from existing hydroelectric power plants already installed on the river. A study conducted by ministry of energy and water show that on average 60% of power output will be lost (from 680 gWh to 272 gWh), a dry year will result in 94% power loss and a wet year will result in 30% power loss. (Osseiran 2014) The loss in power is assumed to be supplied by private generators in the region which in turn will affect the affordability of electricity, energy security and increasing pollution. It is clear that these policy interventions present challenging tradeoffs between the availability of water for irrigation, for domestic use and for energy supply.

An alternative solution to decrease groundwater pumping is a plan to ***reduce leakage from the water system***. The current Lebanese water system looses around 30% (Lebanon MoEW 2010) of its water due to leakage and a comprehensive plan that target these losses could ultimately diminish the amount of water being pumped since water consumers will be receiving water more efficiently from springs, rivers and water networks. The capital cost for this policy option was approximated by this study by relying on data provided by the MoEW in a study that covers leakage control on the whole Lebanese territory. Similarly the quantity of water saved was also extrapolated to fit the specific local conditions. (Lebanon MoEW 2010)

Additionally the MoEW developed a plan to ***store water*** artificially relying on the construction of new dams and hill lakes that capture water for irrigation or storage. The plan consists of the construction of two dams in Khardaleh and Kfarsir and six storage lakes in Chohour, Jinsnaya, Jarjour, Azibeh, Kfarhouna and Barhacha. The dams will have a capacity of 135 MCM split into 23 MCM for water storage and 112 MCM for irrigation and will cost $295 million. The lakes will have a capacity of 3.91 MCM split into 2.11 MCM for water storage and 1.8 MCM for irrigation and will cost $123 million. (Lebanon MoEW 2010) The plan is thought to create 15,000 hectares of new irrigated land, will decrease the cost of acquiring water as water users will be subjected to a more reliable water system and rely less heavily on pumping water from wells.

3.2.2.1.2.Water Demand Management

Water resources could also be sustainably managed from the demand side. Reducing demand for water in the irrigation sector or for domestic use will consequently reduce demand for groundwater. Improving water use efficiency through the introduction of modern irrigation technologies such as sprinklers and drip irrigation is paramount to reducing water consumption. (Wong 2010).

Moreover, the majority of Lebanese households are facing issues accessing sufficient water. The main obstacles to water access in Lebanon are its availability and its price. At the national level, not having enough water storage facilities is a constraint for 13% of the population.(FAO 2015) In Beirut, 80% of households reported that water is too expensive. In the South, the main problem is availability of water where 95% of household are suffering from water access (FAO 2015). This calls for a thorough demand reduction campaign that can be exemplified, in the agriculture sector, by changing to crops that are less water intensive; introducing water meters and water tariffs that can hinge wasteful consumption; and subsidising irrigation technologies such as drip irrigation or sprinklers.

The ***Crop change*** policy option adopts the findings from the paper by (Mohammad 2011). It relies on the CROPWAT software that optimises crop selection based on an increase productivity and reducing water demand. The crop change scenario focuses on crops (such as cabbage, fresh beans, onions and tomatoes) that have high yields, high prices at farm gate but low water demand. The scenario applied for this study reduces water consumption by 1% but increases net return in agriculture by 24.1%.

The MoEW with the coordination of the Ministry of Agriculture could stimulate farmers to adopt more efficient irrigation techniques such as ***sprinklers and drip irrigation***. One issue with sprinklers and drip irrigation is the quality of water supplied from the Litany river. The high concentration of alleges prevents the use of these irrigation techniques without applying filters to the water source because the water will clog the holes in the sprinklers and the drip irrigation cables. Additionally the lack of awareness among farmers about these methods and their advantages prevents higher market penetration. One way to overcome this issue is to provide subsidies on sprinklers and drip irrigation. The LRA already applies one form of subsidies in providing reduce pricing on water for farmers that use these techniques. These subsidies have proven to be successful, the Litany river basin enjoys a relatively high utilisation of efficient irrigation, just 65% of farmers used conventional flooding techniques compared to 78% the national average. (Lebanon Ministry of Agriculture 2006)**.** However a consolidated understanding from both ends, improving Litany 's water quality and/or a market solution that decreases the initial cost of sprinklers and drip irrigation techniques will further increase the penetration of these techniques in the basin. For the purpose of this study we will consider an increase in ***10,000 sprinklers and drip irrigation*** technique in the basin with 6,040 new drip irrigation installations and 3,980 sprinklers. The new irrigation installations decrease water consumption by 30.1%

Another way to decrease water demand, that targets more sectors and not just agriculture, is applying ***water meters*** for water consumption. Water meters alone cannot influence demand without changing the ***tariff structure*** for water. Currently a flat rate is applied to water however changing the current tariff structure to one that takes into consideration volumetric consumption could have significant impact on decreasing water demand. The policy options studied will assume an increase in water prices for the LRA and Water establishments. The price of water from the Litany river will increase from 0.3$/m^3$ to 0.4$/m^3$ and the water acquired from the Water establishments will increase from 0.43$/m^3$ t0 0.53 $/m^3$. The aforementioned increased water tariffs reduced water consumption by 5%.

3.2.2.2. Improve Water Quality

The second policy objective to what concerns the communities living on the Litany River Basin is the apparent deterioration of the quality of water of the river. The main sources of pollution in the river are waste water and industrial waste. According to local residents, who chose to remain anonymous, the main industrial polluters of the river are sand factories whose owners have political coverage to illegally dump their industrial waste. This issue can only be addressed through a political decision and will not be tackled by this study. On the other hand, waste water is a significant issue throughout Lebanon, only 8% of the water consumed is being treated (Lebanon MoEW 2010) compared to a regional average of 32%. New Waste Water Treatment Plants (WWTP) are therefore essential to improve the Litany river's water quality.

The quality of water resources of the Litany is unsuitable for most water uses. The bulk of urban and industrial waste is released untreated into the river. The impact of these releases is intensely felt during the summer months, when naturally dry conditions accompanied by major extraction of groundwater and surface water for irrigation reduce the river flow to a trickle. The problem is exacerbated by pollution from irrigation, leaching from landfills and the common practice of dumping solid waste near or into the river channel (Forward 2003).

Findings from a recent extensive water quality survey conducted under the USAID-sponsored Litany Basin Management Advisory Services (BAMAS) project, show a river system under a great environmental stress with seriously and progressively degraded water quality. The river system is obviously bacteria infested throughout the year, with extremely high counts of Fecal Coliform (FC) that exceed 1,20,000 CFU/100 ml at some locations during the summer. These results are indicative of a wide-scale pollution that escalates to epidemic levels during warm and dry summer conditions. This is particularly worrisome as water demand, particularly for irrigation, increases substantially during the long rainless summer season.

3.2.2.2.1 Treating Waste Water

Two policy options have been suggested in this regard. The first comes from the leading planning agency in Lebanon, the Council for Development and Reconstruction (***CDR***). CDR has developed an environmental master plan that will oversee the establishment of wastewater drainage network and treatment facilities for most of the communities in the basin (CDR 2005). The plan calls for the construction of seven secondary ***treatment wastewater treatment plants*** (WWTPs) across the basin for a total cost of $105 million million. Upon completion, the CDR plants with a total capacity of about 118,530 m^3/day will serve 446,000 (2005 estimate) people spread over 75 towns. The second plan was developed by **t**he Camp Dresser and McKee **(CDM)** and assesses the feasibility of a more decentralised wastewater treatment approach. Adopting a think-small approach that emphasises serving smaller clusters of communities, the **CDM** plan calls for the development of six smaller WWTPs to serve 11 towns with a total estimated population of 51,550 (2005) 14,840 m^3/day and would cost $9.94 million. (Assaf 2008) In both cases it is assumes that the treated water will mostly be used for irrigation.

3.2.2.3. Increase Return in Agricultural Production

Finally, the third strategy tackles the farmers economical status where they are being increasingly put under pressure by different factors. The state can intervene by providing subsidies to different aspects of their cost structure. Three policy instruments were suggested in this regard, the first tackled one of the major constraints in agriculture investment which is the high cost of agricultural materials, the second deals with the discrepancy in prices between market prices and prices at the farm gate and the third tackles the high cost of water.

3.2.2.3.1. Decrease Cost of Agriculture Input

Removing Tax from agricultural input can be translated by removing the custom tariffs on fertilisers, seeds and machinery. According to data from Lebanon's custom tariff, (Custom tariffs) an average 5% custom tariff is applied on most agriculture inputs. For the purpose of this evaluation this cost was removed from the cost of production of agriculture activity. However this policy instruments could translate negatively on local production of agricultural input making imported products more competitive with the local market and in turn affect employment. Additionally , making fertilisers cheaper i.e more accessible could negatively affect water quality in the basin.

Market access for farmers is a major constraint for most farmers in Lebanon. The government could intervene by the construction new COOPs in the Litany River Basin increases crop prices at farm gate. A low 10% estimate was used because not all the farmers of the basin will benefit from the new COOP built in the area. This is a conservative measure since some reports suggest that the prices a farm gate could be 30% lower than market prices. Investing in COOPs would decrease exploration of farmers by middlemen and lower the discrepancy between market prices and prices that the farmers actually receive. Actually, only 5.71% (Lebanon Ministry of Agriculture 2006) of Lebanese farmers have access to COOP and 40% of Litany Basin's farmers consider not being able to sell their produce as primary concerns for their agriculture activities(Lebanon Ministry of Agriculture 2006).

Solar Pumping is a policy instrument that ought to replace diesel water pumps by solar water pumps. In fact, solar pumps decrease fossil fuel consumption in agriculture, decrease the cost of production and delink the food sector from international energy prices. For the sake of this evaluation 15,000 new solar pumps are considered with the government covering 10% of their cost. Effectively the government would remove custom tariffs on the imported technology and provide soft loans provided to facilitate the acquisition of this new pumping technique.

3.2.3. Selection of the Evaluation Criteria

Selecting the evaluation criteria most suitable for Litany River Basin case study is a complicated task. The data available needs to be studied closely so that the evaluation criteria selected are carefully measured. Data availability for the value of water is difficult to assign. Some data sets relating to water consumption withdrawals, renewable freshwater resources, water pollution or water productivity exist. They are published by sources such as UN Water, the FAO's AQUASTAT, the World Bank or the World Resources Institute), however it becomes more difficult to find data when the studied area is different from the national level. Data availability on energy and water becomes even more challenging when looking at it from a water–energy nexus perspective. (Ferroukhi et al. 2015) While, for instance, there could be adequate data available on water consumption and on electricity generation, data on water consumption for electricity

Table 3.3. Criteria Tree of the Proposed Nexus Framework

Main Criteria	Sub-Criteria	Unit
Cost	Capital Cost	$
	Value of Ag produce/ annual Cost	No Unit ($/$)
	Unit of Irrigated Land(ha)/Annual Cost	Ha/$
Energy	Electricity Affordability	$/Kwh
	Energy Imports	%
	Energy Consumed/ Irrigated Land	Gwh/ha
	Fossil Energy Consumed/ Irrigated Land	Gwh/ha
Water	Water Affordability	$/m³
	GroundWater Budget	%
	Water Quality	Ordinal Scale
	Water Consumed/ Irrigated Land	m³/ha
Food	Change Income from Ag/ Ag Land	$/ha
	Food Imports	%
	Yield/Water Consumed	Tonnes/m³
	Fossil Energy/ Amount of crops produced	Gwh/Tonnes
Social	Employment	# jobs
	Social Acceptability	Ordinal Scale
	Land Use Change	ha

generation or energy consumption in water systems remain much more limited. The data available needs to be thoroughly examined before the selection of the evaluation criteria.

Additionally the local conditions needs to be examined in order to fulfil a relevant evaluation under MCDA. Nexus tools such as CLEW or the FAO nexus methodology use a set of criteria that aren't necessarily applicable for any specific case study. The CLEW method uses climate, land, energy and water as its main criteria for evaluation and the FAO methodology uses cost, energy, water, food and labor as their main set of criteria. However the proposed framework offers its users the flexibility to determine the appropriate criteria and sub-criteria that are specifically relevant for each case study.

Having said that, there are certain guidelines that needs to be followed for relevant evaluations. Bizikova et al. 2013 consider the WEF resources in terms of their utilisation, accessibility and availability characteristics combining human and natural systems, all within an enabling governance structure. The nexus framework presented in this study is driven by risk to better understand the relationship between environmental pressures, resource security and economic disparity. It highlights the importance of considering the social and economic dimensions of development in relation to the WEF system. It emphasises that failure to achieve security across all three WEF sectors will result in social instability and economic decay. (Biggs et al. 2015) In this regard the set of criteria/sub-criteria shown in **table 3.3** will be used to assess the Litany Basin Case study.

The **Cost** criteria assess the the economic performance of each policy instrument. The first sub-criterion measures the *Capital Cost* of each policy instrument, this is particularly important for policy makers who are trying to optimise the use of public funds, it is equally important to tax payers who are concerned of how public resources are being spent. The second sub-criterion ***Δ****Value of Agricultural Produce/Annual Cost*, measures the change in the value of the agricultural production against the annual cost of each policy instruments, the ratio will help depict the most cost efficient policy when it comes to the change in agricultural productivity. The third sub-criterion ***Δ****Unit of Irrigated Land/Annual Cost(ha/$)*, it measure the change in the the amount of irrigated land created or lost against the annual cost of each policy instruments, this ratio will help depict the most cost efficient policy when it comes to creating new agricultural land.

The **Energy** criteria assess the effects of each policy instrument have on energy security, energy affordability and energy consumption in agriculture. The first sub-criterion is ***Δ****Electricity Affordability*, measures the percentage change in the cost of acquiring electricity by the local residents of basin's area. ***Δ****Energy Imports,* is a measure of energy security, it depicts the dependence of the country on energy imports. A lower measure will be given a higher score, since dependence on energy imports subjects the country to the availability and prices of energy that are outside the control of local conditions. The value is presented in percentage changes of each policy's impact on energy imports. The third sub-criterion links energy to food, ***Δ****Energy Consumed/Irrigated land.* It depicts the food sector's dependence on energy production. It is a quantitative ratio measured in (Gwh/ha). Similarly, the fourth sub-criterion ***Δ*** *Fossil Energy Consumed/Irrigated land.* It depicts the food sector's dependence on fossil energy production. It is a quantitative ratio measured in (Gwh/ha).

The **Water** criteria assess the effects each policy instrument have on water security, water affordability, water quality and water consumption in the food sector. The first sub-criterion is ***Δ****Water Affordability,* it measure the percentage change in the cost of acquiring water by the local residents of the basin's area. ***Δ****Groundwater Budget* is a measure of water security as groundwater is seen as a strategic resource that stores water for future generations. It is measured in percentage change depicting the impacts of each policy on the groundwater resources budget. *Water quality,* is a qualitative measure that has been extracted from the survey shown in Appendix 3, this survey was handed to local water experts who qualitatively assessed the performance of water quality following the potential implementation of each policy instrument. ***Δ****Water Consumed/Irrigated Land* measures the change in the amount of water consumed by the agriculture sector, it is a quantitate ratio measured in (m^3/ha).

The **Food** criteria assess the effects of each policy instrument have on food security, profitability of the agricultural sector and the dependence of the agricultural sector on energy and water consumption. The first sub-criterion ***Δ****Income from Agriculture/ Agricultural Land,* measures the change in income of the local framers per agricultural land. It is a quantitative ratio measured in $/ha. ***Δ****Food Imports,* is the second sub-criterion. It is used as an indicator for food security depicting the local food sector's dependence on imports. The policy instrument will have a different effect on food imports with a higher value given a lower score. ***Δ****Crop Yield/Water Consumed* is the third sub-criterion, it measures the change in the amount of crops produced relative to the amount of water consumed, it is quantitative ratio measured in (Tonnes/$m^{3)}$. ***Δ****Fossil Energy/Amount of Crops Produced*, it is the fourth sub-criterion under the food sector criteria, it measures the dependance of agricultural production on fossil energy, it is a quantitate ratio measured in (Gwh/Tonnes).

Finally, the **Social** criteria assess each policy's performance according to three social sub-criteria. The first is *Employment,* it is measured in the change in number of jobs created or lost under each policy instrument. The second is qualitative criteria entitled *Social Acceptability,* it is extracted from the survey shown in Appendix 2. This survey qualitatively measures the social acceptance of each policy measured as they are viewed by leaders of local communities (municipality presidents). The third, is the ***Δ****Land Use,* it measures effects each policy has on land use, it a quantitate measure and will be assessed in hectares (ha).

3.2.4. Weighting of the Evaluation Criteria

In order to complete the MCDA, this survey shown in Appendix 1 allows policy makers, water users and academic researchers determine the weights of each criteria, enabling the full assessment of policy instruments concerning the Litany river basin. The surveyors are asked to assign a score from one to five to determine the relative importance of each criteria. As mentioned above the AHP method was used to determine the weights of each criteria/sub-criteria in a pair wise comparison of the main criteria and similarly a pair wise comparison of the sub-criteria within each main criterion. An AHP software was used to translate the data collected from the survey to aggregate weights for each criteria. After the corresponding weights of each criteria is produced the observed values are grouped for each policy instruments. The results are then produced in the table

Table 3.4. Agricultural activity of litany river basin

Crop Type	Farms	Land Area per Crop (ha)	Land Area per Crop (%)	Land Flood Irrigated (Ha)	Land Sprinklers Irrigated (ha)	Land Drip Irrigated (Ha)
Cereals	7998	7895.88	18.42%	2559.89	1538.11	673.29
Legumes	3723	2750.30	6.42%	1103.67	393.01	494.95
Forage	434	626.54	1.46%	242.53	154.47	40.42
Vegetable - Leaves	3462	2435.23	5.68%	1388.54	519.82	476.92
Vegetable - Fruits	9042	4943.53	11.53%	2491.99	597.03	1300.12
Tuber, roots, bulbs	3256	5311.58	12.39%	1843.39	2340.94	972.27
Industrial crop	5643	2119.68	4.95%	791.08	136.35	134.48
Citrus fruits	3886	1051.91	2.45%	711.11	113.69	137.24
Pome fruits	6468	2432.15	5.67%	1679.34	93.26	399.72
Stone fruits	16050	5069.03	11.83%	2469.45	190.44	915.27
Grape vines	6389	2666.93	6.22%	957.99	144.01	636.99
Nuts	2258	611.30	1.43%	351.94	33.57	73.91
Olives	14833	3056.88	7.13%	984.68	109.23	177.44
pine	432	166.41	0.39%	88.60	11.94	21.19
bananas	347	206.20	0.48%	81.41	8.91	114.09
med fruits	5510	1056.04	2.46%	594.91	65.74	80.50
exotic fruits	842	332.39	0.78%	179.22	59.21	80.14
Other Fruit Trees	548	83.40	0.19%	60.42	4.11	6.39
None	1484	44.02	0.10%	1.78	0.21	0.09
Total	92605	42859.40	100.00%	18581.96	6514.06	6735.41

shown in Appendix 4 using excel computations. The table shows the ordinal scores of each policy instrument and the aggregate score which is calculated by adding the ordinal score of each instrument and dividing it by the number of sub-criteria used in the study.

3.2.5. Evaluation of Policy Instruments

The studied area consists of 191 villages across the basin and covers an agricultural land of 42,859 hectares. 92,605 farms were examined as part of the study. These farms employ 67,900 permanent workers however seasonal workers can increase significantly depending on the time of the season. The agricultural activity of Litany river basin are is shown in **table 3.4,** the data was acquired from the Ministry of Agriculture's publication entitled: Agricultural Strategy and Policy, Food and Agriculture Organisation, project support to the Agricultural Census" Oct, 2006.

The data shows the land area occupied by each type of crop and the land area occupied by each irrigation technique for each crop. The crop yields expressed in kilograms per hectare and the water demand per crop expressed in cubic meters per hectare were retrieved from the latest FAO STAT (2013) and (Mohammad 2011), respectively. The total cost of production, expressed in USD per hectare, includes the fixed and the variable costs, i.e the cost of fertilisers, pesticides, machinery The data was obtained from the ministry of Agriculture who provided the cost of production of each crop in Lebanon with reference to the report about "Cost of Plant Products in Lebanon".(Lebanon Ministry of Agriculture 2006) Additionally, the price of crops on farm gate was also acquired from (Mohammad 2011). The crop characteristic data are shown in **table 3.5**.

There were no readily available data on total water consumption of the studied area. It was alternatively calculated by multiplying the water requirement of each crop per hectare by the land area each crop occupies. Additionally, in order to have more a accurate measurement, the efficiency of each irrigation technique was taken into consideration to calculate water demand. (For

Table 3.5 Crop Characteristics of Litany River Basin

Crop	Yield (Tones/ Hectare)*	Water Demand (m^3/hectare)**	Cost of Production($/ hectare)***	Price at farm gate($/ Tones)****
Cabbage	40	446.5	8800	1320
Pepper	45	535.8	8430	950
Lettuce	12	232.8	1596	350
Corn (silage)	40	685.3	1511	320
Wheat	5	455.3	2180	550
Potato	40	491.9	4870	400
Fresh Beans	6.5	305.7	5005	650
Garlic	8.2	223.4	2200	1350
Maize Grain	8.8	738.2	2536	550
Dry Beans	1.2	498.6	514.8	2200
Olives	24	320.7	2100	1800
Cauliflower	35	1100.6	7700	1350
Sugar Beet	35	1603.6	4870	250
Onion	15	307.6	3750	500
Onion Green	20	286.9	4280	300
Cucumber	25	511.3	3504.7	900
Tomato	45	696.5	4745	380
Water Melon	60	515.9	3200	550
Banana	12	1199.2	4411	600
Stone Fruits	27	1049.1	3200	1100
Citrus	45	812.6	2400	1650
Almonds	1	363.2	1318.1	700
Table Grapes	8	1170.8	1262.5	1200

* Refers to the amount of crops produced per hectare, FAO STAT 2013
** Refers to the water demand per crop in Lebanon, computed by CROPWAT in Optimisation of WaterAllocation Under Deficit Irrigation Case Study: Agricultural AreasAlong the Litany River Basin.
** The total cost of production, includes the fixed and the variable costs, The data were obtained from the ministry of Agriculture who provided the statistics done in 2006 on the cost of production of each crop in Lebanon with reference to the report about "Cost of Plant Products in Lebanon".
**** Refers to the price the farmer received at his/her farm gate, 2006 data

the sprinklers a conservative 60% efficiency was used and for drip irrigation a conservative 75%).

(World Bank 2003)

The total amount of crops produced was calculated by multiplying the crop yields by the land area that each crop occupy. The profitability of the food sector was then calculated by subtracting the cost of production of each tone of crop produced from the prices at the farm gate.

Total Energy consumption in agricultural activity in the Litany river basin was calculated by taking into consideration the different energy consumptions of the water consumed from different sources. Four sources of water were used with their respective energy consumption ratio. The first is a river source with an energy consumption ratio of 0.92 kwh/m^3 (Raluy 2004)**.** Second, water retrieved from pumping groundwater, the energy consumption ratio used was 3.3 kwh/m^3 (Nelson 2012). Water retrieved from water distribution networks, the energy consumption ratio used was 0.04 kwh/m^3 (Plappally 2012). And finally, for energy consumed by waste water treatment plants, the value used was 0.47 kwh/m^3 (Muñoz 2010)**.**

Water prices are also different when water is consumed from different water sources. For water consumed from the Litany river, the Litany River Authority (LRA) apply different costs on water users, depending on the irrigation system used by the farmer. The pricing is 300$ per hectare per season when drip irrigation is used, 400$ per hectare per season when traditional surface irrigation is used. (LRA 2004) Water consumed from ground water depends on the depth of the well, it is also subjected to the variation of fuel prices and the quantity of water consumed. It is thus difficult to assume a single price of water consumption in Lebanon, 3 water pricing were applied for the purpose of this study:

- Water pumped from the Litany river a flat rate of 0.3$/$m^3$ was used, a 100$/hectare was subtracted from the water bill of farmers who use either sprinklers or drip irrigation techniques;
- Water from distribution a flat rate of 0.43$/m3 was used (Lebanon MoEW 2010);
- Water pumps a flat rate of 0.66$/$m^3$, this rate corresponds to a 0.89$/L fuel price. (Shahadeh 2015)

The cost of water per source was included in the cost of production per crop. The calculation takes into account the amount of water consumed from each source. This gives a more accurate approximation to the cost of production per crop retrieved from the Ministry of Agriculture.

The data described in this section were used to produce the aggregate performance of each policy instruments. (Appendix 4)

3.2.6. Institutional Status

Each of the policy instrument being evaluated by the Litany Basin case study fall under the legal jurisdiction of different governmental institutions. The overlapping responsibilities of these institutions makes a common strategy hard to achieve. The management of the Litany River falls under the jurisdiction of three main institutional bodies: the Ministry of Energy and Water (central authority), the South Water and Wastewater Establishment (potable water supply), and the Litany River Authority (irrigation water supply and discharge monitoring). The management of activities on the Litany River is controlled by the LRA, which reports to the Ministry of Energy and Water. The management of exploitation of the surface water of the Litany River is restricted to the South Water and Wastewater Establishment. The Litany water quality and quantity is monitored by the Litany River Authority, which conveys all the data to the Ministry of Energy and Water. The Ministry of Health monitors the quality of the water that is supplied for domestic use from the Litany River (Water Decrees 5469/1–5469/16–5469/25–5469/40 1966; Law121/2001). However there seems to be little coordination between these institutions, as an example dams projects are usually developed by the water entity inside the ministry of energy and water and hydroelectric components are not included in the initial design. The energy entity inside the ministry comes in at later stage to reassess the design. This process is clearly inefficient as the dams location are sometimes not suitable for hydroelectric power generation. (Osseiran 2015). One option could be creating a single entity responsible for all water infrastructure projects that takes into account water for irrigation, water for power and water for potable use. The institutional status of the Litany river basin are shown in **table 3.6**.

Table 3.6 Institutional Framework of Litani River Basin

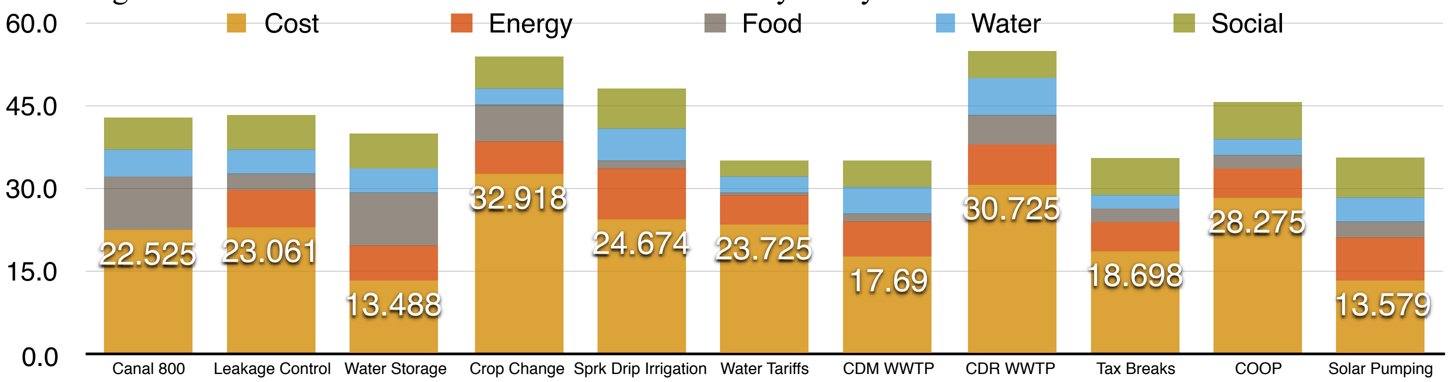
Government Entities	Expected Role by Law
Ministry of Energy & Water (Water Sector)	Develop national scale studies related to large scale irrigation projects, water resource management, monitoring, controlling and conducting hydro-geological research Licence wells and water extractions Implement artificial recharge of groundwater and regulate volumes of groundwater resources Design build and implement major water facilities (dams, hill lakes, water and waster water treatment and water networks
Ministry of Energy & Water (Energy Sector)	Develop national scale studies related to electricity infrastructure (production, transmission and distribution) Implement security standards, technical requirements and environmental requirements Controls EDL which mandates the responsibility of the generation, transmission and distribution of electrical energy.
Water Establishments	Plan and distribute water resources Operate and maintain the system Plan and Implement Waste Water Treatment Plants
The Litany River Authority	Plan and Operate Irrigation systems of the Litany River Basin Plan and Operate hydro-electric power plants of the Litany River Basin
CDR	Mobilise funds and implement support to the ministries approved by the council of ministers
Ministry of Finance	Provide budgets of implementation projects
Ministry of Environment	Evaluate Environmental Impact Assessment Control and regulate all activities that impact the environment
Ministry of Public Helath	Monitor and control drinking water quality and ensure water quality standards are met
Ministry of Agriculture	Develop national scale strategies related to agriculture infrastructure, food safety and quality, animal and plant health, and post harvest marketing and handling Study irrigation projects and provide technical supervision during implementation
Council of the South	Build Water Supply systems in the South and west Bekaa regions

3.2.7. Sensitivity Analysis

3.2.7.1 Cost Criteria Sensitivity Analysis

The results have been produced relying on the multi-criteria decision analysis by attributing maximum weights to each the main criterion separately versus all the other main criteria. **Figure 3.4** show the policy instruments' performance where the Cost criteria are given the highest weight and the energy, water, food and cost criteria are all given equal low weights. The cost criterion highlights the cost efficiency of the instrument in delivering the most agricultural benefit. The policy that target a crop change campaign is ranked highest since it delivers the highest return in agriculture as oppose to its low cost of implementation. The second highest instrument is the WWTP plan suggested by CDR. It is the most rounded policy in terms that it delivers multiple benefits to the communities living on the Litany . The planned WWTP treat the contaminated water, provide water for irrigation and diverts water usage from groundwater. It is followed by the policy that provides subsidies for sprinklers and drip irrigation techniques. It also have a relatively low cost, it reduces water consumption significantly, thus performing high on energy and water criteria. Water storage has the highest capital cost among the policy options examined and is ranked last

Figure 3.4. MCDA Results for Cost Criteria Sensitivity Analysis

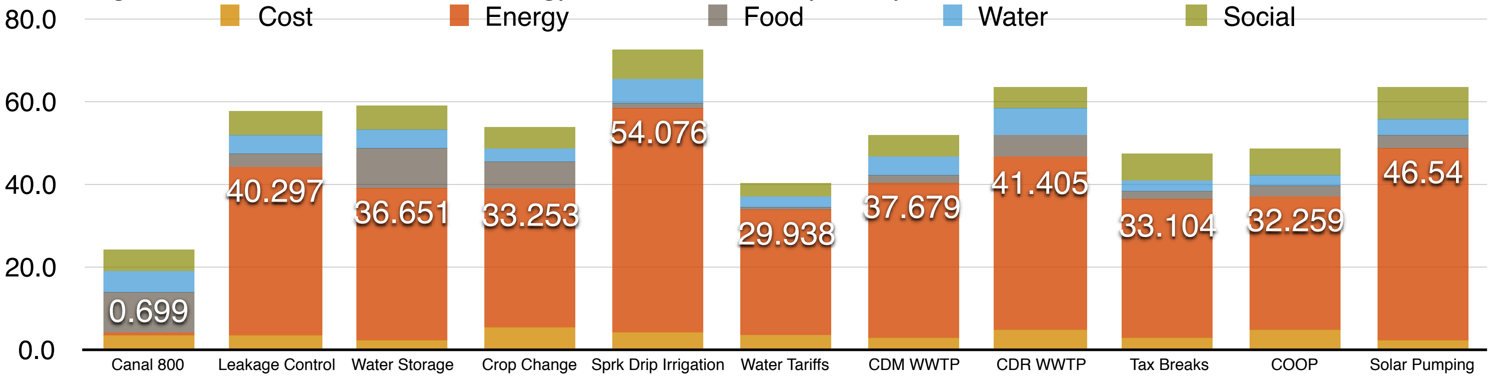


within the cost criteria alone. It is also ranked lower overall than the two other infrastructure projects (Canal 800 and Leakage Control). Leakage control is cheaper option than the canal 800 hence it outperforms within the cost criteria. Increasing Water Tariffs provides the biggest return in turns of government spending and is ranked fifth within the cost criteria alone. However it increases the cost of agricultural production and it is ranked last in water affordability and social acceptability. Hence it is the lowest ranking policy options overall along with WWPT plan suggested by CDM. The CDM plan is important in the sense that it fills the gaps of the uncovered areas by the CDR plan, however when examined alone, this policy option doesn't offer significant agricultural benefits due to its relatively small-scale impact. Finally the three policy options that tackle agriculture cost directly (Market Access for farmers, Tax Breaks and Solar Pumping), Market Access is the highest performing policy instrument among the three. It is the cheapest options with the highest benefits to farmers, it is ranked third within the cost criteria alone. The Tax breaks performs better in terms of cost effectiveness compared to solar pumping but is ranked lower overall. In fact, subsidising solar pumps is a much more rounded policy options with better social, energy, water and food criteria performances.

3.2.7.2. Energy Criteria Sensitivity Analysis

Figure 3.5 shows the aggregate performances of the policy options when the Energy criterion is weighed highest. The Canal 800 is undoubtedly the worst performing instrument in this evaluation. It ranks worst in Energy Affordability since it decreases power supply from EDL and shifts it to the more expensive private generators. It is also ranked worse under Energy Imports since decreasing hydropower means importing foreign fuel to cover the loss in power. All the other instruments are ranked relatively high in energy performance this is due to the comparative nature

Figure 3.5. MCDA Results for Energy Criteria Sensitivity Analysis

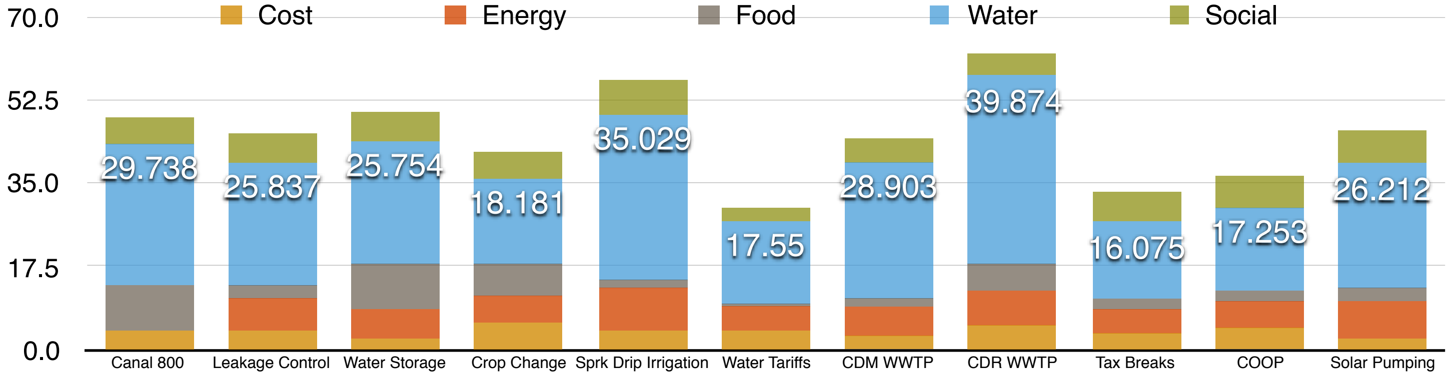


of the MCDA method used in this study. The best policy option when it comes to energy performance in agriculture is the sprinklers and drip irrigation option. The reduced demand in water translate positively in energy consumption in agriculture. WWTP plan by CDR is the second highest ranking options, as it was discussed before it is a well rounded policy. It decreases energy consumption in agriculture by decreasing the amount of water pumped from groundwater resources to a less energy intensive source, waste water treatment. Replacing diesel pumps by solar pumps is the third best option in this evaluation but the second best performance within the energy criteria. It has the lowest consumption of fossil energy in agriculture and it has the best effect on energy imports. The leakage control option performs well under the energy criteria, reducing leakage from the water system significantly improves water availability in the basin and therefore reduces the reliance on groundwater resources especially in the dry summer season. In effect, the amount of energy consumed in agriculture decreases when water is available in the distribution network and farmers don't rely as heavily on wells. The Water storage option provides the most quantity of water of all the other instruments, it decreases the reliance on groundwater resources which in turn decreases energy consumption but the the disproportionate amount of water increase compared to the other instruments does not offset to lower energy consumption. The crop change scenario used by this study reduces demand in water consumption, this in turn translates into lower energy consumption in agriculture. It is less effective in reducing water demand than the sprinklers and drip irrigation policy option, therefore to what concerns energy consumption it performed worse. On the other hand, increasing Water Tariffs decreases water demand more effectively but the water reduction is attributed to increasing tariffs of water from distribution and from the river. To what concerns energy consumption in agriculture increasing water tariffs has the opposite effect, it encourages farmers to rely more heavily on underground aquifers since the cost of acquiring water from the wells becomes closer to the cost water from other sources. It is thus the second worse policy options after the Canal 800 and is ranked tenth. The WWTP plan suggested by CDM decreases water pumping by providing an alternative source of water that is less energy intensive. It performs better than the tax breaks and market access options and is ranked seventh. The market access policy option is ranked higher than the tax breaks however the tax breaks options performs better within the energy criteria. This is mainly due to the effect on the prices at the farm gate the market access policy option has. The higher the prices the more encouraged the farmers will be in investing in their land, this in turn will effect water consumption from all water sources and eventually increasing energy consumption in agriculture. The market access option is ranked higher in total due to its bigger range of benefits compared to tax breaks that performs better just within the energy criteria but worse overall.

3.2.7.3. Water Criteria Sensitivity Analysis

The water criteria are weighted highest in **Figure 3.6** compared to the other evaluation criteria. It is apparent that the WWTP plan suggested by CDR is the best performer in this evaluation. It is scored highest in water quality and water affordability since it provides a significant amount of water from a water source that is cheaper than pumping water. It is also the fourth best performer when it comes to increasing the groundwater budget. The second best policy option is providing subsidies for Sprinklers and Drip Irrigation techniques. It is the best performer when it comes to the change in water consumed per irrigated land. It reduces groundwater extraction by

Figure 3.6. MCDA Results for Water Criteria Sensitivity Analysis

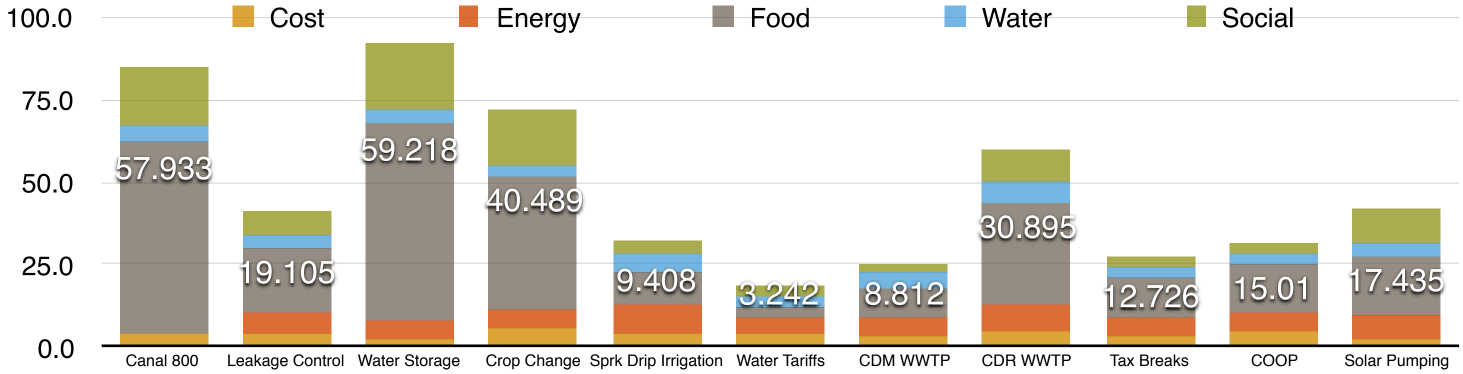


reducing the total amount of water consumed from all water sources and subsequently has a positive effect on water affordability since the total amount of water consumed decreases. Water Storage is the third highest ranking policy option, outperforming the Canal 800 option by a small margin. In fact, the Canal 800 performs better within the water criteria alone but worse overall. This is largely due to the Canal's performance under the energy criteria. These two infrastructure projects divert the most water usage from groundwater resources towards surface water. Subsequently they have positive effects in terms of water affordability but increase total consumption of water in agriculture the most. The Canal 800 performs better within the water criteria mainly due to its performance in the water quality criterion outperforming the water storage options in water quality since water storage include the construction of two new dams. The next policy option in rank is the Solar Pumps subsidies option. It has a positive effect on water affordability since the subsidies decrease initial cost of this technology, the operational cost becomes negligible when compared to extraction water while relying on diesel generators. Leakage Control performs slightly better than the Water Storage option whiten the water criteria but is ranked lower. Its lower rank is mainly due to the its performance within the food criteria which shows an apparent advantage to the Water Storage option. The WWTP plan suggested by CDM performs better than Solar pumps and Leakage control within the water criteria strictly but is ranked lower when aggregate scores are considered. The Crop change scenario considered for this study reduces water consumption, reduce groundwater consumption and doesn't represent a major concern for water quality. It isn't as effective as the other water reduction policy options and is ranked eighth under this sensitivity analysis. The water tariffs option is ranked last but performs better than two remaining policy options (Market access and Tax breaks) in terms of water criteria. It is the worse performing criteria in terms of water affordability, but it is effective in reducing water consumption from distribution networks and the Litany river but has the opposite effect concerning groundwater. The remaining two policy options Market access and Tax breaks are ranked ninth and tenth respectively. These two policy options increases water consumption per irrigated land, have negligible effect on water affordability and increase pumping of groundwater. The market access for farmers performs better under water quality since the tax breaks include tax breaks on fertilisers which increase their consumption, consequently negatively affecting water quality.

3.2.7.4. Food Criteria Sensitivity Analysis

Figure 3.7 considers the food criteria as the most important, it includes four sub-criteria namely, food imports, change in income from agriculture per irrigated land, change in yield per water consumed and change in fossil energy consumed per amount of crops produced. The best performing policy options are the two infrastructure projects that create the most agricultural land (Water Storage and Canal 800). They are the best performing options when it come to first three food sub-criteria. These two policy instruments have the best effect on food imports since they improve local food production the most, they provide the largest increase in income for farmers per agricultural land and increase yield the most relatively to the amount of water consumed. When it comes to fossil energy consumed per the amount of crops produced the water storage and the canal 800 are second and third respectively. The better performance of the Water Storage option under this sub-criteria is mainly due to the larger amount of water provided by the Water Storage from water distribution networks as opposed to the Canal 800 option where the added water source is

Figure 3.7. MCDA Results for Food Criteria Sensitivity Analysis

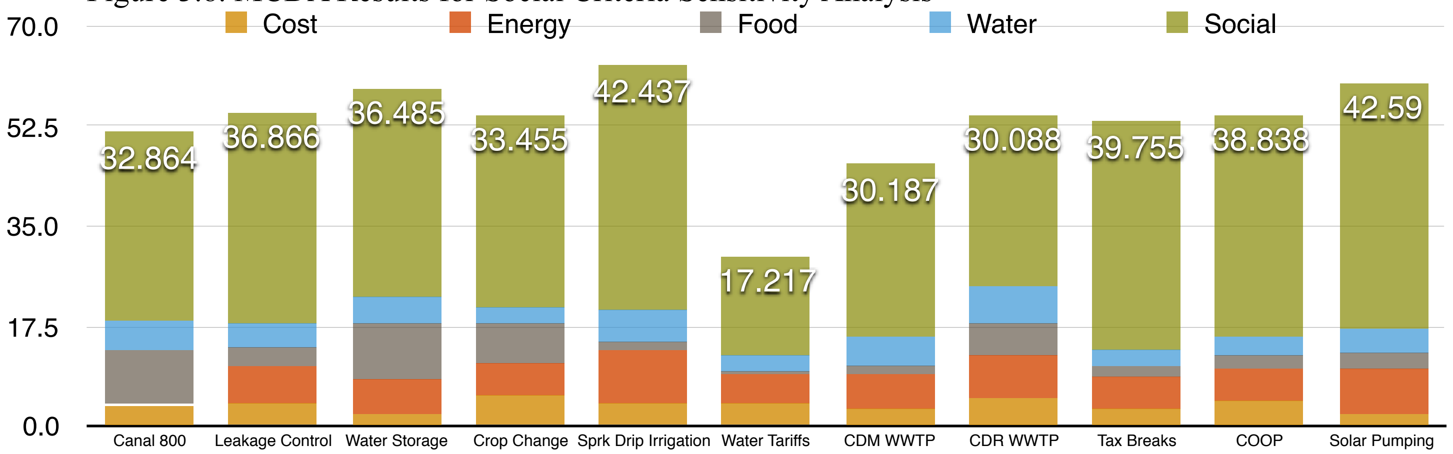


restricted to water from the river which consumed more energy per cubic meter than water from distribution networks. The Crop change scenario considered by this study was chosen to reduce water consumption and maximise return from agriculture by focusing on crops that have high yields, high prices and low water demand. It is the best performing options under change in fossil energy per amount of crops produced. This is mainly due to the characteristics of the crop chosen under this scenario, they have high yields and low water demand affecting in turn the energy consumed per amount of crop produced. It is ranked third in change in crop yield per water consumed and third in change in income per agricultural land. The WWTP plan suggested by CDR is ranked next under this evaluation. The treated water water is mainly used for irrigation so the policy option performs well under all of the food sub-criteria. It is third in food imports, third in change in yield per water consumed, fifth in change in income per agricultural land and fifth in fossil energy per amount of crops produced. Leakage control is next in rank, the water distribution network suffers from too many losses so a leakage control campaign that focuses on minimising these losses benefits directly the agricultural sector. This policy option alternates between fifth and sixth best performance under the four food sub-criteria and is the fifth best performer overall. The sixth policy under the food criteria evaluation is Solar pumping. It performs well under change in fossil fuel consumption per amount of crops produced. It is in fact the fourth best performer. This instrument would probably rank higher under this sub-criteria if it was applied on a larger scope (>15,000 solar pumps) Additionally, providing subsidies for solar pump has positive effect on food imports and the change in income per agricultural land since it decoupled energy prices from the cost of production. Providing subsidies for the Sprinklers and Drip irrigation techniques is the next policy option under this evaluation. However it performs worse than Tax breaks and Market Access policy within the food criteria. Notably, the Market Access policy options is the fourth policy options in terms of change in income per agricultural land and the tax breaks is fourth in ranking under change in food imports sub-criterion. The sprinklers and drip irrigation outranks these two policies in overall performance mainly due to its performance under the remaining criteria. Last performing policy options under the food criteria are the WWTP plan suggested by CDM and increasing Water Tariffs. The CDM plan has positive effects in all four food sub-criteria but its effects are minimal in scale compared to the other policy options. Water tariffs is clearly the worse policy option to be considered under the food criteria evaluation. It is ranked last it increases food imports the most, it decreases income per agriculture land the most and reduced yield per water consumption the most compared to the other policy options. It only has a minimal positive effect in the change in fossil energy per amount of crops produced since it effectively decreases the amount of water consumed.

3.2.7.5. Social Criteria Sensitivity Analysis

This brings us to the last set of criteria, the weights of the social criteria are weighed higher than the remaining evaluation criteria. **Figure 3.8** shows that the best policy option performing under the social criteria alone is the Solar pumps however it is ranked second to the sprinklers and drip irrigation options in overall performance. Solar pumps is ranked highest in the social acceptability survey, in fact it was given a maximum score by all the community leaders who have taken the survey. It doesn't affect land use greatly as compared to the other options but it creates less jobs than other policy options. The sprinklers and drip irrigation option scores high in the social

Figure 3.8. MCDA Results for Social Criteria Sensitivity Analysis



acceptability survey and land use is not affected by the introduction of this policy option. The third overall performing policy option is the Water Storage option. It is ranked fifth in social criteria alone but third overall mainly due to is well rounded performance under all of the criteria. Along with the Canal 800, these two policy instruments create the most jobs scoring highest in employment but on the other hand are the worse performing criteria in terms of land use change. The water storage option performs better within the social criteria because of its higher performance in the social acceptability survey. The fourth ranked policy option is leakage control, although the policy creates less jobs than water storage it outperforms the water storage option within the social criteria mainly due to the difference in land use change the two policies generate. The Market Access for farmers has its highest ranking when the social criteria are amplified. It has minimal effects on land use, it creates jobs by increasing return on agriculture and it ranks third highest in the social acceptability survey. It is ranked fifth relative to the other policy options. Crop change doesn't have any effect on land use since the scenario adopted by this study maintains the same agriculture land prior to the policy interventions. However the type of crop that have increased require more workers per hectare thus this policy options had a positive impact on employment. On the social acceptability survey it ranked fourth to last. Overall it was the sixth policy option under this evaluation. The CDR WWTP ranked seventh, the increase in water supply created more irrigated land and thus more jobs, the land use change is among the worse of the policy examined by this study and the social acceptability score was among the lowest. The low performance in the social acceptability survey is suspected to be caused by the failure of older waster water treatment facility built on the Litany river basin in delivering water suitable for irrigation. The tax breaks policy option is ranked eighth, which is its highest position compared to its performance in the above evaluations, it has the third highest score when the social criteria are evaluated alone. It has a positive impact on job creation. It has low land usage change and is the second highest performing policy options in the social acceptability survey. The Canal 800 is ranked ninth, as it was mentioned earlier it the best options in creating jobs, the worst in land use change and its social acceptability score is among the worst. Its low performance in the social acceptability acceptability survey is mostly due to the fact that the community leaders that where questioned don't all belong to the area that benefits from the Canal 800 the most. CDM's WWTP policy option is the second lowest performing policy when the social criteria are amplified, it is the second lowest criteria in job creation and in social acceptability score, it only performs relatively high in change in land use. Finally, increasing water tariffs was lowest value in the social acceptability survey and in job creation as it was the only policy option that has a negative effect on employment. It is ranked last within the policy options when the social criteria were amplified.

CHAPTER 4

POLICY RECOMMENDATIONS

The multi-criteria decision evaluation proposed by this thesis shows the performance of each policy intervention under a range of criteria. This evaluation is mostly beneficial to policy makers who are considering several policy options to achieve different objectives. It creates dialogue between different government institutions by including policy options that fall under different legal

Table 4.1 Top Ranked Policy Instruments

Rank	Equal Weights	Cost	Energy	Water	Food	Social
1	Water Storage	CDR WWTP	Irrigation Techniques	CDR WWTP	Water Storage	Irrigation Techniques
2	CDR WTP	Crop Change	CDR WWTP	Irrigation Techniques	Canal 800	Solar Pumping
3	Irrigation Techniques	Irrigation Techniques	Solar Pumping	Water Storage	Crop Change	Water Storage
4	Crop Change	COOP	Water Storage	Canal 800	CDR WWTP	Leakage Control
5	Solar Pumping	Leakage Control	Leakage Control	Solar Pumping	Leakage Control	COOP

or institutional jurisdiction. It also depicts the priorities that policy makers needs to consider when making decision about the three Nexus resources. Upon the completion of this evaluation it became apparent that the sprinklers and drip irrigation option is one best policy options studied. It populated 5 of 25 top ranked policy instruments within all the evaluations **(table 4.1)**. The sprinklers and drip irrigation option has energy and water benefits, it has a low cost of implementation and performs well in the social criteria. It is policy option that should be implemented by the ministry of agriculture but the social, energy and water benefits do not represent concrete policy priorities for the ministry of agriculture. This calls for greater coordination between government institutions which tend to focus on one sector and ignore the other. This issue is however not unique to the sprinklers and drip irrigation option.

The quality of water is monitored by the Ministry of Health, the Water Establishments are responsible of building and operating waste water treatment plants and the funds need to be mobilised by CDR. The WWTPs have clear beneficial attributes when it come to the food production sector and are positively synergetic with energy consumption and security and water consumption and withdrawals. The centralised waste water treatment plan (CDR WWTP) is one of the highest scoring policy instruments it appears 5 times within the top ranked policies. The multi-criteria evaluation highlights the interconnections between the resources and stresses on the importance of treating waste water not just from an environmental or health perspective but also from cost effectiveness, social acceptance, energy consumption and agriculture productivity. The waste water treatments plants suggested will offer further benefits if alternative power sources were suggested. In fact if renewable energy was to supply the waste water treatment plants this would decouple water consumption in agriculture from energy prices even more. It is an option that should be seriously considered in future studies. In any case, if the government is to chose between the two WWTP plans considered by this thesis, CDR's plan should be considered as the main priority. The CDM plan in isolation doesn't perform well in the evaluation but has an important role in covering the villages neglected by the CDR's plan. CDM's low performance highlights one of the limitation of the MCDA nexus methodology proposed by the framework. The CDM's plan performance brings forward the fact that the policy instruments being evaluated should be similar in scope so that the results don't come in favour of the larger scale impact options.

Furthermore, Leakage control should be considered as a priority for the Lebanese government regardless of its performance in the current evaluation. The results presented can be used in favour of accelerating the implementation of this policy option. Reducing leakage confined to being viewed as wasteful water management but can provide greater water availability for farmers, decrease total energy consumption in agriculture and ultimately enhancing food security. It appears 4 times in the top ranked policy instrumented should be given serious consideration by the ministry of energy and water, the ministry of agriculture, the ministry of environment and CDR.

Moving on, increasing water tariffs has always been considered an effective market solution for reducing wasteful water consumption. Furthermore it is the only policy instrument in this study that translates positively in the government's budget. But, increasing water tariff in agricultural turns out to be the worst policy options under the three main criteria, namely the energy, food and social criteria. Policy makers should reconsider the implementation of this instrument for the agricultural sector. The tradeoffs that come into play between the different WEF criteria especially in the food sector are too important to ignore. The government could instead apply water meters and increase water tariffs in domestic and industrial usages. In the agricultural sector, the government could resort to a systematic awareness campaign for better water usage in irrigation without resorting to price increases, also the government could offer a reward based system for farmers that are using water less intensively. Tradable water permits can be useful way to ensure that water use remain below a certain threshold in turn rewarding farmers who limit their water use.

The market access for farmers policy option (COOP) doesn't take into consideration the resulting decrease in energy consumed in food transportation. The policy's performance under the energy criteria would have increased if more data was available on energy consumption in food transport. Nevertheless it is remains to be a viable policy option that improves return in agricultural activity with a low cost of implementation. It populates 2 of the top 25 ranking positions and should be included in the government agenda if there is a serious effort in improving the agricultural sector.

The tax breaks option on agriculture input such as seeds, fertilisers and agricultural machinery affects an important source of the government revenues (custom tariffs). However it has positive effects on the cost of production in the agricultural sector but could affect local production of agricultural input. As a result imported goods become more competitive which this in turn could affect employment, but reliable data is missing in this regard and was not considered by the current research. Further investigation should be performed to truly examine this policy option and more effort should be dedicated to reduce the increasing prices of agriculture input. One option to consider is encouraging local production of these products by closely examining the needs of this local manufacturing sector that would in effect increase the local production of seeds and fertilisers with a cost that can be accommodated by local farmers.

The crop change scenario is a low cost policy to implement and has social, energy, water and food benefits however the feasibility of implementation of such policy was not examined in this study. This could be another limitation of the proposed framework. The feasibility of implementation is sometimes more important of the design of the policy itself. Further work should be dedicated to surpass the shortcomings of the methodology. This could be achieved by including a qualitative criteria that deals with feasibility. In any case, the crop change scenario appeared 3 time in the top ranked policies. Changing cropping patterns would become a more pressing issue under a climate change scenario where frequency of drought occurrences are more likely to increase.

The solar pumps was the most popular policy option when the community leaders examined the policy instruments under evaluation in this study. It populated 4 out of the 25 top ranked policy positions. By subsidising the high capital cost of solar pumps and an effective awareness campaign will lead to higher market penetration of this technology. Solar pumps decouple food cost from oil prices but encourage groundwater pumping. For certain farmers groundwater is often the only water resource available, therefore subsidising solar pumps become a necessary technology in replacing diesel pumps if big infrastructure are not implemented to provide water from clean surface water sources.

This brings us to the two infrastructure projects examined by this study. The Canal 800 and the Water storage option provide approximately the same quantity of water for irrigation. The Canal 800 is the worst policy option considered under the energy criteria but it offers the largest food benefits, contributes to water affordability and reduces groundwater pumping. It appears twice in the top ranked policies. On the other hand the water storage option provides the same benefits of the Canal 800 without the energy implication but the large amount of water supplied can only be achieved by the construction of two new dams on the Litany river which in turn seriously affect water quality. In any case the water storage option populated 5 of the 25 top ranked policy positions. It is clearly the more preferred policy options between the two. However the tradeoffs between these two policy options cannot be taken in isolation by one government institution. The Canal 800 could become a better policy option if the loss in power from hydroelectric power plants was supplied by another sustainable power source but without system planning, the water storage option becomes the more preferred policy instrument when taken in isolation.

It is strikingly apparent that an increase in government spending is needed on the Litany river basin. The basin suffers from a lack of supply in quantity and in quality of water, food and energy and without effective government interventions the quality of these resources will only deteriorate. The evaluation conducted during this thesis highlighted the need of larger institutional dialogue and reforms however this is not easily achieved in the real world. Osseiran 2015, suggested the creation of a governmental water body that manages all water resources in the country. Its responsibility would include financing, monitoring, implementing and planning all the aspects of the surface and groundwater resources. Under such institutional reform this kind of holistic evaluation will lead to more successful planning and policy implementations.

CHAPTER 5

CONCLUSION

In conclusion, the proposed framework had clear limitation highlighted in the chapter above. However it remained a valuable tool when examining a nexus area of interaction in a developing country context with limited data. That being said more effort should be dedicated towards energy consumption in agriculture especially to what concerns energy consumption in acquiring water (pumping, lifting transporting), energy consumption in the food production process from transportation to refrigeration to distribution. Additionally the weighing methodology used by this study should be re-examined. Stakeholder engagement in the WEF nexus methodology require expert knowledge for the preference elicitation. A wide range of stakeholder engagement was proven to be unsuccessful however the sensitivity analysis performed where each criteria was given maximum weight proven to be a valuable tool for examining the different policy instruments. Furthermore, the proposed framework should be tested in different case studies in order to fully assess its effectiveness. In any case the results obtained by the framework produced a holistic understanding of the policy instruments being examined. System thinking proved to be valuable in policy evaluation within a nexus area of interaction. The relationship between the water, energy and food resources should be fully understood before the implementation of policy measures in areas where the nexus resources are interconnected. The policy evaluation should be further extended to cover a wider range of policies such as removing electricity subsidies and water desalination for irrigation. Further studies should also extend the system boundaries of the area examined and create a national WEF assessment. This tool require the creation of a central planning agency for the whole country responsible for resource planning and filling data gaps. Without the creation of such entity the proposed Nexus methodology will remain a study tool that cannot greatly affect policy implementation.

Appendix 1 - Survey Determining Criteria Weights

Explanation of Ranking Criteria

You can make the evaluation by grading each comparison with the grades ranging from 1 to 5.

1: Equal Importance
2: Somewhat more important
3: Much more important
4: Very much more important
5: Absolutely more important

1/x: Inverse scale (If first item in the question is less important than second item)

Example

How much ‘Energy' is more important than 'Cost'?

If you think ‘Energy' is somewhat more important than 'Cost' then your answer should be 2.

If you think 'Cost' is somewhat more important than 'Energy' then your answer should be 1/2.

Survey

Please answer the following questions based on your assessment:

Pair-wise Comparison of Main Criteria

How much ‘Cost' is more important than ‘Energy’?

How much 'Water' is more important than ‘Food’?

How much ‘Cost' is more important than ‘Water’?

How much 'Energy' is more important than ‘Food’?

How much ‘Food' is more important than ‘Cost’?

How much ‘Energy' is more important than ‘Water’?

How much ‘Social' is more important than ‘Cost’?

How much ‘Energy' is more important than ‘Social’?

How much ‘Social' is more important than ‘Water’?

How much ‘Food' is more important than ‘Social’?

Pair-wise Comparison of Cost Sub-Criteria

How much ‘Capital Cost' is more important than ‘∆Value of Ag produce/ annual Cost ’?

How much ‘∆Value of Ag produce/ annual Cost' is more important than ‘∆Unit of Irrigated Land(ha)/Annual Cost’?

How much ‘∆Unit of Irrigated Land(ha)/Annual Cost' is more important than ‘Capital Cost’?

Pair-wise Comparison of Energy Sub-Criteria

How much 'Energy Imports' is more important than 'Electricity Affordability '?

How much '∆Energy Consumed/ Irrigated Land' is more important than '∆Fossil Energy Consumed/ Irrigated Land'?

How much '∆Fossil Energy Consumed/ Irrigated Land' is more important than 'Energy Imports'?

How much 'Electricity Affordability' is more important than '∆Energy Consumed/ Irrigated Land'?

How much '∆Energy Consumed/ Irrigated Land' is more important than 'Energy Imports'?

How much 'Energy Imports' is more important than '∆Fossil Energy Consumed/ Irrigated Land'?

Pair-wise Comparison of Water Sub-Criteria

How much 'Water Quality' is more important than 'Water Affordability'?

How much 'Water Quality' is more important than '∆Water Consumed/ Irrigated Land'?

How much '∆Water Consumed/ Irrigated Land' is more important than '∆Groundwater Budget'?

How much '∆Groundwater Budget' is more important than 'Water Quality'?

How much 'Water Affordability' is more important than '∆Water Consumed/ Irrigated Land'?

How much 'Water Affordability' is more important than '∆Groundwater Budget'?

Pair-wise Comparison of Food Sub-Criteria

How much '∆Income from Ag/ Ag Land' is more important than 'Food Imports'?

How much 'Food Imports' is more important than '∆Yield/Water Consumed'?

How much '∆Fossil Energy/ Amount of crops produced' is more important than 'Food Imports'?

How much '∆Fossil Energy/ Amount of crops produced' is more important than '∆Income from Ag/ Ag Land'?

How much '∆Income from Ag/ Ag Land' is more important than '∆Yield/Water Consumed'?

How much '∆Fossil Energy/ Amount of crops produced' is more important than '∆Yield/Water Consumed'?

Pair-wise Comparison of Social Sub-Criteria

How much 'Employment' is more important than 'Social Acceptability'?

How much 'Land Use' is more important than 'Employment'?

How much 'Social Acceptability' is more important than 'Land Use'?

Appendix 2- Survey Social Acceptability

Kindly, assign a score from 1-10 to the following policy instruments based on level of acceptance of each policy. A score of 1 will be given to the policy that is least favourable to the community and a score of 10 will be given to the policy that is most favourable.

Policy Instruments	**Social Acceptability Score**
Canal 800	
Leakage Control	
Water Storage	
Crop Change	
Sprinklers and Drip Irrigation	
Water Meters and Water Tariffs	
Decentralised Waste Water Treatment Plants	
Centralised Waste Water Treatment Plants	
Remove Tax from agricultural input (fertilisers, seeds, machinery)	
Market Access for farmers	
Solar Pumping	

Appendix 3- Water Quality Survey

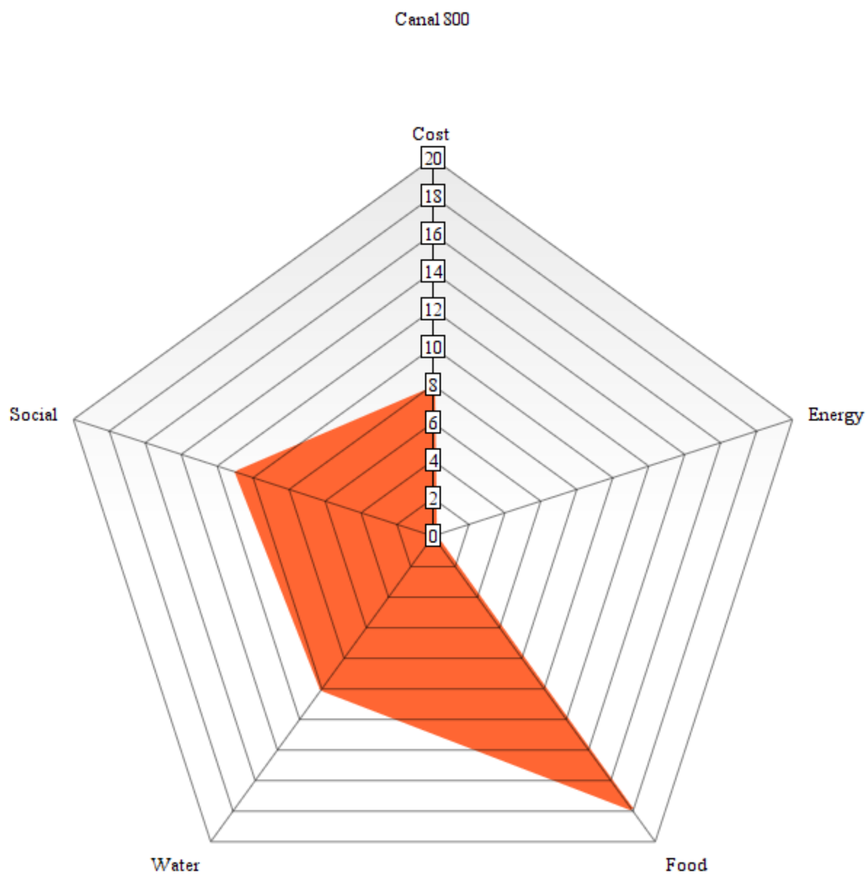
Please assign a score between -5 and 5 to the policy measures based the impact the policy measures will have on surface water (rivers, springs) and on groundwater. A score of -5 will be given to the policy that causes most harm to the water bodies, a score of 5 will be given to the policy that improves water quality the most and a score of 0 would be assigned if the policy has no impact on the water bodies. Also, in case you have any comments please add them in the comment box below.

Policy Instrument	**Surface Water (-5;5)**	**Ground Water (-5;5)**	**Comments**
Canal 800			
Leakage Control			
Water Storage			
Crop Change			
Sprinklers and Drip Irrigation			
Water Meters and Water Tariffs			
CDR Waste Water Treatment Plants			
CDM Waste Water Treatment Plants			
Remove Tax from agricultural input (fertilisers, seeds, machinery)			
Market Access for farmers			
Solar Pumping			

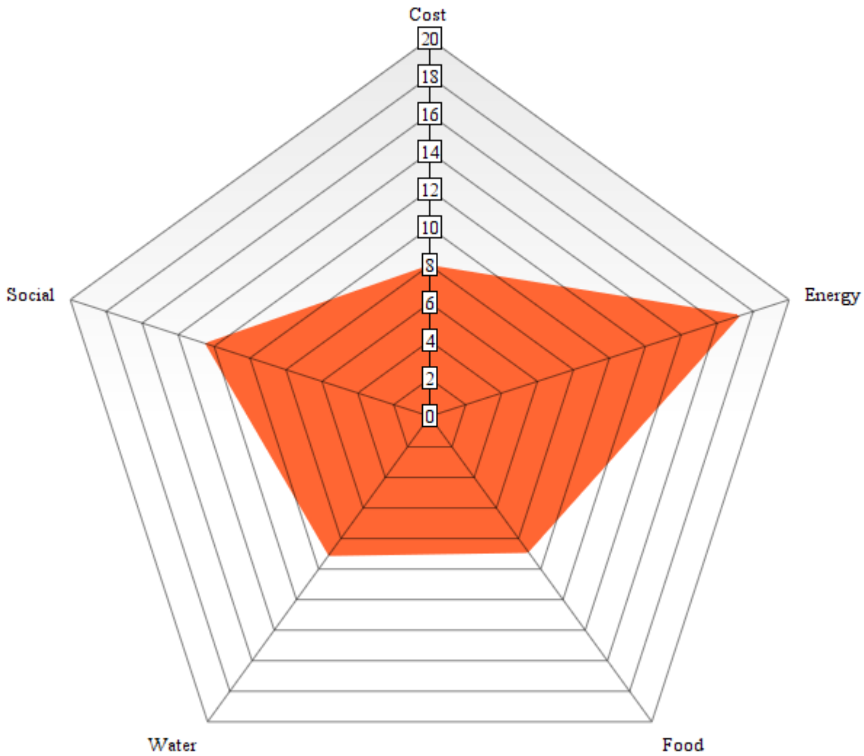
Appendix 4 - MCDA Results Table

Main Criteria	Sub-Criteria	Canal 800	Leakage Control	Water Storage	Crop Change	Sprinkle & Drip Irrigation	Water Tariffs	CDM WTTP	CDR WWTP	Tax Breaks	Market Access for farmers	Solar Pumps
Cost	**Capital Cost**	18.7	52.4	0.0	64.8	64.8	100.0	64.9	49.7	66.0	64.8	61.4
	ΔValue of Ag produce/ annual Cost	3.5	1.3	2.5	100.0	58.7	1.0	0.0	4.1	6.7	42.5	0.0
	ΔUnit of Irrigated Land(ha)/ Annual Cost	90.5	61.7	65.0	0.0	0.0	17.7	23.7	100.0	20.9	34.2	6.5
Energy	**Electricity Affordability**	0.0	99.6	99.6	99.7	99.5	99.7	99.6	99.6	99.7	99.7	100.0
	Energy Imports	0.0	99.9	99.9	99.9	100.0	99.9	99.9	99.9	99.9	99.9	100.0
	ΔEnergy Consumed/ Irrigated Land	2.9	42.9	27.8	13.7	100.0	0.0	32.1	47.5	13.1	9.6	10.3
	ΔFossil Energy Consumed/ Irrigated Land	1.8	26.2	17.0	8.4	61.0	0.0	19.6	29.0	8.0	5.9	100.0
Water	**ΔWater Consumed/ Irrigated Land**	0.1	34.4	0.0	46.4	100.0	54.5	45.5	24.9	45.9	45.2	43.9
	Water Affordability	85.6	47.8	71.7	29.2	41.8	0.0	40.6	100.0	28.9	26.8	87.5
	Water Quality	12.5	50.0	0.0	37.5	37.5	62.5	87.5	100.0	25.0	37.5	37.5
	ΔGroundwater Budget	100.0	40.1	100.0	8.1	54.3	0.0	19.1	40.9	7.4	5.5	5.9
Food	**Food Imports**	100.0	32.1	100.0	15.2	17.2	0.0	15.9	48.0	43.0	16.6	20.5
	ΔIncome from Ag/ Ag Land	100.0	32.5	99.7	69.7	27.3	0.0	22.8	58.4	23.3	62.3	26.4
	ΔYield/Water Consumed	100.0	38.8	99.9	85.0	18.2	0.0	19.1	55.8	18.4	19.6	24.7
	ΔFossil Energy/ Amount of crops produced	86.2	24.0	95.1	100.0	0.0	21.6	1.0	43.8	0.2	1.6	44.6
Social	**ΔEmployment**	99.3	30.6	100.0	15.3	38.5	0.0	12.8	45.8	12.2	13.0	13.2
	Social Acceptability	65.2	73.9	82.6	52.2	73.9	0.0	39.1	43.5	87.0	82.6	100.0
	ΔLand Use	0.0	80.0	0.0	100.0	100.0	86.2	99.2	61.3	99.8	98.7	100.0
Aggregate Performance		48.1	48.2	58.9	52.5	55.1	30.2	41.2	58.5	39.2	42.6	49.0

Appendix 5- Nexus Radial Charts for each Policy Instrument

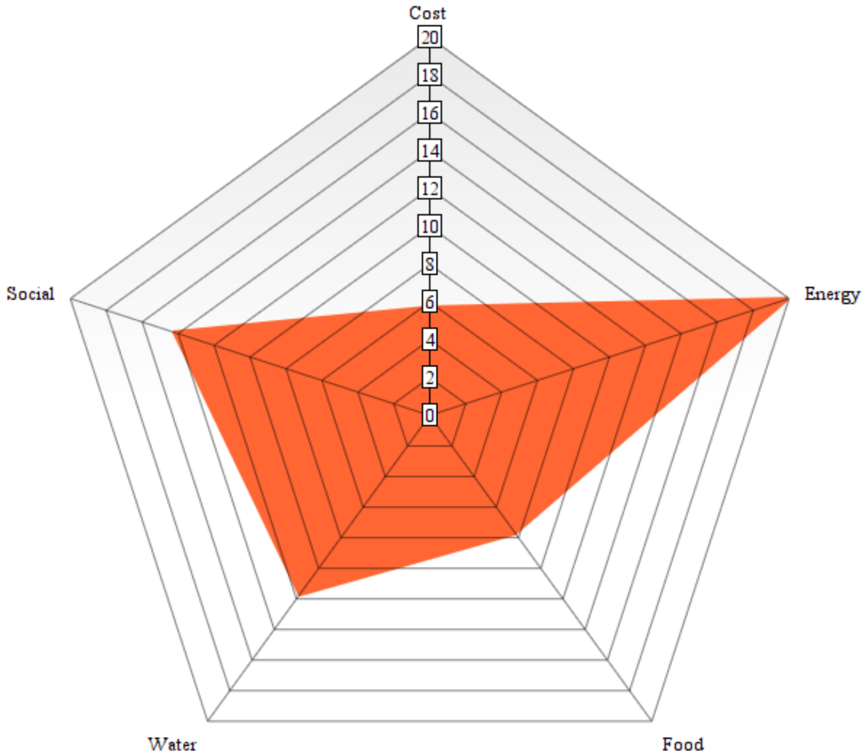


Leakage Control

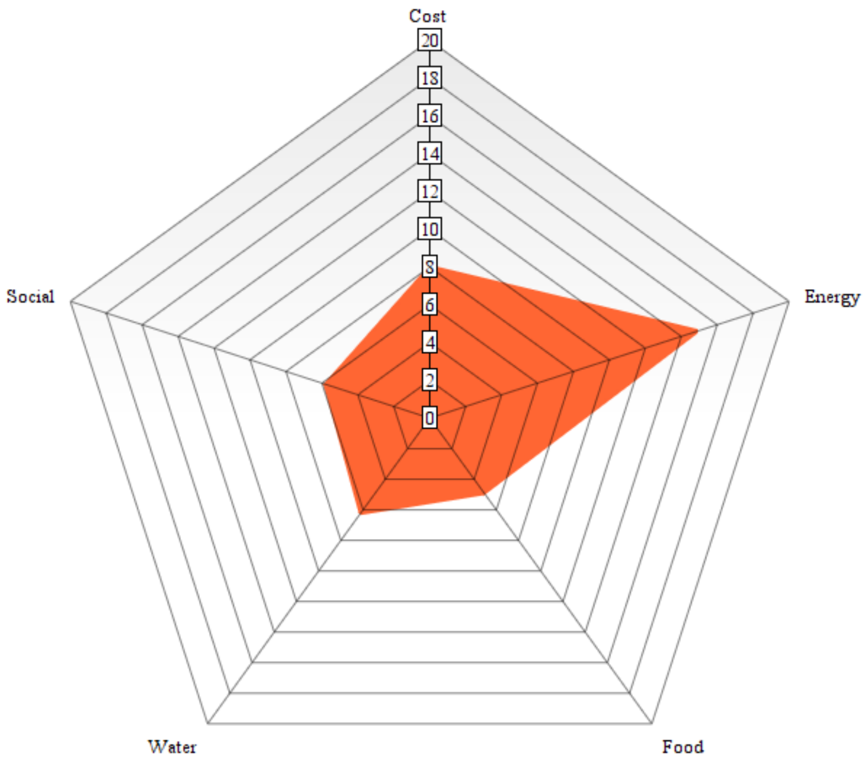


Water Storage

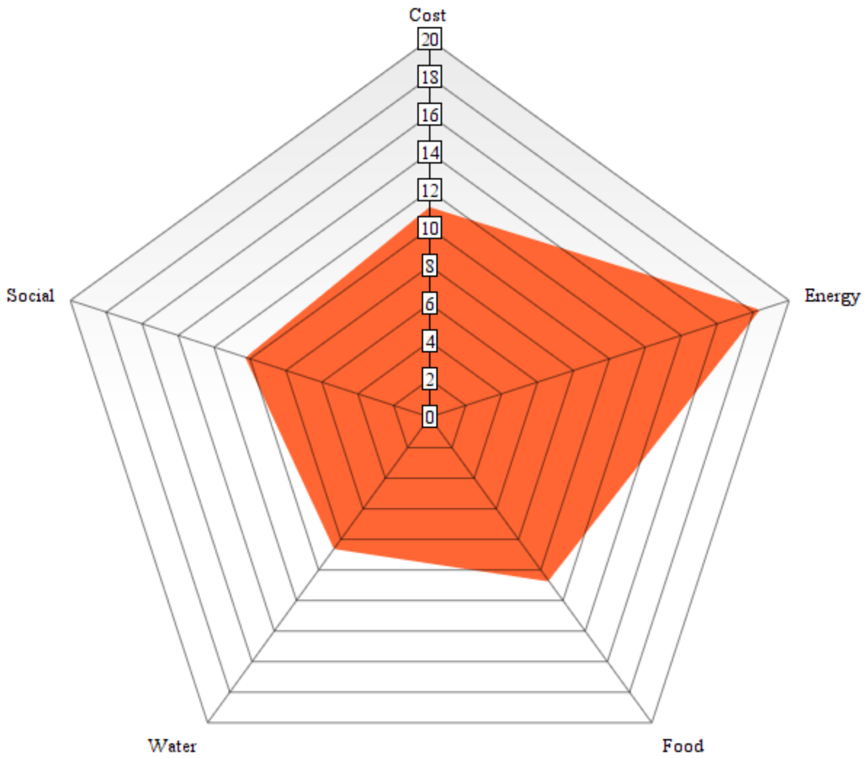
Spinklers & Drip Irrigation



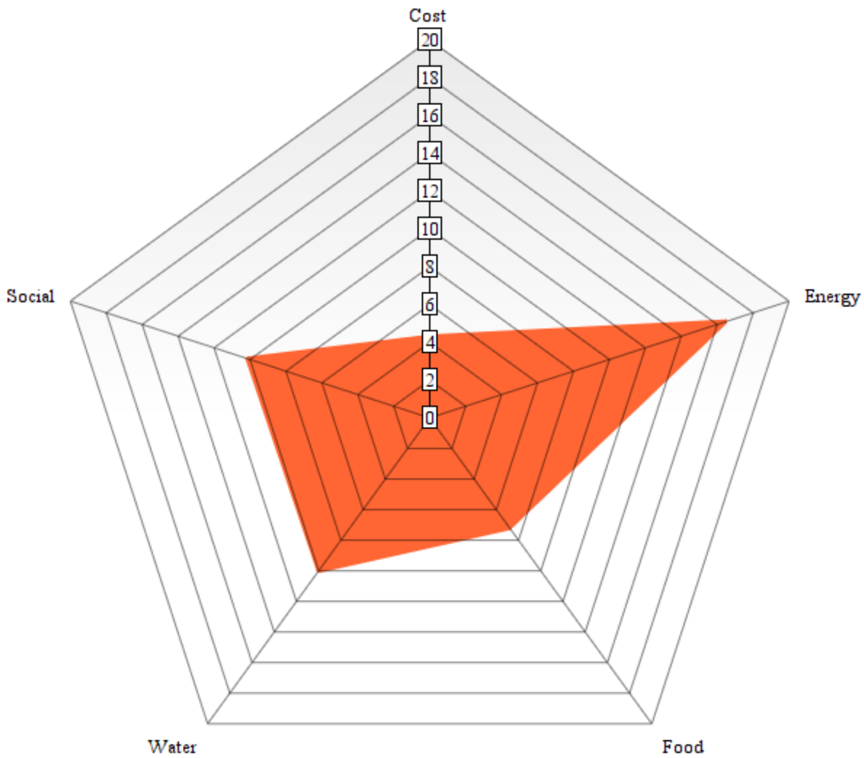
Water Tariffs



Crop Change



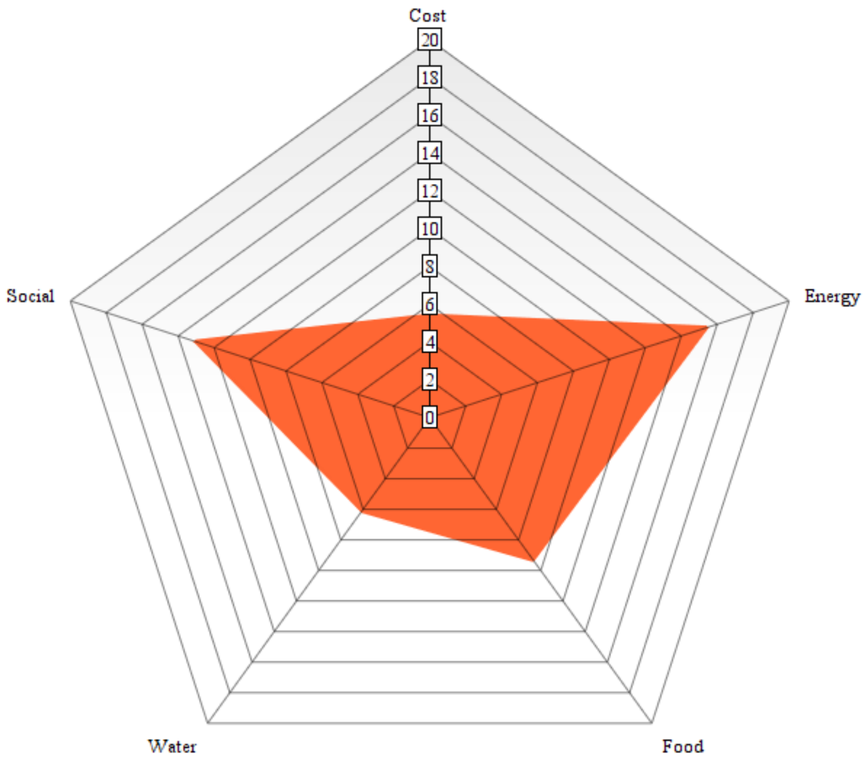
WWTP CDM



CDR WWTP

Tax Breaks

Market Access



Solar Pumps

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