Utility Demand-side Management for Solar Thermal Technology Transfer to Countries Subsidizing Electricity

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ABSTRACT

Oil producing countries in the Middle East and North Africa (MENA) region have a common policy of offering higher energy subsidies compared to other countries. MENA countries depend on fossil fuels to meet their domestic energy needs. Supplying electricity to meet the demand in these countries requires a huge subsidy, placing an extensive burden on the available financial resources.

Although solar thermal technologies have been generally proven to be economically feasible in many countries with abundant solar energy, MENA countries have yet to adopt these technologies to meet their energy needs. This is attributed to the low cost of electricity owing to higher subsidies, which have made it difficult for renewable technologies to penetrate these markets.

Although previous research and international organizations have recommended the removal of energy subsidies as an approach to addressing the budget deficit crisis, these recommendations did not offer realistic solutions because the resources used for generating electricity are national resources, of which the people feel that they deserve to have a share. In the present study, demand-side management (DSM) programs promoting solar thermal technologies are proposed to overcome this problem. The methodology targets replacing electricity use with that of solar energy, reducing not only the electricity demand and the required subsidies but also the emissions of carbon dioxide and other harmful gases.

Two case studies were conducted for the province of Erbil, (Kurdistan Region, Iraq) to develop the methodology. First, the economic feasibility of promoting solar water

heaters (SWHs) by DSM was investigated. An estimated investment of US$90 million was required. The net present value (NPV) of installing the SWHs as part of a DSM program was US$776.6 million for a life cycle of 10 years. The program would have the advantage of reducing electricity sales (which are greatly subsidized) for preparing domestic hot water in 100,000 houses. Second, the benefits of replacing standard air conditioners with solar-assisted air conditioners through DSM were assessed for 100,000 offices, costing the utility US$80 million. It was found that a capacity requirement at an estimated cost of US$138 million would be avoided for at least 10 years. Furthermore, the program would help reduce consumer annual energy consumption by approximately 37%, thus removing the need for subsidies.

It would be appropriate to differentiate between the two categories of countries in the MENA region, i.e., oil exporting countries and developing oil-producing countries. There would be differences in the DSM approach promoting solar thermal technologies between these two categories of countries as oil exporting countries have stronger financial reserves compared to developing oil-producing countries. Developing oil-producing countries, owing to a fiscal deficit and typically low quality power systems, face challenges in developing their infrastructure as well as meeting the high pre-tax subsidy. The proposed approach would have better implementation potential in developing oil-producing countries as it would facilitate deferral of the construction of new power plants and associated infrastructure; simultaneously, the electricity sales would be reduced significantly.

Keywords: Demand side management, solar thermal technology, Polysun software, solar water heater, electric water heater, solar assisted air conditioner, electricity subsidy, and oil producing countries.

ÖZ

Orta Doğu ve Kuzey Afrika (MENA) bölgelerinde petrol üretimi yapan ülkelerin yaygın politikası diğer ülkelerle kıyaslandığında daha yüksek enerji sübvansiyonları vermeleridir. MENA ülkeleri, yurt içi enerji ihtiyaçlarını karşılamak için fosil yakıtlara bağımlıdır. Bu ülkelerde talebi karşılamak üzere elektrik temini için çok büyük sübvansiyonlar gereklidir ve bu da mevcut finansal kaynaklar üzerine muazzam bir yük bindirmektedir.

Bol güneş enerjisi alan pek çok ülkede solar ısıl teknolojilerin genelde ekonomik olarak uygulanabilir olduğu kanıtlanmış olsa da MENA ülkeleri kendi enerji ihtiyaçlarını karşılamak için bu teknolojileri henüz benimsememişlerdir. Bu durum, yüksek sübvansiyonlar sayesinde elektriğin düşük maliyetli olmasına bağlanmaktadır ve bu da yenilenebilir enerji teknolojilerinin söz konusu pazarlara girmesini zorlaştırmıştır.

Önceki araştırmalar ve uluslararası kuruluşlar bütçe açığı krizinin ele alınması için yaklaşım olarak enerji sübvansiyonlarının kaldırılmasını önermişlerse de bu öneriler, gerçekçi çözümler sunmamıştır çünkü elektrik üretiminde kullanılan kaynaklar ulusal kaynaklardır ve halk bu kaynaklarda payı olduğunu düşünmektedir. Bu çalışmada, bu sorunun üstesinden gelinmesi için solar ısıl teknolojileri destekleyen talep tarafı yönetimi (DSM) programları önerilmektedir. Kullanılan metodolojide, elektrik kullanımı yerine güneş enerjisi kullanılması hedeflenmekte ve böylece hem elektrik talebi ve gerekli sübvansiyonlar hem de karbondioksit ve diğer zararlı gazların emisyonları azaltılmaktadır.

Metodolojinin geliştirilmesi amacıyla Erbil ili (Kürdistan Bölgesi, Irak) için iki örnek teknolojinin incelemesi yapılmıştır. İlk olarak, DSM ile solar su ısıtıcılarının (SWH) teşvikinin ekonomik uygulanabilirliği araştırılmıştır. Tahmini olarak 90 milyon Amerikan doları yatırım gerektiği tespit edilmiştir. DSM programının içinde SWH'lerin kurulmasının bugünkü net değeri (NPV) 10 yıllık bir döngüde 776,6 milyon Amerikan dolarıdır. Program, 100.000 eve sıcak kullanım suyu hazırlanmasında (büyük oranda devlet destekli olan) elektrik satışlarını azaltma avantajı sunacaktır. İkinci olarak, elektrik şirketine maliyetinin 80 milyon Amerikan doları olacağı öngörülen DSM ile standart klimaların solar destekli klimalar ile değiştirilmesinin yararı, 100.000 ofis için değerlendirilmiştir. Tahmini olarak 138 milyon Amerikan doları kadar maliyetli bir kapasite gerekliliğinin en az 10 yıl boyunca gerekmeyeceği bulunmuştur. Ayrıca program, yıllık enerji tüketimini %37 oranında azaltmaya yardımcı olacağından sübvansiyon ihtiyacını önemli ölçüde azaltacaktır.

MENA bölgesindeki ülkeleri ikiye ayırmak uygun olur: petrol ihraç eden ülkeler ve gelişmekte olan petrol üreticisi ülkeler. Petrol ihraç eden ülkelerin, gelişmekte olan petrol üreticisi ülkelere kıyasla daha güçlü finansal rezervleri olduğundan solar ısıl teknolojilerin bu iki kategoriye tanıtılması için kullanılan DSM yaklaşımında farklılıklar olacaktır. Bütçelerinde bulunan mali açık ve tipik olarak düşük kaliteli enerji sistemleri nedeniyle, gelişmekte olan petrol üreticisi ülkeler altyapılarını geliştirme ve yüksek olan vergi öncesi sübvansiyonları karşılama konularında zorluklar yaşamaktadır. Önerilen yaklaşım yeni enerji tesislerinin ve bunlarla ilişkili altyapının yapımının geciktirilmesini kolaylaştıracağı ve elektrik satışları kayda değer oranda düşeceği için bu yaklaşımın gelişmekte olan petrol üretici ülkelerde uygulama potansiyeli daha iyi olacaktır.

Anahtar Sözcükler: Talep tarafı yönetimi, solar ısıl teknoloji, Polysun yazılımı, solar su ısıtıcısı, elektrikli su ısıtıcısı, solar destekli klima, elektrik sübvansiyonu ve petrol üreticisi ülkeler.

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LIST OF ABBREVIATIONS

A/C	Air Conditioner Split Unit
DNI	Direct Normal Irradiation
DSM	Demand-side Management
EWH	Electric Water heater
GCC	Gulf Cooperation Council countries
kW	Kilowatt, Power
kWh	Kilowatt hour, Energy
L_c	Current Peak Demand Load
L_f	Future Peak Demand Load
NPI	Net Present Investment
NPS	Net Present Saving
NPSR	Net Present Value Subsidy Recovery
NPV	Net Present Value
O&M	Operation and Maintenance
P_c	Cost Paid by Customer
P_s	Pretax Subsidy
P_{s_post}	Posttax Subsidy
P_w	Electricity Supply Cost
STT	Solar Thermal Technology
SWH	Solar Water Heater

Chapter 1

INTRODUCTION

1.1 Overview

In many countries, especially those that produce petrol, it is common to subsidize electricity consumption, leading to very low electricity costs. Although solar thermal technologies have proven to be economically viable and are widely used in many countries, they have not been able to penetrate markets in countries with low electricity costs and in countries where electricity is subsidized even with high irradiation of solar energy. Table 1.1 shows the amount of global direct normal irradiation (DNI) received by different regions on earth (NASA, 2018).

Table 1.1: Average Values of Global DNI, (NASA, 2018)

World Regions	DNI (kWh/m^2/yr)
Asia	865
Middle East, North Africa, and Greater Arabia	3,040
Europe	2,190
North America	1,991
Central America and the Caribbean	2,606
South America	938
Sub-Saharan Africa	2,009
Australia and Oceania	2,164

The average DNI in the Middle East and North Africa (MENA) countries is approximately 3,000 kWh/m^2/year, as shown in Table 1.1. This clearly indicates that these countries have a great potential for utilizing solar thermal technologies.

Owing to the existence of hydro-carbon reserves in the MENA region, these countries have a tradition of subsidizing energy, leading to very low energy prices compared to other countries. Figure 1.1 illustrates the electricity prices in different countries (IMF 2018; Statista 2018). It is clear that none of MENA countries sell electricity with a price higher than US$0.1/kWh.

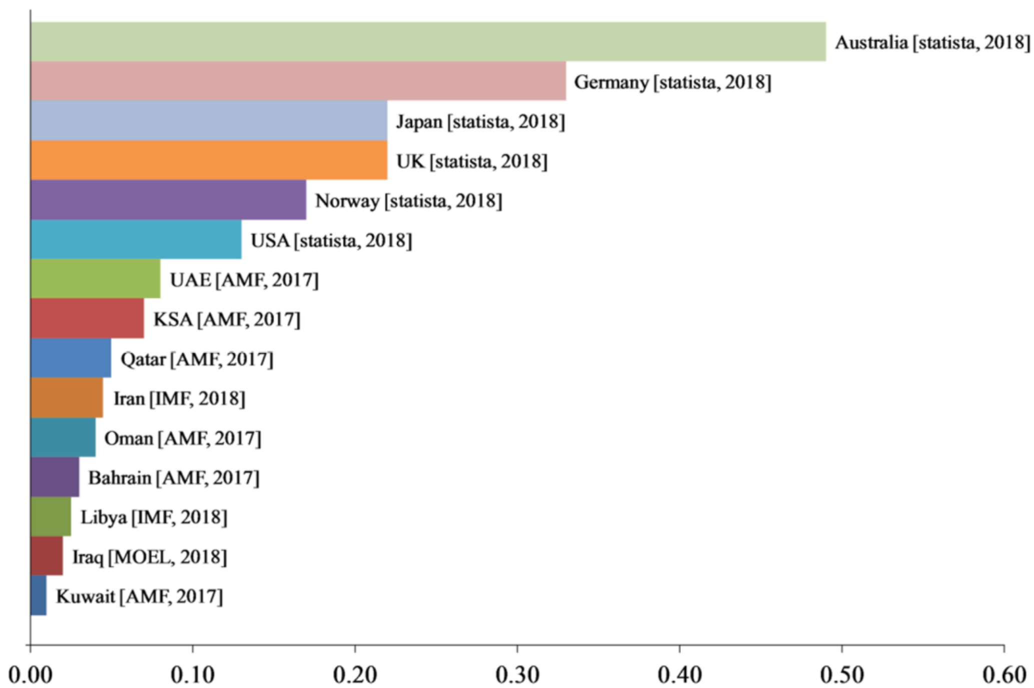


Figure 1.1: Average Electricity Price (US$/kWh)

The total energy subsidy in countries in the MENA region is approximately US$236.5 billion, which is equivalent to 8.6% of their GDPs or equivalent to 22% of their revenue (IMF 2018); the electricity subsidy is approximately 26% of the total energy subsidy as shown in Figure 1.2. Each country has fixed a different subsidy price for electricity per GDP percentage, with the highest and lowest electricity subsidies being approximately 12.8% and 3.7% of GDP, respectively, as indicated in Table 1.2.

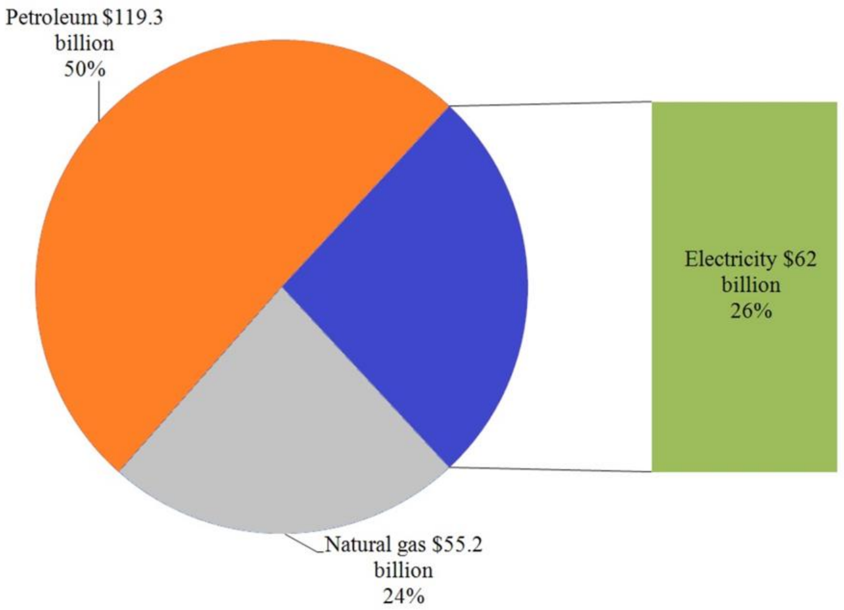


Figure 1.2: Energy Subsidy Components, (IMF, 2018)

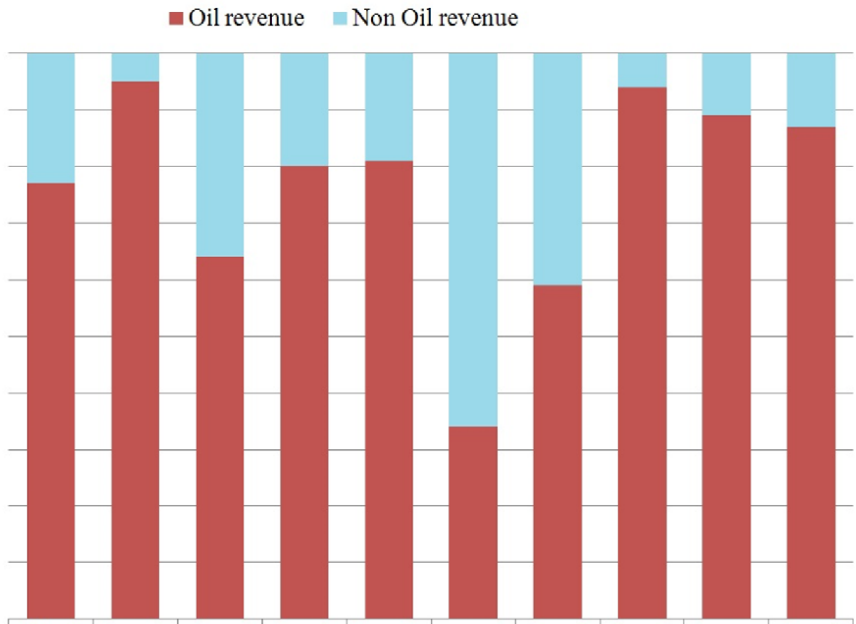
Table 1.2: Electricity Subsidy in GDP Percentage, (IMF 2018; Statista 2018)

Countries	Pre-tax energy subsidy (in % of GDP)
Iran	12.8
Iraq	11.6
Algeria	10.8
KSA	10.0
Libya	8.9
Bahrain	8.0
Kuwait	7.4
Oman	6.1
UAE	5.8
Qatar	3.7

1.2 The Problem

The remarkable fall in oil prices from a peak of US$115 per barrel in the middle of 2014 to under US$35 at the beginning of 2016 caused oil producing countries to slip into significant financial distress, and the cost of petrol extraction became higher than its sale price (IMF, 2018). Some of these countries, especially the Gulf countries, were wealthy enough to absorb the low oil price. However, in most of MENA oil producing countries, the national budgets were generally based on the revenues of petrol sales, and, at the same time, they fully depended on fossil fuel consumption to meet domestic energy requirements, as shown in Figure 1.3.

Starting in 2015, some of MENA oil producing countries faced serious challenges with regard to the domestic supply of energy. Moreover, as the funds for expanding the electricity power lines were mainly dependent on the sale of petrol, most of these countries had to cancel or postpone their short- and long-term development projects owing to their economic problems.



	Saudi Arabia	Iraq	UAE	Kuwait	Qatar	Iran	algenria	Libya	Oman	Behrain
Non Oil revenue	23%	5%	36%	20%	19%	66%	41%	6%	11%	13%
Oil revenue	77%	95%	64%	80%	81%	34%	59%	94%	89%	87%

Figure 1.3: Oil and Non-Oil Fiscal Revenue, (Percentage of Total Governmental Revenue) (IMF, 2018)

Iraq is one such country that felt the impact of falling oil prices after the 2015 crisis. In Erbil (a capital city of Kurdistan region of Iraq), the loss of revenue from petrol sales caused a large economic recession that led to a shortage in all parts of the power sector, namely, generation, transmission, and distribution. On the other hand, demand for power continued increasing significantly, following the trend of the previous years. The electric utility in Erbil could only supply power for an average of one third of a day in 2017. According to official statistics (MOEL, 2018), the utility is far from equipped to meet demand and the peak demand placed in the winter season, with a power capacity shortage of 1450 MW. The peak in the winter can be attributed to the water heating, which is done traditionally using electric water heaters (EWHs).

In 2017, the electric utility in Erbil announced the following critical news about the state of power generation (MOEL, 2018):

- A majority of the electric feeders, power substations, and transmission lines were overloaded.
- Overloaded power lines caused a drop in voltage, leading to electricity shortages.
- The utility was unable to distribute electricity equally to all its customers.
- There were delays in the repair and maintenance of the electric system owing to a multitude of obstacles and overload problems.
- New connections were limited owing to these problems.

In recent years, the use of solar-powered technologies has quadrupled owing to the application of the following two policies by certain countries (Aguilar et al., 2005):

- Long-term stimulus programmes, in which the utilities give direct support to consumers and apply lower taxes as incentive programmes to promote the use of SWH technology (such as in Germany, Austria, Cyprus, etc.)
- Making the use of SWHs mandatory (such as in Israel) through municipal laws and regulations with respect to buildings, houses, and the residential, tourist, commercial, and industrial sectors.

It is noted that many of the above-mentioned countries that support renewable energy technologies are non-petrol producers. As petrol-producing countries obtain the needed power easily from domestic natural resources such as oil and gas, they do not have any incentive to use alternative power sources such as solar energy.

A consumer subsidy in the electric industry is defined as the difference between the electricity supply costs, including the transmission and distribution (T&D) costs, and the price paid by consumers. There are two types of consumer subsidies: pre-tax subsidies and post-tax subsidies (Clements et al., 2013).

The countries with emerging economies that produce large amounts of oil usually offer very high pre-tax subsidies in electricity sales. These are mostly located in the Middle East and North Africa. This region accounts for 48% of the countries that subsidize energy worldwide (IMF, 2014d). They will eventually need to introduce reforms to reduce or eliminate subsidies from the energy markets to achieve sustainability.

1.3 Scope and Objectives

The present study builds on related studies in the literature that mainly focused on using demand side management (DSM) as a tool to defer the construction of additional power generation plants through a novel approach that shifts the current electricity subsidy to subsidies that help to accelerate the penetration of solar thermal technologies in the energy markets of MENA oil producing countries. The main objective of the present work is to develop a DSM strategy for promoting solar thermal technologies to deal with the financial burden caused by high electricity subsidizing.

This research was carried out to investigate different solutions for high-subsidy systems, which were then compared to using a conventional reform system. Following the proposed policy, a new subsidy will be rolled out and will entail providing solar thermal devices at no cost to consumers in oil-producing MENA countries. The approach is meant not only to decrease dependence on subsidies but also to raise societal acceptance of solar thermal technologies while allowing for more realistic electricity costs to ensure sustainable development.

1.4 Organization of the Thesis

The rest of this thesis is organized as follows: Chapter 2 provides a complete and extensive literature review, which investigates DSM programmes from the perspective of utilizing solar thermal technologies and electricity subsidy policies. In chapter 3, an experimental case study is presented whereby DSM is utilized as a tool to promote SWHs. In chapter 4, the possibility of applying DSM with hybrid solar air conditioners and solar adsorption chillers to switch the electricity price subsidy to renewable energy systems is investigated.

A general methodology and NPV formula are developed for countries where electricity is subsidized and, it presented in chapter 5. Finally, conclusions are drawn.

Chapter 2

LITERATURE REVIEW

2.1 Overview of the Topic

The present study examines the possibility of implementing DSM program in oil producing countries, where electricity sales are below the cost price. A new approach that helps to improve the economic crises in these countries and penetration of the renewable technology in their markets was developed from lessons learned from previous studies and reform policies.

2.2 DSM Background

The energy crises of the 1970s that affected the markets of many of the power companies in the world, particularly those in the USA, resulted in many of them putting various strategies in place to address this problem. The period saw a sharp increase in the cost of fuel and interest rates, and skyrocketing inflation rates significantly increased the of financing, building, and operating power plants. These factors together led to an increase in the cost of electricity. Utility companies recognized the value in ensuring that their energy demands were projected accurately and putting measures in place to conserve the existing energy resources, consequently, the concept of DSM has been originated (Capuano, 2018).

At the time, DSM was used only for the demand side of the utility. However, over the years, DSM has undergone a significant amount of development and evolution, and this has seen its application, implications, and measures also used for the supply side of an electric utility network. With these developments, the definition of DSM and various DSM concepts that are widely accepted in the power industry is introduced. Additionally, the various DSM techniques and research findings in this area are provided in the later part of this study.

DSM refers to the planning and implementing of various activities by a power utility company with the aim of influencing the manner in which consumers make use of electricity to generate desired consumption patterns or utility load shapes. DSM affects two main components of utility demand: the load capacity and the load shape. Utility programmes can effectively implement DSM to the following activities: new uses, electrification, load management, strategic conservation, customer generation, and market share adjustment.

2.2.1 Benefits and Implications of DSM

As briefly mentioned in the section above, DSM programmes first came into existence when utility companies realised the rapid depletion of energy resources and the world becoming increasingly concerned about the pollution of the environment. Though a DSM programme is mainly targeted at the management of the electric power industry, it syncs with various programmes that include those targeted at environment protection and national plans for sustainable development. A DSM programme has various benefits for stakeholders, including utility companies, consumers, enterprises, and the society. The first major benefit is the apparent improvement in the efficiency of power and/or energy systems. An improvement in efficiency could be achieved through an improvement in the reliability and quality of power supplied to consumers, and a reduction in adverse environmental impacts, power shortages and cuts. Additionally, a DSM would allow the deferment of heavy investment in new power generation facilities and therefore the construction of new transmission and distribution lines. The improved efficiencies would lower the cost of delivering power to consumers, which in turn contributes to local and national economic development. Furthermore, a DSM program promotes new innovations and technologies that would translate into the creation of new long-term jobs.

2.2.2 DSM Load Levelling Techniques

Loads shape techniques can be characterised into six main categories. This research pays more attention to some of DSM measures as opposed to others. Nonetheless, all the six categories are elaborated on below to get a clear conceptual basis for load management. It is important to understand that, most of the time, these load shape objectives are not mutually exclusive as they are often combined. The load shape objectives as adapted from a previous study are illustrated in Table 2.1 (Gellings, & Chamberlin, 1993).

Table 2.1: Standard DSM Load – Shape Techniques, (Gellings & Chamberlin, 1993)

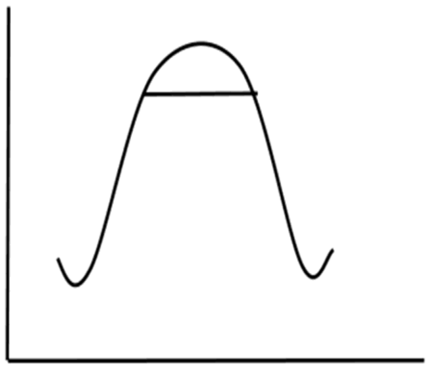
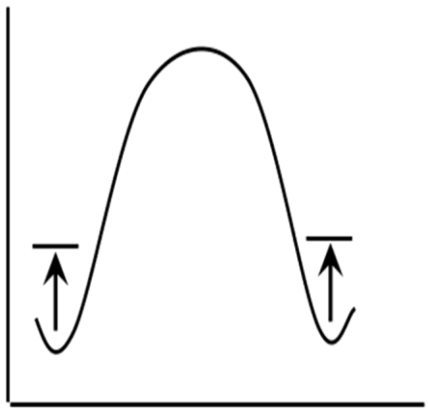
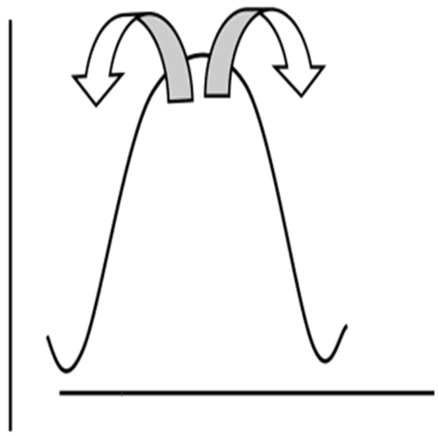
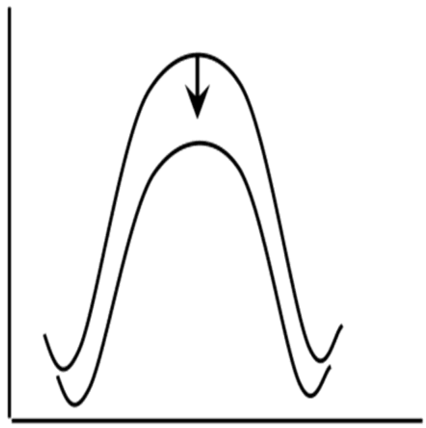
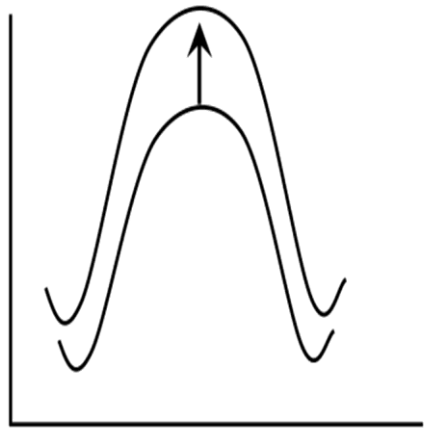
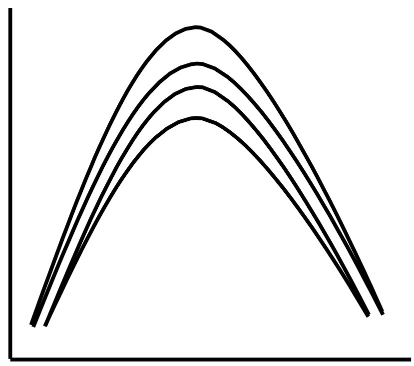
a) Peak Clipping In the power/energy sector, peak clipping as illustrated in the figure is the process through which the peak demand on the utility system is reduced. Peak clipping is critical in helping power companies defer the need for building additional power plants. Peak clipping reduces the total energy consumed and therefore reduces the peak demand. To achieve peak clipping, the utility company can excise direct control over the appliances used by consumers or the end-use equipment.	
b) Valley Filling The concept of valley filling involves the building or increasing of the consumption of energy during the off-peak period. Valley-filling occurs when the capacity of the system is greatly under-utilised during a certain period. Valley filling is usually suitable when there is additional capacity which can operate at low cost fuels. This would increase the total amount of energy consumed but not the peak demand. Energy thermal storage is a good example of a valley filling approach.	
c) Load Shifting As the term denotes, load shifting entails the shifting of the consumer loads from the on-peak period to off-peak period. This shifting leads to a reduction in the peak demand, but the total energy consumed remains constant. Load shifting is achieved using various techniques that include the use of storage devices or time-of-use (TOU) billing.	

Table 2.1: Continued

d) Strategic Conservation In this approach, end-use consumption is reduced. Based on the coincidence factor, strategic conversion results in a reduction in the total energy consumed and peak demand. Some of the strategic conversion techniques that are used by utility companies include improving the efficiency of appliances and building energy conversion techniques.	
e) Strategic Load Growth In this approach, the utility company focuses on growing the overall levels of sales. As a result, this increases both the total amount of energy consumed as well as the peak demand. Some of the strategic conversion techniques that are used by power utility companies are increased electrification rates and increasing commercial and industrial heating processes. Other strategies used to increase the intensity of energy consumption in both industrial and commercial sectors are considered strategic load growth techniques.	
f) Flexible Load Shape In this approach, the utility company promotes initiatives that vary the quantity or reliability of services. This variation is conducted to change the shape of the load by interrupting supply when necessary. Flexible load shape approaches may lead to small changes in the total energy consumption as well as a net reduction in peak demand.	

The figures presented above have one objective in common, i.e. either the administration of the timing of consumption or the level of demand to achieve the desired load objectives. A valley filling approach may be desirable in a situation where the capacity is greatly underutilised. In contrast, peak clipping or strategic conversion may be suitable for oil-producing countries in that they can be used to reduce the undesirable impact on the environment occasioned by the construction of new and expensive power plants. This, in turn, would lead to an improvement in customer service and maximize national economic benefits.

2.3 DSM and Solar Thermal Technologies

A power supply network or chain comprises two main sides or processes: the demand-side and supply-side processes. With lower energy prices and lower connection levels, many of the electric utility companies in the world focussed mainly on the supply-side of the network, and this entailed increasing the generation capacity to ensure the existing demand levels were satisfied. This period also saw low levels of environmental pollution; therefore, stakeholders did not have the impetus to focus on demand-side processes. However, with time, more challenges cropped up on the demand-side, which has seen utilities switching their focus to DSM. DSM refers to the process where the government through utility companies develops various strategies that are targeted at influencing the amount of energy that consumers use or the timing of the use of this energy to achieve overall societal benefits (Gellings & Chamberlin, 1993). DSM methodologies are meant to reduce the demand for electricity through the introduction of strategies for improving the efficiency of consumption (Bhattacharyya, 2011). For this reason, they contribute to energy conservation.

With the various investments made into DSM programmes, Capuano (2018) indicated that the stakeholders have so far ensured that the funds had been put to good use. For example, (EIA) annual energy outlook indicated that, in 2008, 86 GWh was recovered using a DSM programme, in which US$3.72 billion was invested in. This amount of energy is sufficient to meet the energy demands for the States of Missouri and Washington. Making use of a DSM programme was also projected in the US to reduce the consumption of electricity by approximately 0.83% for the period 2008 to 2030, when demand is expected to rise by 1.07% (Annual Energy Review, 2010).

Different countries in the world have implemented DSM programmes with various degrees of success. The United States has also implemented various DSM programs in different states with the aim of reducing capacity as opposed to the consumption of energy. One such program is that developed between the Jacksonville Electric Authority (JEA) in Florida in the U.S., the Sierra Club, and the American Lung Society. In this agreement, the JEA was tasked with developing a clean power program with an output of 120 MW by 2004. The capacity was to be increased to 350 MW per year by 2015. The programme was stimulated by an incentive with a rebate of US$11/m^2 for installed SWH systems that was given to solar grid companies (Aigbavboa, 2015).

South Africa has also witnessed the implementation of a similar DSM programme in which Eskom Electric replaced approximately 925,000 EWHs with SWHs in residential buildings over a 5-year period. Peak power demand before the replacement was causing system stability problems and therefore frequent power rationing. The programme offered or maintained 3,500 GWh of electricity savings annually, but after 7 years of implementation, only 11% of the work had been done because the programme was not supported by robust monitoring and verification (M&V), and feedback programmes (Kritzinger, 2016).

In Oman, the potential savings from the use of SWHs were illustrated by a study using advanced mathematical modelling. The study, which was conducted in SEEB district using the RETScreen Clean Energy Project Analysis Software (Chang, & Chung, 2011), found that approximately 2.6 million oil barrels per year with a value of US$300 million translating to approximately 335,431 MWh of electricity would be saved through the programme. Generating such an amount of energy would need a 38.3 MW plant. Furthermore, the study indicated that the use of SWHs would reduce greenhouse gas emissions by approximately 148,590 tonnes of carbon dioxide per year.

Another study in Oman was also conducted to assess how renewable energy resources such as solar energy and wind energy were being utilised or being considered as future energy sources (Timilsina, et al., 2000). The study also developed a DSM programme that was aimed at encouraging the use of renewable energy sources in residential buildings. The study found that many of the oil-exporting countries do not have policies to encourage the use of SWHs and other renewable energy sources, and therefore put forward recommendations to utility companies to encourage the use of SWHs. The lack of policies was attributed to the highly subsidised cost of electricity.

In the USA, between 1970 and 1980, a considerable number of studies and demonstrations on solar thermal absorption cooling technologies were conducted. However, the demonstrations did not have a significant impact on the market owing to several factors such as high initial costs, fewer cost-effective demonstrations, impartial assessments by institutions, and the absence of commercial hot water driven absorption chillers (Kulkarni, 1994). Solar absorption technology is a potential DSM area.

2.4 DSM and Electricity Subsidy

Electricity subsidies are an important economic factor in many developing countries. However, they need to be used carefully. To poor consumers, subsidies provide a lot of economic uplift; however, subsidies have been found to mainly benefit wealthy people. Moreover, electricity subsidies take away the much-needed income that the government needs to finance education, healthcare, and infrastructure development. Furthermore, subsidies encourage activities/industries that are more capital intensive while discouraging those that create more employment opportunities; moreover, they promote overconsumption and environmental damage. Nearly half of the subsidies in the global energy sector have been shown to be mainly located in countries in the MENA region.

The reasons above indicate that subsidy reforms can have huge economic benefits and promote greater economic and social growth as well as equity. However, the implementation of subsidy reforms is a complex issue both politically and technically. Thus, it requires a considerable amount of careful planning, timing, and pace for implementation. Additionally, it needs to address the issues facing the class of the consumers who may be hardest hit once the subsidies are removed, which can be addressed through cash transfers. Additionally, creating awareness by holding awareness rallies to educate consumers on the benefits of the reforms and to gather enough political and public support is a key to ensuring that a subsidy reform programme succeeds.

For many years, countries in MENA have used subsidies to reduce the social and economic burden on some of its people, and keeping their hydrocarbon resources to used in the future by its new generation.

An estimate provided by the IMF indicated that the region had a pre-tax energy subsidy of approximately US$237 billion in 2011. A pre-tax subsidy is the difference in the cost of electricity between the recovery cost price per kWh (the cost of producing one kWh by the utility) and the price paid by customer per kWh (the customer billing cost) as illustrated in Figure 2.1. This amount of money is equivalent to 22% of the national revenue or 8.6% of the regional GDP. Globally, the region's share of electricity subsidies is approximately 48% (Clements et al., 2013). Furthermore, it was also noted that the value of subsidies provided by these countries to electrical energy consumers ($237 billion) was far above the value of other subsidies (e.g. food subsidy stood at 0.7% of GDP) being provided.

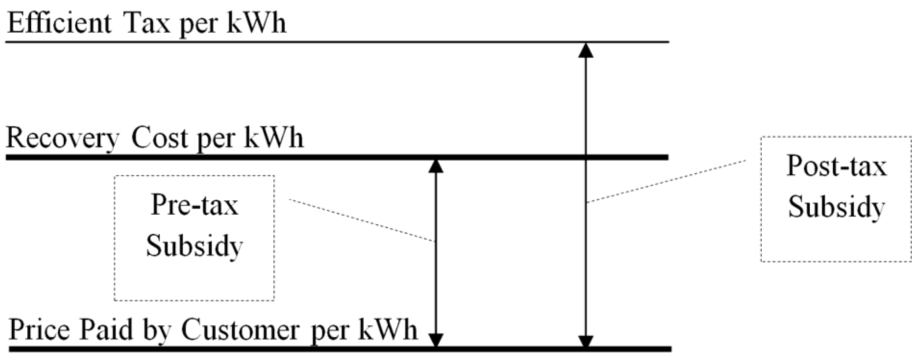


Figure 2.1: Component of Pretax and Posttax Subsidies

The energy subsidies in MENA countries are split into two main categories: approximately one-half is offered for petroleum products and the rest is offered for natural gas and electricity. As illustrated in Figure 2.2, subsidies are relatively distributed in the region but are predominant in countries that export oil. The subsidies in approximately two-thirds of the countries exceeded 5% of the GDP.

In some of the countries, the budget does reflect the true cost of subsidies that are offered for energy products. For example, in 2007 Iraq did not include energy subsidies in the budget although the country offers very large subsidies to its citizens. Additionally, Iraq offers very large subsidies to domestic power plants and refineries; therefore, the fuel prices in Iraq are considerably lower than those in other countries. In 2011, the subsidies accounted for more than 11% of the country's GDP.

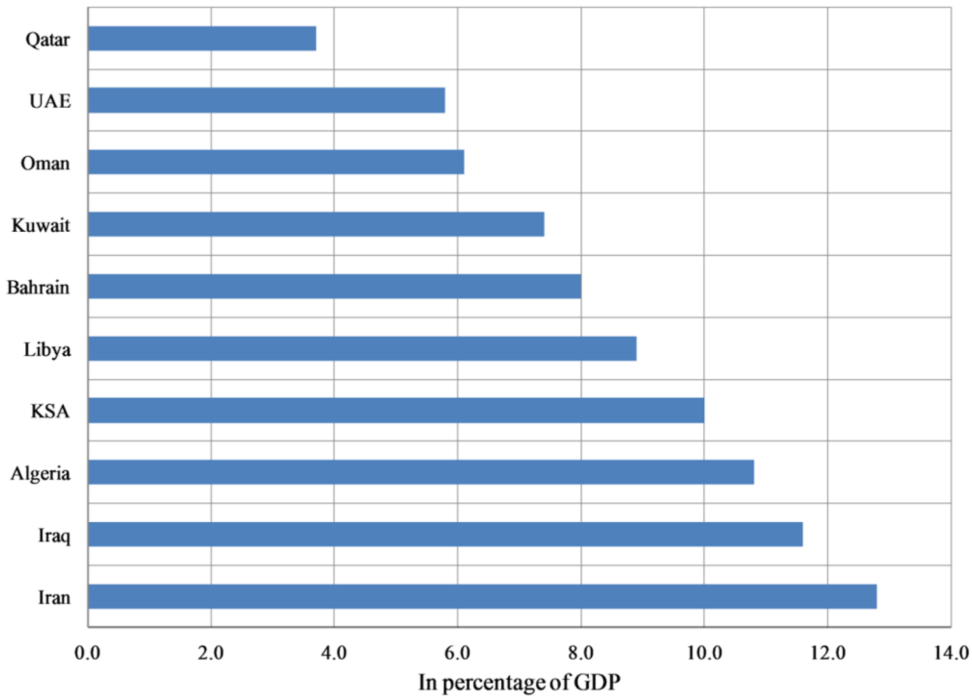


Figure 2.2: MENA Pretax Energy Subsidies, (Clements, 2013).

Most of the governments in the world prefer to use energy subsidies as opposed to using other social safety nets such as direct income support and cash transfer schemes. This is because energy subsidies are easier to administer compared to others approaches. Oil producing countries also consider energy subsidies as a way of redistributing the national wealth to its people. However, studies have found that subsidies create more challenges and problems than those that they are developed to address. Although thought to help the poor, energy subsidies do not effectively support the poor as they have an adverse impact on the economy of the country. This is because subsidies create economic distortions that also adversely affect large oil producers, who do not show a concern for budgetary and balance of payments implications.

The majority of countries with oil producing capacity have policies that tightly control energy prices in the domestic market. This is because energy prices are used as a tool for promoting diversification and industrialization, which are targeted at protecting the income of citizens as well as distributing the country resources to the entire population. Owing to these subsidies, these countries also experience some form of economic regression, which with time makes their economic model unsustainable. For these reasons, many of the countries in the MENA region need reforms in their energy pricing even though the issue is economically and politically delicate. However, with their diversity, MENA countries will require more than a one reform agenda to ensure equality in the region (Fattouh & El-Katiri, 2013).

Different countries, in both the developed and developing world, have pursued and implemented several reforms since the 1980s to streamline their electricity sectors. These strategies and reforms were implemented to increase the efficiency of the sector, lowering the cost of electricity, accelerating innovation, and enhancing customer services.

Though these reforms started early, oil-producing countries such as Iran, Algeria, Kuwait, United Arab Emirates, and Saudi Arabia began legislating and implementing these types of reforms in the 1990s. The reforms were delayed because of the inexpensive resources used for the production of energy. However, these five countries have recently adopted structures that are more market-oriented, but are yet to implement their target sector models (Dyllick-Brenzinger & Finger, 2013).

By examining the number of different types of DSM programs specific countries implemented during the 1970s, when development of DSM programmes was undertaken, a spatial comparison can be made (Warren, 2015). The summary of the findings is found in Figure 2.3. The great diversity of the DSM programs implemented in USA, China, UK, Australia, Canada, and Denmark is highlighted in the figure. The implementation and evaluation of 67 different DSM policies have already been undertaken in the USA, and the implementation and evaluation of a total of 65 different policies were undertaken by the other five countries.

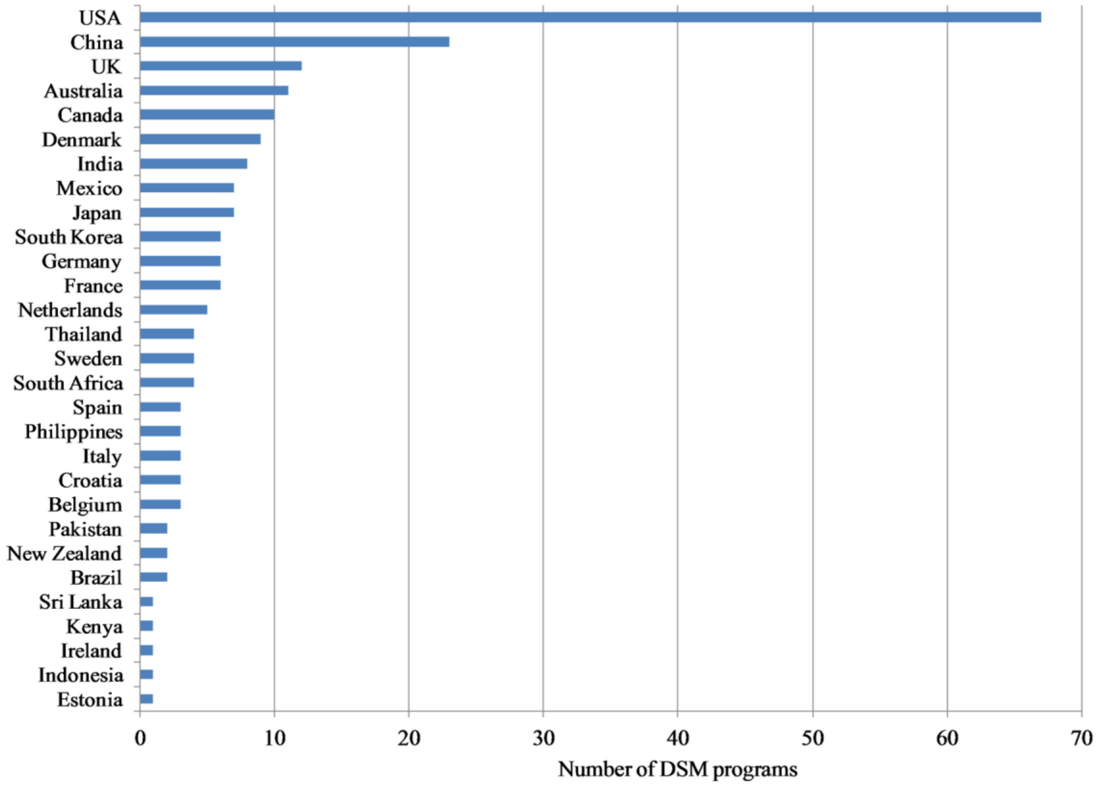


Figure 2.3: Number of DSM Programmes per Country, (Warren, 2015)

Table 2.2: Diversity of DSM Programmes, (Warren, 2015)

Motivation for the implemented DSM program	USA	UK	China
Incentive payment-based demand response	√	√	√
Price-based demand response	√	√	√
Utility business models	√	√	√
Research and Development	√	√	√
Market transformations	√	√	
Voluntary programs	√		√
Utility obligations	√	√	
Labelling	√	√	√
Information campaigns/Loans & subsidies	√		√
Information campaigns	√	√	√
Performance standards	√	√	√
Loans and subsidies	√	√	√

Figure 2.3 and Table 2.2 express the similarity of implemented number of evaluation programs in the top three countries. Nonetheless, each of them has several individual DSM policy packages. The implementation of seven individual DSM programs, for example, has been undertaken by every one of the three countries. These individual DSM programs are incentive payment-based demand response, price-based demand response, utility business models, research and development programs, labelling, information campaigns, performance standards, and loans and subsidies. Two policies—market transformations and utility obligation—are, in addition, present in the UK and USA. The last two policies, information campaigns/loans & subsidies and voluntary programs, are present in the USA and China. Each individual DSM policy, therefore, is present in not less than two of the top three countries, with the majority being present in two or in all of the three countries.

Implementation of DSM programs is undertaken for a diversity of reasons, such as guaranteeing energy security, improving economic productivity (in the form of efficient energy production and new business opportunities), decreasing carbon emission, and reducing the energy bills of consumers. The total results are displayed in Figure 2.4.

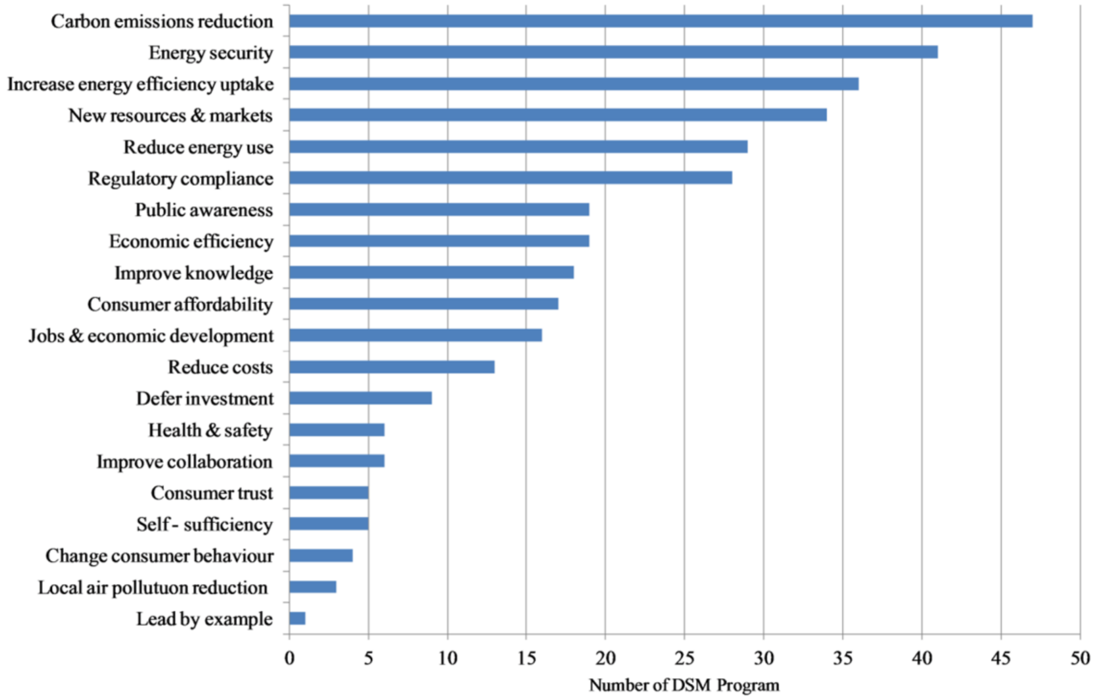


Figure 2.4: Policy Objective of Implemented DSM Programmes, (Warren, 2015)

These are the top four reasons for the implementation of DSM programs by countries: to reduce carbon emissions (47 programs), to ensure energy security (41 programs), to increase the uptake of energy efficient technologies (36 programs), and to create new resources and markets (33 programs). All environmental improvement features with the exception of the reduction in local air pollution are referred to as the first policy objective. All 47 programs, nonetheless, directly or indirectly made reference to reducing carbon emissions. Reference was also made to the supply and demand balance, primarily at a national or state-level as the second policy objective, even though, in one evaluation, reference was made to improving on-site energy security in the building. In the 41 programs, reducing peak load, considered to be part of the ‘energy security’ policy objective, instead of ‘reducing energy use’, was generally stated. This stems from the ‘reduce energy use’ policy objective referring to the total reduction in energy use, instead of load shifting. A range of precise goals like increasing the uptake of certain technologies by consumers, improving the national building fabric and value through retrofitting, and improving the efficiency of energy use throughout the country form the third policy objective. Creating new markets for DSM and stimulating investment in DSM are referred to as the fourth policy objective.

The fact that the implementation and evaluation of the evidence base for DSM policy, with regards to the number of programs and the number of different policies already implemented in countries such as the USA, the UK, and China. In addition, the four most important reasons for the implementation of DSM policies are carbon emissions reduction, energy security, increasing the uptake of energy efficient technologies, and developing new resources and markets. With regard to carbon emissions reduction, although a majority of the countries have implemented DSM policies (Sorrell, 2015) contends that larger and faster reductions in energy demand are needed for this policy objective to be met, compared to what was accomplished in the past.

None of these DSM program motivations has been implemented because of the energy subsidy. The driving force of the proposed DSM program is not similar to those of previous ones. Therefore, the motivation of the present study is to relieve the financial burden placed on electric utilities by electricity subsidies.

Chapter 3

PROMOTION OF SOLAR WATER HEATER BY DSM

3.1 Introduction

With the decline in the prices of oil in 2015, the financial distress suffered by petrol-producing countries was significant, as evident in the reduced economic growth rate of the countries and the introduction of austerity measures by their governments (Demirbas et al., 2017). In many of these countries, budgets are generally based on the revenues of petrol sales and, at the same time, the countries fully depend on fossil fuel consumption to meet domestic energy requirements. The cost of petrol extraction in such countries often exceeds the revenue from petrol sales, while the domestic consumption of electricity is subsidized because of the high income obtained from sales to other countries. Consequently, starting from 2015, some petrol-producing countries have faced serious challenges in securing the domestic supply of energy while coping with the expenses associated with the expansion of the power transmission and distribution sector, which is mainly dependent on petrol sales. Moreover, most of these countries have also had to cancel or postpone their short- and long-term development projects in construction and other sectors because of economic problems.

Owing to the significant role that the electrical energy sector plays in Middle East countries, the consumption of electrical energy increased by 70% between 1990 and 2008 as compared to the other sources of energy (Al-Mulali, & Che, 2018). One of the countries that felt the impact of reduced petrol prices due to the 2015 crisis was Iraq. The effects of the financial crisis were significantly felt in Erbil as evidenced by the power supply shortages in all the power sectors including generation, transmission, and distribution. At this time, the power demand still went up as was the trend in the previous years. These shortages saw the major utility conducting power rationing that lasted approximately 8 to 9 hours a day in 2017, with the Ministry of electricity (2018) indicating that the utility was less equipped to address consumer demand. The annual supply and demand load curves for Erbil are illustrated in Figure 3.1, which also indicates that during the winter season, the peak power demand could not be met, with a shortage of 1450 MW. The large difference between the peaks for winter and summer is caused by water heating, which mainly depends on EWHs.

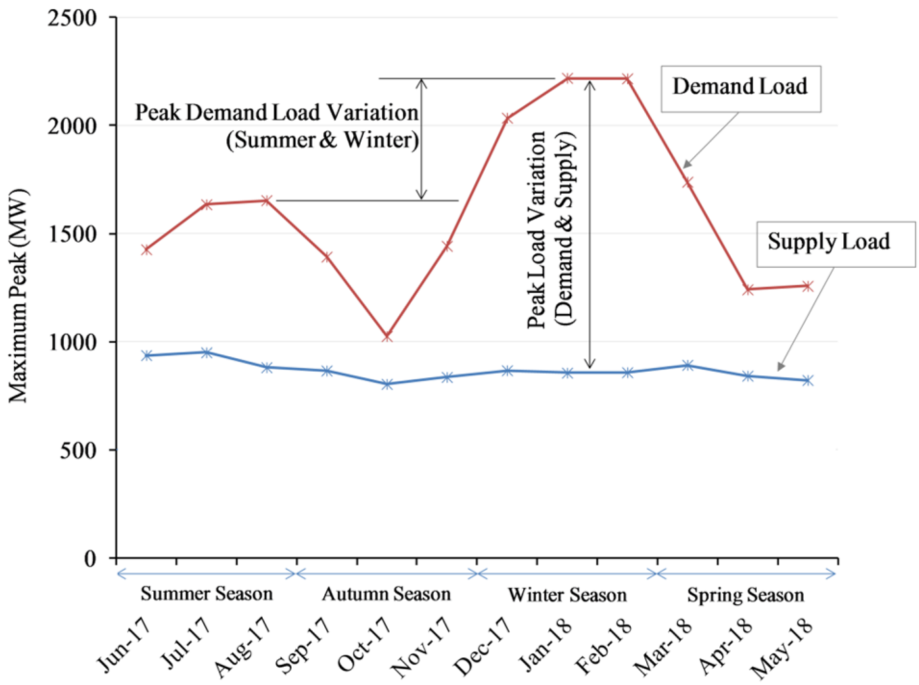


Figure 3.1: Annual Supply and Demand Load Curves in Erbil, (MOEL, 2018)

In 2017, the state of generation of power in Erbil was announced by the Ministry of Electricity (MOEL, 2018) to be in the following state:

- A huge percentage of substations, transmission lines, and feeders were overloaded
- Exceeding the loading capacity of power lines was associated with voltage drops that resulted in power shortages
- Consumers could not be supplied with electricity equally owing to utility capacity problems
- Overload problems and other obstacles caused a delay in the repair and maintenance of the electric system
- These problems hindered the connection of new consumers

A study by (Aguilar et al., 2005) indicated that 30% to 50% of domestic electricity consumption is attributed to water heating. This made the use of SWHs an attractive solution to the energy problem, in addition to contributing to lower carbon dioxide emissions. However, because of the low cost of electricity, consumers did not view SWHs as the most economically attractive solution to their problems.

The Hawaiian Electric Company (HECO) conducted a practical example of demand-side programs by electric utilities. HECO is the electricity utility in the islands of Oahu, Hawaii, Maui, Lanai, and Molokai. In its DSM program, HECO installed 19,525 SWHs to replace EWHs from 1996 to 2002. For every successful installation, a rebate of $750 was offered. This led to a massive reduction in electricity demand by 12.7 MW with annual savings of 53.8 MW. The HECO campaign also sped up the absorption of solar systems in the market, creating 12 new businesses employing over 150 people at the end of the program.

A similar program was also implemented by Jacksonville Electric Authority (JEA) of Florida (USA). JEA entered into an agreement with two partners, the American Lung Society and the Sierra Club, to develop a 120 MW per year clean power program by 2004. The program was to be enhanced to 350 MW by 2015 per annum. The deal entailed reducing capacity as opposed to consumption. JEA developed a DSM program in 2001 to install SWH systems. For every square meter of solar system installed, a rebate of US$11 was offered (Aigbavboa, 2015).

Eskom electric utility company in South Africa also embarked on a similar program in 2008 with a target of replacing 925,000 EWHs with SWH over a five-year period under a rebate program. The use of EWH significantly contributed to power rationing by pushing power demand to the peak. The program had a target of reducing annual electricity consumption by 3,500 GWh, but owing to lack of monitoring, verification, and feedback systems, Eskom was only able to implement 11% of the project after 7 years (Covary and Kritzinger, 2016).

Through the use of advanced mathematical modelling software named RETScreen Clean Energy Project Analysis Software, the potential of implementing SWHs in SEEB district in Oman was discussed by (Chang et al., 2011). The modelling indicated that SEEB district had the potential to save US$300 million, which is equivalent to ~2.6 million oil barrels/year. This amount of energy is equivalent to the cost of generating 335,431 MWh of electricity by a 38.3-MW power unit.

Furthermore, the successful implementation of this project would see a reduction in greenhouse gas emissions by 148,590 tCO_2 per year.

In Oman, (Timilsina et al., 2000) assessed the use of solar and wind energy in the residential sector by discouraging the use of EWHs under a DSM program with a regular incentive. They found that the majority of oil exporting countries did not have any regulation to encourage the use of SWHs, and this was attributed to low electricity cost.

In Thailand, (Al-Badi et al., 2009) reported that it was feasible to replace EWHs with SWHs in residential buildings and this would reduce the generation of electricity by 3.8% between 2000 and 2015. This reduction in generation would also reduce the emission of greenhouse gases such as CO2 and NOx

(Gastli and Charabi, 2011) indicated that the spread of SWHs was mainly influenced by financial incentives. Under a 6-year incentive program from 1986 to 1991, the government of Taiwan implemented a DSM program that subsidized the cost of SWHs by 50%. From 2000 to present, it also engaged in another subsidy program. These two DSM programs are considered to be major influencing factors for the wide adoption of SWHs by homes, which contributed to reduced electricity consumption.

(Atikol, 2013) also designed a DSM program that entailed fixing timers to EWHs to ensure that peak times were avoided. Each household got a rebate of $242 under the program with the DSM program having the potential to save ten million dollars by eliminating the need to build new power plants. The challenges facing the Irish electric power systems were also studied by (Qazi and Flynn, 2012). They observed significant variations in domestic hot water (DHW) demand through data collection, which indicated that a DSM program could be implemented.

The cost of installing renewable energy systems is minimized to some extent through the use of incentive programs. In the last decade, the Chinese SWH market has significantly grown to see the country become the leading producer and consumer of SWHs. China, however, does not have a policy document that acts as guidance for the adoption of SWHs. The challenges facing widespread use of SWHs are attributed to the multi-administration policy nature of the Chinese energy sector. The energy sector is under eight ministries including the Ministry of Land and Resources and the Ministry of Water Resources, which have obligations that differ from each other (Yu & Gibbs, 2018).

In Spain, photovoltaic electricity generation systems were first installed in new buildings in 2005. Spain also became the second country in Europe to install solar water heating systems (Burrett et al., 2006). The huge potential of using SWHs to mitigate the emission of GHG has been seen in Australia. This commitment was evident in the signing of the National Greenhouse Strategy between governments at the federal and state level. The strategy outlines 86 measures and a road map to address the emission of GHG. The agreement was motivated by the fact that 22% of greenhouse gas emissions come from water heating and therefore the government offered subsidies for installing SWHs to encourage adoption (Bahadori & Nwaoha, 2013).

The adoption of global trends to reduce GHG emissions has also been done by MENA countries. These countries have prioritized renewable energy sources and even set targets for various sectors. For example, Qatar has set targets for its transportation sector while Jordan, Libya, and Morocco have set targets for SWHs despite having a considerable amount of solar energy.

SWHs have a huge impact on renewable energy sources in comparison to other solar energy technologies despite SWH being an effective and low-cost technology for improving the energy performance in buildings (Jablonski & Tarhini, 2013). For the UAE and Jordan, the installation of SWHs in new buildings is mandatory while Morocco and Tunisia have also implemented such programs (RCREEE, 2015). (Sgouridis et al., 2016) observed that 75% of UAE hot water demand could be met by installing SWHs in new villas and labour accommodations. Within this region, Israel has the largest SWH system and, by the end of 2014, the country had deployed **3.2** GWth of SWH, which could be attributed to the early 1976 enactment of regulations that compelled every residential facility to have an SWH unit (Meir et al., 2012).

In their work, (Roulleau and Lloyd, 2008) indicated that several countries have seen the utilization of solar powered technologies increase tremendously owing to the application of targeted policies. For example, countries such as Cyprus, Austria, and Germany have instituted long term stimulation programs in which consumers are directly supported by utility companies through the reduction of taxation to promote the utilization of SWHs. Israel has also passed several municipal laws and regulations that makes it mandatory for all buildings in residential, commercial, tourist and industrial sectors to install SWHs.

It should be noted that a large number of the countries mentioned above that have programmes supporting the adoption of renewable energy technologies are not petroleum producing countries. This is attributed to the ability of petroleum producing to obtain their energy from domestic natural resources such as fossil fuels; therefore, the use of alternative sources of energy such as solar do not seem attractive to them.

In the electricity sector, a consumer subsidy refers to the difference between the price paid by the consumer and the cost of producing and supplying electricity, which includes the cost of transmission and distribution. Two main types of consumer subsidies exist: pre-tax subsidies and post-tax subsidies (Clements et al., 2013).

High pretax subsidies are usually offered by countries with emerging economies and large oil deposits such as those located in the Middle East and North Africa. Approximately 48% of the electricity subsidies in the world are offered by countries in this region (IMF, 2018). To achieve sustainability in the long run, these countries will need to introduce reforms aimed at eliminating or reducing the subsidies in the energy sector.

The present work is concerned with the design of a DSM program for SWH promotion to relieve the financial burden placed on electric companies by electricity subsidies. The related literature is mainly focused on using DSM as a tool to defer the build-up of additional power generation capacity and accelerate the penetration of

SWHs into the market. The incentive for utilities is related to compensation for increased blackout occurrence. Therefore, the driving force of the proposed DSM program is not similar to that of previous ones, which adopted a different decision-making approach. Moreover, the program described herein aims not only to decrease dependence on subsidies but also to raise the societal acceptance of SWHs while allowing for more realistic electricity costs to ensure sustainable development.

3.2 Promotions of SWHs Through DSM

3.2.1 Economic Feasibility Approach

Using the net present value (NPV) in evaluating the feasibility of energy project during its lifetime (Karunanithi et al., 2017), the sum of the net present investments (*NPI*) should be less than the sum of net present savings (*NPS*) as follows:

$$NPV = \Sigma NPS - \Sigma NPI. \quad (1)$$

For the project to be feasible, the NPV should be greater than zero as indicated in Eq. (2):

$$NPV > 0. \quad (2)$$

For countries with pre-tax subsidies (P_s) on electricity consumption, the utility usually faces financial challenges. This means that the feasibility of the study is increased when this cost is recovered. (Clements et al., 2013) defined feasibility as

$$P_s = P_w - P_C. \quad (3)$$

where P_w denotes the cost of supplying electricity and P_c is the price paid by consumers.

The use of a DSM program that promotes the use of renewable energy can make it possible to reduce the consumption of electricity and thus avoid the use of subsidies.

In areas where electricity is subject to subsidies, the feasibility of DSM projects is expressed as:

$$NPV = \Sigma NPS - \Sigma NPI + \Sigma NPSR \,. \quad (4)$$

The equation of the net present value of subsidy recovery (NPSR) from (Atikol et al., 2013) is expressed as

$$NPSR = (E_{sav} \times P_s) \times (1 + i)^{-n} \,. \quad (5)$$

In equation (5), E_{sav} stands for the amount of electrical energy that is saved through the use of renewable energy for a year, i stands for the discount rate, and n is program duration in years.

The estimation of NPS in a DSM cost analysis is done as follows:

$$NPS = PV_{AG} + PV_{A(T \wedge D)} + PV_{AF} \,. \quad (6)$$

where

PV_{AG}: Present value of costs due to avoided generation including O&M;

$PV_{A(T \wedge D)}$: Present value of avoided costs required for T&D systems expansion to accommodate extra generated power;

PV_{AF} : Avoided fuel cost.

PV_{AF} is expressed as follows (Engineeringtoolbox.com, 2018):

$$PV_{AF} = Fuel_{priCe} \times \frac{E_{sav}}{LHV_{fuel} \times \eta_{Plant}}, \quad (7)$$

where LHV_{fuel} is the lower fuel heating value and η_{Plant} is the efficiency of the power plant.

NPI is also estimated using the following expression:

$$NPI = PV_{inv} + PV_{LR} \,. \quad (8)$$

In expression (8), PV_{inv} stands for the total program investment with rebates and PV_{LR} stands for the loss of revenue due to deferment of the construction of new power plants. For countries with subsidies PV_{LR} is equal to zero.

3.2.2 Energy Equations

The use of SWHs would lead to some energy savings. To assess energy saving due to the utilization of renewable energy technologies, a simulation was conducted to evaluate the performance of the approach in the present study. The SWH solar collector useful energy component is provided as follows (Velasolaris.com, 2018):

$$E_{solaruseful} = E_{sol} - E_{los} . \qquad (9)$$

where E_{sol} is the irradiation energy in an area, and E_{los} is energy lost from the collector.

The collector efficiency is given by

$$rJ_{ColleCtor} = \frac{E_{solaruseful}}{E_{sol}}. \qquad (10)$$

The solar fraction *SF* is obtained using the following expression:

$$SF = \frac{E_{sol}}{E_{sol}+E_{aux}}, \qquad (11)$$

where E_{aux} represents the auxiliary energy.

The fractional solar savings (Velasolaris.com, 2018) can be calculated as

$$F_{SS} = 1 - \frac{(Eaux)_{SWH}}{(Eaux)_{EWH}}, \qquad (12)$$

where

$(Eaux)_{SWH}$ - Total electrical energy consumptions from the auxiliary SWH;

$(Eaux)_{EWH}$ - Total electrical energy consumptions from auxiliary EWH.

3.2.3 Reform Policy Approach

In the reform policy approach, the present study conducts an assessment with the aim of understanding the components and magnitudes of subsidies the government or the utility company offers consumers to lower the cost of electricity. The overloading of the transmission and distribution lines is related to these subsidies.

The reform approach is intended to develop a DSM program to promote the utilization of clean energy technologies such SWHs. The successful implementation of this program will lead to peak clipping, especially during peak hours, which will help in deferring the construction of additional power units and also save the government a considerable amount of money that is offered as subsidies. This will allow the creation of a reform plan that will get consumers to commit to the program by signing a contract expressing their agreement to participate in the rebate programme and facilitate the reduction or elimination of subsidies for consumers outside the contract.

To determine the practicability of this program from the utility or government perspective, an economic feasibility analysis has to be performed. If the NPV > 0, then the project is considered to be economically feasible. A revision of the subsidy reform plan is then done to allow for the selection of a more efficient and reliable SWH that is economically viable for the program. Before rolling out the program, it is advisable that a survey is conducted to measure the social acceptance of the program and the contract making policy. A diagrammatic illustration of the reform policy approach is provided in Figure 3.2.

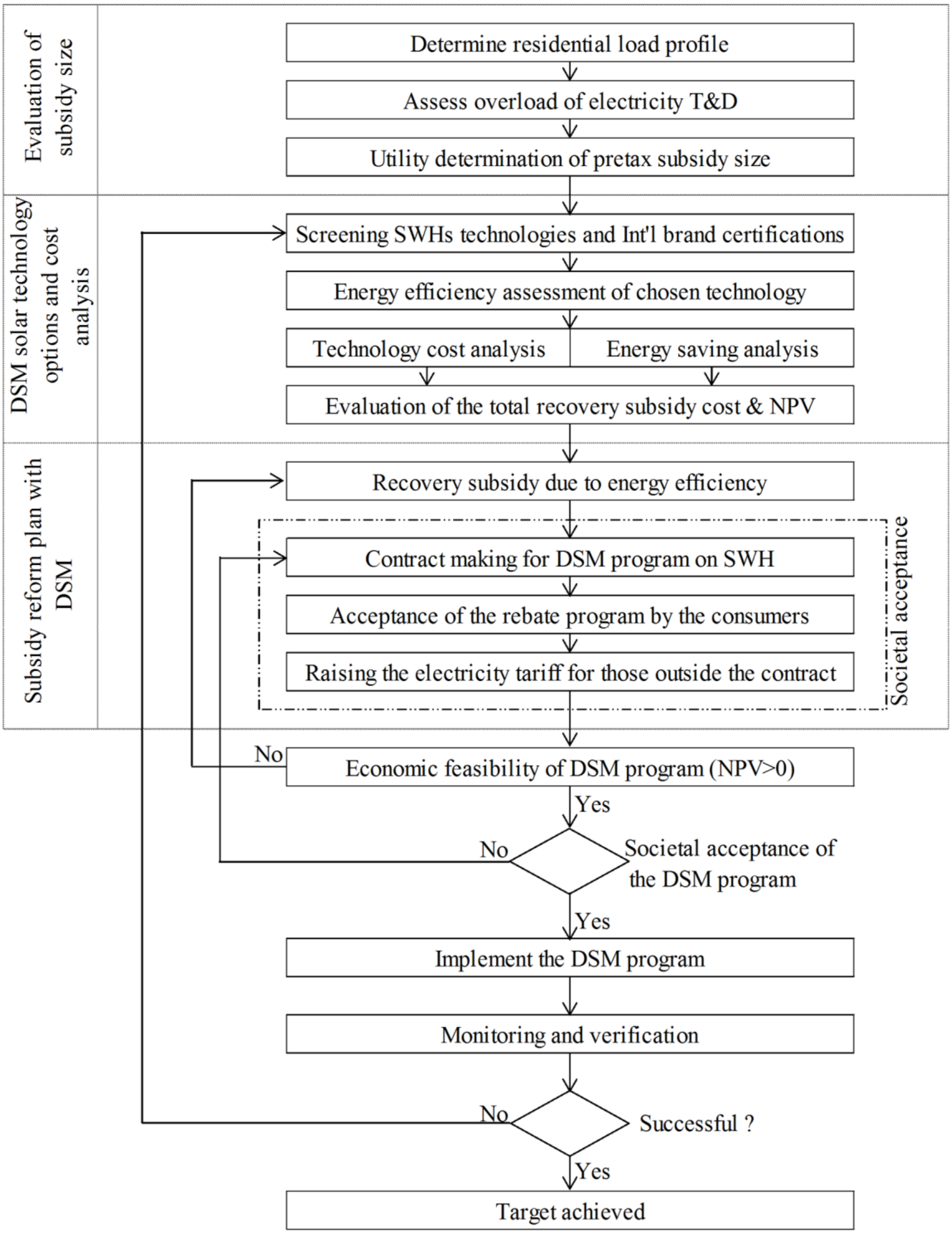


Figure 3.2: Simple Setup of the Reform Policy.

3.3 Simulation

The POLYSUN software (version 10.2; license number: 167114) developed by Vela Solaris, Switzerland, was used to conduct the annual simulations (Velasolaris, 2018). Transient simulations of solar systems with time steps of 1 s to 1 h, which are useful for solar system optimization. Can be achieved using POLYSUN. (Gantner, 2000) previously considered and validated the POLYSUN simulation software and found it to have an accuracy of 5%–10%.

Figure 3.3 provides the design and specifications of an EWH. The commercial product simulated in the present study was obtained from Wuxi Wankang Solar Water Heater Co., Ltd., a TÜV-certified company (Wksolargroup, 2018). Figure 3.4 presents the design and specification of a commercial SWH.

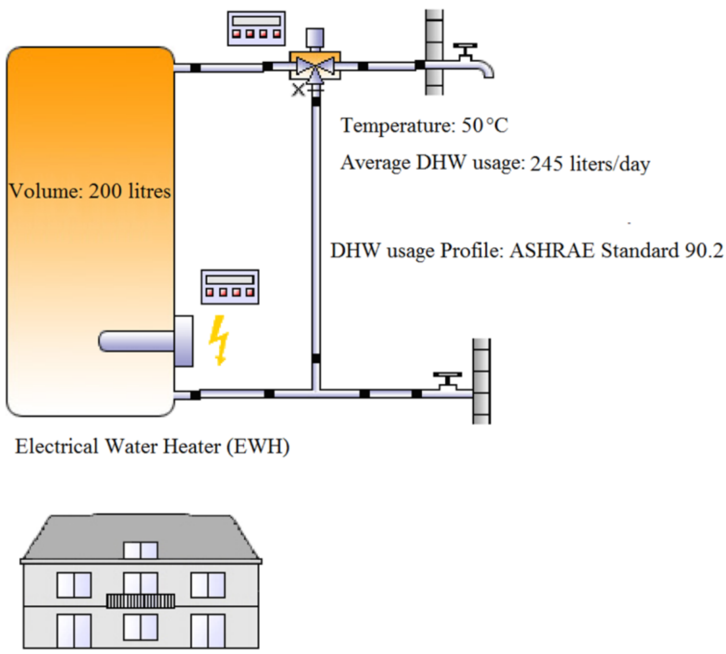


Figure 3.3: EWH System: Consumption is Based on 4.8 Occupants per House.

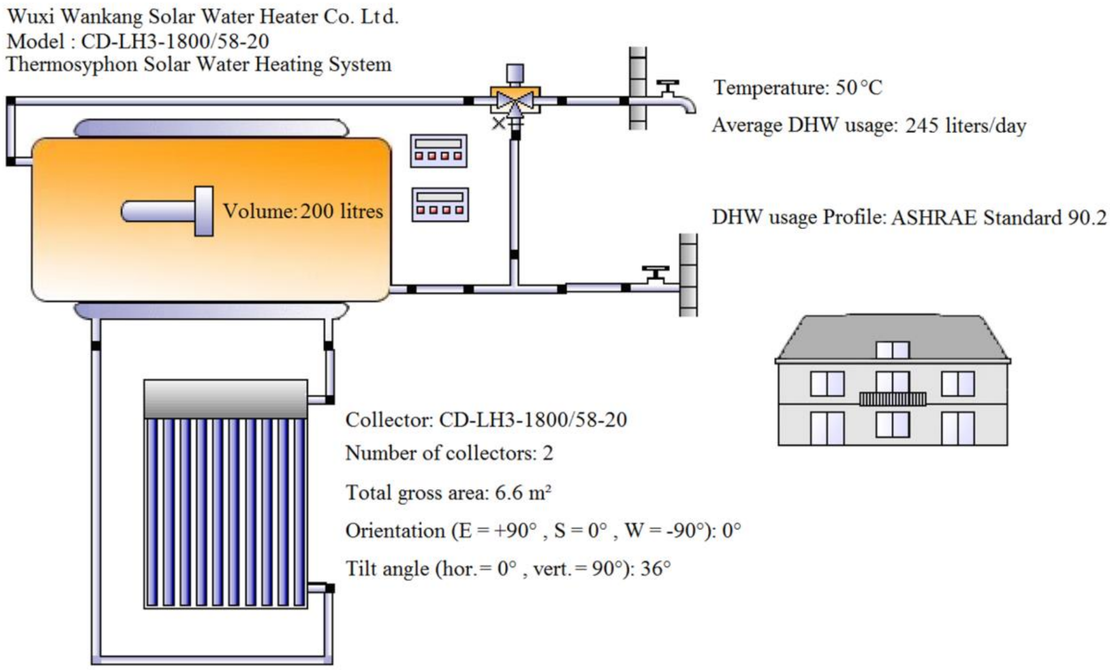


Figure 3.4: SWH System: Consumption is Based on 4.8 Occupants per House.

The assumption made in the present study is that 100,000 households with 4.8 occupants each participated in the DSM programme (KRSO, 2018). For each of these households, the daily average hot water consumptions were taken as 245 l per day (Hobbi & Siddiqui, 2009). Different daily DHW draw profiles are included in the POLYSUN profile with steps of less than 1 h. For the simulation, ASHRAE Standard 90.2 (ANSI/ASHRAE Standard 90.2, 2007) was chosen because a local standard was not available, and it provides modelling for typical daily and hourly hot water withdrawal (Figure 3.5).

The two temperature sensors placed above the electrical immersion heater allow for auxiliary heating control. As the switch-off temperature is normally higher than the switch-on temperature, the on/off control model was selected for the simulation. The switch-on temperature was set to 50 °C, while the switch-off temperature was set to

80 °C. This implies that, on cloudy days or nights, a drop in the temperature of hot water to 50 °C will switch the immersion auxiliary heater on to heat the water.

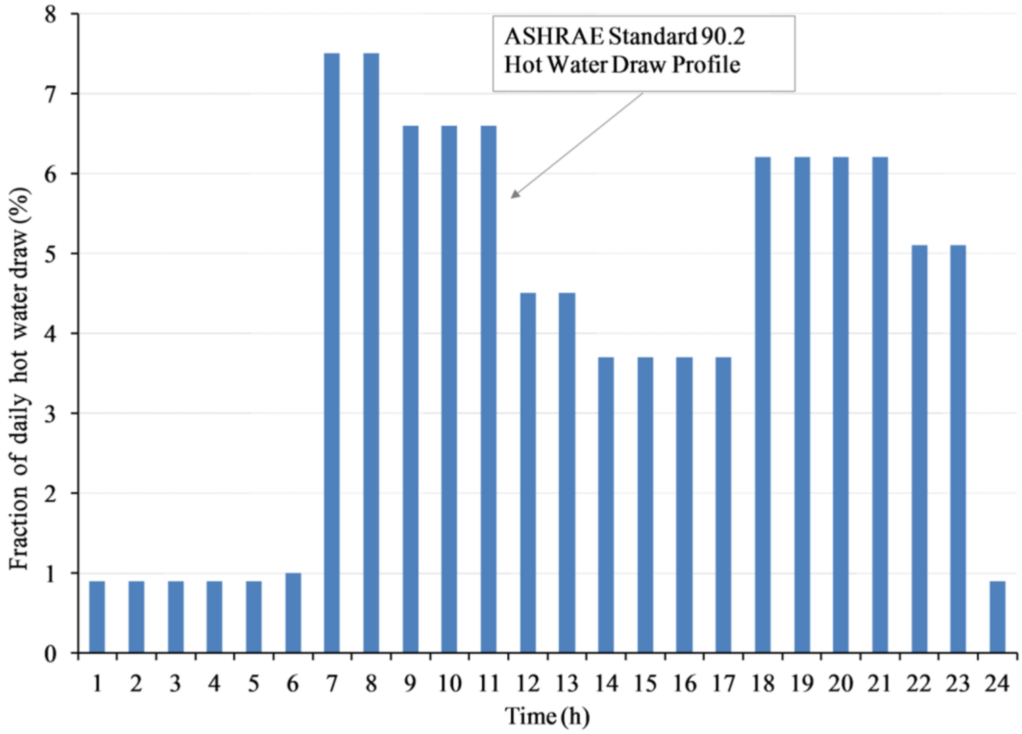


Figure 3.5: ASHRAE Standard 90.2 Hot Water Withdrawal Profile Used in the Analysis of 100,000 Households.

The simulation was performed for a year for both EWHs and SWHs, and was completed using the log and 'parameterize' functions provide by POLYSUN.

3.4 Simulation Result

For the 100,000 households using EWHs and SWHs, the annual electricity consumption was estimated to be 830,240 MWh and 366,870 MWh, respectively. Hot water in Erbil is mostly used during three main seasons: autumn, winter, and spring. The least quantities are used during summer. Table 3.1 presents this data.

The use of SWHs solely benefits consumers because the electric utility in Erbil occasionally suffers from grid loss problems in its transmission and distribution networks. The grid loss problems can be placed in two categories: technical losses and non-technical losses. Technical losses are losses that occur right from the generation stage at the power plant to transmit and distribute electricity up to the consumer's energy meter. On the other hand, the non-technical losses are those associated with illegal electricity connections as well as the low accuracy of consumer energy meters.

According to the Ministry of Electricity (2018), grid losses in Erbil equal to 40%, with 17% and 23% being attributed to technical and non-technical losses, respectively. In the present study, we assume that the T&D losses occurring at the generation and consumption points are technical and therefore equivalent to 17%. The reality of the Erbil electrical network was taken into consideration in the calculation. The annual energy savings that the utility realized on the generation side were estimated at ~463 GWh/100,000 households (Table 3.1). The application of the DSM program would lead to energy savings as illustrated in the hatched section in Figure 3.6.

Table 3.1: Annual Electrical Energy Consumptions (MWh/year/100,000 households; Obtained from POLYSUN)

Months	E_{EWH} (MWh) Total Electrical Energy Consumption for EWH	E_{SWH} (MWh) Total Electrical Energy Consumption for SWH	E_{sav} (MWh)
Jan	74,200	58,600	15,600
Feb	68,400	50,900	17,500
Mar	67,400	38,000	29,400
Apr	60,200	30,200	30,000
May	53,900	11,400	42,500
Jun	45,300	–	45,300
Jul	41,600	–	41,600
Aug	42,600	–	42,600
Sep	46,800	1,800	45,000
Oct	57,100	23,000	34,100
Nov	62,900	38,000	24,900
Dec	68,700	52,600	16,100
Annual Energy Consumed at consumer-Site (Consumer-end) (kWh)	689,100	304,500	384,600
Annual Energy Consumption at Supply-Side (kWh) including Grid Losses (17%)	830,241	366,867	463,373
Energy Losses in Grid (kWh)	141,141	62,367	78,773

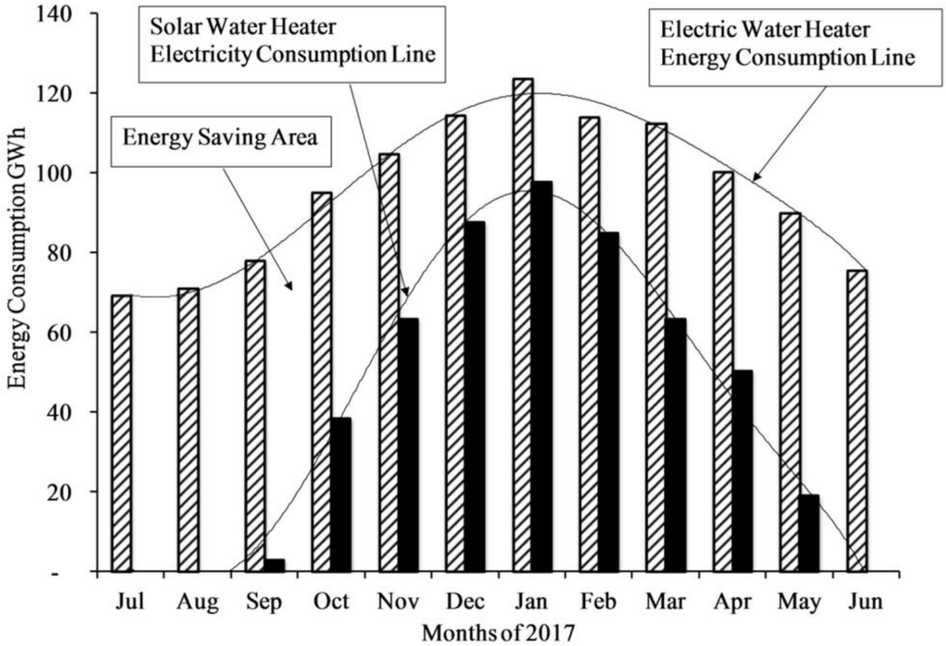


Figure 3.6: Annual Energy Savings Realized by the EWH-to-SWH Transition in the Present Case Study.

On February 4th, 2017, EWHs recorded maximum peak loads, i.e. at the lowest level of global horizontal solar irradiation (GHI) in winter. The difference between SWHs and EWHs peaks was found to be ~54 MW (Figures 3.7 and 3.8). Diurnal load variations featured peak reductions during the morning and evening. Moreover, with increasing GHI, the energy consumed by the auxiliary SWH decreased. In the evening, larger load reductions were observed compared to mornings because SWHs produced a sufficient amount of hot water during the afternoon, which was dependent on domestic hot water use patterns in households.

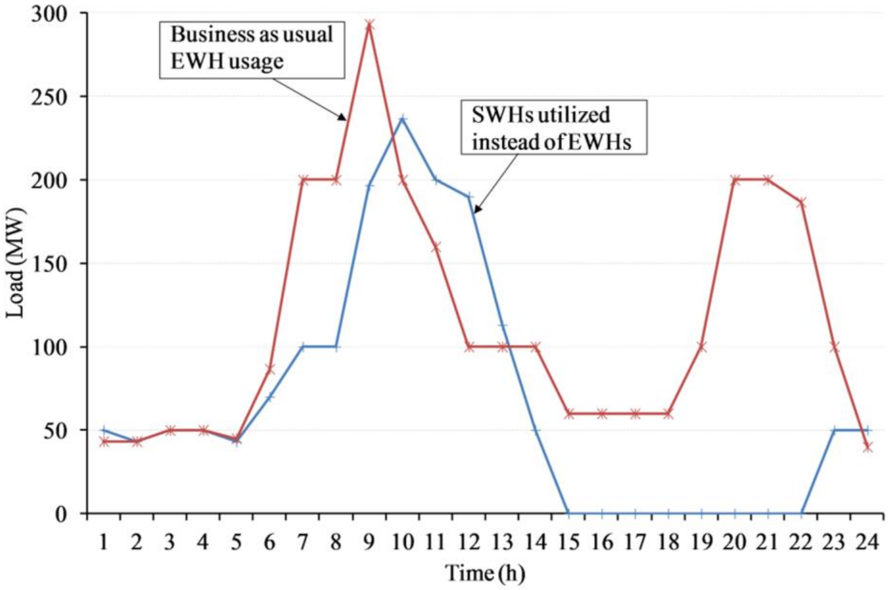


Figure 3.7: Typical Hourly Maximum Demand Curves on February 4th Estimated for 100,000 Households Employing EWHs and SWHs, with the Maximum Outdoor .Temperature Equalling 1.3 °C

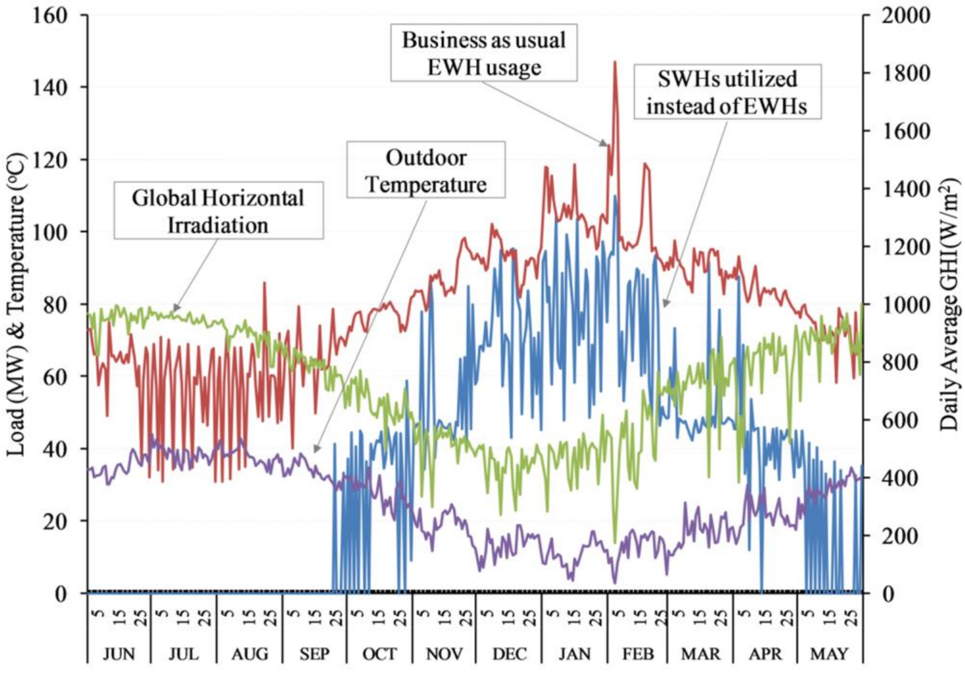


Figure 3.8: Typical Average Daily Demand Curves for Water Heating Estimated for 100,000 Households Employing EWHs And SWHs: Daily Average GHI Curves and Outdoor Temperature Variation for Four Seasons.

3.5 Assessment of the Proposed DSM Programme for the Case of Erbil

In the present study, various recommendations are made, but these will be subject to changes in the subsidies that are currently being provided by the utility. Under the policy proposed by this study, the subsidy programme will be implemented by providing free SWHs to households. Additionally, the current subsidized price will be increased for consumers who are not willing to participate in the program to not only allow the utility company to recoup the cost of the subsidy but also encourage consumers to switch to the use of solar energy for water heating.

The total subsidy for the proposed number of households that make use of EWHs incurred by the utility company is approximately US$75 million. The implementation of this DSM program would reduce this figure to US$33 million (Table 3.2). Thus, for the 100, 000 households, subsidy savings are approximately US$42 million annually.

Table 3.2: Subsidy Recovery Value

Description	Parameters	Results
Price of subsidizing EWH-electricity use by the utility	P_{S_EWH} (US$/year)	74,721,687
Price of subsidizing SWH-electricity use by the utility	P_{S_SWH} (US$/year)	33,018,072
Utility's subsidy recovery	$P_{S\_subsidy\ recovery}$ (US$/year)	41,703,614

The cost of water heating per household is approximately US$138, with the implementation of the DSM program expected to reduce this number of US$61 per household. This means that each household will save approximately US$77 in the cost of water heating per year. Furthermore, the DSM program will allow the utility company on average to recover ~788 kWh per year per household in technical grid losses in the transmission and distribution network as shown in Table 3.3.

Table 3.3: Advantages of Applying the DSM Programme

Calculation parameters	DSM Programme		Description
	Before	After	
Subsidy (US$/kWh) for year 2017	0.09	0.09	Full subsidy will still be provided to households participating in the DSM programme
Annual energy consumption at site (consumer side) (kWh/house)	6,891	3,045	Energy saving on consumer side: **3846 kWh per year per household**
Annual energy supply by utility (kWh/house)	8,302	3,669	Total energy savings by utility: **4634 kWh per year per household**
Utility grid loss	1,411	624	Recovery of grid losses: **788 kWh per year per household**
Annual recovery cost (US$/house)	913	403	Annual saving of recovery cost: **US$510 per year and household**
Annual price paid by consumer (US$/house)	138	61	Consumer savings: **US$77 per year per household**

The implementation of this DSM programme will defer the generation of an additional 4172 GWh of electricity for 10 years (i.e. E_{sav} = 4172 GWh). The lower heating value of heavy fuel oil (HFO) is 10.83 kWh/kg (Engineeringtoolbox.com, 2018), and the price of HFO per ton is US$350. The efficiency of the RICE power plant is estimated to be 45%. From Table 4, within this period, the total fuel cost will stand at approximately US$333 million, using Eq. (7).

Electricity consumers pay a price of 0.02 US$/kWh, but the cost of the electricity supplied by the utility is 0.11 US$/kWh. This implies that the pre-tax subsidy is US$0.09/kWh. Assume that during the period of implementing the programme, the US dollar attracts an annual interest of 2%; then, the net present value of the subsidy recovery will be approximately US$381.4 million using Eq. (5) (Table 3.4). This figure is based on the savings for the 100,000 households.

The construction of an equivalent power plant, on the other hand, such as a reciprocating internal combustion engine (RICE) power plant to adequately handle the peak load during winter, will require approximately US$76.8 million in funding over ten years, as indicated in Table 3.6 (Atikol et al., 1999). Additionally, the cost of construction or expansion of T&D lines that is avoided is estimated to be US$75.6 million for the 54 MW peak load reduction taking into account that the avoided cost for the T&D network is approximately US$140/kW, as provided by the electrical utility company in Erbil (Ministry of Electricity, 2018).

For the 100,000 households, the total rebate cost is estimated at US$900 per household (Table 3.6). This amount is for the purchase and installation of the solar thermal collector as quoted by the Wuxi Wankang Solar Water Heater Co., Ltd. (Wksolargroup, 2018), an SWH producing company that is included in the POLYSUN library. The price for these SWHs seems low because of the large number of units that are purchased for the project. This translates into total costs of

~US$90 million for all the 100,000 participating households. For a country with subsidized electricity prices, the amount of revenue that is lost is equal to zero because the electric utility does not earn any profits. Using Eq. (4), the NPV of the implementation of a DSM programme for Erbil can be estimated as approximately US$776.6 million/100,000 households Table 3.5.

Table 3.4: Net Present Value in the Proposed DSM Programme for Ten Years

Avoided Generation Capital and O&M Cost (US$)	PV_{AG}	76,762,620
Avoided T&D Capital and O&M Cost (US$)	$PV_{A(T\&D)}$	75,600,000
Avoided Fuel Cost (US$)	PV_{AF}	332,780,800
Net Present Savings *NPS* (US$)		485,143,420
Total investment (US$)	$\mathrm{PV}_{\mathrm{inv}}$	90,000,000
Lost Revenues (US$)	$\mathrm{PV}_{\mathrm{LR}}$	–
Net Present Investment *NPI* (US$)		90,000,000
Net Present Value of Subsidy Recovery NPSR (US$)		381,436,257
By spending US$1 the utility will gain approximately US$9.6 at the end of the programme		9.6
Net Present Value NPV (US$)		776,579,677

Approximately 80% of the benefits of the programme are due to the avoided fuel costs (PV_{AF}) and subsidy recovery (*NPSR*). The subsidy provided by the electric utility is an everyday expenditure and is a significant component of the country's budget when it comes to subsidies; thus, it is a major issue for the energy sector and utility companies.

Table 3.5: Deferred Power Generation Prices, (EIA, 2013)

Power Plant Type	Power Plant Capacity	Capital Cost		Fixed O&M (10 Years)		Variable O&M (10 Years)		Total Cost (10 Years)
Suitable Type	(MW)	(US$/kW)	(US$ million)	(US$/kW-yr)	(US$ million)	(US$/MWh)	(US$ million)	(US$ million)
Reciprocating Internal Combustion Engine (RICE)	54	1,342	72.5	6.9	3.7	5.85	0.57	76.8

Table 3.6: Analysis of Future DSM for the Erbil Case Study in Contrast with the Traditional Reform Plan

DSM Programme	Explanation	Rebate cost /house (US$)	Estimated Participating houses	Total DSM Cost (US$m)	NPV (US$m/10 years)	Winter Peak Load reduction (MW)
Replace Electrical Water Heaters (EWH) with Solar Water Heaters (SWH)	Houses that take part will receive the SWH fat no cost provided that the installation is carried out by the utility.	900	100,000	90	776.6	54

Compared to the works cited in the introduction of this thesis (Timilsina et al., 2000; Burrett, et al., 2006; Al-Badi et al., 2009; Chang et al., 2011; Gastli and Charabi, 2011; Meir et al., 2012; Jablonski and Tarhini, 2013; Bahadori and Nwaoha, 2013; Aigbavboa, 2015; RCREEE, 2015; Kritzinger and Covary, 2016; Chang et al., 2018; Yılmaz, 2018; Sadiq, 2018; Yu and Gibbs, 2018), the present study makes use of a different economic assessment and approach as it has a different methodology and different goals. In this context, the prices of electricity are subsidized, i.e. the DSM programme put forward by this study entails complete reimbursement of the cost of SWHs. Further, the use of SWHs is linked with a subsidy, while in the studies cited above, incentives were given for procurement of SWHs as well as passing legislation to compel usage of SWHs.

At this point, it is important to note that an ideal solution does not lie in eliminating the use of electricity because it is a way of ensuring that people in a country get a share of the resources of their country. For this reason, the present study proposed a slightly different DSM strategy that still provided subsidies while allowing for peak load reduction through the utilization of solar thermal technology. This combination is crucial for the success of a DSM programme in an oil producing country.

3.6 Remarks on SWHs in a DSM Programme

The present study was carried out in the high electricity subsidy Erbil province. Faced with various capacity and reliability problems, the electricity utility company did away with a comprehensive electricity cost subsidy for the commercial sector in March 2017. The utility also moved further to implement a plan for removing subsidies for other categories of consumers in the coming years. In line with this plan, the present study investigated different solutions for highly subsidized systems and compared them with the solutions that have been implemented in conventionally reformed systems.

In particular, the present study developed a DSM programme to promote the use of SWHs in a high subsidy country. Under this programme, residential households will be supplied with SWHs at no cost.

The results of the study can inform the development of a DSM programme, which may make deferred construction of new power plants feasible. In the DSM programme proposed herein, it was found that, at the end of the programme, the utility will gain approximately US$9.6 per US$1 spent upfront. To implement this programme, an investment of US$90 million is needed, and this will see the company saving approximately US$866.5 million, which is inclusive of the subsidy recovery and savings attained by deferring the construction of a 54 MW power plant for at least 10 years. With duration of 10 years, the estimated NPV stands at US$776.6 million.

In using solar thermal technologies, the subsidy reform proposed in the present study is an original DSM approach for countries that offer high subsidies to electricity consumers and has a high likelihood of benefiting the utility company in terms of reliability and capacity, and consumers through better supply and prices.

Chapter 4

PROMOTION OF SOLAR AIR CONDITIONING BY DSM

4.1 Introduction

The demand for electricity goes up with an increase in the use of electrical appliances in offices, homes, companies, and shops. This study aims to lower the rising demand for electrical energy by using a DSM approach that promotes the use of solar-assisted air conditioners.

Over 70% of offices and commercial buildings in the USA making use of a DSM programme make it possible for the energy consumers to prevent the overuse of electricity, therefore reducing energy-related expenses (Holt, 2016). A study indicated that participation in a DSM programme that was largely successful and the number of participants in the next programmes become double. In Connecticut, every dollar invested in the electricity and gas sector yielded a three-dollar return for participants in the Energy Efficiency Fund programme. The analysis of the transfer of DSM strategies between countries by addressing country specific problems involves several assumptions. The level of transferability is higher between countries when they share a considerable number of similarities. Three levels exist and these include direct copying, adaptation, and inspiration (Warren, 2017).

In Erbil, there exists a major interest in having the peak load modified to create an electricity system that is more sustainable as a sample for developing oil-producing countries. The cost of electricity is too low that consumers do not see the need to use solar energy that is available in plenty. In the present study, a special case of transferring solar-assisted air conditioning technology to Erbil using a DSM system with the intention of modifying the peak demand is provided. This is because the application of the DSM programme would significantly adjust the peak demand and T&D losses as it is measured of approximately 40% (MOEL, 2018), and reduce fuel consumption, therefore saving the utility from putting up expensive power plants in the future. Additionally, this will cut on the use of fossil fuel, which can then be exported to increase the revenues of the country (Alasseri et al., 2017).

The focus of the present study is the commercial sector (offices and commercial buildings) mainly because the work day starts in the morning and ends in the evening, which means that electricity consumption is continuous during this time. Additionally, the majority of these buildings have air conditioning (use of split units), and cooling expenses form a major portion of their energy expenses.

4.2 Solar Thermal Cooling Technologies

4.2.1 Technologies Brief

(EIA, 2012) projected that from 2010 to 2035, there will be an increase in the amount of power that is generated from renewable sources and will stand at 31% of total power generated globally. The utilization of renewable energy sources will effectively address the increase in the amount of energy needed worldwide and the effects of climate change. Renewable energy sources could be used to run air conditioning systems instead of fossil fuels. A review of several solar cooling technologies was provided by (Hwang et al., 2008). Studies up to 2007 were reviewed and classified into three main groups as illustrated in Figure 4.1. A thermally operated solar cooling system has three main technologies: open cycles, closed cycles, and thermo-mechanical cycles.

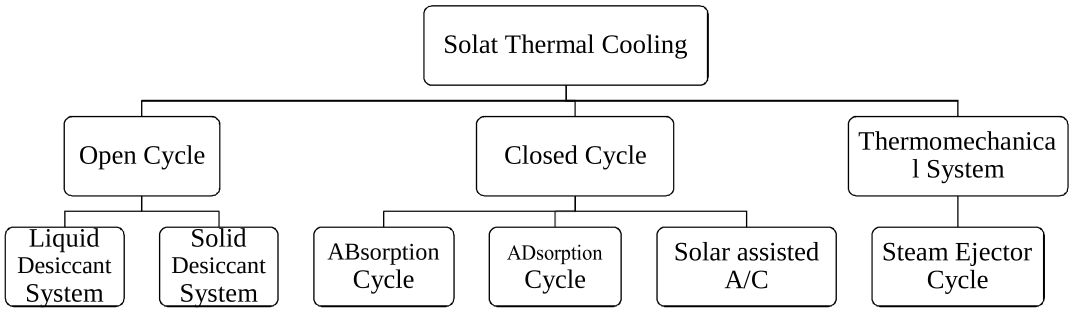


Figure 4.1: Category of Solar Cooling Technologies

The current section of this thesis focuses on the application of solar thermal technologies in cooling applications. Thus, the main focus of this chapter is solar thermal cooling technologies. The chapter provides a summary of the advancements in the technologies. Furthermore, a brief comparison of the technologies is performed to allow for the identification of a technology that is economically feasible for countries producing oil, will result in peak load reductions, and is most cost effective for utilization with a DSM programme.

4.2.2 Technology Comparisons

The main characteristics of the different types of solar thermally powered cooling systems are summarized in Table 4.1. A review of thermally powered cycles such as adsorption, absorption, desiccant cooling, hybrid solar cooling, and ejector cycles is provided. The summary provides a comparison of various factors that include the initial cost per kW cooling, advantages, disadvantages, COP, and technology installation area of the various solar thermally powered cooling systems.

Table 4.1: Comparison of Solar Thermally Powered Cooling Systems, (Balaras et al., 2007; Pridasawas & Lundqvist, 2007)

Solar Thermal Cooling Technology	**Advantage**	**Disadvantage**	**COP**	**Area (m^2/ kW_c)**	**Cost (US$ /kW_c)**
Desiccant cooling systems	* Working fluid is water and therefore friendly to the environment * Can make use of a solar collector given the driving temperature is low * Integration with heating and ventilation systems possible	* Has moving parts in the rotor wheel of the solid desiccant system and therefore requires regular maintenance * Not suitable for humid areas as control is difficult * Poor process control in liquid desiccant systems leads to crystallization	0.5	4.5	3000
Absorption cooling systems	* One moving part- the pump * Has the ability to use a low temperature supply	* When LiBr-H2O is used as working medium, there is an evaporating temperature * Has some level of complexity and therefore difficult to service	0.6	6.5	2000
Adsorption cooling systems	* Has no moving parts (except valves) * Low operating temperatures can be achieved.	* No suitable for high capacities. This can lead to long term problems * Difficult to achieve air tight conditions * Sensitive to low temperature * An intermittent system.	0.4	2.5	3500
Solar-assisted cooling system	* Affordable and cost effective * High COP * High efficiency * Maximum energy savings.	* Electrical energy used is approximately 60% while solar energy is approximately 40%	1.5	0	100
Ejector refrigeration systems	* Can use low temperature heat source * Has low installation and operating costs	* Low COP * complicated ejector design * Works in a narrow range of ambient temperatures	0.3	2.5	1500

As the electrical energy consumption in solar-assisted air conditioners is approximately 40% less than that in an ordinary air conditioner, solar-assisted air conditioners are a very promising technology when it comes to a DSM programme owing to their low capital cost, simple installation set up, and high COP. They appear to be the most suitable technology for air conditioner applications in households and small offices. Additionally, a large area is not required for installation of thermal solar collectors; moreover, they are easy to use and have low maintenance costs.

Solar-assisted air conditioners also have a high economic potential in countries that sell their electricity below the generation cost; a high capital investment as well as a long payback period (more than 10 years) is associated with other cooling systems. However, solar hybrid air conditioners have a low investment cost and a payback period of less than a year. This makes solar hybrid air conditioners a viable technological investment for both clients and electrical utilities.

The following parameters are needed when solar cooling technology is used with a DSM programme (Warren, 2017):

- Lowest initial cost
- Easy installation
- Low maintenance cost
- Highest electrical energy savings
- Small area required
- Easily spread for implementation

4.2.3 Solar-assisted Air Conditioning System

A solar hybrid air conditioning system utilizes both electrical energy and solar energy for cooling purposes. Solar energy is used as an additional heat source, which reduces the amount of electricity that is consumed by the compressor.

This type of system functions much like a conventional air conditioner in that a liquid with a very low boiling point is evaporated to facilitate refrigeration. The evaporation of the liquid absorbs and takes heat away, and this occurs continuously until all the liquid has boiled or the subzero boiling point has been reached (Assadi et al., 2016).

The difference between this air conditioner and a conventional one lies in the way the gas is converted back into a liquid to be reused. In regular air conditioners, the gas is pressurized by the compressor to force it to become a liquid in the condenser coil. This change of state of the refrigerant occurs two thirds of the way down the condenser. On the other hand, a different method is used by a solar hybrid air conditioner. The refrigerant is superheated using the solar heat from the sun to facilitate the change of state of the refrigerant at the top two thirds of the condenser coil (Ha & Vakiloroaya, 2015). Using this technique, the solar hybrid air conditioner reduces the amount of compressor power that is needed to achieve the cooling process in a regular cooling system, in addition to using more of the cooling face of the condenser coil (Assadi et al., 2016). Furthermore, only a portion of gas is converted into a liquid in a conventional air conditioner to allow the refrigerant entering the metering device to be a saturated vapour. On the other hand, the cooling process in a solar radiation air condition allows for a large portion of the refrigerant to change into liquid form quicker, in addition to allowing the transformation of more liquid in the metering device. At the output of the compressor, the refrigerant steam with a high temperature and high pressure is conveyed into the solar vacuum tube collector by means of the absorbed solar power increasing the temperature further to 85 °C from 75 °C. The cooling effect is, to a large extent, improved by the superheated cooling gas when cooling exothermic into liquid in the condenser.

For better efficiency, the sizing of the condenser and the evaporator with respect to the compressor was matched by using more heat exchanging surfaces larger than those in a regular air conditioner to allow for better utilization of heat from solar power. This promotes reduced electrical energy consumption. Alongside other factors, the solar radiation air conditioner as shown in Figure 4.2 works in an efficient way to achieve a super high energy efficiency ratio (EER) of at least 5.0 (Super Green Solar, 2018).

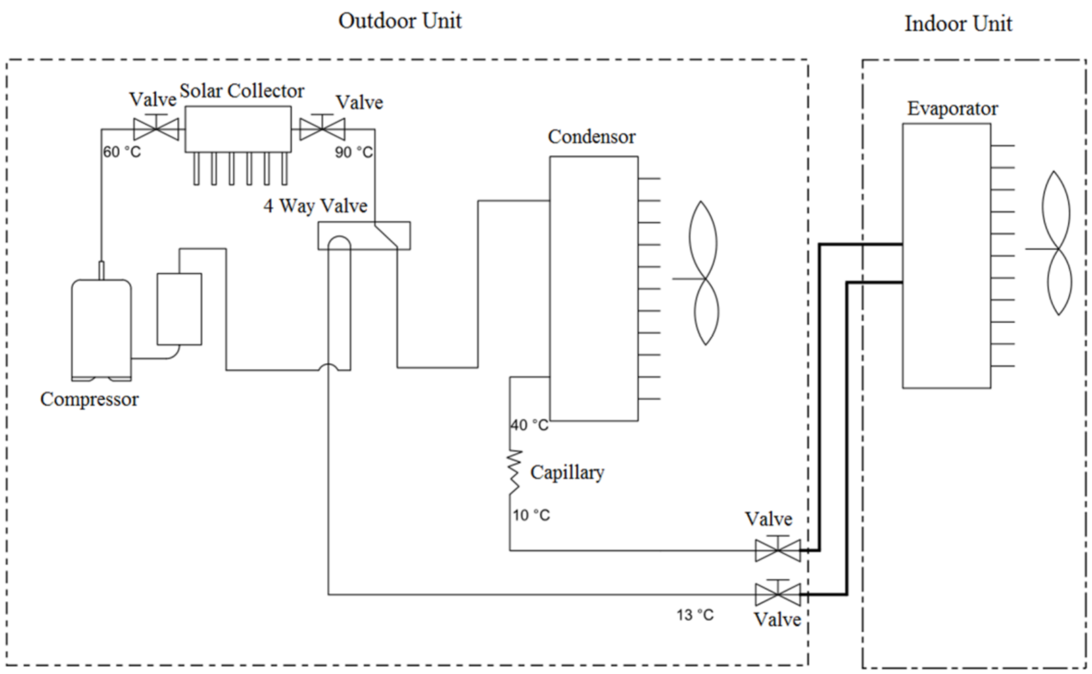


Figure 4.2: Solar-assisted Air Conditioner

Given that the majority of these parameters are found in a solar hybrid air conditioning system, in this study, an evaluation of the possibility of applying the DSM programme during the summer season in oil producing countries that tend to have high energy subsidies with a solar cooling technology was conducted with an office in Erbil as a case study.

4.3 Methodology

Before making a proposal for any DSM programme, it is critical that the amount of investment required for the installation of a solar-assisted A/C system is first known. The method that is employed in this study is illustrated in Figure 4.3. The rebate amount and the number of participants signed to a DSM programme define the total cost of a DSM programme. Estimation of the peak load reduction and determination of the programme feasibility are conducted. The reduction in the electrical load E_{AC} due to replacing the standard A/C with a solar-assisted AC is estimated from

$$E_{AC} = E_{Standard\_AC} - E_{Solar\text{-}assisted\_AC} \quad (13)$$

The post-tax subsidy that is equivalent to the efficient tax when the pre-tax subsidy is not available (Clements et al., 2013) and the proposed reform policy of the present DSM programme are utilized in the post-tax plan for commercial sectors as follows:

$$P_{s\_post} = (P_w + t^*) - P_C, \quad (14)$$

where P_w is the electricity recovery cost, t^* is the efficient tax, which is assumed to be approximately 3% of the recovery cost, and P_c is the cost paid by the consumers (El-Katiri, & Fattouh, 2017). The economic feasibility indication for applying DSM is *NPV* (Karunanithi et al., 2017):

$$NPV = \Sigma NPS - \Sigma NP/, \quad (15)$$

where *NPS* represents the net present savings from replacing the technologies, and *NPI* represents the net present investments for applying the programme. The positive value of NPV is the main indication of viability of the project:

$$NPV > 0 \ . \tag{16}$$

The NPV in a commercial building is obtained according to the general equation

$$NPV = \Sigma\, NPS - \Sigma\, NP/ + \Sigma\, NPt^{*}. \tag{17}$$

The net present savings obtained by replacing the technologies are calculated using

$$NPS = PV_{AG} + PV_{A(T\&D)} + PV_{AF} \ , \tag{18}$$

where PV_{AF} represents the avoided fuel expenses, $PV_{A(T\&D)}$ represents the present value of the avoided costs necessary for improving the transmission and distribution electricity structure, and PV_{AG} represents the present value of avoided generation fees.

Furthermore $NP/ = PV_{inv}$ and the net present value of subsidy recovery are represented by *NPt** (El-Katiri & Fattouh, 2017). This can be calculated as

$$NPt^{*} = (E_{AC} \times P_{s\_post}) \times (1 + i)^{-n} \ , \tag{19}$$

whereas *n* represents the number of years of the project, and *i* signifies the discount rate.

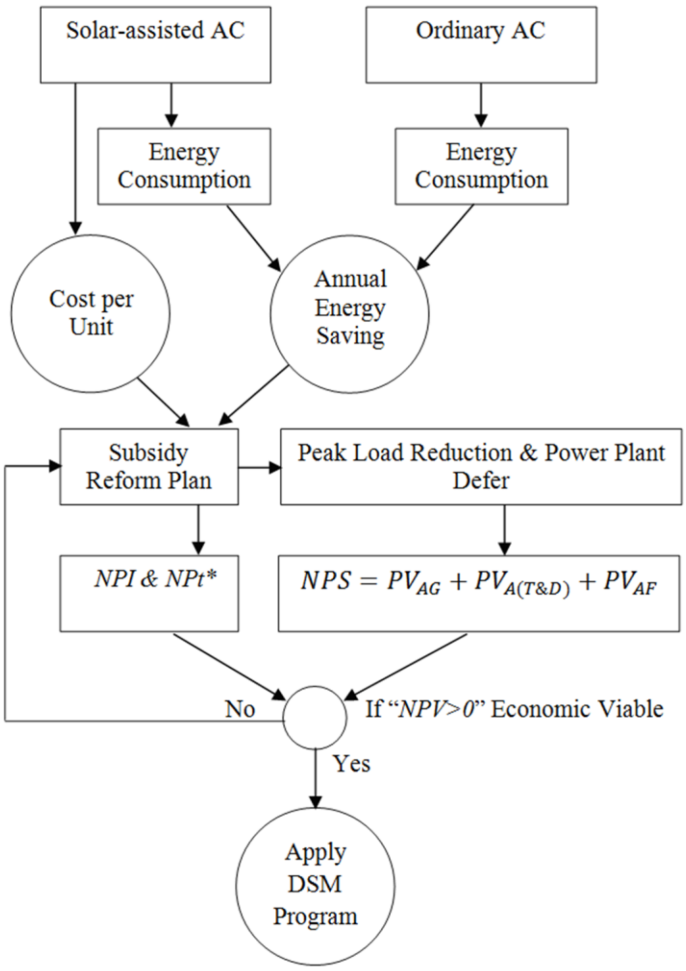


Figure 4.3: Methodology Approach

4.4 Experimental Set-Up and Procedure

The office building in which the experiment was conducted has nine rooms each fitted with a split A/C system (Figure 4.4). Two rooms with identical features on the outside and inside were chosen for the experiment, and these are Office number one and Office number two, as illustrated in Figure 4.5. In Office number two, an ordinary A/C unit is used and in Office number one, the ordinary A/C system was replaced with a solar hybrid air-conditioning unit with the same cooling capacity of 24,000 BTU/hr (2 ton refrigeration capacity).

The indoor temperatures for the rooms were set to 20 °C, and a data logger was used to monitor the power consumption of both the standard A/C unit and the solar-assisted A/C unit to obtain the load difference. Both offices are open from 9 am to 6 pm on a daily basis. The purpose of the experimental study was to examine the difference in energy consumption of both technologies and the effect that load reduction had on the electricity subsidy. The data logger uses a stick memory to collect the energy data from an inbuilt multifunction voltage ampere power energy meter (AC80/260V/100A) communication module with temperature sensors and a current transformer.

Figure 4.4: Case Study Office

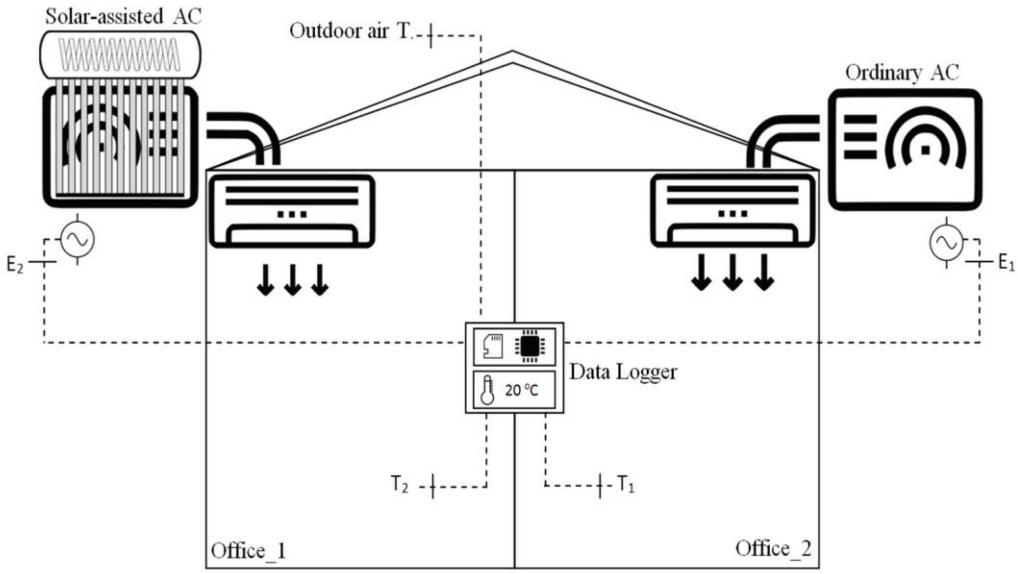


Figure 4.5: Experimental Layout

Electrical energy consumption data were collected for the ordinary A/C system in room number 2 and the solar-assisted A/C system in room number 1 from 1st of September to 30th of September/2017, as were the indoor and outdoor temperatures. The rooms have the same size, a similar solar orientation, windows with the same size, the same indoor temperature of 20 °C, and an equivalent number of employees working in each room. The estimation electrical energy consumption for a year was obtained based the A/C systems working 197 days per year according to the following schedule:

1) During the months of April, May, October and November because during the spring and autumn the outdoor temperature is approximately 20 °C (comfort temperature) and usually the people do not operate air conditioners.
2) On Fridays, the office is closed.
3) The holiday days during the year in the office are eleven days as following: (Christmas – 1 day, Nawroz- 3 days, Eid Al-Fitr - 3 days, Eid Al-Adha - 4 days)

Once the experimental component devices were set up, the system was plugged in, and the data logger started to read and record the energy consumptions for both air conditioners; the indoor and outdoor temperatures were also recorded. The data was saved on the Memory Stick Micro. The reading was recorded every two seconds, and every 10 days, the data was backed up from the Memory Stick Micro after the work day ended. Thirty days' worth of data was collected and was ready for data analysis to assess the proposed DSM programme.

4.5 Experimental Results

The experiments revealed that an ordinary A/C system consumed a daily average of 25.2 kWh (annually 4,964 kWh), while a solar-assisted A/C system consumed 15.9 kWh (annually 3,416 kWh) (Figure 4.6). A difference in daily energy consumptions between both technologies was clearly observed, and it is approximately 9.4 kWh (annually 1,548 kWh) per A/C unit. Figure 4.7 illustrates the demand load of each A/C system; the average load required during daytime is approximately 2.8 kW and 1.93 kW for the ordinary A/C and solar-assisted A/C, respectively. This suggests that there is a load reduction of approximately 873 W per A/C split unit on the demand-side is possible, which would reduce the significant demand load during hot days in the summer season. Figure 4.8 also shows the current load (A) for both types of A/C systems; the ordinary A/C and solar-assisted A/C required 12.6 A and 8 A, respectively. The current load reduction is approximately 8.5 A per A/C split units.

Furthermore, during the month of September 2017, the ordinary AC system consumed 755.3 kWh per month, while the solar-assisted system consumed 477.2 kWh per month.

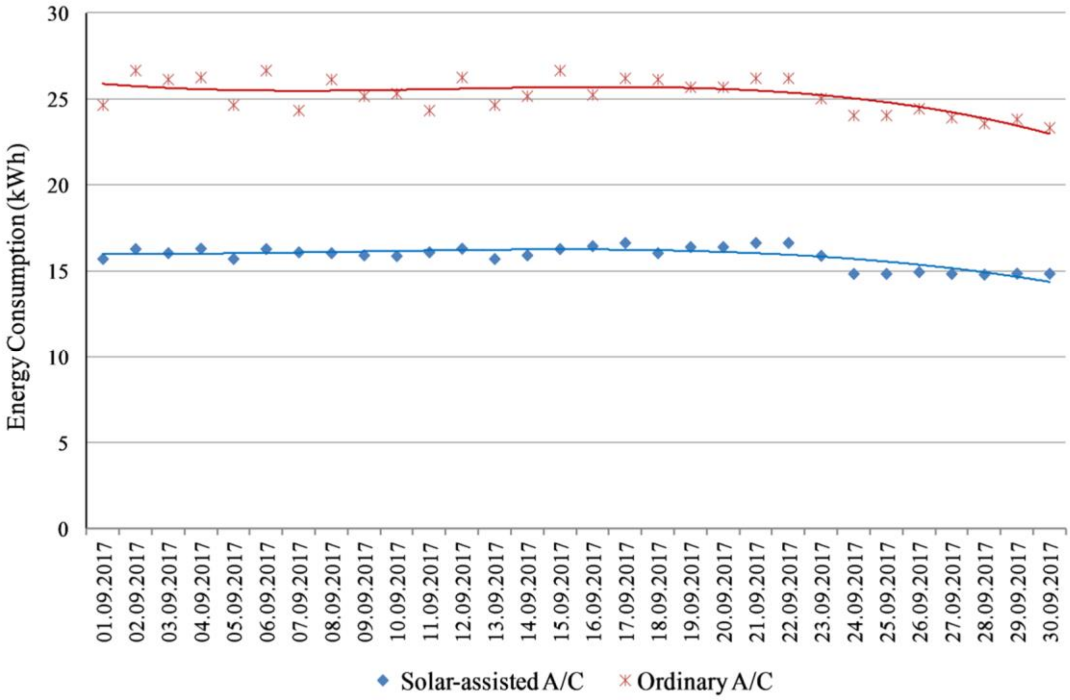


Figure 4.6: Monitored Energy Consumption During September 2017

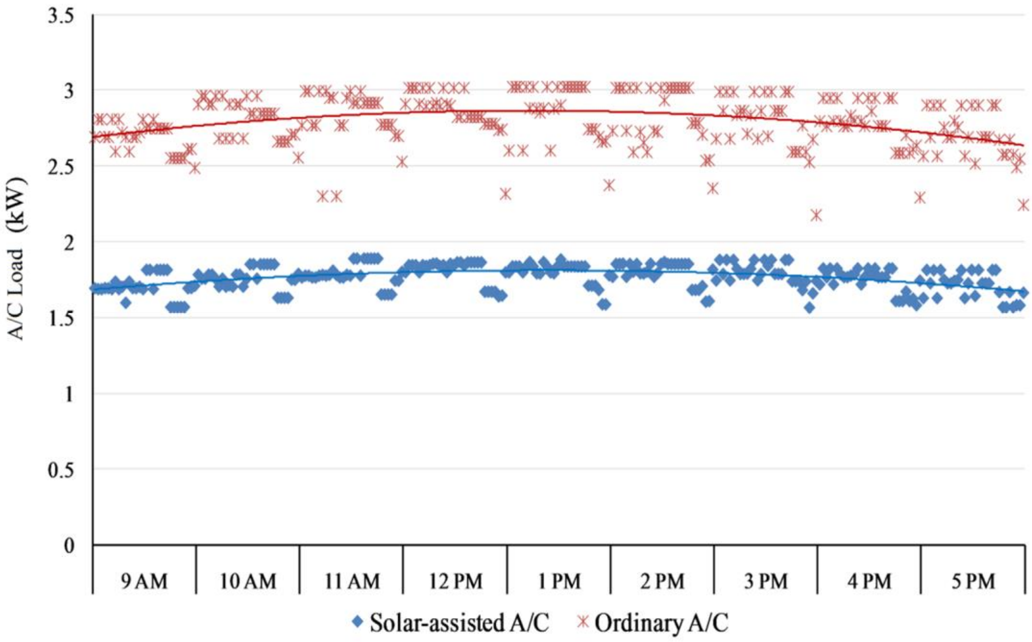


Figure 4.7: Average Daily Power Consumptions of Both Types of ACs

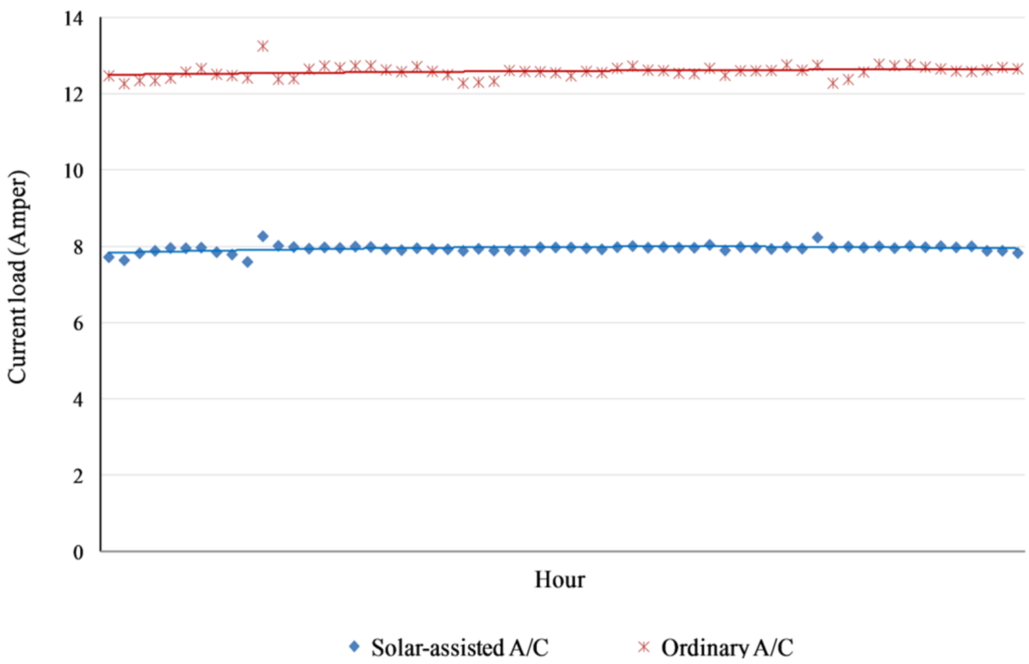


Figure 4.8: Current Load, A

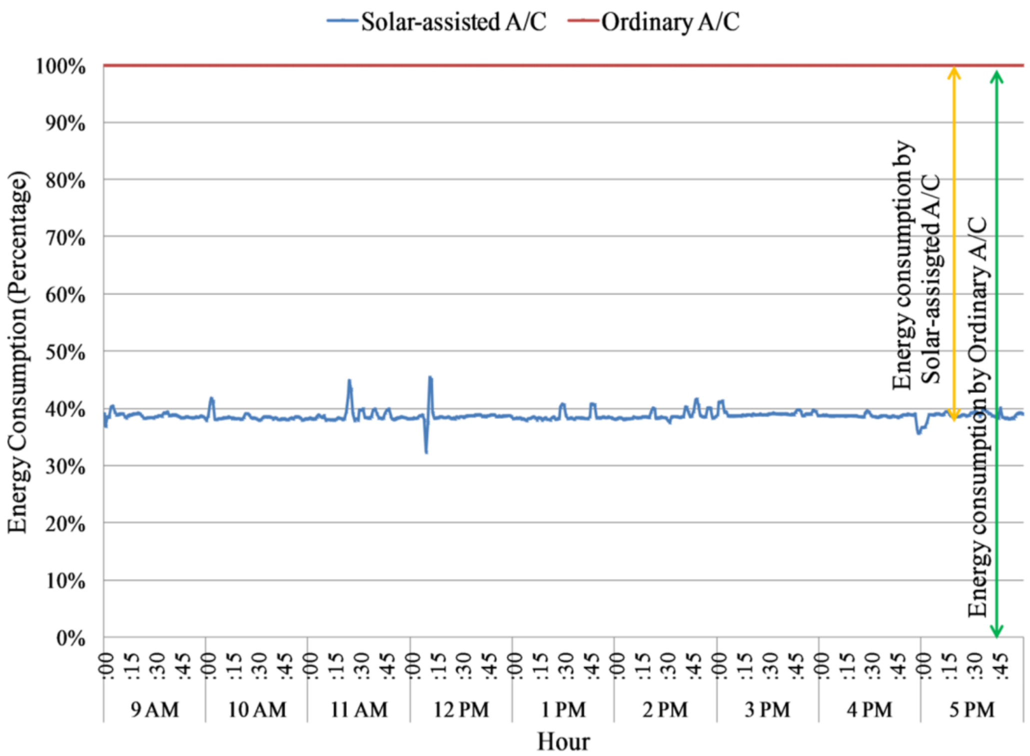


Figure 4.9: Solar-assisted A/C Energy Saving Percentage Compared with that of an Ordinary A/C

As shown in Figure 4.9, the solar-assisted AC system saves and reduces approximately 37% of energy and demand load, respectively. Its matches with specification references as provided by the manufacturer (Vakiloroaya, 2012). This reduction in the load indicates that the application of the DSM programme using thermal technologies in countries that export petroleum products is viable given that they have solar energy in abundance.

4.6 Uncertainty Analysis on the Experimental Data

Uncertainty can be considered a property of the system. It describes the human error in reading the values. Various studies conducted on this topic have identified types of uncertainty and a variety of theories. The state of uncertainty creates positive and negative deviations from expected results. Uncertainty types are the following:

1. External uncertainty: Environmental factors are the most important sources of error. Sudden wind, cloud cover, and shaking are all factors that cause an error test, and are known as external errors. The skill and knowledge of the experimenter can reduce this error.
2. Random uncertainty: The usual source and the most significant reason for this error are random error sources. There is a random error in each experiment. Error factors are generally divided into random and systematic variables.

The energy consumptions by a solar-assisted A/C and conventional A/C were recorded by a data logger; the calculation sample of the deviations is presented in Appendix. The general formula for calculating the average value of energy consumption E_{AV} (sometimes also called mean value) (Holman, 2011) is as follows:

$$E_{AV} = \frac{1}{n}(E_1 + E_2 + E_3 + \ldots + E_n) \,. \qquad (20)$$

where n is the number of repeated measurements (for this study n = 435278 per each A/C device). The average value of the energy measurement for the solar-assisted A/C and the values of the deviation from the average value are used to calculate the experimental error. The quantity that is used to estimate these deviations is known as the standard deviation of energy consumption S_E and is defined as (Holman, 2011)

$$S_E = \sqrt{\frac{1}{n-1}\left[(E_1 + E_{AV})^2 + (E_2 + E_{AV})^2 + (E_3 + E_{AV})^2 + \cdots + (E_n + E_{AV})^2\right]} \qquad (21)$$

where the standard deviation squared is the sum of squares of deviations from the average value divided by (n - 1). The subscript usually indicates the quantity that the standard deviation is calculated for, e.g., S_E stands for the standard deviation of energy measurements. We use the standard deviation as the value of the experimental error. The final result of measurements and error analysis shown in Table 4.2:

Table 4.2: Uncertainty Analysis Results

Type of Devices	E_{AV} (kWh)	S_E (kWh)	General format of Uncertainty result	Error
Solar-assisted A/C	0.0010962	0.000059	0.0010962 ± 0.000059 (kWh)	0.054
Ordinary A/C	0.0017352	0.000084	0.0017352 ± 0.000084 (kWh)	0.048

From the above results of experimental uncertainty, we noted that an uncertainty analysis may aid us in selecting alternative methods to measure a particular experimental variable. It may also indicate how one may improve the overall accuracy of a measurement by focusing on certain critical variables in the measurement process.

4.7 DSM Programme Developments for Erbil

4.7.1 Energy Brief

Erbil city is the capital city of the Kurdistan Region in Iraq (KRI). With an estimated population of 2.01 million people, the city contains 525,000 households and 60,000 commercial consumers (MOEl, 2018; KRSO, 2016). Assuming every commercial building has five rooms (MOEL, 2018), then the total number of offices would be 300,000.

Currently, 872 MW of electricity is generated, while the peak demand for electricity surpasses 2,000 MW, with the demand showing a constant upward trend, as illustrated in Figure 4.10. Additionally, the capacity of the power distribution is limited. This is associated with intermittent electricity supply as well as service. (MOEl, 2018) reported that there is a daily blackout of electricity for more than 10 h. Because of this, commercial offices, shops, and other consumers had to seek private sources of power, such as generators, to power their buildings during business hours.

The flow of refugees to Erbil province caused by uprisings, internal disputes, and the security problems in Syria and other cities of Iraq led to an increase in the population of the province. Furthermore, the electricity utilities are always fighting against illegal connections of electricity. The reasons above have led to an increase in the peak demand of electricity within the last decade (Figure 4.10).

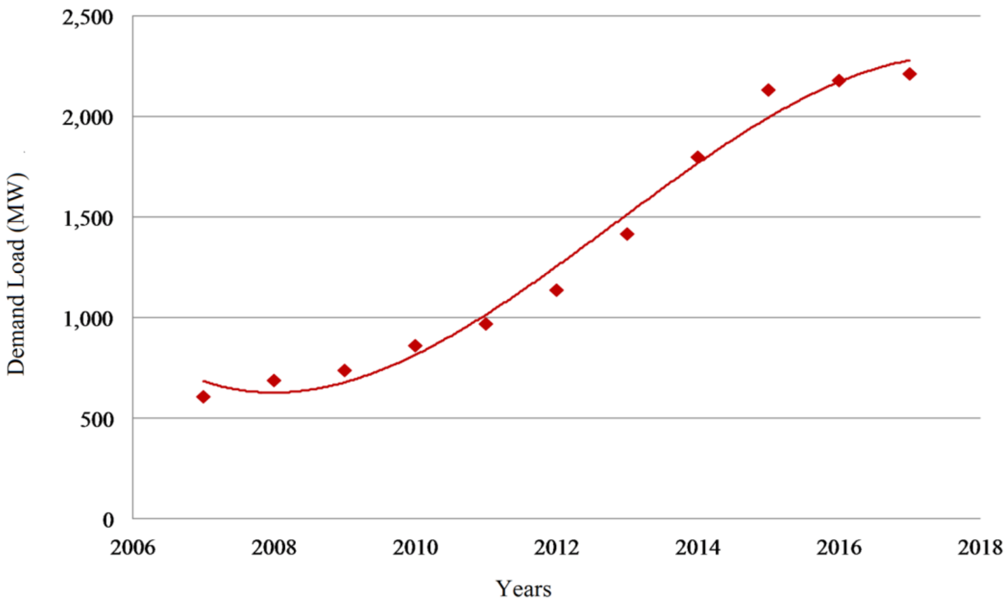


Figure 4.10: Trend of Growing Demand Load in Erbil Province, (MOEl, 2018)

The key to development in the power sector is controlling the increasing demand for electricity. The ordinary air conditioning system used by the commercial sector makes use of compression technology that is driven by electrical systems. These A/C systems have a high electrical energy consumption given that the city of Erbil has a hot climate in summer. The needed comfort is provided by these A/C systems. The high usage of these A/C systems translates into high electricity bills and impacts the environment because of the technology that theyuse.

With the price of oil now at half the price four years ago, a significant effect on saving a lot of electrical energy is realised through the application of DSM programme.

4.7.2 Climate Brief

There are four variations of climate in Erbil, with a temperature difference of 30 ℃ between winter time and summer time.

The daily DNI is approximately 5.94 kWh/m^2 (Table 4.3) (NASA, 2018); furthermore, annually, 71% of the days are sunny (obtained from statistical data recorded for eight years). The Erbil climate is suitable for thermal driven technologies (World Weather Online, 2018) (Statista, 2018).

Table 4.3: Direct Normal Irradiation and Percentage of Sunny Days per Month of Erbil Province, (NASA, 2018)

Months	Percentage of Sunny Days per month	Direct Normal Irradiation (kWh/m2/day)
Jan	55%	3.91
Feb	59%	4.31
Mar	47%	5.17
Apr	54%	5.54
May	56%	6.92
Jun	90%	8.61
Jul	96%	8.23
Aug	98%	7.79
Sep	92%	7.25
Oct	67%	5.4
Nov	69%	4.45
Dec	67%	3.68
Average value of DNI	71%	5.94

4.8 Assessment of the Proposed DSM Programme

From the experimental results, the annual electrical energy consumption of the ordinary A/C and solar-assisted A/C were approximately 4,964 kWh and 3,416 kWh respectively. The cost per kWh of the electricity for the commercial sector is

US$0.11/kWh; thus the annual running cost of an ordinary A/C will be US$546 (4,964 kWh x US$0.11/kWh). However, the cost of a brand new ordinary A/C is approximately US$450. On the other hand, a brand new solar-assisted A/C costs approximately US$710, but the annual running cost will be US$376 (3,416 kWh x US$0.11/kWh). Replacing an ordinary AC system with a solar-assisted A/C system would translate into annual savings of up to 1,548 kWh (4,964 kWh/year − 3,416 kWh/year = 1,548 kWh/year) from the customer side as it is equivalent to 2,580 kWh from the utility-side with a 40% of grid loss consideration. The replacement of each A/C leads to reductions of approximately 1.46 kW from 9 am to 6 pm ([1,548 kWh/year x 1.67 loss factor] / [9 hrs x 197 days/year]). These savings translate to approximately US$170 per year per A/C unit (US$546−US$376).

A DSM programme that utilizes solar-assisted A/Cs installed in 100,000 commercial offices and shops would translate to a reduction of electricity consumption for approximately 37%, as shown in Figure 4.9. This is a key step in reducing and postponing the number of power plants to be constructed for at least 10 years. This is a wise and highly effective method for assisting the government in overcoming the current financial challenges facing the country. In light of the foregoing, the electricity utility could make an invest of US$80 million ([US$710/unit cost + US$75/unit shipping + 15 US$/unit installation] x 100,000 units) (Table 4.5), and achieve a power load reduction of approximately 87 MW from the customer side, which needs at least of 146 MW ([1,548 kWh x 10^2 x 1.67 loss factor] / [9 hrs x 197 days/year]) of power plant generation from the utility side. In comparison, a gas turbine plant with a capacity of 146 MW costs approximately US$231 million

([US$1,100,000/MW x 146 MW] plant capital cost + [US$0.0175/MW/year x 146 MW X 10 years] fixed O&M + [US$3.5/MWh/year x 146 MW x 8760 h x 10 years]

variable O&M) (Table 4.4) (EIA, 2013). In other words, using solar-assisted A/C systems means that the utility would be 146 MW power plant costing US$80 million if the office replaces its A/C systems, translating into savings of US$17 million annually (US$170 x 100,000 offices).

Table 4.4: Power Plant Cost, (EIA, 2013)

Suitable Power Plant Type	Plant Capacity (MW)	Capital Cost (US$ million)	Fixed and Variable O&M Cost for 10-yrs (US$ million)	Total Cost (US$ million)
Gas Turbine (CT)	146	161	70	231

Table 4.5: Analysis of Proposed DSM for Erbil

DSM Programme	Cost/ AC-unit plus rebate (US$)	Total DSM cost (US$ million)	Peak load reduction (MW)	NPV (US$ million-10yrs)
Replace ordinary air conditioner with solar-assisted air conditioner for 100,000 units	800	80	146	370

With the demand for electricity in Erbil rising, the electric utility is overwhelmed and does not have the capacity to meet this demand. Therefore, there is need to construct new power plants. However, the application of DSM provides the utility company with an option of deferring the construction of the new power plants for several years. The net present value NPV of the programme is approximately US$370 million for ten years. With implementation of the DSM programme by utilizing solar-assisted A/Cs, the energy saving would be purely on the consumer-side;

the electricity network in Erbil experiences technical and non-technical grid losses amounting to 40% (MOEL, 2018). This indicates that the load reduction results on the demand side will be equivalent to the demand load reduction plus the grid loss, as per the following formula:

$$L_{demand-side} = L_{Power\ Generation} - L_{Grid-loss} \tag{22}$$

$L_{demand-side}$ = Load reduction from demand side "Customer-side" (MW)

$L_{Power\ Generation}$ = Total Power Plant electricity Generation "Utility-side" (MW)

$L_{Grid-loss}$ = Electricity Power Losses from T&D network " (MW)

The result of load reduction on the demand side is approximately 87 MW and the grid losses are 40% (MOEL, 2018), giving 146 MW as the power plant generation capacity that will be deferred. Additionally, the fall in the prices of oil has seen the government face economic hardships. The demand for electricity in the last 10 years, according to the Ministry of Electricity, has risen by an average of 12.3% per year, as shown in Figure 4.10 (Electricity, 2017). The following formula can be used to estimate the future peak demand L_f (Atikol et al., 1999):

$$L_f = (1 + X)^Y \times L_C \tag{23}$$

where, L_C = current peak load (MW)

Y = number of years

X = rate of growth of peak

In 2017, the peak demand load was 2,218 MW. Using an increase in the demand rate of 12.3%, the peak demand load in 10 years would be approximately 7,000 MW. Additionally, the DSM programme should be highly encouraged as it contributes to energy efficiency. Its application today or in the future would help to reduce the rise in electricity demand and, therefore, significantly impact the infrastructure and the economy of the country (Saffari et al., 2018). The inability of the utility to meet the current demand for electricity raises the question of how it will meet and satisfy the increase in demand in the future.

4.9 Remark on Model Development and Analysis

In this study, a DSM programme making use of solar thermal technologies is proposed for petrol exporting countries as a solution to the rising demand of electricity. These countries have an abundance of solar energy, and therefore, they could use these technologies to address rising demand challenges. In turn, they could export their fossil fuels to increase revenues for their countries. This study proposes offering solar-assisted air conditioners to commercial building at no cost. The results can then be utilized in developing a DSM programme and evaluating opportunities that will allow the deferment of plans for the construction of new power plants.

Applying the results of this study to the Erbil case, it can be summed that the application of DSM as a new plan to mitigate the rising electricity demand using solar-assisted air conditioners can lead to deferment of plans to construct a new power plant with a capacity of 146 MW at a cost of US$231 million and a net present value NPV of approximately US$370 million for 10 years; the cost for putting a DSM plan in place is US$80 million. Furthermore, the programme allows consumers to reduce their annual consumption of electrical energy as well as energy bills by approximately 37% and US$170 per unit, respectively.

Chapter 5

AVOIDING SUBSIDIZED ELECTRICITY BY MEANS OF DSM: A WAY TO A SUSTAINABLE POWER SYSTEM

5.1 Overview

The methodological approaches described in Chapters 3 and 4 are developed to solve the distinctive problems in the energy price policies of the oil producing countries in the region of MENA. Some of these countries subsidize the prices of particular products, typically fuels, electricity, and food. As per estimation from the (IMF, 2018), pretax energy subsidies in the region equal to 48 percent of global subsidies, 8.6 percent of regional GDP, or 22 percent of their government revenue, as shown in Table 5.1.

Table 5.1: Global Pretax Energy Subsidies by Region, (IMF, 2011)

Regions	Amount of subsidy (U$D)	In % of GDP
Sub-Saharan Africa	19,300,000,000	1.6
Advanced Economies	25,400,000,000	0.1
Central and Eastern Europe and Commonwealth of Independent States	72,100,000,000	1.7
Emerging and Developing Asia	2,300,000,000	0.9
Latin America and Caribbean	36,200,000,000	0.6
Middle East and North Africa	236,500,000,000	8.6

When the oil prices dropped in 2014, the oil producing countries were exposed to a tightening global financing situation and ongoing global economic distress. At the same time, a more challenging global environment, with tighter global financial conditions, rising trade, and geopolitical tensions, underlined the need for oil producing countries to speed up their reforms. Although they have varying economic stances, all the MENA oil producing countries confront similar fiscal challenges, and because of their high dependence on oil revenue and the high contribution of oil to GDP growth, as shown in Table 5.2 (IMF, 2018), there is an incentive for MENA oil producing countries to remodel the energy subsidy structure. Furthermore, there is an urgent need to accelerate the diversification of their economies away from oil and promote a dynamic private sector. This can be achieved by investing in technologies that promote renewable energy to reform their energy policy plan. With oil prices expected to decline in the medium term, there is no room for complacency.

Table 5.2: Oil Revenue Contribution in Percentage of GDP Growth, (IMF, 2018)

Oil producing countries	2018		2019	
	Oil contribution	Non-oil contribution	Oil contribution	Non-oil contribution
Qatar	2.8	2.1	3.2	2.2
UAE	3.2	2	3.9	2.8
Kuwait	2.7	1.7	4.3	1.7
Bahrain	3.5	0	2.8	0
KSA	3	1.1	3.2	1
Oman	2	1.2	5.3	1.3
Iran	-1.8	0.2	-3.8	-1
Iraq	2	0	6.8	2
Algeria	3	0	3.2	2.1

It is essential to approach the problem from two aspects: economic and environmental sustainability. The present energy rates in these countries cannot be sustained. For this reason, the power system should be made more efficient or renewable energy systems should be adopted as a more realistic energy-rate structure is deployed. It should be noted that global warming and climate change issues have led to an increased amount of drought, floods, extreme heat, and poverty. The United Nations warns that the world has 12 years to limit a climate change catastrophe if it does not act appropriately (Rhodes, 2019). Therefore, any solution to the energy problem in these countries should also include clean energy sources, such as solar, hydro, wind, or ocean energy.

In the MENA region’s oil producing countries, the energy subsidy has been historically developed as an essential component of an unwritten social contract (to share the countries' wealth with their citizens). Consequently, the low price of conventional fuels, such as diesel, natural gas, and fuel oil, has contributed to the low electricity price. It has driven various issues that have been noted in the electricity network, extensive power consumption, and a massive expenditure of the countries budget. For instance, studies have shown that a great majority of the electric feeders, power substations, and transmission lines are overloaded. The overloaded power lines cause a drop in voltage, leading to electricity shortages. The utility is unable to distribute electricity in equal rations to all its customers, and there are delays in the repair and maintenance of the electric system owing to a multitude of obstacles and overload problems.

5.2 DSM Approach

It was observed that, recently, tighter global financial conditions have forced some of these countries to make reforms in their electricity policies. It is not sustainable to keep on subsidizing electricity sales as the demand is growing fast and there are not enough funds to purchase new power units and improve the transmission and distribution infrastructure. Under these circumstances, it seems that reducing the demand may work out to be better for the utilities. DSM can be a tool for simultaneously reducing the demand while potentially opening doors for cleaner and more sustainable energy solutions.

The proposed approach involves selecting renewable energy technologies and assessing their techno-economic feasibility to design DSM programmes for reforming the electricity subsidy policies. An assessment is carried out in order to examine the components and magnitude of the subsidies given by the government to keep electricity prices low. The results reveal that the environmental benefits are global common benefits. The goal is to develop a DSM programme where clean energy technologies such as SWHs, solar-assisted air-conditioning systems, etc. are promoted. This would lead to peak clipping during the maximum peak hours, not only deferring the need for additional power units but also saving the utility or the government from spending money on the subsidies. In this way, it is possible to design a reform plan to reduce or eliminate subsidies.

An economic feasibility analysis was conducted to evaluate the practicability of the programme from the utility or government point of view using *NPV*, a good economic indicator of a project's feasibility, as the benchmark. The subsidy reform plan was revised until an economically viable DSM programme was achieved as shown in Figure 5.1.

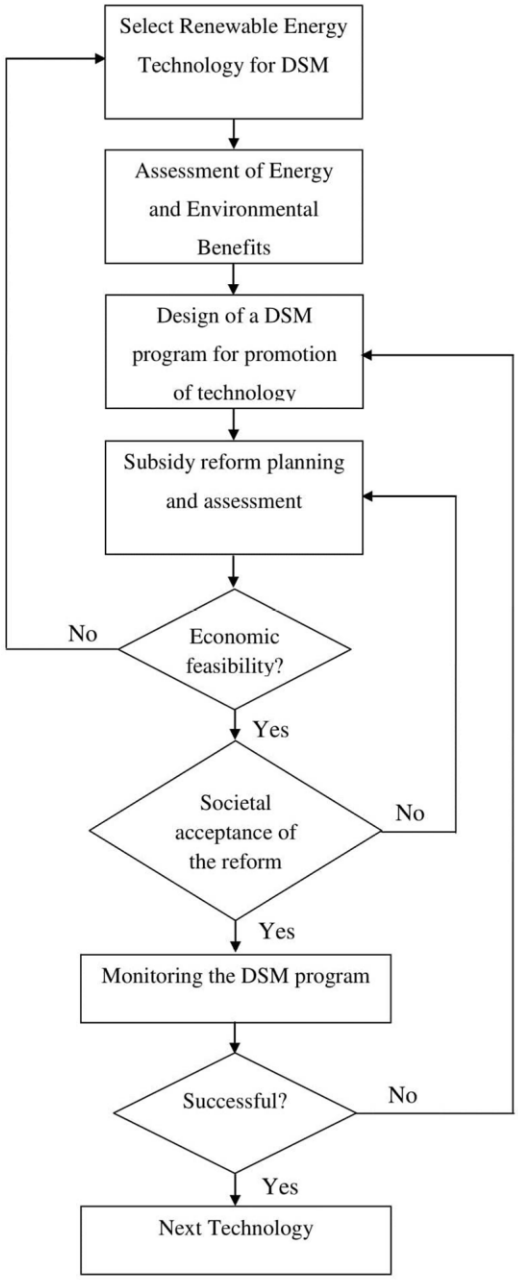


Figure 5.1: Methodology Approach

5.3 Strategy for Sustainable Demand-side Planning

To design a successful DSM programmes to re-structure the reform policies, it is essential to take into account the following factors:

a) The DSM programmes should be economically feasible. The investments made for the DSM programmes should be less than the current expenditures for the electric power capacity considered.

$$NPV = \sum \underbrace{PV_{saving}}_{\substack{Avoided\ Generation\ Capital \\ +\ Avoided\ Generation\ O\&M \\ +\ Avoided\ T\&D\ Capital \\ +\ Avoided\ T\&D\ O\&M \\ +\ Avoided\ Fuel\ Cost}} - \sum \underbrace{PV_{investment}}_{\substack{Rebate\ OR\ Purchasing\ Cost_{technology} \\ +\ Program\ Administrative\ Costs}} + \underbrace{\left\{PV_{recover\ subsidy\ value}\right\}}_{Pretax\ Subsidy\ OR\ Posttax\ Subsidy} \qquad (24)$$

where $\Sigma\ PV_{saving}$ are the total programme savings, $\Sigma\ PV_{investment}$ represents the total programme investment with rebates, and $\Sigma\ PV_{reCovery\ subsidy\ value}$ is the recovery amount that should be paid for the subsidy policy, which is only available in the countries where the electricity sale price is under the cost price. Expression (24) is the general formula that will be used to determine the NPV of the DSM programmes in those countries where the price of electricity is highly subsidized.

b) Transition to a more sustainable energy system should be sought. This requires continued supply of clean energy to the consumers. Therefore, it is essential to assess the availability of renewable energy sources. The region in which MENA countries lie is rich in solar energy and in some areas there is enough wind to run wind turbines. The presence of oil blocks suggests that geothermal power could also be available.

According to the International Energy Outlook (2018) provided by the United States (EIA, 2018) and (Capuano, 2018), the exploration of renewable energy in any country provides various benefits, including future supply security and improvement in the economic value chain by providing energy free from import dependencies and creating technologically advanced jobs. Renewable energy also provides environmental benefits through reduced greenhouse gas emissions.

Realizing maximum benefits from renewable energy implies taking advantage of the geographical features of a country (Menichetti et al., 2019) and (Arcia-Garibaldi et al., 2018). For many of the oil producing countries, longer sun-hours are achieved compared to European countries, which use solar energy with low sun-hours. Renewable energy in these countries offers flexible benefits that match those of fossil fuels and can, therefore, be used to meet both base and peak loads. Solar energy peak production coincides with the peak demand for these countries during the summer, which also witnesses high utilization of air conditioners.

The financial impact of renewable energy technologies, such as solar energy, is high for MENA countries just like other countries and is dependent on the volume of renewable energy investment in the region. However, globally, the cost of renewable energy is falling and therefore the financial aspect of investment in renewable energy in the region is expected to go down in the future. One benefit of the use of renewable energy technology is arises the abundance of country's capital; sustainable subsidy policy would play a crucial role in promoting the adoption of renewable energy technologies.

Solar and wind energy, as well as hydroelectric projects, can support the country's energy requirements, especially in rural areas, which costly electricity expansion networks cannot easily reach. Investment in this area might also create new jobs and income opportunities.

c) Campaigns should be conducted to explain to consumers the benefits of DSM programmes and new policies. The objective is to establish social acceptance of new technologies that are introduced. According to (Arab Barometer, 2014), several challenges face the process of reforming the subsidy programme and replacing it with environmentally and economically sustainable programmes. In the short run, subsidy elimination will lead to inflation, which will affect the competitiveness of the industries that depend on subsidized products and services as their inputs. However, in the medium term, positive effects will be attained by eliminating distortions, increasing oil export revenues, rationalizing energy utilization, increasing the competitiveness of the industry, and ultimately strengthening the country's budget.

The removal of the subsidy programme will probably face the biggest challenge from those benefiting from it (IMF, 2013b). The beneficiary of the subsidy would like the status quo to be maintained for them to continue reaping its benefits. The loser of the subsidy as a result of the reform can express their resistance using a small but well-organized group.

These challenges can be addressed using properly defined elements of the reform. In particular, transparent information on the cost of the subsidy and how the reform will provide advantages to all the beneficiaries should be provided.

There are several common features of successful subsidy reforms. Successful reforms are those that deliver better support to citizens while ensuring that significant and durable or quasi-fiscal savings are achieved. Although there is no one-size fits all approach to subsidy reforms, a study on subsidy reforms involving various countries found that the political, social, and economic conditions of a country should be considered first, and this means that the reform strategies should be tailored to the individual situation of a country. Several factors were identified by the study as crucial for successful implementation:

- The reform should have comprehensive, detailed, and careful planning and diagnostics that clearly set out the breadth and pace of the reform. The role of the various stakeholders, including international donors who offer assistance in designing, sequencing, and implementation, should be clearly defined.
- The government should also demonstrate strong ownership and commitment to the reform project. Commitment can be attained through achieving a consensus regarding the reform by calling for the involvement of various stakeholders such as the private sector, civil society, and political parties, as well as clearly conveying the cost of the subsidy, its beneficiaries, and the benefits that the reform will bring.
- For multiparty governments, consensus building for reforms through the involvement of various parties increases the likelihood that the project will succeed and not be reversed in the future.

The implementation of reforms in other areas (World Bank, 2017b) shows that parallel or advance measures can be implemented before the launching of a comprehensive reform as a way of preparing the ground for future action. In particular, the government can provide data on the costs and benefits of the subsidies as well as how the energy consumption will shift in the future and its impact on the country's stability. The success of previous reforms has been shown to hinge on thorough preparation, the building of a consensus, and the implementation of well-designed programmes. Therefore, there is a need for the government to start acting early and engaging stakeholders as a way of preparing for successful and long-lasting reforms.

5.4 Applicability in Different MENA Countries

The MENA area covers approximately 22 countries located in the Middle East and North Africa. Approximately 6% of the world's population, 60% of the world's oil reserves, and 40% of the world's natural gas reserves are all located in this region (IMF, 2014d). In terms of economic activities, the remarkable reserves of petroleum and natural gas found in the region have made the MENA countries an essential global source of stability.

Most of the countries that make up the nations of OPEC, which are 12 in number, are part of the MENA region. The region characteristically includes the nations spanning the area from Morocco, which is located in Africa's northwest region, to southwest Asia, where the country of Iran is located, and going down the African continent to Sudan, although no standard list of the countries that belong to the MENA region exists.

The diversity of the MENA region means that there is the possibility of it becoming segmented in several different ways. (BrIEf, 2013) classified the MENA countries into three categories based on oil resources and economic size. In the present thesis, the same categories are used but with additional macro indications that are related to the electric power sector, such as the quality of the electricity infrastructure system, the size of the pre-tax subsidy, power installation capacity, and energy consumption. MENA countries, on the basis of those factors, are capable of being categorized into three major groups as shown in Figure 5.2:

A. Oil exporting counties (Gulf Cooperation Council countries GCC "Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates")
B. Developing oil-producing countries (Algeria, Iran, Iraq, Syria, Libya and Yemen)
C. Oil-importing countries (Egypt, Morocco, Tunisia, Jordan, Israel and Lebanon)

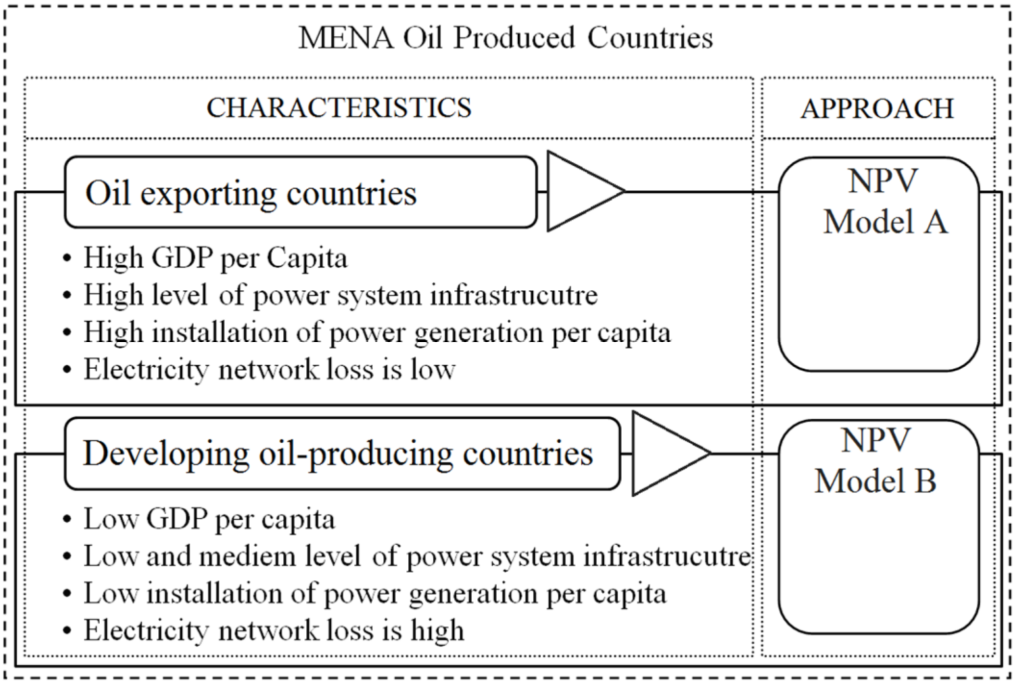


Figure 5.2: Level of Macroeconomic Indications

Our focus here is on the sub-groups of A and B, as they make major contributions in the MENA region to producing and exporting oil. It was expected that growth would increase by 3% and 3.2% in 2018 and 2019, respectively, on the assumption that there is geopolitical tension moderation and a modest increase in the price of oil

(Arab Monetary Fund, CGAP, 2017a). Table 5.3 demonstrates the macroeconomic indications of the oil rich countries (export more than one million bbl per day) in the MENA region. It shows the average amount of exported crude oil per day is approximately 330 barrels per day per a thousand people, and the average GDP per capita is approximately US$21,000.

It is anticipated that oil exporting counties (GCC economies) will lead the stronger growth in the region, with a GDP rate per capita of approximately US$32,000. This is backed by the easing of fiscal adjustments and investment in infrastructure in the power sector, where the electricity network loss per output is approximately 7.7, as it is a good indication of the electricity grid quality. Furthermore, they commenced reforms to promote activities in the non-oil sector to diversify the countries' income. The forecast is that oil exporting counties will, as a group, witness a growth of up 2% in 2019 from 0.7% in 2018.

The power installation per capita in developing oil producing countries is nearly half capacity compared to that of oil exporting counties as the GDP rate per capita is approximately US$5,000 and the exported crude oil is approximately 90 bbl per day per thousand people. However, they have low and bad quality electricity infrastructure, and the electricity loss between the supply side and demand side is approximately 35% of the output power generation. The Islamic Republic of Iran, which boasts of having the largest economy and the best electricity infrastructure among the developing oil producing countries, anticipated a growth increase of 4% in 2018. A more expansionary fiscal stance is taking place in Algeria compared to what was planned previously, and there is expectation that this will help increase growth in the short term. It is expected that the activities of Iraq will lead to improvement in the midst of additional favourable security conditions.

Table 5.3: Macroeconomic Indicators in MENA Oil Produced Countries, (World Bank database, 2019)

Categorized MENA oil producing countries	Name of Countries	Installed generating capacity (kW per capita per year)	GDP per capita per year (current US$)	Electric T&D losses (% of output)	Electric energy consumption (kWh per capita per year)	Crude oil Exports bbl per capita per day	Pre-Tax energy subsidy (in percentage of GDP)
Oil exporting counties	Qatar	2.80	63,249	6.1	15,309	0.632	3.7
	UAE	2.75	40,699	6.8	11,263	0.254	5.8
	Kuwait	4.24	29,040	11.7	15,213	0.466	7.4
	Bahrain	2.53	23,655	3.9	19,592	0.116	8.0
	KSA	1.80	20,849	6.8	9,444	0.248	10.0
	Oman	1.52	15,668	10.9	6,553	0.252	6.1
	Average (A)	2.61	32,193	7.71	12,895	0.33	6.83
Developing oil-producing countries	Libya	1.12	5,978	69.7	1,857	0.228	8.9
	Iran	0.83	5,594	12.6	2,986	0.032	12.8
	Iraq	0.31	5,018	40.6	1,306	0.080	11.6
	Algeria	0.31	4,055	17.1	1,356	0.030	10.8
	Average (B)	0.64	5,161	35.01	1,876	0.09	11.03
Average		1.82	21,380	18.63	8,487	0.23	8.51

The electricity industry is one particular industry that bears all the responsibility for the high pollution level experienced in that region. While the population and GDP MENA countries has grown at a yearly average rate of 2.4% and 5.5%, respectively, between 1981 and 2014 (IMF, 2013d), the power plant installation is approximately 2 kW per capita, and its production of electricity has expanded at a yearly average rate of 7.2%, thereby outperforming all the other regions such as East Asia at 6.2% and Latin America at 4.5% on average.

This fast rise in electricity production has resulted in a significant environmental challenge that MENA countries have to grapple with as fossil fuels power 96% of their installed electricity capacities (Boughanmi & Khan, 2018) and the electricity sector in MENA countries is one of the world's least environmentally friendly.

The diversity of macroeconomic factors between the oil exporting (Model A) and the developing oil producing countries (Model B) in the MENA region has led to differences in the proposed method of utilizing the DSM as a tool to restructure the subsidy policies. The differences between these two categories of MENA countries would be due to the variety of fuels used, the quality of the electricity networks, the dependency on conventional power plants, and the variations in pre-tax subsidy policies.

It would not be surprising to obtain different results in feasibility analyses for the same DSM programme with different infrastructures and subsidy policies. As stated in Table 5.4, the quality of the electricity infrastructure, the percentages of the subsidy, and the fuel used to power the generation units significantly affect the economic feasibility of a DSM programme, which is expressed in terms of the NPV. For example, the losses in the grid systems for oil exporting and developing oil producing countries are 8% and 35%, respectively. A DSM program would be expected to have less economic feasibility in oil exporting countries (Model A) as they have a better electricity network with less power losses. Similarly, the feasibility is also affected by the amount of subsidy recovery, which is designed differently in the two groups of MENA countries. The pre-tax subsidy is applied commonly to selected goods in the MENA region at a rate of more than 8.5% of their GDP. The feasibility of the DSM programmes is likely to be greater in the developing oil-producing countries (Model B) as their electricity subsidy is on average 11.03%, while that of oil exporting countries is on average 6.83% of their GDP.

Table 5.4: NPV Formula for Model A and Model B

Models	NPV formula
Model A	$NPV = \underbrace{\sum PV_{saving}}_{\substack{\text{Avoided Generation Capital \{High\}} \\ + \text{ Avoided Generation O\&M \{High\}} \\ + \text{ Avoided T\&D Capital \{N/A\}} \\ + \text{ Avoided T\&D O\&M \{N/A\}} \\ + \text{ Avoided Fuel Cost \{High\}}}} - \underbrace{\sum PV_{investment}}_{\{High\}} + \underbrace{\{PV_{recover\ subsidy\ value}\}}_{\{Low\}}$
Model B	$NPV = \underbrace{\sum PV_{saving}}_{\substack{\text{Avoided Generation Capital \{Low\}} \\ + \text{ Avoided Generation O\&M \{Low\}} \\ + \text{ Avoided T\&D Capital \{High\}} \\ + \text{ Avoided T\&D O\&M \{High\}} \\ + \text{ Avoided Fuel Cost \{Low\}}}} - \underbrace{\sum PV_{investment}}_{\{Low\}} + \underbrace{\{PV_{recover\ subsidy\ value}\}}_{\{High\}}$

Based on the macroeconomic indicators mentioned in Table 5.3, there may be adjustments in the proposed approach described in the previous section. Because oil exporting countries have a strong economy and very good quality power systems, the

DSM programme can be designed accordingly (Table 5.4). The oil exporting counties (Model A) do not face difficulties with the budget deficit, electricity blackout, and the quality of power system, which would allow them to refine the subsidy system for promoting renewable energy sources on both the demand and supply side. In contrast, the developing oil producing countries (Model B) have blackouts, low quality electricity systems, and a fiscal deficit that is required to bring about a different approach which promotes renewable energy. Consequently, reforming the subsidy to minimize the budget deficit and improve the electricity network would decrease the electric power losses.

Chapter 6

CONCLUSION

In the present thesis, a DSM programme based on solar thermal technology is proposed for oil-producing countries in the MENA region to meet the rising electricity demand. The electricity sectors in these countries are characterized by policies that provide high electricity subsidies. As solar energy is abundant in these countries, solar thermal technology could be employed to address the challenges these countries face owing to the rising electricity demand; in turn, the countries could export their fossil fuels to increase revenues for their countries. This research was conducted to investigate different solutions for high-subsidy systems, which were then compared with those obtained from conventional reform systems. Following the proposed policy, a new subsidy will be rolled out and will entail providing solar thermal devices to commercial and residential electricity subscribers at no cost to consumers in oil-producing MENA countries. These MENA countries are categorized into two groups based on a few macroeconomic indicators: oil exporting countries and developing oil-producing countries. An alternative DSM programme has been proposed because of the diversity of macroeconomic factors—the economy of oil exporting countries is stronger and more stable than that of developing oil-producing countries. Owing to this difference, an alternative solution and a DSM programme were proposed to refine the economy of the country and promote renewable energy as an alternative source of energy to replace the use of fossil fuels as a long-term strategic plan. Simultaneously, electrical power systems in developing oil-producing countries face problems such as fiscal deficit and low quality; therefore, this research proposes a DSM program that can address the challenges that hinder the economic developments of these countries. This solution is also aimed at addressing the problems these countries face in terms of power blackouts and high expenditure to meet the high pre-tax subsidy.

The following conclusions can be drawn from this study, which was conducted in Erbil province as a case study for developing oil-producing countries:

1. Utilizing SWH systems: The study proposed that SWHs be supplied and installed at no cost to replace the conventional electrical water heaters as part of a demand-side management program in residences in Erbil. By immediately investing US$1, the utility will gain approximately US$9.6 by the end of the program. Furthermore, the program provides the utility with an opportunity to save US$867 million, including the recovery of subsidy costs and costs associated with the construction of 54 MW worth of new power units, which can be deferred for a minimum of ten years by investing US$90 million. In addition, the NPV for the program duration of 10 years is approximately US$777 million.
2. Utilizing solar-assisted air conditioning systems (solar-assisted A/C split unit): The study investigated the feasibility of designing a utility DSM program that involved installing a solar-assisted air conditioner in an office in Erbil. The performance of the solar-assisted air conditioner was compared with that of the ordinary air conditioner. The implementation of the proposed DSM program could result in the deferment of future plans to construct a new power plant at the cost of US$138 million for a minimum of 10 years. This cost excludes fuel consumption and running costs during the period of the program. A total of US$80 million has been invested in the entire

program, which allows consumers to reduce their annual energy consumption and electrical bill by approximately 37% and US$170 per unit, respectively.

The results indicate that the development of DSM programs using solar thermal technology will mitigate the rising electricity demand and costs. The extensive use of solar technologies can lead to deferment of the construction of a new power plant as well as eliminate the O&M and fuel consumption associated with running a power plant.

Two NPV models that represent a different policy approach (Model A and Model B designs for oil exporter and oil developing countries, respectively) have been developed. Furthermore, the implementation of such a policy in both oil exporting and developing oil-producing countries will help consumers reduce their monthly bills. The proposed policy will serve both utilities and consumers better eventually in the future. Simultaneously, it will play a significant role in promoting the adoption of renewable energy technology in MENA countries that have abundant solar energy throughout the year; furthermore, it is environmentally beneficial as it releases less CO_2 into the atmosphere.

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APPENDIX

Sample of measured data and Uncertainty calculation

Date	Time	Solar-assisted A/C			Ordinary A/C		
		E_n Energy (kWh)	(E_n-E_{AV})	$(E_n-E_{AV})^2$	E_n Energy (kWh)	(E_n-E_{AV})	$(E_n-E_{AV})^2$
10th of September 2017	9:00:02	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.70×10^{-06}	2.89×10^{-07}	8.35×10^{-14}
	9:00:04	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.40×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}
	9:00:06	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.80×10^{-06}	3.89×10^{-07}	1.51×10^{-13}
	9:00:09	5.40×10^{-06}	-1.11×10^{-07}	1.23×10^{-14}	8.30×10^{-06}	-1.11×10^{-07}	1.23×10^{-14}
	9:00:11	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.80×10^{-06}	3.89×10^{-07}	1.51×10^{-13}
	9:00:13	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	7.50×10^{-06}	-9.11×10^{-07}	8.30×10^{-13}
	9:00:15	5.70×10^{-06}	1.89×10^{-07}	3.57×10^{-14}	8.80×10^{-06}	3.89×10^{-07}	1.51×10^{-13}
	9:00:17	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.50×10^{-06}	8.89×10^{-08}	7.90×10^{-15}
	9:00:20	5.80×10^{-06}	2.89×10^{-07}	8.35×10^{-14}	8.20×10^{-06}	-2.11×10^{-07}	4.46×10^{-14}
	9:00:22	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.80×10^{-06}	3.89×10^{-07}	1.51×10^{-13}
	9:00:24	5.40×10^{-06}	-1.11×10^{-07}	1.23×10^{-14}	7.80×10^{-06}	-6.11×10^{-07}	3.73×10^{-13}
	9:00:26	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.80×10^{-06}	3.89×10^{-07}	1.51×10^{-13}
	9:00:28	6.50×10^{-06}	9.89×10^{-07}	9.78×10^{-13}	7.80×10^{-06}	-6.11×10^{-07}	3.73×10^{-13}
	9:00:30	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.80×10^{-06}	3.89×10^{-07}	1.51×10^{-13}
	9:00:33	5.20×10^{-06}	-3.11×10^{-07}	9.68×10^{-14}	8.60×10^{-06}	1.89×10^{-07}	3.57×10^{-14}
	9:00:35	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	7.80×10^{-06}	-6.11×10^{-07}	3.73×10^{-13}
	9:00:37	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.80×10^{-06}	3.89×10^{-07}	1.51×10^{-13}
	9:00:39	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.50×10^{-06}	8.89×10^{-08}	7.90×10^{-15}
	9:00:41	5.60×10^{-06}	8.89×10^{-08}	7.90×10^{-15}	8.60×10^{-06}	1.89×10^{-07}	3.57×10^{-14}
	9:00:43	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	7.90×10^{-06}	-5.11×10^{-07}	2.61×10^{-13}
	9:00:46	5.70×10^{-06}	1.89×10^{-07}	3.57×10^{-14}	8.30×10^{-06}	-1.11×10^{-07}	1.23×10^{-14}
	9:00:48	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.80×10^{-06}	3.89×10^{-07}	1.51×10^{-13}
	9:00:50	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.50×10^{-06}	8.89×10^{-08}	7.90×10^{-15}
	9:00:52	4.50×10^{-06}	-1.01×10^{-06}	1.02×10^{-12}	7.70×10^{-06}	-7.11×10^{-07}	5.06×10^{-13}
	9:00:54	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.20×10^{-06}	-2.11×10^{-07}	4.46×10^{-14}
	9:00:57	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.60×10^{-06}	1.89×10^{-07}	3.57×10^{-14}
	9:00:59	5.50×10^{-06}	-1.11×10^{-08}	1.23×10^{-16}	8.80×10^{-06}	3.89×10^{-07}	1.51×10^{-13}