Architecting the Saudi Solar Manufacturing:
Using Enterprise Architecture Framework

by

Bassel F. Alsultan
Bachelor of Science, Industrial and System Engineering 2005
Virginia Polytechnic Institute and State University, Blacksburg VA 24060

Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management
at the
Massachusetts Institute of Technology
[FEBRUARY 2013]
October 2012

10/23/2012

Author ______________________________

Bassel F. Alsultan
System Design and Management Program
October 2011

Advisor ______________________________

Dr. Donna H. Rhodes
Senior Lecturer, Engineering Systems
Principal Research Scientist, SEAri and SSRC
Director, System Engineering Advancement Research Initiative

Director ______________________________

Patrick C. Hale
Director, System Design and Management Program

This page has been left intentionally blank

بسم الله الرحمن الرحيم[1]

Dedication

I dedicate this study to my parents, brother (Bader), and sisters (Basma and Dalal), especially my mother (Samia), and my older sister (Basma), who invested a lot of time and effort during my early education years. I also dedicate this work to my sweetheart (Maram) for her continuous motivation, contribution and ideas throughout the study, and for creating the ideal environment to work. Finally, I dedicate the work to my son (Sultan), who will hopefully benefit from the results of this study.

Acknowledgments

I thank Saudi Aramco for sponsoring my masters' program and special thanks goes to Dr. Ashraf Al-Ghazzawi for his guidance, and support. Also, I would like to thank my advisor; Dr. Donna Rhodes for her guidance and encouragement through the entire process. I would also like to thank Khalid Al-Ahmed, Yahya Al-Khoshi, and Saleh Al-Agili for their feedback, contribution, and cooperation. Finally, I would like to thank MIT's professors, staff, and colleague for the great learning experience.

[1] In the name of Allah, most gracious, most merciful

This page has been left intentionally blank

Abstract

The demand for Saudi oil is increasing locally and internationally, and being one of the major oil exporters in the world, the government of Saudi Arabia needs to balance between local consumption and international demand. To address this challenge, Saudi Arabia is adopting an aggressive strategy to use solar energy instead of oil to generate electricity. This strategy creates an opportunity to diversify the country's GDP by building solar manufacturing industry.

This thesis uses the Enterprise Architecture Framework, developed by Nightingale and Rhodes, to propose the optimal architecture for the Saudi solar manufacturing in terms of organization, policy, strategy, product, services, infrastructure, and R&D. The first stage of the framework identifies the landscape and the major stakeholders in the solar manufacturing, and then studies the current situation of the Saudi solar manufacturing. The second stage analyzes the different proposed architectures. The third stage evaluates the different architectures, and the fourth stage selects and validates the winning architectures.

The evaluation criteria for the different proposed architectures are based on three angles: "Attractiveness", which measures the level of compatibility between the architecture and the needs of the Saudi government. The "Effort", measures the human and financial effort required to deploy the architecture. The "Risk", which measures the different risks associated with the architecture.

The winning architecture encourages Saudi businessmen to acquire international companies along with building local manufacturing for products in the lower end of the solar manufacturing value chain. The strategy in this architecture is to build fast capabilities in the technology and process side by acquiring international companies and steady capabilities in the production side by gradually moving up in the value chain. Also, the architecture proposes focusing and building the local R&D capabilities to improve the productivity, and profitability of the solar manufacturing companies.

This page has been left intentionally blank

Table of Content

Introduction

Motivation

Saudi Arabia's GDP has grown by almost 4% annually for the period 2003-2010 including a positive 0.1 % during the 2009 global recession[2]. During that period, the local consumption of oil has increased from 1.6 million barrels per day in 2003 to around 2.3 million barrel in 2010. This increase in local consumption is expected to increase in the coming year until the local consumption matches the total oil exports by 2026 (Bourland & Gamble, 2011) . There are three reasons for this increase in oil consumption; the first is the expected increase in Saudi population to reach 54-60 million by 2050, which represents 100%- 120% increase from the current population of 27 million (Alahmed, 2012). The second is the high energy subsidies in Saudi Arabia, which leads to more waste and lower utilization of energy in both industry and home uses. The third is the industrial expansion the country is pursuing, which also leads to increase in energy consumption.

Saudi Arabia's oil exports represent 10% of the global demand, which makes Saudi Arabia one of the major oil exporters in the world. The increase in local oil consumption affects the world, because it leads to reduction in oil exports, which creates an unbalance in the supply and demand for oil, leading to higher oil prices, hence slowing the global economy. Therefore, the government of Saudi Arabia will benefit from finding the right balance between local energy consumption to diversify the local economy and oil exports to maintain steady global development.

In 2012, King Abdullah City for Atomic and Renewable Energy (K.A.CARE) announced an aggressive solar plan for the next twenty years to produce electricity using different solar technologies. (Figure 1: Solar Energy Production for the Next 20 Years) shows that Saudi Arabia is planning to produce forty-one gigawatts of electricity, including twenty-five gigawatts from the Concentrated Solar Power (CSP) technology and sixteen gigawatts from the Photovoltaic (PV) technology (Al-Gain, 2012).

---

[2] http://www.indexmundi.com/g/g.aspx?c=sa&v=66

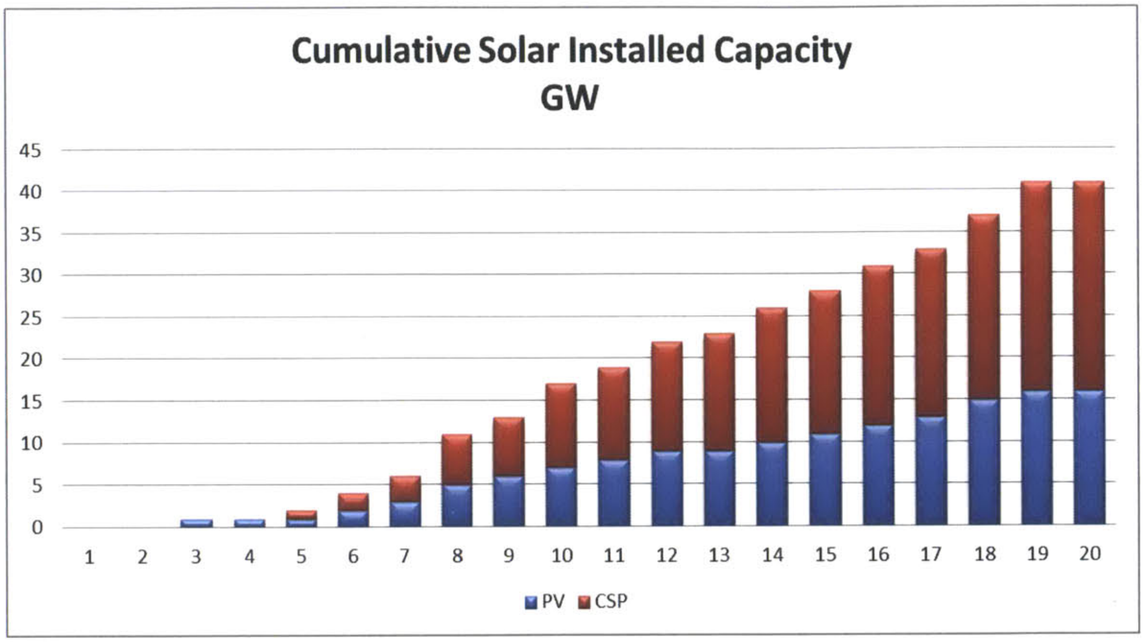


Figure 1: Solar Energy Production for the Next 20 Years

The Saudi government is also trying to establish a stronger industrial sector to increase the contribution of the sector to the Gross Domestic Product (GDP), and increase the Saudi exports of non-oil products. Currently, Saudi exports depend heavily on prime industries and resources as they contribute to almost 91.2% of the total exports of 2004 (76.2% for prime industries, and 15.6% for resources), and the remaining 8.8% is divided between low technologies, medium technologies, and high technologies industries. By comparing these numbers to world's averages (Table 1: Comparing Saudi Exports to World Average), it becomes clear that the government of Saudi Arabia needs to emphasize more on building the vertical integration for product manufacturing in order to increase the added value and capitalize on the country's competitive advantages (*Saudi national industrial strategy*2008).

Exports based on Industry Type	Saudi Arabia	World Average	Difference
Prime Industries	76.2%	12.0%	+ 64.2%
Resources	15.6%	15.9%	- 0.3%
Low Technologies	1.9%	16.7%	- 14.8%
Medium Technologies	5.7%	33.1%	- 27.4
High Technology	0.6%	22.3%	- 21.7

Table 1: Comparing Saudi Exports to World Average

The gaps between the Saudi exports and world average in both the low and medium technologies along with the K.A.CARE aggressive solar deployment creates an opportunity for the industrial sector to venture into the Solar Manufacturing. This industry is yet to mature, which creates an opportunity for Saudi manufacturing to enter the market without facing a high barrier of entry. Utterback, in his book "The Dynamic of Innovation" explains the correlation between the number of firms and the development of a dominant design. He shows that during the initial phases of a new technology, a small number of firms enter the market. With time, and initial success, the number of firms starts increasing, which helps crystalizing the dominant design. Once the dominant design appears, the number of firms starts decreasing with more companies leaving the market (Utterback, 1994).

This research studies the different architectures the Saudi Government can adopt in order to become leader in this industry. The thesis is based on the *Enterprise Architecture Framework*, developed by D. Nightingale and D. Rhodes, which leads to creating an optimal enterprise transformation strategy.

Thesis Structure

Chapter one provides background on the different solar technologies and the current solar installations around the world. After that, the chapter provides background on solar implementation to generate electricity in the kingdom of Saudi Arabia. The final part of this chapter talks about the current and future electric needs in Saudi Arabia.

Chapter two explains the Enterprise Architecture Framework, which is the framework used in this study to evaluate the different proposed architectural concept for the Saudi solar manufacturing. This chapter covers the architecting sequence model, and the ten elements model, which are the main two models in the enterprise architecture framework.

Chapter three focuses on the current situation of the solar manufacturing in Saudi Arabia. The chapter starts by understanding the solar landscape and the internal and external stakeholders. After that, the chapter details the Saudi solar as-is architecture via the different view elements.

Chapter four details and evaluates the different architectural concepts. The chapter starts by articulating the vision of the Saudi solar manufacturing, followed by creating evaluation criteria for the proposed concepts based on their attractiveness, effort, and risk. Next, the chapter introduces, and explains the different architectural proposal, and finally, the chapter evaluates those different concepts based on the evaluation criteria.

Chapter five selects the winning architectural concept, validates the concepts and ensures it is feasible and that it addresses the needs of the stakeholders, and finally, proposes an implementation plan for this architecture.

Chapter six is the conclusion for this thesis study, and it includes evaluation of the Enterprise Architecture Framework, and future studies related to Saudi solar manufacturing.

Chapter 1: Background

Background of the Solar Technologies in the World

This section briefly explains the different solar technologies, used to generate electricity, followed by statistics on the global installation of solar technologies to generate electricity.

Solar Technologies to Generate Electricity

The two main solar technologies are: the Concentrated Solar Power (CSP), and the Photovoltaic (PV). CSP technology is based on concentrating the solar energy to generate steam used to run steam turbines. There are two main ways to concentrate solar power; the first is called "Parabolic Through"; in this type, water runs in pipes positioned on top of focusing mirrors to generate steam from the water. The mirrors can rotate to follow the sun in order to increase the interaction time with the sun. The below diagram simplifies the parabolic through concept.

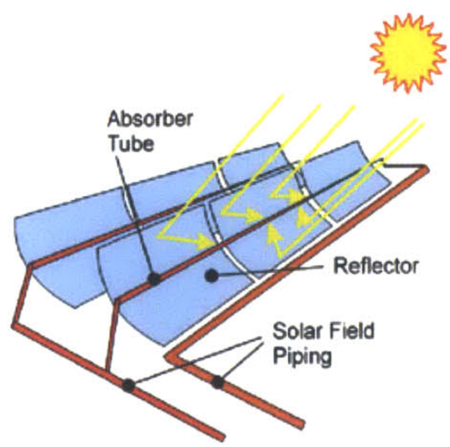
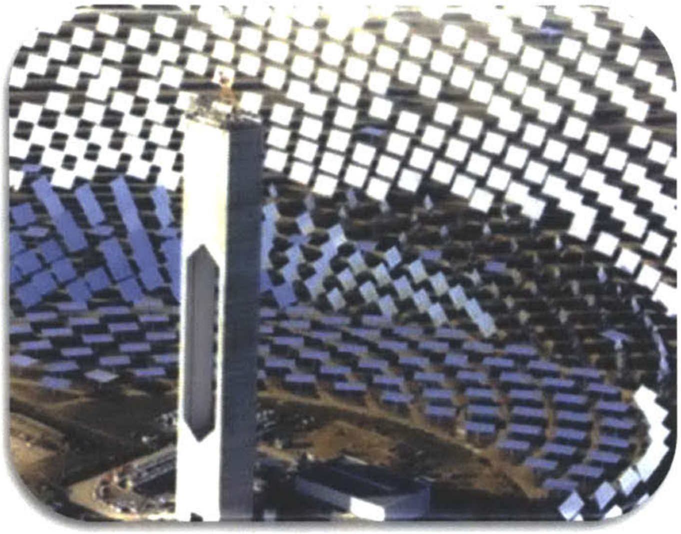


Figure 2: Sketch for CSP Parabolic Through[3]

The second way to concentrate the solar power is by using a "Power Tower System"; In this system, a large set of mirrors are used to concentrate the sunlight into a large tower. Water, which runs in this tower, get heated by the concentrated sunlight to generate steam, which is then used to operate the steam turbines. The mirrors used in this method could also be movable to increase the time and intensity of the sunlight. The below picture is for Solar Power Plant in Seville, Spain.

---

[3] http://www.nrel.gov/csp/troughnet/solar_field.html



Picture 1: Solar Power Plant[4]

The Photovoltaic (PV) technology uses a completely different technology to generate electricity than the CSP technology. While the CSP uses the solar energy to generate steam which is then used in operate steam turbines to generate electricity, the PV technology directly converts solar energy into electricity by absorbing photons from the sun. The two main solar types are: "single or multi Silicon Crystalline" and "Thin Film". The major difference between the two technologies is the material used as the semiconductor that converts the sunlight into electric current. For the silicon crystalline, different forms of silicon is used while in the thin film technology other semiconductor materials are used, including amorphous silicon (a-Si), copper indium diselenide (CIS), copper indium gallium diselenide (CIGS), or cadmium telluride (CdTe).

Although the silicon crystalline technology cost higher than the thin film technology, it has a better efficiency (11%- 20% compared to 5%- 13% for thin film) and as a result, the silicon crystalline is the dominant technology with market share of almost 80- 85% (Platzer, 2012). (Figure 3: Different PV Technologies) from National Renewable Energy Lab shows the progress in efficiency for the different materials used in the PV solar technology (NREL, 2012).

---

[4] http://insideclimatenews.org/news/20090429/world%E2%80%99s-largest-sky-scraping-solar-plant-goes-live-spain

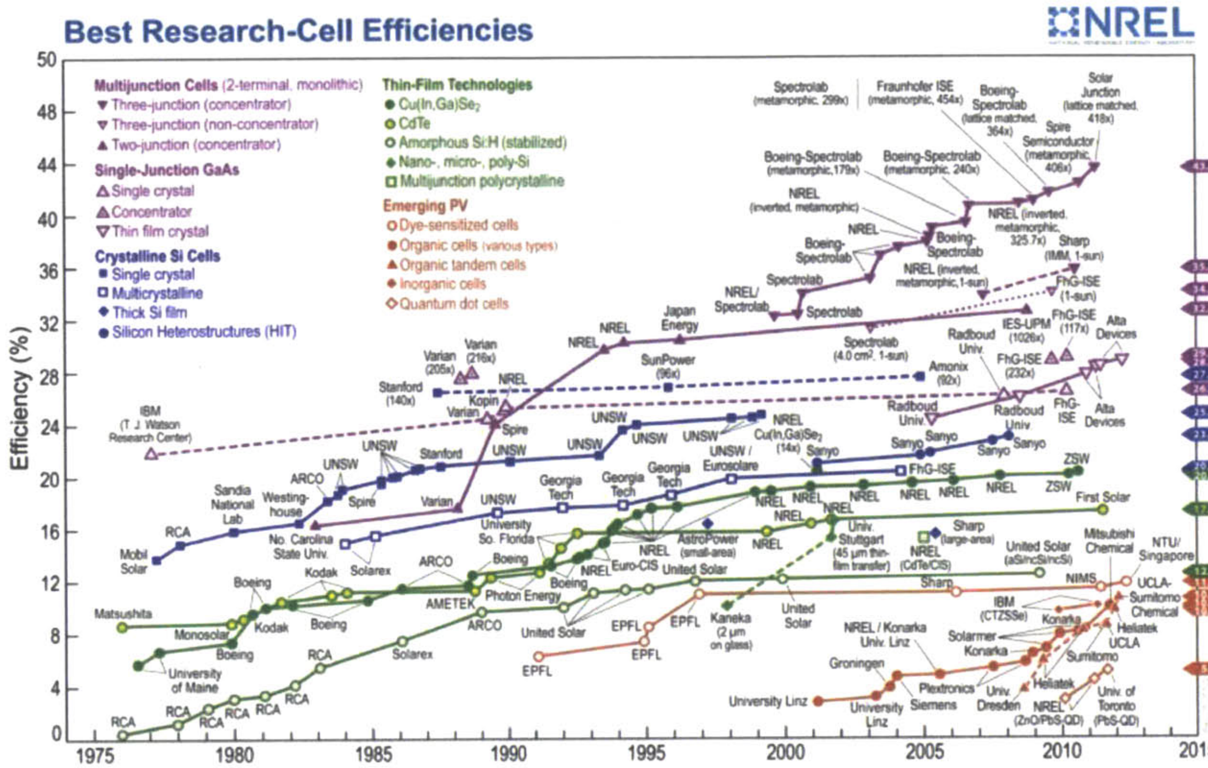


Figure 3: Different PV Technologies

Global Solar Installations

As of the end of 2010, there are 1,318 MW of cumulative installed CSP capacity worldwide, with Spain leading the way with 55.4% of this total capacity, followed by the United States with 38.5%, and Iran 5.0%. The first CSP solar project was in California, USA using the Trough technology, and was installed between 1986- 1991with a capacity of 354 Mega-watts. Since then, there have been a total of thirty-two CSP solar projects, most of them are pilot and small projects with capacities less than 50 Mega-watts.

Out of the thirty-two plants, Spain has seventeen; fourteen of them are based on "Trough" Technology producing 700 MW of electricity, two "Tower" projects in 2006 and 2009 producing 30 MW of electricity, and one pilot project based on Compact Linear Fresnel Reflector (CLFR) technology with a producing capacity of 1 MW of electricity. Spain is planning to build another CLFR plant to produce 30 MW to generate electricity (Wolff, 2012). Spain is also planning to build another fourteen trough projects to produce additional 500 MW of electricity and a tower plant to produce 17 MW.

The United States comes in second place with nine CSP projects, including five projects based on "Trough" Technology producing close to 500 MW of electricity, one "Tower" project producing 5 MW, 1 CLFR technology producing 5 MW, and 1 project based on "Dish" technology producing 2 MW of electricity.

In addition to the 67MW "Trough" plant in Iran, the Middle East North Africa (MENA) region along with China are showing high interest in producing energy using the CSP technology capitalizing on a new design strategy called "Integrated Solar Combined Cycle" (ISCC). This design combines heat from the natural gas turbine and the solar field, achieving capacity gains without increasing emissions. It is expected that another 800 MW of electricity will be produced using the CSP technology in the coming years from Spain, China, and MENA region (Ardani & Margolis, 2011). (Table 2: Future CSP Projects) summarizes future CSP projects in Spain, China, and MENA region.

Country	Technology	# of Plants	Total Capacity (MW)
Spain	Trough	10	500
	CLFR	2	30
	Tower	1	17
	Dish	1	1
China	eSolar	1	92
	Himin Solar	2	4
UAE	Trough	1	100
Egypt	Trough	1	20
Algeria	Trough	1	20
Morocco	Trough	1	20

Table 2: Future CSP Projects

At the end of 2010, The European Photovoltaic Industry Association (EPIA) estimates that global cumulative installed PV capacity is close to 40 gigawatts (GW) (Figure 4: PV Installations as of 2010). The European Union (EU) is leading the way with 29.3 GW, which represent 74% of the total installed capacity, followed by Japan with 9%, and the United States with 6%. Germany is leading the EU production with 17 GW, followed by Spain with 3.8 GW, and 2.3 GW for Italy (Ardani & Margolis, 2011). Most of the PV installations are for home and residential use, which makes it difficult to identify the exact installation capacity along with the exact utilization of this installed capacity. The EPIA estimates a growth of almost 870% in the PV industry by the year 2020, increasing the PV installations from 40 GW in 2010 to 345 GW in 2020 (El-Yousfi, 2012).

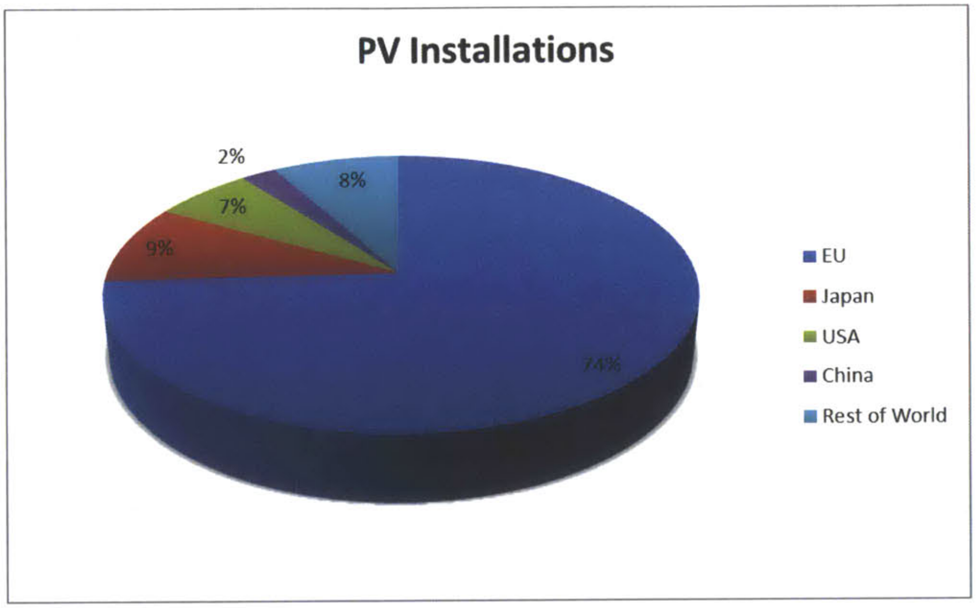


Figure 4: PV Installations as of 2010

Background on Solar Implementation in Saudi Arabia

This section provides a background on some of the major solar projects that took place in Saudi Arabia to generate electricity. Although, the country plans to use solar technologies for both electricity generation and water desalination, the focus of this thesis study is to analyze the opportunities of solar technologies to generate electricity.

Since the 1960s, the Saudi Government has understood the importance of using sustainable energy to generate electricity, with their first major project with the French to install photovoltaic (PV) at Al-Madinah airport (Hepbasli & Alsuhaibani, 2011).

In 1977, the Electricity Corporation established "Solar Energy Committee", which worked with a French company to produce five kilo-watts of electricity using solar energy for the "Research and Agricultural Development Center" in Derab[5]. In the same year, King Abdul Aziz City for Science and Technology (KACST) established Energy Research Institute (ERI) to work and develop solar energy technologies. One of their main projects was the Solar Village Project, located 50 km north-west Riyadh, the capital of Saudi Arabia. The village was completed in 1981, and produced 350 kW of electricity using PV technology (Huraib, Hasnain, & Al-Awaji, 2000) . These villages of Al-Jubaila and Al-Uyaina were the first villages in the Middle East to use solar energy to generate power without being connected to the central system (Hepbasli & Alsuhaibani, 2011) . The technology worked well in the desert environment, yet there were several observed problems and lessons learned including the 20% degradation in power, the increase in cell's temperatures, and the shortage of sink assembly for cooling the cells (Huraib, Hasnain, & Al-Awaji, 2000).

The Saudi Atlas Projects was initiated in 1994 to provide accurate measures of solar radiation in the kingdom of Saudi Arabia. The project was a joint effort between the Energy Research Institute (ERI) of KACST and the National Research Energy Laboratory (NREL) in the U.S. In this study, twelve locations that represent the different Saudi terrains were selected. These locations were: Riyadh, Gassim, Al-Ahsa, Al-Jouf, Tabuk, Madinah, Jeddah, Qaisumah, Wadi Al Dawasir, Sharurah, Abha, and Gizan. These stations were connected to a central unit for data collection and all instruments were calibrated every six months to ensure the quality and accuracy of the collected data (Hepbasli & Alsuhaibani, 2011) .

In addition to those two major projects, ERI has performed several projects (Table 3: Pilot Solar Projects Related to Electricity) to pilot specific attributes of the electricity generation using solar technologies (Hepbasli & Alsuhaibani, 2011).

---

[5] Interview with the Chairman of the "Solar Energy Committee", Eng. Fahad Alsultan.

Project		Location	Duration	Application
1.	350 kW PV System	Solar Village	1981-87	DC/AC Electricity for Remote Area
2.	3 kW PV Test System	Solar Village	1987-90	Demonstration of Climatic Effects
3.	4 kW PV System	South KSA	1996	DC/AC Electricity Remote Areas
4.	6 kW PV System	Solar Village	1996-97	Grid connection
5.	Long-term PV Performance of (3 kW)	Solar Village	Since 1990	Performance Evaluation
6.	Solar Radiation Measurement	12 Stations	1994- 1995	Saudi Solar Atlas
7.	Energy Management in Buildings	Dammam	1988-93	Energy Conservation

Table 3: Pilot Solar Projects Related to Electricity

In 2010, King Abdullah University for Science and Technology (KAUST) announced the completion of a two Mega-Watts top roof installation on its buildings. This installation is based on two rooftop solar installations with a capacity of 1 MW each (Bkayrat, 2010).

Picture 2: Top Roof PV Installation at KAUST[6]

[6] http://www.solarserver.com/solar-magazine/solar-news/current/2012/kw02/conergy-to-provide-pv-modules-for-200-kw-rooftop-pv-plant-in-riyadh-saudi-arabia.html

In 2011, the Saudi Electric Company inaugurated its first solar –powered electricity generation plant in Farassan Island, Jazan. This 500 kilo-Watts plant built by a Japanese company shows the commitment of the Saudis, and the potential of the solar technologies in Saudi Arabia. The Japanese company will own the plant for fifteen years before it is transferred to the Saudi Electric Company (SEC).

In 2012, Saudi Aramco produces 10 Mega-Watts of electricity using thin film CIS technology from Solar Frontier. These solar panels are located on top of the parking lots of the new high rise building (Kushiya, 2012)

Current and Future Electric Consumption in Saudi Arabia

Currently the peak electric demand in Saudi Arabia is almost 50 GW. This peak happens during the summer months, where the outside temperature in most cities is more than 40 °C. According to (Figure 5: Saudi Daily Energy Demand), the peak demand of 50 GW lasts less than one third of the year, while the rest of the year, the peak is less than 40 GW. This means that by finding innovative ways to reduce electric consumption during the summer season (June, July, and August); the peak demand in Saudi Arabia can be reduced by almost 20% (Al-Shehri, 2012).

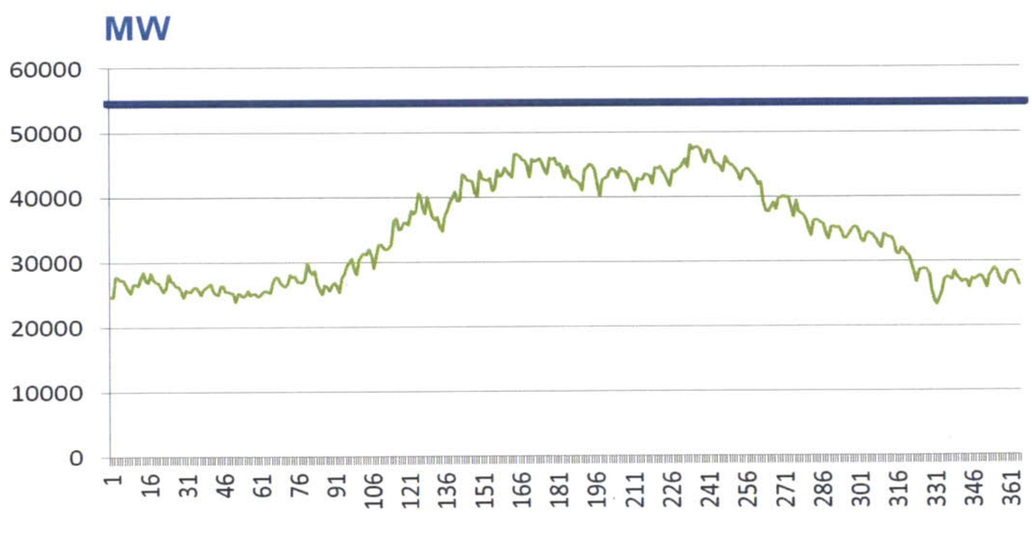


Figure 5: Saudi Daily Energy Demand

The analysis of the Saudi energy consumption shows that 50% of the energy is for residential use, followed by 18% for industrial use (Figure 6: Energy Consumption per Sector and Energy Consumption in Residential). Seventy percent of the electric consumption in the residential sector is used for cooling, mainly air-conditioning and refrigerators. There are several reasons for this very high consumption including low energy costs and low equipment efficiency. The Saudi Electricity and Cogeneration Regulatory Authority (ECRA) is proposing five programs to address and solve the high residential consumptions. These programs are: replacing of old low efficiency A/Cs, developing new building efficiency measures, implementing direct load control, implementing interruptible tariffs, and curtailable load management (Al-Shehri, 2012).

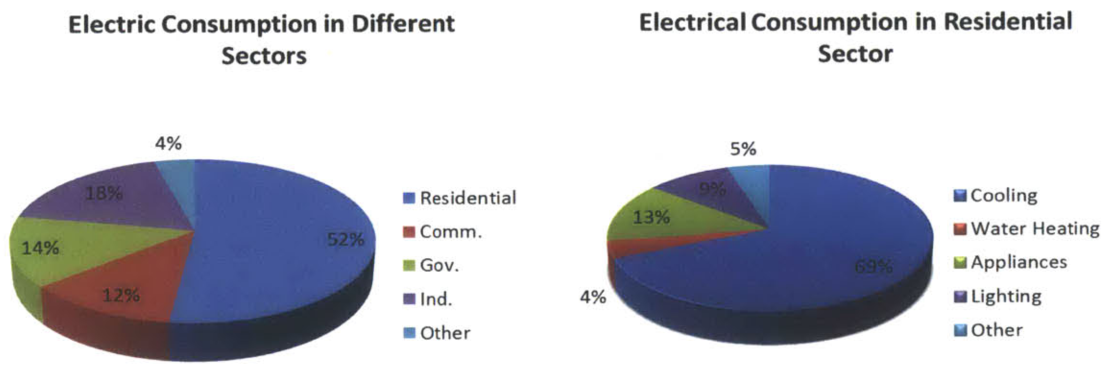


Figure 6: Energy Consumption per Sector and Energy Consumption in Residential

The peak demand in Saudi Arabia is expected to reach 120 GW by the year 2032(Al-Shehri, 2012), which means the demand for energy will increase by almost 2.5 times the current amount (Figure 7: Forecast Energy Demand Until 2032). This huge increase puts the Saudi Electric Company (SEC) under extreme pressure to meet this increase in demand and forces the company to find innovative ways to meet the rapid demand.

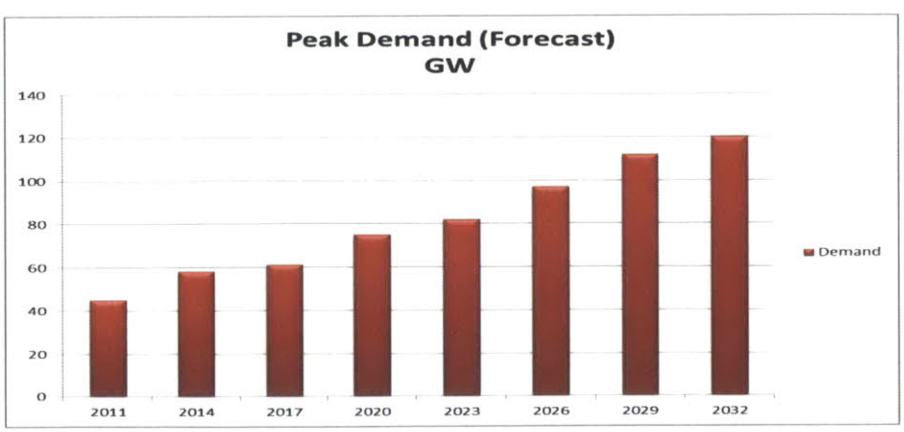


Figure 7: Forecast Energy Demand Until 2032

Chapter 2: Research Approach

Enterprise Architecture Framework

Enterprise architecting is "applying holistic thinking to conceptually design, evaluate and select a preferred structure for a future state enterprise to realize its value proposition and desired behaviors" (Rhodes, Ross, & Nightingale, 2009). This architecture approach evaluates the enterprise from a broad holistic view that takes into account new paradigms and environmental drivers before architecting the transformation strategy of the organization.

The enterprise architecture framework, developed by Nightingale and Rhodes, combines the "The Architecting Sequence Model" and "Ten View Elements" to achieve the goal of creating the Enterprise transformation strategy.

<u>The Architecting Sequence Model</u>

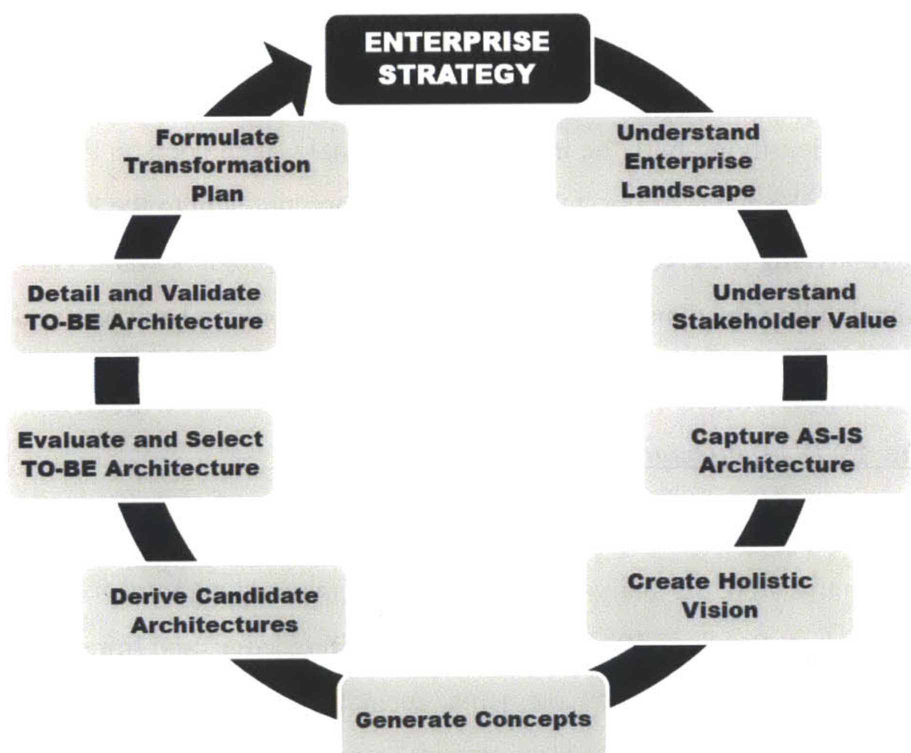


Figure 8: Architecting sequence model, © Nightingale and Rhodes 2011

The architecting sequence model is a model developed by Nightingale and Rhodes (Figure 8:) to establish a step by step process leading to developing an enterprise strategy. This nine step process can be divided into four main categories: The first category is understanding the current situation and this is done be analyzing the enterprise landscape, the stakeholders' values, and the AS-IS architecture. The second category is generating the different proposed architectures and this is achieved by creating a holistic vision for the enterprise, followed by generating candidate architectural concepts to achieve that vision. The third category is evaluating the different candidates to select the optimal in terms of attractiveness, effort, and risk. The fourth and final part of the architecting sequence model is validating the architecture and creating the transformation plan.

Understanding the Enterprise Landscape

This step helps in setting the scope and boundaries of the problem by understanding the landscape within the internal boundary such as capabilities, resources and constraints, and the external landscape such as politics, economics, environment, and technology.

Understanding the Stakeholders' Values

This step helps in identifying both the internal and external stakeholders in the enterprise. It also helps in prioritizing the needs of the stakeholders and mapping them to the Enterprise's performance. Analyzing the enterprise landscape and the stakeholders' values are crucial because they help understanding the dynamic interaction between the internal and external forces affecting the enterprise.

Capturing the AS-IS architecture

This step focuses on understanding the current position of the enterprise based on the different view elements. In this step, the analysis is made to the remaining eight view elements (Strategy, Organization, Product, Services, Process, Information, Knowledge, and Infrastructure), while the current position for the other two view elements (ecosystem and stakeholders) are discussed in the previous steps. The result of those three steps is a complete understanding of the enterprise current state.

Creating holistic vision

The next step in the architecting sequence model is creating a new holistic vision drawn from the gaps between the enterprise current state and the stakeholders' values. This holistic vision is the cornerstone for the transformation plan, and therefore, it needs to be clear and specific.

Generating concepts

This step comes after developing a clear and specific vision, where brainstorming sessions takes place to generate concepts for addressing the vision. Different techniques are used in this step to generate creative high level concepts.

Deriving the candidate architectures

The concepts generated from the previous step get crystalized in this step and become clear architectures. This is usually done by combining, detailing, and explaining the original concepts. The result of this step should be a set of proposed architectures ready for evaluation.

Evaluating and detailing the architectures

This step represents the third category in the architecting sequence model, where the different proposed architectures are being evaluated based on their attractiveness, effort, and risk. There are several techniques used to evaluate the different architectures including the must and want model, the weighted average, the Pugh analysis, and the benefit to cost analysis.

Although the actual evaluation process takes place after detailing the different architectural concepts, the evaluation criteria must be completed before the concept generation step in order to eliminate the biases toward specific architectures.

Detailing and validating the TO-BE architecture

Once the winning the architectural is identified, this step comes to further detail this architectural, validate the feasibility of implementation, and fulfillment to the vision.

Formulating the transformation plan

This is the final step in the architecting sequence model and it focuses on developing an action plan to deploy the different elements of the winning architectural. This step also includes the contingency and mitigation plans for each part of the architectural concept.

The Ten View Elements

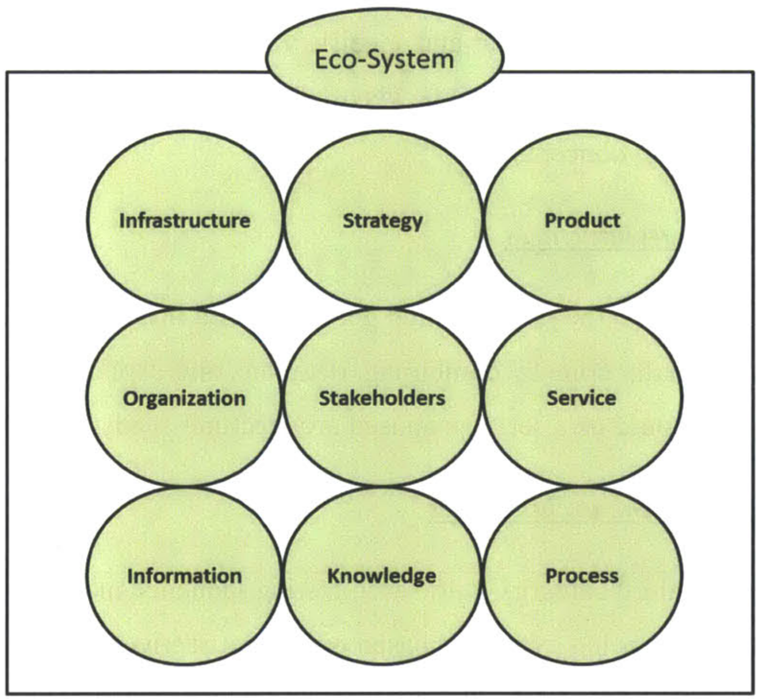


Figure 9: Ten View Elements

The ten view elements (Figure 9: Ten View Elements) help in thinking holistically to evaluate different aspects of an enterprise. Those ten elements guide the analysis to consider the outside boundaries of the enterprise (ecosystem), the internal operation of the enterprise (strategy, process), the interactions within the enterprise (organization, stakeholders), the capabilities of the enterprise (infrastructure, information, knowledge), and the deliverables of the enterprise (product, service). This method studies the following:

Ecosystem

The ecosystem view element considers the exogenous elements that affect the performance of the enterprise. Policies, economics, political stands in which the enterprise operates in are examples of exogenous elements considered in this view element. This view elements links the enterprise to the outside world and this is very important because enterprises do not work in vacuum and if there is no clear understanding of the surroundings, the chances the enterprise fails increase.

Strategy

The strategy view element analyzes the vision, mission, strategies, and direction of the enterprise, including business model and enterprise's competitive environment. The importance of the strategy view element comes in setting the proper direction and path forward.

Process

This view element studies the alignment of the internal/external work processes to the vision and strategies of the enterprise. By having a clear vision and strategies along with adequate work processes to deploy these strategies, the enterprise becomes capable to work efficiently and creates value to its stakeholders.

Organization

This view element studies the organizational structure of the enterprise, culture of the enterprise, and the communication channels within and outside the enterprise. This view element also studies the employees, behaviors, and boundaries between individuals, teams and organizations.

Stakeholders

This view element helps focusing on the complete set of stakeholders in the enterprise. This view element helps to understand the needs of each stakeholder. It also helps to analyze the enterprise's performance and effort to address those needs. Understanding the different needs of the stakeholders and the organization's culture is very important to create the interaction map inside the enterprise.

Infrastructure

This view element focuses on the physical capabilities of the enterprise including information technology (IT), building, machines, and other assets.

Information

This view element studies the external information the enterprise needs to deliver its products and services. This includes patents and other knowledge that are not owned by the enterprise.

Knowledge

While the information focuses on the external knowledge, the knowledge view element focuses on the internal skills and know-how. Combining the internal and external knowledge, and understanding the physical limitations of the enterprise helps to draw a realistic image of the capabilities of the enterprise. It also helps to envision what is needed to take the enterprise to new levels.

Products and/ or services

The product and/ or services view elements focus on the deliverables of the enterprise, including the main products/ service the enterprise provide and the supporting services it offers.

This thesis uses the Enterprise Architecture Framework as the overall framework to study the solar manufacturing in Saudi Arabia. This is achieved by following the architecting sequence model, and using the ten view elements (lenses) in each step of the architecting sequence model in order to perform a complete and holistic analysis of that step.

Chapter 3: Current Situation of the Solar Technology in Saudi Arabia

The objective of this chapter is to assess the current position of the solar manufacturing in the Kingdom of Saudi Arabia, and this is achieved in two parts. The first part of this chapter defines the industry's landscape and identifies the major needs for its different stakeholders. The second part explains the AS-IS architecture for the solar industry by using the ten view elements (Ecosystem, Stakeholders, Organization, Strategy, Infrastructure, Product, Services, Information, Knowledge, and Process).

Understand the Landscape and Stakeholders' Value

In order to establish a successful solar manufacturing in Saudi Arabia, it is important to understand the dynamics and interactions between the internal and external stakeholders and this can be achieved by:

- Identifying both the internal and external stakeholders and their needs
- Evaluating solar manufacturing current performance to address the stakeholders' needs
- Understanding the stakeholders' influence on the Solar Manufacturing
- Mapping the interaction between the different stakeholders

Internal and external stakeholders and their needs

To have a successful deployment for solar manufacturing in the Kingdom of Saudi Arabia, it is very important to identify all the stakeholders in the industry. This step sets the stage for addressing their needs, hence ensuring successful implementation for the industry. The list of the solar manufacturing stakeholders include: the Government of Saudi Arabia, technology providers, local businesses, household consumers, the Saudi Electric Company (SEC), and research and development centers (R&D).

The Saudi Government is the major stakeholder in the solar manufacturing. The government has several needs including: extending the life and availability of its oil, diversifying the economy, availing energy resources to current and future electricity generation, and creating employment opportunities.

Saudi Arabia depends heavily on oil and oil products as they represent close to 85% of total revenues, and at the same time, the local consumption of oil and its products is increasing and is expected to reach 6.5 million barrels by 2030 if no action is taken, which is more than half of Saudi Arabia's production (Bourland & Gamble, 2011) . The government also understands that building the economy on a single industry creates a potential risk. Furthermore; the government is expecting a huge increase in the Saudi population to reach between 54-60 million by 2050, which represents 100%- 120% increase from the current population of 27 million. The vision to diversify the economy along with the huge population increase exerts extra pressure to produce electricity (Alahmed, 2012). Also, this increase in population creates another pressure on the government to create and/or facilitate job opportunities for the citizens of the country.

The government of Saudi Arabia created several entities to address these challenges, and those entities are the stakeholders' representing the government of Saudi Arabia in solar manufacturing. Those entities are: King Abdullah City for Atomic and Renewable Energy (K.A.CARE), Industrial Clusters, Saudi Industrial Property Authority (MODON), Royal Commission of Jubail and Yanbu (RCJY), Ministry of Labor (MOL), Electricity and Cogeneration Regulatory Authority (ECRA), Sustainable Energy Procurement Company (SEPC), and Saudi Arabian General Investment Authority (SAGISA).

King Abdullah City for Atomic and Renewable Energy (K.A.CARE)

The rule of this city is to act as the legislative arm for atomic and renewable energy in the kingdom of Saudi Arabia. In addition, it is responsible to develop and implement strategies for renewable and atomic energy, and manage relations with local and international businesses. Furthermore, it should contribute to the R&D in the renewable and atomic energy sector. In order to better represent the needs for K.A.CARE in this thesis study, I consider the legislative role as the main role for K.A.CARE, while leaving the technology deployment role to be the role of Sustainable Energy Procurement Company (SEPC), and the R&D role to be included with the different research centers in Saudi Arabia.

Industrial Clusters

Industrial Clusters, is a government entity supervised by both the Ministry of Commerce & Industry and the Ministry of Petroleum & Mineral Resources. The role of the Industrial Cluster is to promote and expand the manufacturing capabilities for the kingdom of Saudi Arabia in order to generate the fastest possible growth in exports. This is achieved by creating manufacturing clusters that leverage KSA's energy, petrochemical and mineral resources. Currently, the Industrial Clusters is creating programs to promote the automotive industry, minerals and metal processing industry, solar energy industry, plastics and packaging industry and the home appliances industry (Industrial Clusters, 2012).

Saudi Industrial Property Authority (MODON)

MODON is a government entity established in 2001 to develop and manage the country's public and private industrial cities. The role of MODON is to "principally in the provision and development of industrial land and services, while the finance, construction, and operations will be undertaken by the private sector competitively" (*Saudi industrial property authority.*2012). A list of the different industrial cities managed by MODON is in (Appendix B: List of Industrial Cities in Saudi Arabia).

Royal Commission of Jubail and Yanbu (RCJY)

The Royal Commission of Jubail and Yanbu is an autonomous organization of the Saudi Government, and was established in 1975 to plan, promote, develop, and manage petrochemicals and energy intensive industrial cities (RCJY, 2012). The two cities of Jubail and Yanbu are among the first industrial cities in the kingdom of Saudi Arabia. While RCJY manages the industrial cities in Jubail and Yanbu, MODON manages the rest of the industrial cities in Saudi Arabia.

Ministry of Labor (MOL)

The Ministry of Labor (MOL) is responsible for "organizing employment of workforce through implementation of labor laws, human resources planning and development and settlement of labor disputes in the private sector."(MOL, 2012)

Electricity and Cogeneration Regulatory Authority (ECRA)

ECRA is a financially and administratively independent Saudi organization, and its role is to regulate the electricity and water desalination industry in Saudi Arabia to ensure provision of adequate, high quality, and reliable services at reasonable prices. The Minister of Water and Electricity is the Chairman of the Board of ECRA. (ECRA, 2012)

Sustainable Energy Procurement Company (SEPC)

SEPC is a new company that will be established to execute K.A.CARE atomic and renewable energy targets. The plan for this company to become a government entity operating in a corporatized manned to be more efficient. SEPC will be responsible to interface with the key stakeholders to establish the boundaries for each solar project. It will also be responsible to draft the project contracts and requirements along with performing on-site control and managing grid control and interconnection. Furthermore, SEPC will negotiate revenue and credit enhancement with SEC and others. Finally, it will be chartered to solicit, evaluate, and select proposals for both atomic and renewable projects (Al-Gain, 2012).

Saudi Arabian General Investment Authority (SAGIA)

SAGIA acts as the "gateway to investment in Saudi Arabia. It seeks to attract sufficient investment to achieve sustainable rapid economic growth while capitalizing on the Kingdom's competitive strengths as the global capital of energy, and as a major hub between East and West."(*Saudi arabian general investment authority.*2012) . To achieve those objectives, SAGIA helps investors to re-locate in the kingdom, provide business support and recruits high quality people.

Technology Providers[7]

Many international companies are now focusing on deploying solar technologies globally. In order for those companies to operate in a new turf, they need guarantees that entering these new turfs result in successful deployment and operation of their technologies. For this to happen, they are looking for clear and fair legislations, enforcement for these legislations, and opportunity to generate profit.

Local businesses

The rules of Saudi Arabia demand any international company that wants to operate in Saudi Arabia to establish a partnership with a local Saudi company. Therefore, understanding and

[7] The term Technology Provider in this study encompasses International Companies that produce solar products, International Companies that license specific technologies, International Companies that provide services in the solar industry, and International investors.

addressing the needs of local investors is very important to establish successful solar manufacturing.

Local investors need incentives in the form of loans, lands, tax breaks along with policies that encourage profitable deployment of solar technologies.

Consumers

There are two types of customers who receive the solar manufacturing final product; the first type is household consumers who install solar panels in their homes. The second type is utility companies who provide electricity to group of people and/or industries. The consumer section focuses on the household consumers and the Saudi Electric Section (SEC) section covers the utility companies.

Household consumers need a reliable technology; that reduces the cost of electricity and at the same time is easy to install, and maintain.

Saudi Electric Company (SEC)

The Saudi Electric Company (SEC) is responsible to generate and distribute electricity in the Kingdom of Saudi Arabia. The company is under an extreme pressure to meet the local electric consumption and therefore, they are looking for additional ways to generate electricity to help meeting this rapid demand.

SEC needs are clear; they need a reliable technology, easy to deploy and maintain, easy to integrate with the existing electric grid, and cost less than the traditional generation methods.

R&D Centers

The Kingdom of Saudi Arabia established several entities chartered to study and improve the solar technology in the country. These entities are: King Abdul-Aziz City for Science and Technology (KAUST), King Abdullah City for Atomic and Renewable Energy (K.A.CARE) and King Abdullah Petroleum Studies and Research Center (KAPSARC). In addition, several local and international universities are contracted to study the country's solar environment and deployment opportunities including King Abdullah University for Science and Technology

(KAUST), King Saud University (KSU), King Fahad University for Petroleum and Minerals (KFUPM), Massachusetts Institute of Technology (MIT), Stanford University and others.

All these research entities need adequate funding to purse their research, opportunity to pilot and test their solutions in real environment, and trained and talented researchers who can generate new and innovative ideas and solutions.

Enterprise Performance to Address Stakeholders' Needs

Two sets of performance/ relative importance maps are created to evaluate the current performance of the different stakeholders to establish a Saud solar manufacturing. The first set evaluates the current performance of each government entity involved in establishing solar manufacturing and compare it to the relative importance to solar manufacturing. The second set evaluates the needs of the different stakeholders, and the relative importance of that need to solar manufacturing.

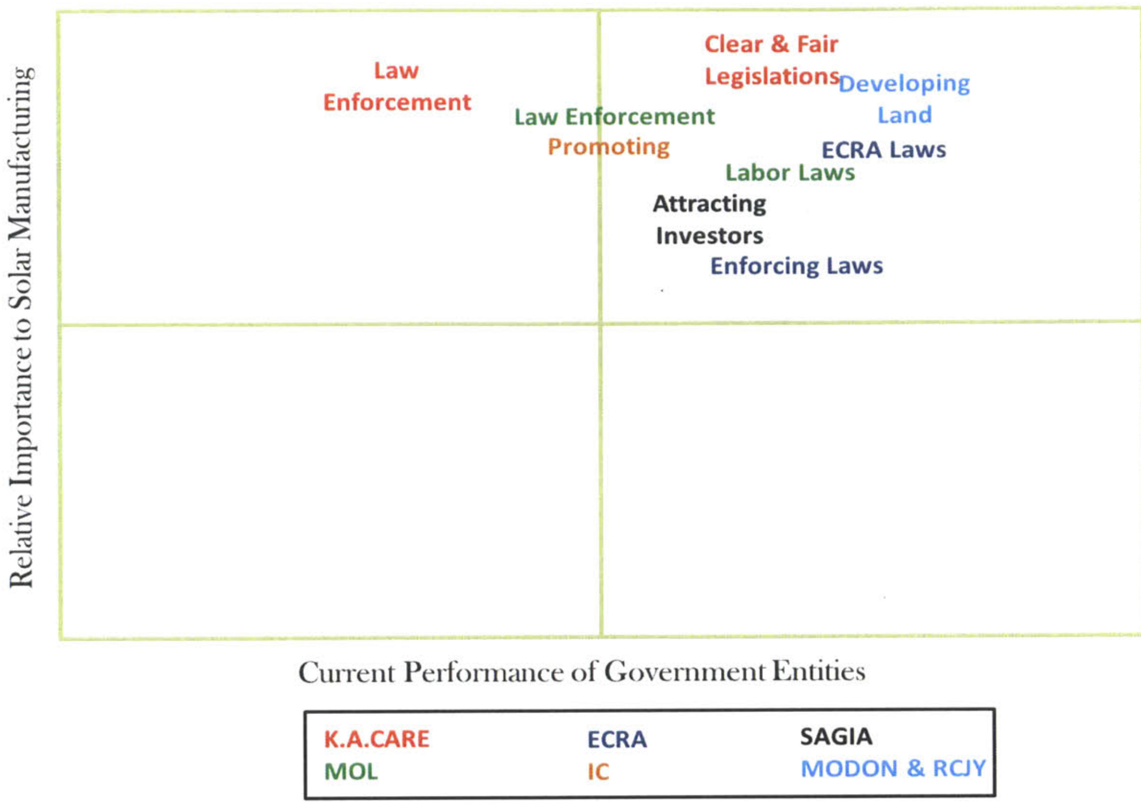


Figure 10: Mapping the Government current performance to solar manufacturing relative importance[8]

This map helps to understand the gaps the different government entities need to address in order to increase the chances of establishing and maintaining a successful solar manufacturing in Saudi Arabia. (Figure 10: Mapping the Government current performance to solar manufacturing relative importance) shows that K.A.CARE needs to develop better processes to enforce legislations. Similarly, MOL, and ECRA need to improve their law enforcement processes. IC and SAGIA need to increase their efforts to attract businesses to the Saudi solar manufacturing.

---

[8] The maps on Figure 10: Mapping the Government current performance to solar manufacturing relative importance and Figure 11: Mapping stakeholders' needs to Solar Manufacturing relative importance are developed based on a survey that captured the opinion of subject matter experts from most stakeholders including local businesses, KAPSARC, K.A.CARE, IC, R&D center, and consumers. The results from this survey can only be used as indicators for the performance due to the small sample size

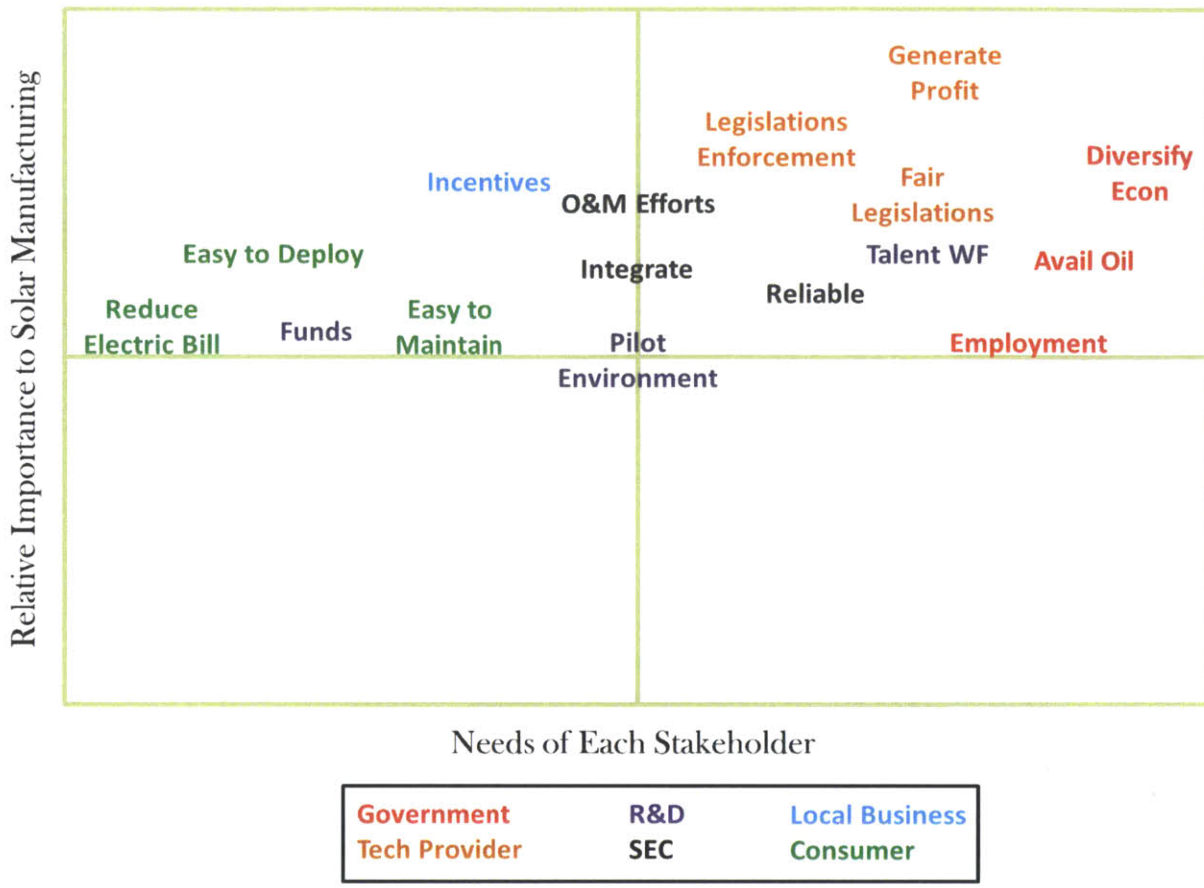


Figure 11: Mapping stakeholders' needs to Solar Manufacturing relative importance

(Figure 11: Mapping stakeholders' needs to Solar Manufacturing relative importance) gives us a clear understanding of the different needs and the importance of those needs to establish and sustain solar manufacturing. Therefore, the needs located on the top right corner should be addressed with higher urgency than the needs in the bottom left. This map is also used to evaluate the different architectural concepts in chapter four.

Stakeholders' Influence on Solar Manufacturing

The Stakeholder Salience Diagram is a good way to understand the influence of each stakeholder on solar manufacturing. The diagram breaks down the stakeholders based on "Power", "Urgency", and "Legitimacy". Understanding the influence of the different stakeholders helps in setting strategies and processes to prioritize, manage, and address their needs.

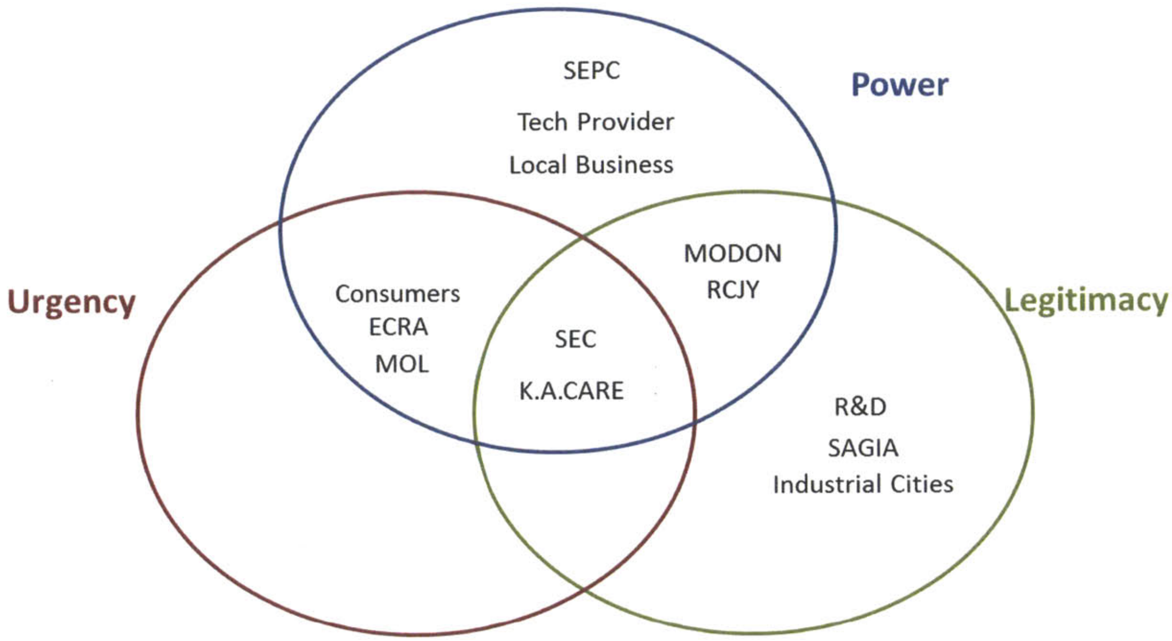


Figure 12: Salience Diagram

The stakeholders can be divided based on their influence on solar manufacturing into five categories: The first category is "Power"; this category includes the technology providers, local business, and SEPC. Vendors and local business are the ones investing money in solar manufacturing and their power appears in the way they decide to manage their assets. SEPC has power because it is responsible to manage and implement the Saudi's solar projects.

The second form of influence is the "Power and Urgency"; consumers, ECRA, and MOL belong to this category. Consumers gain their influence because they are the recipient of the final product and therefore, their satisfaction is crucial. ECRA is responsible to regulate electricity production and this gives them the power authority, also, addressing their requirement should be in an urgent manner. MOL is the entity that manages and regulates the labor workforce in the Kingdom of Saudi Arabia, thus they exert power and urgency on solar manufacturing.

The third form of influence is the "Legitimacy" and the stakeholders' that have this type of influence are: R&D centers, Industrial Cities, and SAGIA. R&D centers are considered the subject matter experts (SMEs) of solar technologies and their opinions and comments should be respected. SAGIA, and Industrial Cities are government entities striving to create a pleasant working environment for solar industry, and their efforts qualify them to have legitimacy influence.

The fourth form of influence is the "Legitimacy and Power"; MODON and YCJY exert these two types of influences because in addition to providing the pleasant environment, they have the authority to dictate on the type of industry and/or technology they allow on their locations.

The final form of influence is the trio influence "Power, Legitimacy, and Urgency". SEC has the trio influence because they are the ones who generate and distribute electricity which gives them both the "power" and "urgency" influence. In addition, they have experience in managing and integrating the power grid which gives them the "legitimacy" influence over the solar manufacturing. In addition to SEC, K.A.CARE has the trio influence too, K.A.CARE is the legislative arm and therefore, they exert both the urgency and power influence, and because they perform research in the solar industry, this grants them the legitimacy influence.

Stakeholders' Interaction Map

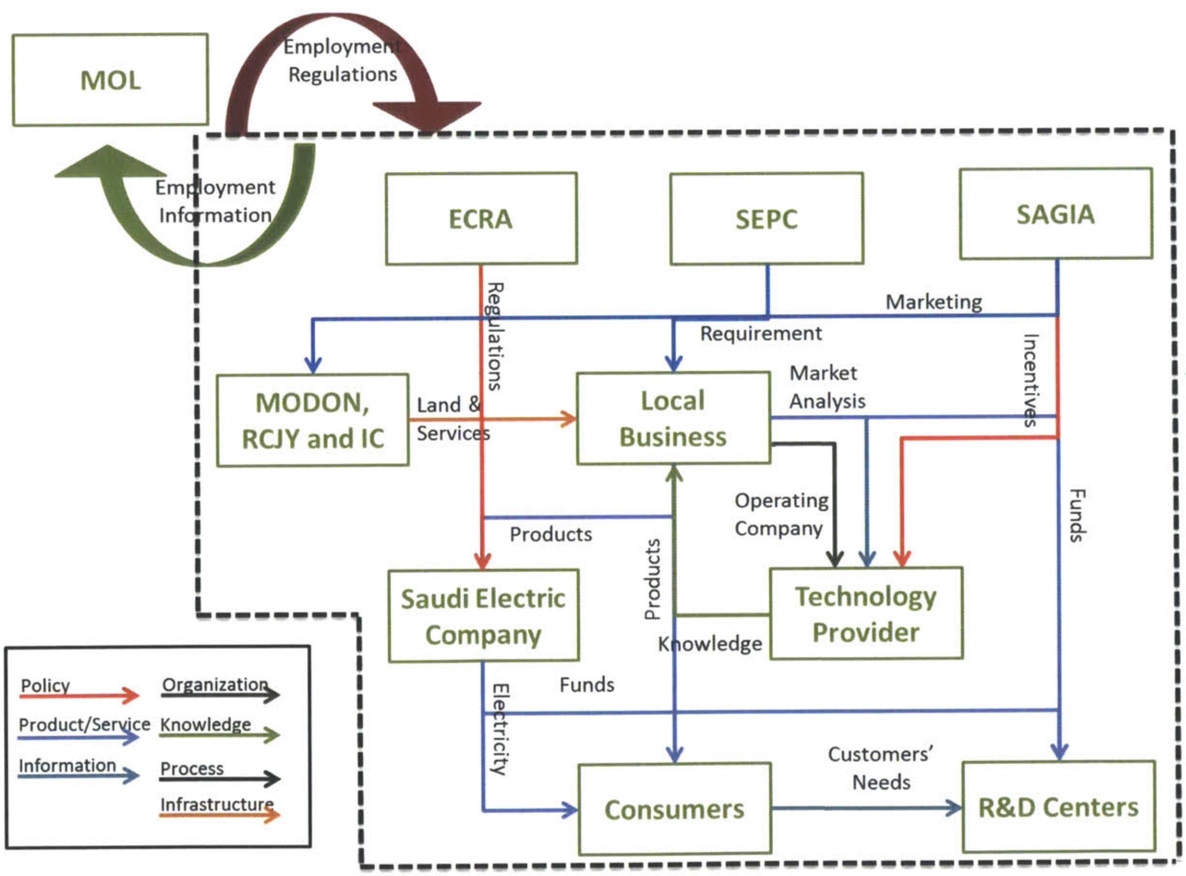


Figure 13: Stakeholders' Interaction Map

The stakeholders' interaction map is a good way to represents the interaction between the different stakeholders with the organization. As shown in (Figure 13: Stakeholders' Interaction Map), the different stakeholders for solar manufacturing and the type of interactions between them.

MODON, RCJY and Industrial Clusters are responsible to provide land and services to the local business, which in returns uses the infrastructure and the project requirements from SEPC to create products for SEC and other types of products that reach the final customers directly. Local businesses also create alliances with international technology providers to help producing these products at competitive prices.

SEC follows ECRA regulations and uses local and international products to generate, distribute, and maintain electric power to its customers. SEC and local businesses also fund local and international R&D centers that use customers' feedback as an input to explore new technologies that can further reduce the cost of products.

The technology providers establish strategic alliances with local businesses to provide them with the latest technologies. In return, local businesses help the technology providers in operating the businesses in Saudi Arabia, and provide them with better understanding to the local market. SAGIA attracts technology providers by creating an attractive working environment and financial incentives. The entire cluster of stakeholders follows the employment regulations of the Ministry of Labor (MOL).

Capture AS-IS architecture

Capturing the AS-IS architecture is one of the most important steps in the enterprise architecture framework, because it helps understanding the current position of the enterprise. Understanding the AS-IS architecture helps to identify the gaps and/or opportunities for the solar manufacturing to go to the next level. This section focuses on eight view elements (Organization, Strategy, Infrastructure, Product, Service, Information, Knowledge and Process). The other two elements (Ecosystem, and Stakeholders) are addressed thoroughly in the previous section (understand the landscape, and stakeholders' values).

Organization

As discussed in the previous section, the government of Saudi Arabia is the prime organization responsible to facilitate the work to establish solar manufacturing in the country. The government does not have a specific organization to manage the entire activities for this industry, but has several entities that together can be defined as the organization responsible for this industry. Those organizations are: K.A.CARE, MODON, RCJY, Industrial Clusters, MOL, SEPC, SAGIA, and ECRA. The roles of each of those entities are discussed in chapter one. These entities report directly to either the Prime Minister of Saudi Arabia (K.A.CARE, RCJY, SAGIA), Minister of Water and Electricity (ECRA), Minister of Commerce and Industry (MODON, Industrial Clusters). The only exception is SEPC as its organization chart has not been released yet.

There are other government entities that have an important role in the Saudi solar manufacturing, but are not considered as part of the "Solar Manufacturing Organizations". These entities include: Ministry of Economy and Planning, Ministry of Commerce and Industry, Saudi Industrial Development Fund, Technical and Vocational Training Corporation, and Human Resources Development Fund. In most cases, these government organizations provide services to "Solar Manufacturing Organizations" and/or investors, and therefore, they are not included as part of "Solar Manufacturing ecosystem".

Most of the organizations in the "Solar Manufacturing Organizations" are established recently, and based on my personal experience, the workforce knowledge and willingness to cooperate and share knowledge is impressing. If those attributes are spread across the entire organizations, then the chances to have successful establishment of solar manufacturing will increase.

Thomas J. Allen is his book "Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R&D Organization" explains the correlation of workers' vicinity and their communication frequency. His study shows that the closer the workers are to each other, the higher the communication rates become. He also talks about the "technology gatekeepers"; those who are experts in their domain and act as references to the entire organization (Allen, 1977). These two concepts are very important and they need to be considered and analyzed, given the fact that the solar manufacturing organization body in Saudi Arabia is scattered across different government entities.

Strategy

In the past few years, King Abdullah (The King of Saudi Arabia) articulated his vision regarding to energy and water generation as "The use of reliable alternative sources for electricity generation and production of desalinated water reduces reliance on hydrocarbon resources and thus provides an additional guarantee for the production of water and electricity in the future. It will also prolong the life of hydrocarbon resources, which will lead to keeping them a source of income for a longer period" (Al-Sulaiman, 2012). This royal vision highlights two elements that are important to the kingdom: The first is diversifying the sources of energy in order to produce electricity and desalinated water and the second is availing more hydrocarbons to be used internally and externally; thus increase the country's income. In addition to the Royal Vision, the Minister of Petroleum and Mineral Resources stated for a French Newsletter "One of the research efforts that we are going to undertake is to see how we make Saudi Arabia a center for solar energy research, and hopefully over the next 30–50 years, we will be a major megawatt exporter" (Hepbasli & Alsuhaibani, 2011).

As a result of the royal, and the minister visions, the government of Saudi Arabia created King Abdullah City for Atomic and Renewable Energy (K.A. CARE) with the strategy of "The development of alternative and sustainable energy by promoting and supporting the public and private sectors in research, studies and solar energy industry projects" (Al-Sulaiman, 2012) Therefore, K.A.CARE is considered an implementation arm for the royal vision and it is chartered to help private and public sectors in deploying solar technologies. K.A.CARE developed a timeline to deploy both solar technologies (Photovoltaic and Concentrated Solar Power) on two or more phases to achieve the country's target of 41 GW of solar power (16 GW from PV technology and 25 GW from CSP technology) (Al-Gain, 2012) by the year 2035. These 41 GW of electricity will produce between 103- 145 TWh/y[9], which represents 16.1% to 22.7% of the kingdom's projected total energy demand. This will result in saving of 361- 523 MBOE/D[10] (Al-Sulaiman, 2012)

---

[9] TWh/Y is Terawatt-hour per year (Terawatt = 10^{12} watts)
[10] MBOE/D is thousand barrels of oil equivalent per day

The aggressive implementation strategy, especially after the pilot phase, shows the high level of interest in utilizing the different solar technologies to generate electricity for the kingdom of Saudi Arabia. (Figure 1: Solar Energy Production for the Next 20 Years)

In-line with the Royal Vision, the government of Saudi Arabia is interested in building its industrial capabilities to increases its contribution to the GDP to reach 20% by 2020 from the initial level of 11.1% in 2006. This is achieved by expanding medium and high technology industry to reach 60% of the total industries from the current level of 30%.(*Saudi national industrial strategy*2008)

Infrastructure

The Saudi Government supported the growth of the industrial sector by establishing twenty-three industrial cities to host industrial, technical, service, residential and commercial projects. The government provides attractive incentives for businessmen to build and operate factories in these cities. These incentives include:

- Starting annual rent is 1 SR per square meter. (1 SR = 0.267 USD)
- Subsidized water and electricity
- Bank loan for up to 75% of the capital cost
- Extended repayment period of up to 20 years
- Export and customs reliefs
- Imported equipment and raw materials duty exemptions

In addition to the government owned industrial cities, there are six additional private industrial cities located in Riyadh and Rabigh. Four of these cities produce electrical products and the fifth focuses on plastics.

In order to manage these cities, the government established the Saudi Industrial Property Authority (MODON) in 2001 and is responsible for the development of industrial cities with integrated infrastructure and services (*Saudi industrial property authority.*2012).

In addition to the government and private industrial cities, the government of Saudi Arabia is building four economic cities in Rabigh, Ha'il, Al-Madinah, and Jazan. The objectives of these cities are: to enhance and diversify the Saudi economy, create new jobs, enhance the Saudi's skill levels, and develop the region. These cities will be built based on four principles:

1. Each city will be built around at least one major industry in order to attract core and supporting businesses to locate in the economic city.
2. Each city will adopt the state of the art technologies to attract industries and ensure their competitiveness.
3. The private sector will be responsible for building these cities and their infrastructure.
4. Each city will offer an attractive life style to attract businesses to locate there.

Each city will have a business friendly regulatory environment (*Saudi arabian general investment authority.*2012). These industrial cities came into reality after the tremendous success for the Royal Commission of Jubail and Yanbu (RCJY). The two industrial cities of Jubail and Yanbu currently host 223 industries with a total investment of more than 244 billion riyals, creating more than 107,000 job opportunities. (RCJY, 2012)

Product

When it comes to the manufacturing of solar systems, it is important to understand the different products, services and the skill levels required for each product and/or service. The solar manufacturing value chain can be broke down to the following high level components: research and development (R&D), original equipment manufacturing (OEM), solar components, engineering procurement and construction (EPC), and finally operation and maintenance (O&M).

The product section covers the different solar components for both the Concentrated Solar Power (CSP) and Photovoltaic (PV). The Knowledge section in this chapter covers the R&D component, the services section in this chapter covers EPC and O&M. Saudi Arabia does not have a strong OEM industry and therefore, OEM is not discussed in this thesis.

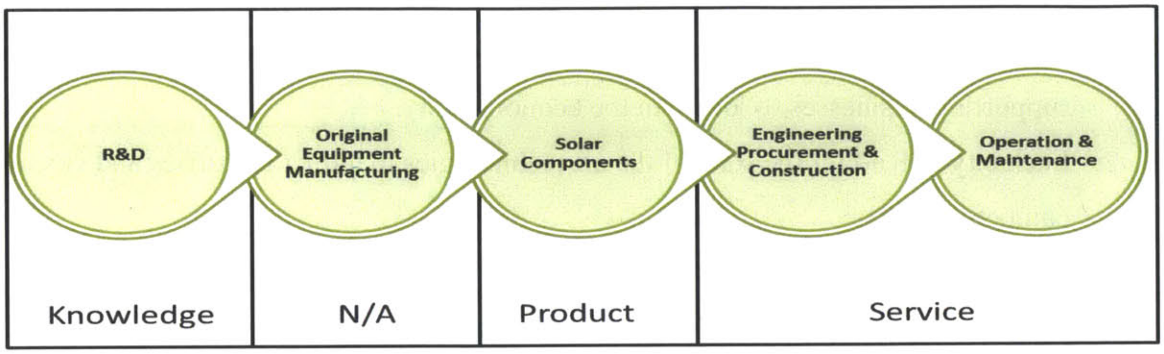


Figure 14: Solar System Value Chain

The CSP technology is based on concentrating the solar energy to generate steam that is used to run steam turbines. There are two main ways to concentrate solar power; the "Parabolic Through" and the "Power Tower System"

When breaking up the value chain for the CSP technology, we find the following industries: raw materials, components, finished products, and distribution. The product section focuses on the materials and components and the services section discusses the finished products and distribution (Gereffi & Dubay, 2009).

- **Raw materials:** The raw materials industries include steel, cooper, bras, concrete, plastic, silica, synthetic oil and molten salt. The majority of these products are manufactured in the kingdom by large, medium and small size companies.
- **Components:** The list of components needed include: collectors, mirrors, heat collection element, steam generator, heat storage, central control … etc.

The PV technology directly converts solar energy into electricity by directly absorbing photons from the sun. There are two main types of solar PV industries: "single or multi Silicon Crystalline" and "Thin Film". The major difference between the two technologies is the material used as the semiconductor to convert the sunlight into electric current.

The PV technology helps establishing several industries including the manufacturing of raw materials (Polysilicon and other materials), manufacturing of product (ingots, wafers, cells, and modules), and manufacturing of supporting systems.

- **Polysilicon manufacturing**: The average investment to construct a polysilicon plan ranges from $500 to $1,000 million, which is almost one fourth the cost of solar panels. Polysilicon is a product produced from sand and is capable to convert sunlight into electricity. This industry is currently dominated by few manufacturing companies in the US, Europe and Japan.
- **Ingots and Wafer manufacturing**: The wafer manufacturing is the process of converting the polysilicon into ingots then thin wafers. These wafers are then cut, cleaned, and coated.
- **Cell and Module manufacturing**: Solar cells manufacturing is shaping the wafers to round, square, or long and narrow shapes. The cells are then mounted together on a plastic backing with aluminum frame. This module is then covered by solar glass to protect against elements and to maximize efficiency. The solar glass manufacturing is another expensive industry and because of the high cost associated with glass shipment, production is usually located near by the module manufacturing facilities.
- **Supporting Systems**: In order to complete the production of solar panels for both PV technologies, other products needs to be manufactured including: batteries (used to store solar energy for use when the sun is not shining), charge controllers, circuit breakers, meters, switch gear, mounting hardware, power-conditioning equipment, DC/AC converters, and wiring (Platzer, 2012).

Services

The services section focuses on the Engineering Procurement and Construction (EPC), and Operation and Maintenance (O&M). Therefore, the major investment in this category is in the Human Capital (workforce). It is extremely important to understand the required skill levels to perform solar services for both the PV and CSP technologies. (Table 4: Skill Levels for CSP Services) details the services required to deploy and maintain the CSP technology and skill level for each service (Al-Mureeh, 2012). The PV technology requires similar skill levels for the same services if the customer is a utility entity and lower skill requirements if the customer is a household owner.

Category	Service	Skill Level
Development	Financial, Legal, Insurance	Very high
	Engineering	High
	Project Management	High
Integration	Engineering	High
	Procurement	Medium
	Installation	Low
Support & Logistics	Training	High
	Certification	High
	Transportation, Rental, Clearance	Low
O&M	Maintenance	Medium
	Cleaning	Very Low
	Security	Very Low

Table 4: Skill Levels for CSP Services

It becomes clear from the table that performing operation and maintenance activities along with the supply- chain logistics require the least amount of skills and therefore, it can be easily performed locally. The required skills increase in order to install and integrate the solar systems; thus requires qualified individuals to perform these activities. The required skills further increase in order to develop, manage the project and train the users; thus requiring highly qualified personnel for those activities.

Information

The information section covers the current status of export manufacturing in the kingdom of Saudi Arabia. Next, it discusses current projects to establish solar manufacturing in the Saudi Arabia. After that, it explains the status of solar manufacturing in the world.

Saudi exports depend heavily on prime industries and resources export as they contribute to almost 91.2% of the total exports of 2004 (76.2% for prime industries,15.6% for resources), and the remaining 8.8% is divided between low technologies, medium technologies, and high technologies industries. Comparing these number to world's average, which are: 12% for basic industries, 15.9% for resources exports, 16.7% for low technologies industries, 33.1% for medium technologies industries, and 22.3% for high technologies industries, it can be concluded that the Saudi Manufacturing is not capitalizing on its natural resources; hence the vision of the government to increase the contribution of high/medium technology industries to make 60% of total industries by 2020.

Solar manufacturing can increase the contribution of high/medium technologies to the overall Saudi manufacturing by capitalizing on the high solar irradiation to deploy solar technologies using locally manufactured products.

The western and southern operation area show increased economic benefits when considering solar power penetration, while the eastern and central operation area's do not have the same economic benefits. This is because the eastern and central operation areas depend on natural gas and Heavy Fuel Oil (HFO) to generate power. This economic analysis did not give a high weight for CO_2 emissions, which if considered will increase the economic attractiveness of solar generation in all operation regions (KAPSARC & Lahmer International., 2011).

The Saudi private sector understands the potential of the solar manufacturing and they are endeavoring into multimillion projects to establish solar manufacturing in Saudi Arabia. Currently, few companies are starting the solar manufacturing, while others are already in the solar services sector. The list of companies is an example of Saudi businessmen who are providing products/services in the solar industry value chain.

In 2010, AZIN; a subsidiary of AZMEEL International; announced the opening of the first thin film manufacturing facility in the Middle East North Africa (MENA) region. The facility is located in the Jubail Industrial City with a total investment of $400 million. AZIN will produce standard PV modules to serve their local and international customers.(Gallego, 2010; KAPSARC & Lahmer International., 2011)

In 2011, Polysilicon Technology Company (PTC); a joint venture between Saudi Mutajaddah Energy Co. and South Korea's Hyundai and KCC Corp to build and produce polysilicon (Business Monitor International, 2011). The plan for this $380 Million project is to produce more than 12,000 Ton of Polysilicon by 2017.

IDEA is another Saudi company that will focus on producing Polysilicon and solar wafers. The company is located in Yanbu, which is on the west side of the country and is planning to produce 10,000 ton per annum of High Purity Polysilicon, ingots, wafers. This will be transformed into about 90 million solar wafers capable of producing 350 MW of clean energy. The company is planning to start production in the fourth quarter of 2014. The first phase of the project will be to produce polysilicon while the emphasis on the second phase will be on ingot and wafers. (IDEA, 2012)

All these companies are capitalizing on their manufacturing skills, in addition to government subsidies in the form of: allocated gas from Saudi Aramco[11], allocated land by the Royal Commission of Jubail and Yanbu, and other government support.

In addition to solar products, Saudi companies also exist in the solar energy services sector; one of those companies is ACWA Power International; The Company started in 2004 focusing on electric generation and water desalinated production. Currently, the company is developing two CSP projects in South Africa and Morocco (Padmanathan, 2012). ACWA Power International services include: building the project's business model, selecting the proper equipment and managing the project construction. (ACWA Power, 2012)

The National Solar System s is another Saudi Company that provides services in the solar industry. The company was established in 2004 and based in Al-Khobar, Saudi Arabia, and its main services are typically turn- key solutions, which include: feasibility studies, engineering and design services, material supply and component sales, installation services and supervision, commission and start-up services, and operations and maintenance. The company provides these services for all types of solar systems ranging from small off-gird systems to large utility scale grid- connected installations. (NSS, 2012)

Understanding the international market is important for Saudi Companies to better position themselves in the solar market. The solar international market can be split into market for solar material, and leaders in solar manufacturing. For the materials, the analysis is on Polysilicon,

[11] Saudi Aramco is the Saudi National Oil Company; a company 100% owned by the government of Saudi Arabia. Saudi Aramco is the sole owner of all oil and gas fields in the country.

thin-film rare materials, and glass while in the solar leaders, the discussion is on the top three manufacturing companies in the world.

Almost 92% of PV cells use semiconductors made of silicon to generate electricity. The process to generate polysilicon used in solar cells is complex and requires capital. Currently, there are three main process used to generate solar-grade polysilicon; Siemens Process, is the most popular process among those three. In addition to 18- 36 months lead time, the Siemens process requires annual cost of $80- $120 to generate one kilogram of solar-grade polysilicon. Traditionally, electronics were the main market for polysilicon, but in 2007, photovoltaic demand exceeded electronics and became the primary driver to polysilicon production. The median estimated polysilicon production in 2010 was 148,750 metric tons (MT), out of which 120,400 MT was used in solar manufacturing (Ardani & Margolis, 2011).

The solar market did not reach the maturity level and therefore, many technologies are entering and exiting the market. Currently, the PV-polysilicon technology has the edge over thin film, but the gap between those two technologies is getting smaller. The overall future demand for polysilicon depends on the future performance of polysilicon PV companies compared to thin film companies.

Thin film technologies use indium, gallium, and tellurium as semiconductor materials instead of silicon. The increase in thin film production requires increase in producing those materials (Ardani & Margolis, 2011). It is important for companies producing thin film cells to control the price of those semiconductor materials in order to prevent upward price spikes, which affects the cells' selling price.

Glass is used in almost all types of solar technologies because it is relatively inexpensive, and is easy to clean. In addition to its use as the reflectors in the CSP technology, glass is also used to cover the PV semiconductor material.

Internationally, the solar manufacturing is heading towards market maturity, yet there are no clear dominant companies, Chinese's manufacturing companies are the major producers for solar cells. It is estimated that 23.9 GW of solar cells were manufactured in 2010. Chinese and Taiwanese companies produced 59% of the total solar cells, 13% in Europe, 9% in Japan, and the rest were manufactured worldwide (Ardani & Margolis, 2011).

It is expected that by the year 2015, the number of companies that produce silicon will decrease from the current level of more than 30 plants to become 10 plants, yet the production level will go from 150 MT to 230 MT. Similarly, the companies that produce wafers will decrease from almost 70 plants to become 20 plants by the year 2015 (Abu-Sharkh, 2012)

Suntech, a Chinese company, is the largest solar manufacturing company in the world with annual production in 2010 of 1,584 MW. This is equivalent to 7% of the total solar cells manufacturing capacity worldwide. The second company on the production list is JA Solar, another China-based company. JA Solar produced 1,464 MW in 2010, which equals 6% of the world's total production. The third company on the top ten list is First Solar, which is an American company specialized in producing thin film. This company is the only company in the top ten that manufactures thin film. First Solar generated more than 5GW of power by producing 66 million solar modules (Asali, 2012). It is important to note that 67% of First Solar production takes place in Malaysia, and the rest is split between the U.S and Germany (Ardani & Margolis, 2011).

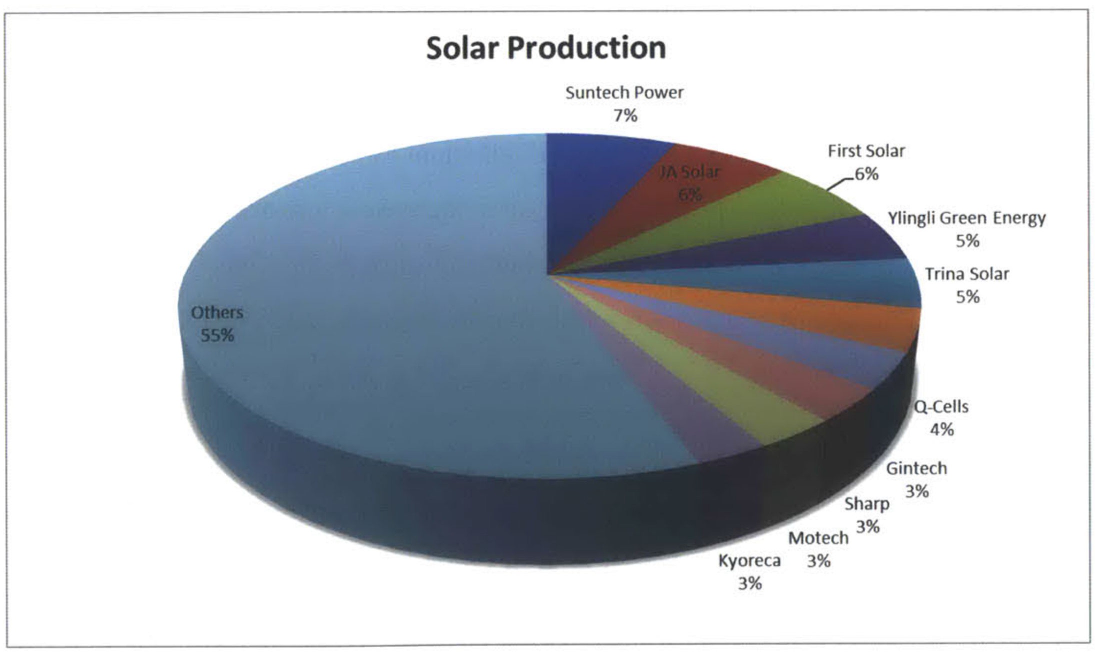


Figure 15: Solar Production

Knowledge

Saudi Arabia's first attempt to deploy solar industry came in the 1960s when a French company installed PV beacon in Al-Madinah local airport. Since then, the country understood the importance of solar technology and therefore created local and international research bodies aiming to expand its knowledge in the solar industry (Hepbasli & Alsuhaibani, 2011).

When it comes to local institutions, Saudi Arabia's has created three non-profit research centers with the aim of building knowledge in energy fields, specifically renewables. The first was "King Abdul-Aziz City for Science and Technology" (KACST) in 1977. The Energy Research Institute (ERI) is one of the three institutes that operates under KACST, and its responsibilities include:

- To develop plans of applied research in conventional & renewable energy
- To contribute to studies related to domestic & international energy policies
- To examine problems related to energy sources & their utilization methods, & to seek appropriate solutions through research & studies
- To work with relevant bodies on energy allocation plan, & monitor its implementation.
- To monitor the implemented results of energy research to assess goal achievement
- To notify relevant bodies of the outcomes of implemented research
- To develop scientific interrelationship among specialized energy centers in KSA
- To attract specialized & scientific experts of energy to work in the center
- To create a national energy database in conjunction with the General Information Department
- To provide scientific & technical consultation to other bodies in areas that fall within the institute's domain of expertise
- To provide an adequate research environment for the institute's researchers
- To propose an HR & work methods development program in the institute in conjunction with the Management Development Administration
- To suggest the organization of scientific activities falling within the institute's scope in conjunction with related departments.
- To submit periodic reports on the institute's activities
- To submit the institute's annual budget proposal

In addition to any other tasks assigned to the institute within its specialty (KACST, 2012)

The second research institute is King Abdullah City for Atomic and Renewable Energy (K.A.CARE). This City should contribute to a sustainable future for Saudi Arabia by developing an alternative energy capacity that is substantial in size and supported by a world-class local industry (KACARE, 2012). The city is chartered to legislate policies related to renewable and atomic energy, develop and implement strategies for renewable and atomic energy, manage relations with local and international businesses, and contribute to the R&D in the renewable and atomic energy sector. This helps in creating a sustainable economic sector for Saudi Arabia anchored by local alternative energy demand market. It should also contribute to creating jobs, which leads to growth in GDP while reducing the negative impact on the environment (Al-Sulaiman, 2012).

The third research institute is King Abdullah Petroleum Studies and Research Center (KAPSRC). The center's mission is "to push forward the insight and understanding of energy challenges and opportunities, both domestically and globally, through high caliber research in energy economics, policy, technology, and the environment, and to advance the knowledge of efficient and sustainable energy production and consumption to create future value and prosperity for humanity" (KAPSARC, 2012) .

In addition to those three non-profit institutes, several local universities are focusing on energy and environment including King Abdullah University for Science and Technology (KAUST), which is a multi-billion dollars research institute that has a specific center for "Solar and Photovoltaic Engineering". Also King Fahad University for Petroleum and Minerals (KFUPM) established a "Center of Research Excellence in Renewable Energy (CoRE-RE), and King Saud University (KSU) has another center for "Sustainable Energy Technologies" (SET) (Hepbasli & Alsuhaibani, 2011).

In addition to the local efforts, the Saudi Government and/or its local research institutes has established several partnerships with leaders in the solar industry including the United State and Germany. These collaboration efforts include the Saudi- United States Solar Program (SOLERAS), the Saudi- German R&D Program (HYSOLAR), and the Saudi KAUST- US National Research Energy Laboratory (NREL).

The SOLERAS partnership lasted between 1977 and 1991, and was focusing on addressing solar energy in terms of technology and economics. The result of this partnership was supplying two villages (Al-Jubaila and Al-Uyaina) with solar energy that was not connected to the electric grid. The HYSOLAR partnership focused mainly on technologies to produce hydrogen that can be stored and used for electricity. The KAUST-NREL partnership established the Saudi Atlas project aiming to have exact measures of solar radiation in Saudi Arabia. The project started in 1994 where solar radiation data were collected every 6 months from 12 different locations in the Kingdom (Hepbasli & Alsuhaibani, 2011).

Process

The process section covers the standard production process, the financing process, the facility construction process, and the K.A.CARE solar implementation process.

Process to produce products including the SCM

A successful product manufacturing needs to develop skills in three areas related to product production. Those three areas are: the supply chain model, the product manufacturing model, and the delivery & installation model.

The supply-chain model is the process of understanding the complete set of components to manufacture the final product, and then decides on elements that need to be manufactured within the enterprise, and the upstream elements that needs to be imported in order to produce the final product of the firm. In order to create the optimal mix of import/ internal manufacturing mix, the manufacturing company needs to be aware of the leading suppliers for the entire product value chain and then decide on the supply-chain model.

The decision on the manufacturing model requires a complete understanding of the skills and capabilities of the enterprise work-force. It also requires the understanding and capitalizing on the company's competitive edges.

Once the product is produced, the organization needs to understand and address the downstream supply-chain. In most cases, this includes the delivery and/or the installation of the product to the next customer in the value chain. It also includes the product support and warranty as they are important elements in any product.

Utterback explains the difference in innovation rates between product and process innovations. He argues that doing the initial phase (fluid phase), the rate of innovation in the product side is higher than the innovation in the process side. Once a dominant design emerges (Transition and specific phase), the innovation in the process side exceed the innovation in the product side (Utterback, 1994).

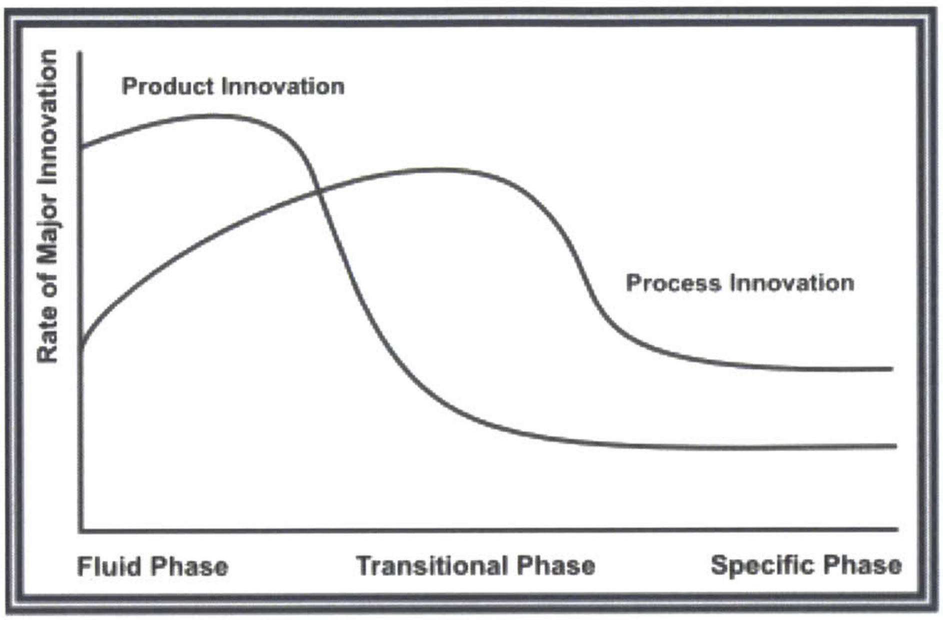


Figure 16: Product and Process Innovation

<u>Process to raise capital, and build plants</u>

There are ample ways to raise capital to build manufacturing facilities in the Kingdom of Saudi Arabia, and this is because the government has the vision of increasing the industrial contribution to the GDP to 20% by 2020 from the current level of 11.1% (*Saudi national industrial strategy*2008). For this to happen, several government entities are willing to raise capital and/or provide guarantees to ease the lending process at commercial banks. The specific lending processes are outside the scope of this study.

In order to build a manufacturing plant, Industrial Clusters has established an agreement with RCJY to support building solar manufacturing plants in the industrial city of Yanbu. In addition, MODON has enough land to build those facilities; whether they will be in the existing industrial cities and/or the new cities given they meet the specific requirements of those cities. The specific processes to own and/or rent lands at MODON and RCJY can be found by contacting those government entities.

Process for renewable procurement by SEPC

K.A.CARE is proposing to create a new company called "Sustainable Energy Procurement Company (SEPC)". The rule of this company is to manage the two-round procurement process to generate atomic and renewable energy in Saudi Arabia. The first procurement stage starts by: issuing a statement of opportunity, drafting Request for Proposal (RFP), receiving comments on RFP, issuing final RFP, and selecting winners and signing contracts. The difference between the first and second procurement stages is the minimum solar quantities, where it is assumed that the threshold for the second stage will be higher than the first stage (Al-Gain, 2012).

Chapter 4: Generate and Evaluate Concepts

This chapter details the second part of the architecting sequence model, which is generating the different proposed architectures and the third part, which is evaluating the different options to select the optimal solution. This chapter starts by articulating a holistic vision to be used as the basis for the solar manufacturing. After that, the chapter develops evaluation criteria, generates detailed architectural concepts, and finally evaluates those concepts against the evaluation criteria.

Map the AS-IS architecture to Saudi Arabia's holistic vision

After analyzing the needs for the Government of Saudi Arabia, it is clear that its focus are to diversify the economy, and create job opportunities; therefore, the holistic vision is: "To help diversifying the economy of Saudi Arabia by building knowledge and manufacturing capabilities in the solar industry and creating job opportunities for the citizens of Saudi Arabia."

Create Evaluation Criteria

The reason to start with the evaluation criteria is to eliminate the biases towards a specific solution during concepts generation and evaluation. The evaluation criteria are based on three angles; the first is "Attractiveness", which evaluates the concepts based on the needs of the government of Saudi Arabia. The second angle is the "Effort" to implement the concept, and the third angle is the "Risk", which studies the risk of implementation for every concept.

Attractiveness

The attractiveness section evaluates the concept architectures against the needs of the main stakeholder in the solar industry, which is the government of Saudi Arabia. The first step is to identify those needs and assign different weights based on their relative importance. The second step is to divide those needs into sub-categories to better analyze those needs. The third step is to score each concept based on the different sub-categories. The scores are between 1 and 5, where 1 represents a low level of attractiveness, and 5 represents a high level of attractiveness. The concept with the highest score is considered the most attractiveness concept for the government of Saudi Arabia

The needs for the government of Saudi Arabia can be extracted from the holistic vision of the Solar Manufacturing, and they include diversifying the Saudi economy, availing crude oil for future generations, and creating job opportunities for the citizens of the country. Furthermore, the government is hoping for this industry to last for a long period of time. The weights of those different needs reflect the AS-IS analysis in chapter three, where it shows a stronger need to diversify the economy, followed by availing oil for the future and creating jobs for local market. The table below summarizes the different categories, their sub-categories, and the percentage of each sub category.

Category	Sub-Category	%	Concept $_x$
Diversify Economy (30%)	Complexity level of the technology	20	
	Time to enter the market	10	
Avail Oil (20%)	Avail Oil for Future Generations	20	
Create Employment Opportunities (20%)	Number of Jobs	10	
	Diversified Skill Level	10	
Long Term Potential 30%	Sustainable Industry	15	
	Expansions	15	

Table 5: Attractiveness Breakdown

Effort

The success of any enterprise depends on controlling and managing three pillars; cost, quality, and time. Each enterprise may have the capability to control two out of those three pillars. This means that if an enterprise wants to control the time to market, and quality of the product, then the production price must be variable. Similarly, if the enterprise wants to control the cost, and quality, then the time to enter the market must be the variable. In this study, the focus is on two of the pillars; cost which is covered in this section, and time, which is covered in the attractiveness section. The thesis assumes a high quality production across all proposed architectural concepts, and therefore, analyzing the different qualities of production is not part of this thesis study.

The effort section focuses on cost pillar, which is broken down into financial cost, and personnel cost in order to implement the proposed architectural concept. The effort analysis focuses on the cost to implement each aspect of the architectural concepts (organization, policy, product, service, process, knowledge, information, and infrastructure), and the cost to hire and train the enterprise workforce.

The first step in calculating the effort is to evaluate the cost (financial and personnel) to implement each aspect. The second step is to calculate the average cost[12] for each aspect across the different concepts. The third step is to calculate the concept's overall average across all aspects. The scoring ranges between 1-5; where 1 is the lowest effort and 5 is the highest effort. The architectural concept with the lowest score is the one that consumes the least amount of effort.

Aspect	Dimension	Concept $_x$
Org	Financial Cost	
	Personnel Cost	
	Average	
Product	Financial Cost	
	Personnel Cost	
	Average	
…		

Table 6: Effort Breakdown

Risk

It is very important for any enterprise to understand and evaluate the risks associated with its business to better assess the benefits to risks ratio, thus making decisions that best matches the enterprise's philosophy. The benefits of each architectural concept are addressed in the "Attractiveness" section, and the risks of those concepts are discussed and analyzed in the "Risk" section.

This study focuses on two types of risks; the first type is "Shareholders' Acceptance", which analyzes the ability of the proposed architectural concept to address the different needs of the stakeholders. The second type is "Operational Risk", which evaluates the challenges to manage the enterprise. In this study, each type of risk is worth 50% of the total risk.

---

[12] The average cost is the average financial and personnel cost for that aspect

The “Shareholders’ Acceptance” risk is measured by how well each concept addresses the needs of the different stakeholders. By addressing the needs of the different stakeholders, their buy-in to the enterprise increase, thus reducing the risks of failure. The first step in measuring the “Stakeholders’ Acceptance” is assigning weights for the different needs of the different stakeholders. The weights are based on both the needs of the stakeholders, and the relative importance to solar manufacturing, which is identified in chapter three. The scoring ranges between 1-5; where 1 means that the need is not addressed, and 5 means that the need is fully addressed. The architectural concept with the highest cumulative score is the concept with the lowest risk of failure.

The “Operational Risk” measures the level of difficulty in managing and operating the proposed architectural concept, where the score of 1 means a high level of difficulty and a score of 5 means a low level of difficulty.

Other types of risks enterprise faces including, changes in policies, financial situation, reputational risks, new technologies … etc. are outside the scope of this thesis study.

Stakeholder	**Need**	**Weight**
Technology Provider	Fair legislations for investors	9.30%
	Fair enforcement of legislations	8.52%
	Opportunities to generate profit	11.02%
Local Businesses	Incentives	7.85%
Consumer	Easy to deploy	7.88%
	Easy to maintain	7.26%
	Reduce electric bill	3.78%
SEC	Easy to integrate to network	6.44%
	Easy to maintain	6.44%
	Reliable	8.39%
R&Ds	Provide funding	7.99%
	Provide pilot environment	7.99%
	Recruit talent workforce	7.13%

Table 7: Need vs. Weight Breakdown

Generate Detailed Architectural Concepts

This section explains the three different architectural proposals for the solar manufacturing in the Kingdom of Saudi Arabia. The three proposals are: "The Fast Vertical", "The Fast International", and "The Classical Horizontal." The concepts are addressed and explained based on the ten view elements.

The Fast Vertical (FV)

In this architecture, the government of Saudi Arabia promotes establishing companies that produce the complete value chain of the PV solar panels including the semiconductor materials, ingots, wafers, glass, cells and modules. This architecture also promotes the manufacturing of the raw materials used in the CSP technology. In order to promote this architecture, solar policy makers ought to set policies in favor of local solar manufacturing. For example, they can pass laws to demand certain percentage of solar panels to be manufactured locally. The government should provide financial incentives to local businesses to venture in the solar manufacturing. From an organizational perspective, the government should promote and encourage creating a solar manufacturing company, similar to the Saudi Arabia Basic Industry Company (SABIC) Company it created in the 1976. In addition to the different products, solar companies are going to provide all the solar services, including product delivery, installation, maintenance, and integration. This proposed architecture concept encourage supporting the local R&D centers by funding those centers to offer the solar manufacturing companies with the latest technologies in the solar field, hence prolong their operations. In this architecture, industrial cities/ clusters ought to have a fast development for land and services to host those manufacturing facilities.

The Fast International (FI)

The essence of this architecture is to capitalize on the international knowledge gained from working in solar manufacturing and use this knowledge to shorten the learning cycle for Saudi Arabia. In this architecture, the government encourages businessmen to fully/ partially acquire successful international solar manufacturing companies. The government in this architecture should ease the process of acquiring international companies and help businessmen in handling international and World Trade Organization (WTO) laws and guidelines. The long term objective of this architecture is transfer all the know-how to the local market, but in the short term, those acquired companies may operate and serve international customers only. In this architecture, the acquired companies are encouraged to established services agreements with local companies to provide local solar services, which may include: product delivery, installation, maintenance, and integration. The majority of the R&D development takes place in the leading R&D centers in the world. This architecture does not pressure industrial cities/ clusters for fast land development, because the acquired facilities are not going to relocate to Saudi Arabia in the short term.

The Classical Horizontal (CH)

This architecture is based on building the industry on a step by step basis. In this architecture, the government promotes establishing manufacturing capabilities in the lower levels of the value chain; specifically in the production of semiconductors materials, and the CSP raw materials. With time, those established companies are expected to gradually go to higher levels in the value chain. The government assists the private sector to sustain its competitive edge in the market by providing low cost energy. This concept requires a steady development for the industrial cities/ clusters to help the private sector in expanding their business. The R&D for the existing and future products should be performed both locally and internationally.

The gradual product introduction in this concept is a replica of Saudi Aramco's product philosophy. This giant Saudi energy company started in the 1930s as a company focusing on oil exploration and production. After building strong competencies in their domain, the company went up the value chain by building and operating refineries, followed by building a gas network, and gas plants. Currently, the company is endeavoring into a new multi-billion dollar project to enter the petrochemicals industry. In the services side, the Saudi Aramco expanded its services and established Vela International Marine Limited to provide marine transportation for Saudi Aramco crude oil. Saudi Aramco also established Aramco Services Company in Houston, Texas to provide engineering and logistic supports to Saudi Aramco.

	Fast Vertical	Fast International	Classical Horizontal
Organization	Government owned Company (full/partial) & Local Businessmen	International acquisitions(full/partial)	Local businessmen
Policy	Subsides and Incentives	International acquisition policies	Subsides
Strategy	Fast internal capabilities	Fast knowledge on technology and process	Steady internal knowledge & capability
Product	PV: Entire value chain CSP: Raw materials	PV: Entire value chain CSP: Entire value chain	PV: Lower products CSP: Raw materials
Services	Deliver and Installation	Sub-contract to local companies	N/A
Infrastructure	Fast development	Slow development	Steady, slow development
R&D	Local	International	Local & International

Table 8: Three Architectural Concepts

Evaluate the Different Concepts

Attractiveness

The first evaluation angle is the attractiveness of the architectural concept to address the needs of the government of Saudi Arabia, which is the prime stakeholder in the solar manufacturing. The needs of the government are: diversify the economy, avail oil for future generations, create job opportunities, and sustain the industry. Table 5: Attractiveness Breakdown shows the weight breakdown for those needs.

The first scoring component is diversifying the economy of Saudi Arabia; and is it evaluated based on the level of technology complexity and the time to enter the market.

As for the technology complexity, the fast vertical has a slight advantage over fast international in the photovoltaic industry because the new companies created by the fast vertical should have the latest technologies, and should be more vertically integrated than the acquired companies. On the other hand, the fast international concept provides more technology complexity in the concentrated solar power (CSP) because it is more vertically integrated than the fast vertical concept. Both, the fast vertical and fast international are more complex than the classical horizontal because of the additional products they produce.

As for the time to enter the market, the fast international is the fastest concept to enter the market because the acquired companies are already in operation, followed by the fast vertical with slight advantage over the classical horizontal because of the lead-time to construct the facilities in the low end of the value chain is longer than the facilities in the high-end of the value chain, which means that the fast vertical can operate partially and outsource the low-end products.

The second scoring component is availing oil for future generation, and the fast international concept scores the highest in this category because the majority of the facilities (in the short term) are located on international turfs; therefore, there is no need to consume local oil products to operate those facilities. The classical horizontal scores slightly more than the fast vertical because this concept requires less number of facilities; hence less energy used.

The third scoring component is creating job opportunities and is divided into number of jobs created and skills required.

As for the number of jobs created; the fast vertical concept creates the most number of jobs because the different products/facilities need to be established. The classical horizontal creates more jobs than the fast international, especially in the short and medium terms, because the objective of acquiring new companies (fast international concept) is to capitalize on the knowledge of the existing workforce, hence the hiring process is slow.

As for the skills required and acquired; the fast vertical scores the highest for skills diversification because of the different processes and products it is producing. The classical horizontal comes in second place with a slight advantage over the fast international, which focuses on its existing international workforce, thus limiting the number of local workforce to gain the skills.

The fourth scoring component is the long term potential, and this criterion can be divided into sustainable solutions and future expansions.

As for the sustainability of the concept, the classical horizontal scores the highest among the three concepts because it is based on the raw materials, which can be used in solar manufacturing and other industries including the semiconductor industry and the construction industry. The fast vertical scores slightly more than fast international because the government of Saudi Arabia can set laws to consume the products manufactured locally, to support the local manufacturing.

As for the future expansion, the classical horizontal concept scores slightly higher than the other two concepts because the concept focuses on the raw materials and waits for the market to mature, then can find and fill the market gaps. When comparing the other two concepts; although the fast international concept companies are already in operation, thus they have the first movers' advantage, the fast vertical companies have better chance serving the local market, especially if the government set laws to favor them.

The table below summarizes the attractiveness scores for each concept to the government of Saudi Arabia. The final results shows that the fast vertical is the most attractive concept with a final score of 3.80 out of 5.0, followed by fast international with a score of 3.65 and finally the classical horizontal with a score of 3.30.

Category	Sub-Category	%	FV	FI	CH
Diversify Economy	Complexity level of the technology	20	4	4	2
	Time to enter the market	10	3	5	2
Avail Oil	Avail Oil for Future Generations	20	3	5	3
Create Employment Opportunities	Number of Jobs	10	4	1	3
	Diversified Skill Level	10	5	2	3
Long Term Potential	Sustainable Industry	15	4	3	5
	Future Expansions	15	4	4	5
Attractiveness			**3.80**	**3.65**	**3.30**

Table 9: Concepts Evaluation (Attractiveness)

Effort

The second evaluation angle is the effort to deploy the architectural concept, and in this angle, I evaluate the financial and personnel cost to perform seven activities. Those activities are:

establishing the organization, developing policies, creating new products, providing solar services, building infrastructure, performing R&D activities, and hiring and training workforce.

The first aspect is the organization; from financial perspective, the fast international concept cost slightly more than the fast vertical due to the royalty cost that has to be paid in addition to the acquired companies assets values. The fast vertical cost more than the classical horizontal because of the extra numbers of facilities in operation. From personnel perspective, the fast vertical requires the most amount of personnel effort because it requires establishing number of facilities to produce different products in a shorter period of time, followed by classical horizontal, and the fast international requires the least amount of personnel support because when acquiring a company, the existing workforce may still want to work for the company.

The second evaluation aspect is the policy; from personnel cost perspective, the fast vertical requires the most amount of personnel support to decide on the optimal set of incentives and subsidies, in addition to close monitoring and adjustments to those subsidies to ensure fairness across the value chain and across the different stakeholders. The classical horizontal requires slightly more personnel efforts than the fast international.

The third aspect is the product; from financial cost, the fast vertical is the concept with the highest cost because the new enterprises are yet to develop mature work processes to reduce the production cost. Furthermore, the Saudi's competitive advantage is in energy, which makes the products in the low parts of the value chain the most attractive, and by going up the value chain, this advantage diminishes and makes these local products compete with international products. The fast international costs slightly more than the classical horizontal due to the nature of the Saudi energy market.

The fourth aspect is the services; from financial cost, the fast vertical cost more than the fast international due to the lack of experience in services. The same applies to the personnel effort. The classical horizontal concept does not propose investing in the services section, hence there is no effort required.

The fifth aspect is the infrastructure; the fast vertical requires the highest effort, both financially and personnel because this concept demands a rapid development for land, and services to host the new facilities. The classical horizontal requires more effort than the fast international, which already has its facilities built and are in operation.

The sixth aspect is the research and development (R&D); both the fast international and fast vertical require almost the same amount of financial effort to compete in this fragmented market by deploying the new technologies to increases the product efficiency and/or decreases production cost. The same effort is not required for the classical horizontal because of the nature and the maturity of the market.

The final aspect is the workforce; the fast vertical requires the highest financial cost to hire and train the high number of employees that need to work in the different facilities. The fast international requires more financial effort than the classical horizontal for to the same reason. As for the personnel effort, the fast vertical requires the highest effort to recruit and manage the workforce, followed by the classical horizontal. The fast international already has its workforce, hence the personnel effort is to manage the existing workforce and further develop their skills and capabilities.

The table below summarizes the effort required to implement the different architectural concepts. The final results shows that the classical horizontal requires the least amount of effort with an average score of 2.67, followed by fast international with a score of 2.71, and finally fast vertical with a score of 4.21 out of 5.0.

Aspect	Dimension	FV	FI	CH
Org	Financial Cost	4	5	3
	Personnel Cost	4	2	3
	Average	**4**	**3.5**	**3**
Policy	Financial Cost	N/A	N/A	N/A
	Personnel Cost	5	2	3
	Average	**5**	**2**	**3**
Product	Financial Cost	4	3	2
	Personnel Cost	N/A	N/A	N/A
	Average	**4**	**3**	**2**
Services	Financial Cost	3	2	N/A
	Personnel Cost	3	2	N/A
	Average	**3**	**2**	**N/A**
Infra	Financial Cost	4	1	3
	Personnel Cost	4	1	3
	Average	**4**	**1**	**3**
R&D	Financial Cost	5	5	2
	Personnel Cost	N/A	N/A	N/A
	Average	**5**	**5**	**2**
WF	Financial Cost	4	3	3
	Personnel Cost	5	2	3
	Average	**4.5**	**2.5**	**3**
Effort		**4.21**	**2.71**	**2.67**

Table 10: Concepts Evaluation (Effort)

Risk

The third evaluation angle is the risk associated with implementing the architectural concepts. The risks are evaluated based on two components: "Stakeholders' Acceptance", which studies aptness of the concept in addressing the needs of the different stakeholders. There are thirteen needs that represent the major needs for the five different stakeholders: technology providers, local businesses, consumers, SEC, and R&D centers. The second component is the "Operational Risk", which studies the difficulty in managing and operating the different concepts.

The first need is setting fair legislations for investors; addressing this need is very difficult for the fast vertical concept because it requires a complete study for the market to identify the optimal combination of incentives to attract investors, while not violating international and World Trade Organization (WTO) regulations and guidelines. It also requires a close monitoring to the market to adjust these incentives. This need is not as difficult to address in the classical horizontal; it only requires initial effort to set the right policies and incentives and periodic monitoring and adjusting. This need is very easy to be addressed for the fast international because the policies and incentives should follow international and WTO guidelines.

The second need is enforcing legislations; and this need is easy to address for fast international concept because the government needs to keep clean records with international and WTO guidelines, otherwise, the country might face dumping charges and penalties. Addressing this need is easier for the classical horizontal than the fast vertical due the fact that the fast vertical requires a very close monitoring to the existing market. Thus, enforcing these incentives becomes harder.

The third need is creating opportunities to generate profit; and this need is well addressed in the classical horizontal, especially if the right policies and incentives are in-place, due to the fact that energy prices is the country's competitive advantage, which means that by operating in the low levels of the Solar Manufacturing value chain, the profit margins are high. These margins tend to decrease when going up the value chain and this is why the fast vertical concept generates less profit (in percentage figures) than the classical horizontal. Addressing this third need in the fast international depends on the acquired companies and their capabilities in operating and generating profits. The other benefit of the fast international is the opportunity to take advantage of the hosting countries incentives and policies.

The fourth need is incentivizing local businesses and businessmen to venture into the solar manufacturing; the classical horizontal concept handles this need by providing loans, and subsidizing land, and energy, which makes the production of basic solar components very attractive. In order to response to this need using the fast vertical concept, energy legislators ought to provide a mechanism for selling the panels in the local market. It can be in the form of: forcing SEC to buy local clean energy, requiring certain percentage of solar panels to be manufactured locally … or other type of legislations. These types of legislations may create deficiencies and decrease in productivity, hence, legislators need to continuously monitor and adjust these laws based on the performance of solar market. Addressing this fourth need is quite difficult in the fast international concept because the acquired companies are not local companies, hence it become difficult to legislate local laws favoring international companies.

The fifth, sixth, and seventh needs respond to the consumer who buys solar panels and install them in his house to reduce the cost of his electric bill. The first service the consumer wants is an easy to install system; fast vertical and fast international concepts are capable to meet this need with a slight edge for the fast international. Similar to the fifth need, the fast international concept addresses the sixth need (easy to maintain) better than the fast vertical.

Currently, none of the three options has the capability to address the seventh need, which is reducing the cost of the electric bill because of the low cost of electricity in the kingdom of Saudi Arabia. Even if the electric prices were higher, it is hard to decide which concept is the best throughout the lifecycle of the asset; it depends on the specifics of each customer.

The next three needs are to address SEC requirements; I give a slight edge to fast international because of the experience the acquired companies have other the fast vertical. While in evaluating the reliability of the product, I give both concepts the maximum score, because I believe that both of them have the capability to produce very reliable products.

The following need is providing funds for R&D; the fast vertical concept aims to have the majority of R&D activities performed locally in order to improve skills and capabilities of local workforce, and therefore, most of R&D funds are directed to the local market. The classical horizontal concept splits the R&D funds between local and international R&D centers, hence the allocated funds to the local market is not as high as the fast vertical. The fast international concept allocates R&D funds to the leading R&D centers in the world, which means that local R&D centers needs to compete for these funds, which means that funds are probably less than classical horizontal funds.

Creating pilot environment is the next need for R&D centers; fast vertical presents the best chance for R&D centers to pilot their new ideas, followed by classical horizontal, while the fast international comes in the final place.

The final R&D need is recruiting talented workforce; and because the fast vertical is awarded with most R&D activities, the chances of recruiting high caliber local workforce is higher than the other two concepts. The classical horizontal comes in second place in addressing this need while the fast international comes in the final place.

The fast vertical concept is the most difficult concept to manage, followed by the classical horizontal. This is because in establishing new enterprises, management face higher risks to fail than the established enterprises.

When calculating the risk of the three concepts, I did not consider consumers nor SEC as part of the classical horizontal stakeholders, because in reality they are stakeholders of the final product (solar panels), and the first few phases of classical horizontal does not produce solar panels.

The table below summarizes the scores of each concept against the different needs of the stakeholders, and the final results shows that the classical horizontal scores the highest in responding to those needs with a final score of 3.16 followed by fast international with a score of 2.96, and finally the fast vertical scores 2.35. This means that the classical horizontal concept has a lower risk of failure than the other two concepts, followed by the fast international.

Stakeholder	**Need**	**Weight**	**FV**	**FI**	**CH**
Technology Provider	Fair legislations for investors	9.30%	1	4	3
	Fair enforcement of legislations	8.52%	2	5	3
	Opportunities to generate profit	11.02%	3	4	4
Local Businesses	Incentives	7.85%	2	1	4
Consumer	Easy to deploy	7.88%	2	3	N/A
	Easy to maintain	7.26%	2	3	N/A
	Reduce electric bill	3.78%	1	1	N/A
SEC	Easy to integrate to network	6.44%	2	3	N/A
	Easy to maintain	6.44%	2	3	N/A
	Reliable	8.39%	5	5	N/A
R&Ds	Provide funding	7.99%	4	1	3
	Provide pilot environment	7.99%	4	1	3
	Recruit talent workforce	7.13%	4	2	3

Risk (Stakeholders' Acceptance) 50%	**2.69**	**2.92**	**3.32**
Risk (Operational Risk) 50%	**2**	**3**	**3**
Risk (100%)	**2.35**	**2.96**	**3.16**

Table 11: Concepts Evaluation (Risk)

Chapter 5: Select, Validate, and Implement

This chapter explains the selection process of the best architectural concept to be implemented in Saudi Arabia, followed by a validation process to ensure the selected option addresses the needs of the stakeholders. The final part of this chapter details the implementation of this concept.

Selecting the Winning Architecture

Attractiveness vs. Effort vs. Risk for the three architectural concepts

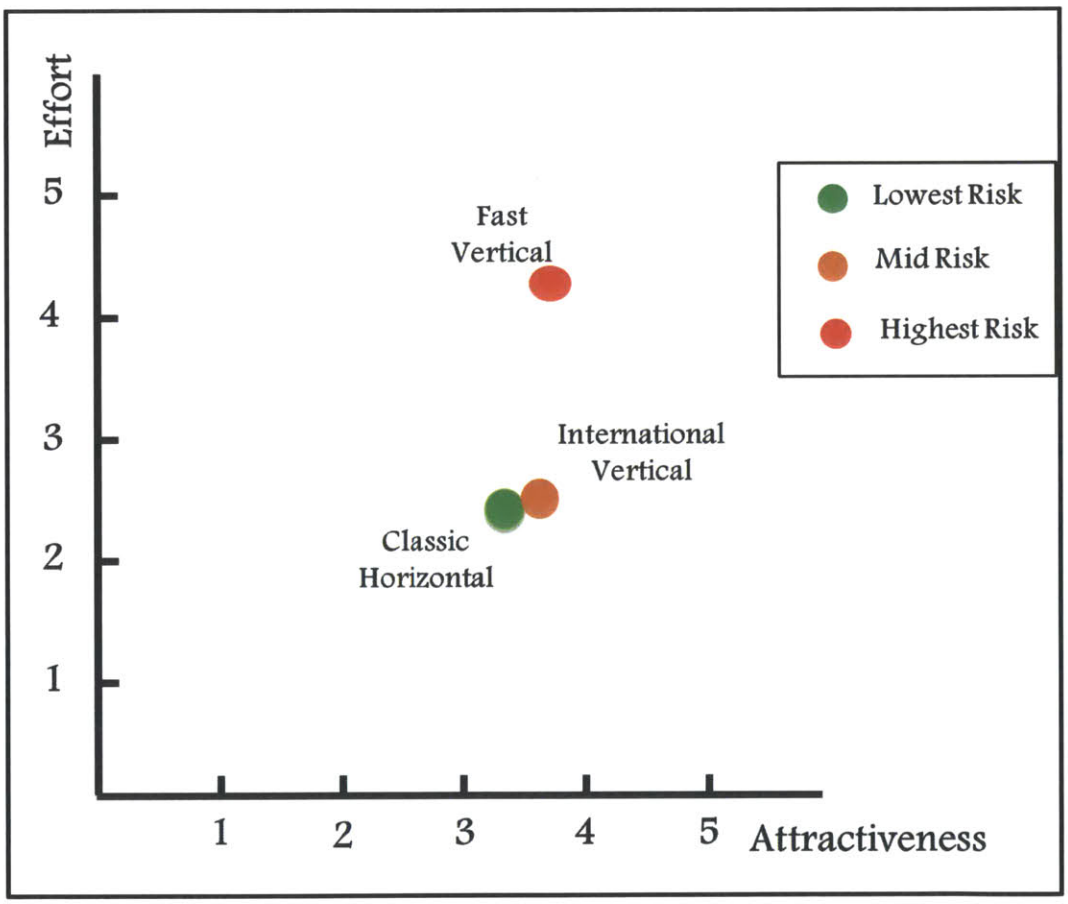


Figure 17: Attractiveness vs. Effort vs. Risk

The above figure shows the results from chapter four; where the three evaluation angles (Attractiveness, Effort, and Risk) are shown for the different architectural concepts (Fast Vertical, Fast International, and Classical Horizontal).

From this figure, it becomes clear that the fast vertical concept is the most attractive concept; yet this concept is only the riskiest among the three and requires the most amount of effort. Therefore, this concept is only considered during emergency times where an aggressive solution needs to be implemented. Fortunately, the current position for Saudi Arabia does not require such aggressive concepts. Saudi Arabia does have the highest oil reserve in the world, which makes the fluctuations in energy prices irrelevant in the short terms. Also the country's debt to GDP ratio was 13.0% in 2011, which is considered one of the lowest ratios in the world (CIA, 2011).

The other two concepts (Fast International and Classical Horizontal) have almost similar scores; although the fast international is slightly more attractive than the classical horizontal, the classical horizontal requires less amount of effort and is a lower risk than the fast international. This makes it difficult to choose between the different concepts because they almost yield the same results.

The closeness in the scores of those two concepts creates an opportunity to merge those two concepts in a new concept, which can be called "Horizontal & International"

Horizontal & International (H&I)

	Fast International	**Classical Horizontal**	**Horizontal & International**
Organization	International acquisitions(full/partial)	Local businessmen	International acquisitions & local businessmen
Policy	International acquisition policies	Subsides	International policies & subsidies
Strategy	Fast knowledge on technology and process	Steady internal knowledge &capability	Fast tech & process, steady capability
Product	PV: Entire value chain CSP: Entire value chain	PV: Lower products CSP: Raw materials	PV: All value chain CSP: All value chain
Services	Sub-contract to local companies	N/A	Sub-contract to local businessmen
Infrastructure	Slow development	Steady development	Steady development
R&D	International	Local & International	More local

Table 12: H&I Concept

Evaluate the "Horizontal & International" architectural concept

Attractiveness

Category	Sub-Category	%	FI	CH	H&I
Diversify Economy	Complexity level of the technology	20	4	2	4
	Time to enter the market	10	5	2	5
Avail Oil	Avail Oil for Future Generations	20	5	3	3
Create Employment Opportunities	Number of Jobs	10	1	3	4
	Diversified Skill Level	10	2	3	3
Long Term Potential	Sustainable Industry	15	3	5	4
	Future Expansions	15	4	5	4.5
Attractiveness			**3.65**	**3.30**	**3.88**

Table 13: H&I Concept (Attractiveness)

Both the fast international (FI) concept and the horizontal and international architectural concept (H&I) help diversifying the kingdom's economy at a similar level and rate, and therefore, they have the same score.

The H&I concept consumes the same amount of oil as the classical horizontal concept (CH) to run and operate those facilities, and therefore, the H&I has the same score as the CH concept.

The number of jobs creates by H&I is equivalent to the sum of the two concepts; this concept creates job opportunities in Saudi Arabia to build, operate, and maintain the new facilities, and at the same time creates jobs in the international companies to help capturing the international knowledge.

Also, the H&I concept helps diversifying the skill level in a similar fashion to the CH concept and therefore, they both have the same score.

Because the H&I concept is a merger of CH and FI, the long term potential is the average of the two concepts and as a result, the H&I scores 4 and 4.5 in sustainable industry and future expansions respectively.

The H&I concept is more attractive than both HC and FI with a score of 3.88, which is 6.3% more than the fast international and 17.6% more than the classical horizontal. The H&I scores even higher than the most attractive concept "Fast Vertical" by almost 2%.

Effort

Aspect	Dimension	FI	CH	H&I
Org	Financial Cost	5	3	5
	Personnel Cost	2	3	3
	Average	**3.5**	**3**	**4**
Policy	Financial Cost	N/A	N/A	N/A
	Personnel Cost	2	3	3
	Average	**2**	**3**	**3**
Product	Financial Cost	3	2	2.5
	Personnel Cost	N/A	N/A	N/A
	Average	**3**	**2**	**2.5**
Services	Financial Cost	2	N/A	2
	Personnel Cost	2	N/A	2
	Average	**2**	**N/A**	**2**
Infra	Financial Cost	1	3	3
	Personnel Cost	1	3	3
	Average	**1**	**3**	**3**
R&D	Financial Cost	5	2	3
	Personnel Cost	N/A	N/A	N/A
	Average	**5**	**2**	**3**
WF	Financial Cost	3	3	4
	Personnel Cost	2	3	4
	Average	**2.5**	**3**	**4**
Effort		**2.71**	**2.67**	**3.07**

Table 14: H&I Concept (Effort)

The H&I concept requires a high financial investment to establish and acquire organizations and therefore, the organization financial cost is at the highest level. The personnel cost is as high as the classical horizontal cost and therefore, they both have the same score of three.

The H&I concept requires the same amount of personnel effort to establish and set the policies and regulations as the classical horizontal; hence they have the same score of three.

The average product cost in the H&I concept is the average of the two concept, and therefore, the score in the product category is two and half.

The H&I concept uses the FI concept in providing the solar services, and therefore, the H&I score is two.

The H&I concept requires a steady development for the infrastructure in order to host the classical horizontal products, and therefore, the infrastructure score is three.

The majority of the R&D activities in the H&I concept is directed to the local R&D centers in Saudi Arabia, and this reduces the R&D cost. Therefore, the financial cost is three.

The H&I concept requires an extra effort both financially and in personnel to develop and maintain the workforce than the other two concepts, therefore, the score is four.

On one hand, the final H&I score 3.07, which is 15% more than the classical horizontal and 13.3% more than the fast international concept, on the other hand, this new concept requires 27% less effort than the fast vertical concept.

Risk

Stakeholder	Need	Weight	FI	CH	H&I
Technology Provider	Fair legislations for investors	9.30%	4	3	3.5
	Fair enforcement of legislations	8.52%	5	3	4
	Opportunities to generate profit	11.02%	4	4	4
Local Businesses	Incentives	7.85%	1	4	3
Consumer	Easy to deploy	7.88%	3	N/A	3
	Easy to maintain	7.26%	3	N/A	3

	Reduce electric bill	3.78%	1	N/A	1
SEC	Easy to integrate to network	6.44%	3	N/A	3
	Easy to maintain	6.44%	3	N/A	3
	Reliable	8.39%	5	N/A	5
R&Ds	Provide funding	7.99%	1	3	2
	Provide pilot environment	7.99%	1	3	2
	Recruit talent workforce	7.13%	2	3	2.5
Risk (Stakeholders' Acceptance) 50%			**2.92**	**3.32**	**3.14**
Risk (Operational Risk) 50%			**3**	**3**	**3**
Risk (100%)			**2.96**	**3.16**	**3.07**

Table 15: H&I Concept (Risk)

The first step in evaluating the risk of the new concept (H&I) is to evaluate the stakeholders' acceptance, and the results for this evaluation are as follows:

For technology providers, the new concept has average scores for fair legislations, fair enforcement, and opportunity to generate profit. For local businesses, the new concept scores slightly above the average of the two concepts because the potential of setting laws to recommend selling the local raw materials to the acquired companies. For consumers, the new concept is adopting the fast international concept and therefore, they both have the same scores for easy to deploy, easy to maintain, and reduce electric bill. Similarly, the new concept has the same scores for SEC as the fast international, with scores of three, three, five for easy to integrate, easy to maintain and reliable. In the R&D, the new concept scores the average of the two concepts in all R&D needs.

The second step in evaluating the new concept is to evaluate the operational risk, and this concept scores the average of the two concepts, which is three out of five.

The new concept scores 3.07 in the risk angle, which means that this concept is slightly riskier than the classical horizontal (2.8%), but it less risky than the fast international concept by 3.7% and the fast vertical concept by 30.6%

Attractiveness vs. Effort vs. Risk for all four architectural concepts

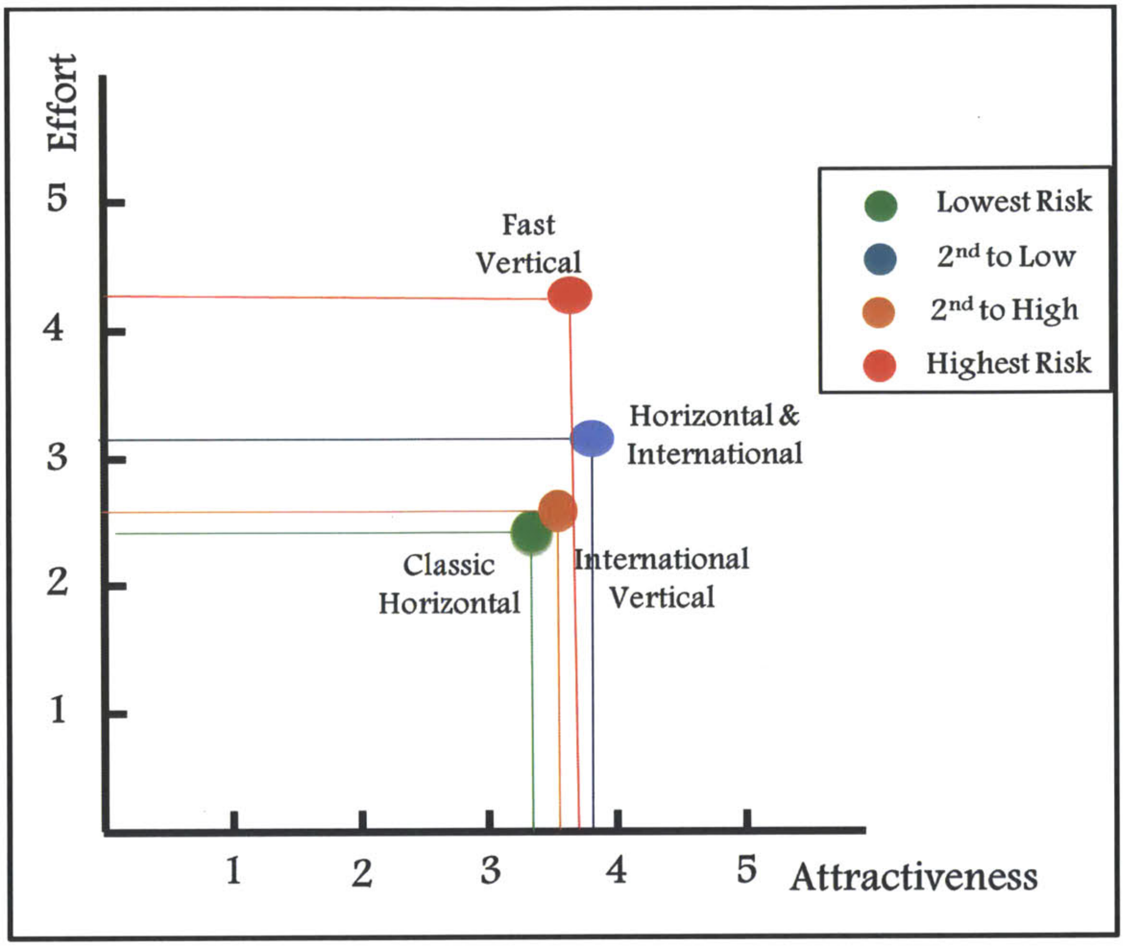


Figure 18: Attractivenss vs. Effort vs. Risk for All Concepts

The new concept (Horizontal and International), which is the merger of the two concepts (fast international and classical horizontal) seems to be the optimal concept because it is the most attractive concept, second to lowest risk, and yet does not require the most amount of effort.

Validating the Winning Architecture

The validation process is designed to ensure the proposed architectural concept is realistic and can be implemented by the different stakeholders.

The **organization** in the new proposal is the group of local companies/ businessmen who are going to invest in the lower products of the solar value chain and/or acquire international companies that have the capabilities to manufacture CSP and VP products. For that to happen, Industrial Cluster and SAGIA should increase their effort to better promote and market the solar manufacturing. MOL should also help by legislating and enforcing laws that favors these companies.

The **policies** in the new concept favor the solar manufacturing by offering subsidies to the local companies and this is the role of MODON and RCJY is to offer subsidies in energy and land while the role of SEPC is to help those companies in financing their facilities.

The **strategy** of the new architectural concept focuses on fast transfer for technology and processes, along with building steady capabilities locally. The role of K.A.CARE is to set laws to force local businesses deploy optimal solutions, which in most cases mean implementing the latest technologies, and the role of local companies is work with the different technology providers to make this strategy successful.

The new concept promotes **producing** the entire solar manufacturing value chain. It also promotes building the local capabilities to provide all the solar **services**. Similar to the strategy component, K.A.CARE should set laws that force local businesses to invest in the entire value chain and work with technology providers to localize the entire products and services.

The new concept does not put a lot of pressure on MODON, IC, and RCJY to prepare **infrastructure** to host the new facilities because building the facilities in this concept is done gradually.

The new concept supports the local **R&D** centers, which puts an extra pressure on those centers to deliver solutions that serve the needs of the different companies in the solar manufacturing.

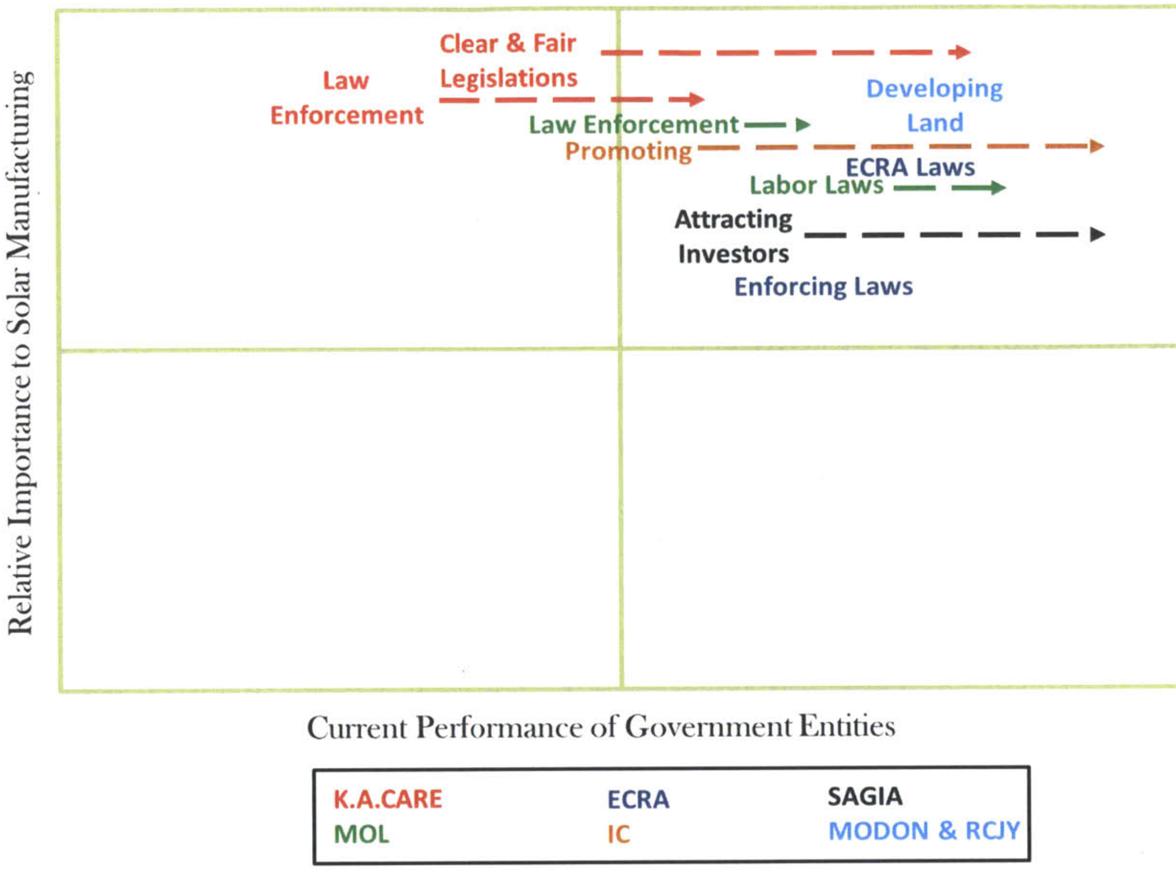


Figure 19: Required effort by Gov. Stakeholders

Implementing the Winning Architecture

The winning architecture is based on building the horizontal industry in the kingdom of Saudi Arabia, and encouraging businessmen to acquire successful international manufacturing companies. From the organization angle, the local manufacturing companies should start manufacturing raw and basic materials immediately in order to gain the necessary knowledge and position themselves in the solar market. They should consider building real-options capabilities in their plants.

The "Real options" concept is building additional capabilities for the facilities in order to mitigate risks. The integration of "real options" analysis changes the design, and helps in evaluating the potential risks and including flexibility in order to overcome those risks. This leads to proactively addressing the risks instead of the classical reactive way. The term "Options" comes from the financial options, which means "rights, not obligations", and the term "Real" means the options are physical rather than financial (de Neufville, 2003).

One way to include the "Real Options" concept is the local manufacturing facilities is to equipped polysilicon facilities with capabilities to produce the high purity polysilicon used in the semiconductor industry. Although this option requires extra investment, it provides the capability for the facility to expand the business and enter new markets.

As for the businessmen who are acquiring solar companies, they need to develop policies and strategies that ensure they do not lose the acquired companies' talents. They should also develop transfer knowledge policies and strategies to slowly build the Saudi knowledge. This could be in the form of "Internship Assignments", and "Cross Knowledge" Programs. Businessmen should also consider, and evaluate the potential of relocating some of the facilities to Saudi Arabia, and this needs to be done as joint efforts between SAGIA, MODON, IC, K.A.CARE, and the investors.

The R&D centers need to increase the emphasis of the solar industry in order to become the attractive destination for the solar manufacturing companies. Those centers need to build stronger ties with the leading solar R&D centers in the world for knowledge transfer. They should create programs to attract talents and high potentials to work for them. They should also establish programs to develop future talents including "Higher Education" programs, and "Field Deployment" assignments to understand the actual reality of the operating facilities, thus linking theory to reality.

During the different strategies development, the decision makers ought to consider the "Real Options" concept and embed it as in the final strategies.

Conclusion

Theory to Reality

This thesis study included four theoretical concepts; these concepts should be used as corner stones for the Saudi solar manufacturing. These concepts are:

The Relation between Market Maturity and the Number of Firms

This study showed that the market for solar manufacturing is heading towards maturity, and this makes the window of opportunity for Saudi companies to venture into solar smaller. Therefore, Saudi Arabian companies need to move fast in order to position themselves in this market.

Workers' Vicinity and Communication Frequency

Communication in the workplace is one of the most important aspects for the success of any enterprise, and currently, there is no clear entity sponsoring the Saudi solar manufacturing. The Sustainable Energy Procurement Company (SEPC) could be the government body responsible for everything related to Saudi solar manufacturing, hence creating a strong link between all government organizations dealing with solar manufacturing.

Product and Process Innovation

The solar manufacturing market is heading towards maturity, which means the different solar companies have almost developed the "Dominant Design". This means that Saudi companies need to heavily invest in process innovation to produce cheaper and more reliable products than their competitors.

Real Options

Building additional capabilities throughout the entire vale chain of solar products helps the solar companies reduce the overall risks of failure. Although building these capabilities requires additional investment in the beginning, they ensure sustainability for longer periods of time.

The Research Framework

Overall, the Enterprise Architecture Framework helped in understanding the challenges of the solar manufacturing and creating solutions to overcome these challenges. The following, summarizes the major benefits of using the Enterprise Architecture Framework in this study:

- The framework helped in creating a roadmap to understand and solve the different challenges.
- The different view elements helped in understanding the challenges holistically.
- The Need/Relative Importance diagram, the Stakeholders' Salience diagram, and the Stakeholders' Interaction map are great tools that present the current reality of the enterprise.
- The Attractiveness/Effort/Risk diagram helped in analyzing the different solutions to select the suitable solutions for the different challenges.

Although the framework was very helpful for this thesis study, there is always room of improvement. Based on my experience with the Enterprise Architecture framework, the following ideas and observations might help in improving this framework:

- Understanding the enterprise landscape and shareholders' values are very important steps and can't be changed throughout the study, therefore, I think it would better to keep them as the first step in the sequence model, and remove ecosystem, and shareholders from the ten view elements.
- I recommend developing internal work processes and/or checklists for the solution validation and solution implementation.

Future Research

The research study shows area for future studies related solar manufacturing and solar generation in the Kingdom of Saudi Arabia. These studies include:

- Detail the implementation plan for the entire value chain using the "Real Options" concept in order to reduce the risk of implementation and increase the chances of implementation success.
- Architect the new proposed enterprise "Sustainable Energy Procurement Company" using the Enterprise Architecture Framework to align this enterprise with the needs of the stakeholders.
- Develop a system dynamics model to study and analyze the benefits of solar manufacturing and solar generation on water distillation in Saudi Arabia.

- Develop a system dynamics model to study the effect of solar manufacturing on the current and future employment opportunities for the citizens of Saudi Arabia.
- Develop a system dynamic model to study, analyze, and identify the optimal government incentives to attract investors to venture into Saudi solar manufacturing.
- Evaluate strategies to attract users to use higher efficiency equipment using system dynamics, and economic analysis.

Appendix A: List of Pilot Projects by ERI

Project		Location	Date	Intent
1.	350 kW PV System	Solar Village	1981-87	DC/AC Electricity for Remote Area
2.	350 kW PV Hydrogen Production Plant	Solar Village	1987-93	Demonstration Plant for Solar Hydrogen Production
3.	Solar Cooling	Saudi Universities	1981-87	Developing of Solar Cooling Laboratory
4.	1 kW Solar Hydrogen Generator	Solar Village	1989-93	Hydrogen Production, Testing & Measurement Laboratory Scale
5.	2 kW Solar Hydrogen	KAU, Jeddah	1986-91	Testing of Different Electrode Materials for Solar Hydrogen Plant
6.	3 kW PV Test System	Solar Village	1987-90	Demonstration of Climatic Effects
7.	4 kW PV System	South of KSA	1996	DC/AC Electricity Remote Areas
8.	6 kW PV System	Solar Village	1996-97	Grid connection
9.	PV Water Desalination ($0.6\ m^3$/hour)	Sadous Village	1994-96	PV/RO Interface
10.	PV in Agriculture (4 kWp)	Muzahmia	1996	DC/AC Grid Connected
11.	Long-term Performance of PV (3 kW)	Solar Village	1990	Performance Evaluation
12.	Fuel Cell Development (100 - 1000 W)	Solar Village	1993-95	Hydrogen Utilization
	Internal Combustion	Solar Village	1993-95	Hydrogen Utilization

13.	Engine (ICE)			
14.	Solar Radiation Measurement	12 stations	1994-95	Saudi Solar Atlas
15.	Wind Energy Measurement	5 stations	1994-95	Saudi Solar Atlas
16.	Geothermal Power Assessment	Different locations	1995-96	Establishment of Accurate Data
17.	Solar Dryers	Hassa, Qatif	1988-93	Food Dryers (dates, vegetables)
18.	Solar Thermal Dishes (2x50 kW)	Solar Village	1986-94	Advanced Solar Stirling Engine
19.	Energy Management in Buildings	Dammam	1988-93	Energy Conservation
20.	Solar Collectors Development	Solar Village	1993-97	Domestic, Industrial, Agricultural

Appendix B: List of Industrial Cities in Saudi Arabia

Industrial City	Major Existing Industries	# of Factories
Sudair	Under development	N/A
Jeddah 2nd	Under development	N/A
Kharj	Under development	N/A
Al-Madinah	Metals, Jewelry, Medicine, Steel, Plastic	10
Tabuk	Metal, Food	9
Ha'il	Food, Metal, Chemical	11
Jazan	Under Construction	N/A
Riyadh 1st	Plastic, Metal, Glass, Paper	54
Riyadh 2nd	Food, Metal, Chemical	1,050
Jeddah 1st	Food, Metal, Chemical	552
Dammam 1st	Metal, Chemical	80
Dammam 2nd	Food, Metal, Chemical	298
Makkah	Food, Metal, Textile & Clothing	60
Al-Qassim 1st	Food, Pharmaceutical, Plastic	43
Al-Jouf	Industrial investment	N/A
Alhsa 1st	Food, Plastic, Paper	52
Riyadh 3rd	Partnership with General Directorate of Prisons	N/A
Najran	Industrial investment	N/A
Assir	Food, Metal, Chemical	35
Ar'ar	Industrial investment	N/A
Shaqraa	Under Construction	N/A
Al-Zulfi	Under Construction	N/A
Al-Taif	Under Construction	N/A

References

Abu-Sharkh, B. (2012). Solar PV value chain- development and localization. *Fourth Saudi Solar Energy Forum,* Riyadh, Saudi Arabia.

ACWA Power. (2012). *ACWA power.* http://www.acwapower.com/ (visited July 2012)

Alahmed, K. (2012). Aggregate model and analysis of the energy dynamics in the kingdom of saudi arabia. *MIT- SDM thesis,* Cambridge, MA, USA.

Al-Gain, M. (2012). Role of solar in K.A.CARE renewable procurement program. *Fourth Saudi Solar Energy Forum,* Riyadh, Saudi Arabia.

Allen, T. (1977). *Managing the flow of technology*. USA: MIT Press.

Al-Mureeh, A. (2012). Local content paradigm. *Fourth Saudi Solar Energy Forum,* Riyadh, Saudi Arabia.

Al-Sulaiman, K. (2012). Solar energy; A pillar of the sustainable energy kingdom. *Forth Saudi Energy Forum,* Riyadh, Saudi Arabia.

Ardani, K., & Margolis, R. (2011). *2010 solar technologies market report*. Department of Energy:

Asali, K. (2012). PV thin film technology- energy yield in desert climates. *Fourth Saudi Solar Energy Forum,* Riyadh, Saudi Arabia.

Bkayrat, R. (2010). Advanced solar power plant: Pilot project development at KAUST.

Bourland, B., & Gamble, P. (2011). *Saudi arabia's coming oil and fiscal challenge*. Riyadh, Saudi Arabia: Jadwa Investment.

Business Monitor International. (2011). Industry trend analysis - plans to switch to solar and nuclear, but thermal reigns in the kingdom. *Business Monitor International,*

CIA. (2011). *The world fact book.* https://www.cia.gov/library/publications/the-world-factbook/rankorder/2186rank.html (visited August 2012)

de Neufville, R. (2003). Real options: Dealing with uncertainty in systems planning and design. *Integrated Assessment, 4*, 26.

ECRA. (2012). *Electricity and cogeneration regulatory authority.* http://www.ecra.gov.sa/ (visited June 2012)

El-Yousfi, A. (2012). Investment in polysilicon production. *Fourth Saudi Solar Energy Forum,* Riyadh, Saudi Arabia.

Gallego, B. (2010). *AZMEEL international are gold sponsors of MENASOL 2010.* http://social.csptoday.com/emerging-markets/azmeel-international-are-gold-sponsors-menasol-2010-and-ceo-sheikh-abdulrahman-bin- (visited July 2012)

Gereffi, G., & Dubay, K. (2009). Concentrating solar power clean energy for electric grid. (pp. 52). Duke University: Center on Globalization Governance and Competitiveness.

Hepbasli, A., & Alsuhaibani, Z. (2011). A key review on present status and future directions of solar energystudies and applications in saudi arabia. *Renewable and Sustainable Energy Reviews,*

Huraib, F., Hasnain, S., & Al-Awaji, S. (2000). Lessons learned from solar energy projects in saudi arabia. *King Abdullah City for Science and Technology,*

IDEA. (2012). *IDEA polysilicon.*http://www.idea-polysilicon.com/ (visited July 2012)

Industrial Clusters. (2012). *Industrial clusters.*http://www.ic.gov.sa/ (visited August 2012)

KACARE. (2012). *King abdullah city for atomic and renewable energy.*http://www.energy.gov.sa/ (visited June 2012)

KACST. (2012). *King abdul-aziz city for science and technology.*http://www.kacst.edu.sa/en/Pages/default.aspx (visited June 2012)

KAPSARC. (2012). *King abdullah petroluem study and research center.*http://www.kapsarc.org/kapsarc/Default.aspx (visited June 2012)

KAPSARC, & Lahmer International. (2011). *Solar energy incentives in KSA*. Saudi Arabia: KAPSARC.

Kushiya, K. (2012). Cu(in,ga)Se2-based thin-film PV technology in the giga-watt production era. *Fourth Saudi Solar Energy Forum,* Riyadh, Saudi Arabia.

MOL. (2012). *Ministry of labor.*http://mol.gov.sa/ (visited July 2012)

Nightingale, D. & Rhodes, D. (2012). ESD.38 Enterprise Architecture Lecture Notes. Massachusetts Institute of Technology (MIT), Cambridge, MA, USA.

NREL. (2012). *National renewable energy lab.* http://www.nrel.gov/ (visited April 2012)

NSS. (2012). *National solar systems.* http://www.national-solar.net/ (visited July 2012)

Padmanathan, P. (2012). Parabolic trough concentrated solar power plants. *Fourth Saudi Solar Energy Forum,* Riyadh, Saudi Arabia.

Platzer, M. (2012). *U.S solar photovoltaic manufacturing: Industry trends, global competetion, federal support* No. R42509)Congressional Research Service.

RCJY. (2012). *Royal commission of jubail and yanbu.* http://www.rcjy.gov.sa/en-US/Pages/default.aspx (visited June 2012)

Rhodes, D., Ross, A., & Nightingale, D. (2009). Architecting the systems enterprise: Enabling constructs and methods from field of engineering systems. *IEEE International Systems Conference,* Vancouver, Canada.

Saudi arabian general investment authority. (2012). http://www.sagia.gov.sa/en/Why-Saudi-Arabia/A-Commitment-To-The-Best/Industrial-Cities/ (visited June 2012)

Saudi industrial property authority. (2012). http://www.modon.gov.sa/English/AboutUs/Strategy/Pages/default.aspx (visited July 2012)

Saudi national industrial strategy(2008). Ministry of Industry and Commerce.

Utterback, J. (1994). *Mastering the dynamic of innovation*. USA: Harvard Business School.

Wolff, C. (2012). Concentrated solar power: Modular fresnel collector technology. *Fourth Saudi Solar Energy Forum,* Riyadh, Saudi Arabia.