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Assessing Photovoltaic Solar Technologies as a Solution for the Problem of Power Shortage in Iraq

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***Abstract*--In a developing country like Iraq, where the infrastructure of the electricity public sector (production, transportation, and distribution) has suffered for a long time from the direct effects of successive wars; lack of technocracy; bureaucracy; neglect; massive corruption; and much more, have all contributed to the failure of this sector. Indeed, the electricity sector in Iraq has not been developed for more than forty years; or even properly rehabilitated and/or maintained its facilities, which has led to a huge gap between the demand and supply (demand is double than the supply). It is obvious that the alternative solutions that have been proposed and implemented since 2003 have not become a solution that could fill even a small portion of the gap. In this paper, a proposed solution that seemingly has never been given a chance to be put on the table by both private and public sectors will be discussed. An assessment for photovoltaic solar panels technologies as an effective, viable, and quick solution for the infrastructure and demand problem was conducted using the Hierarchical Decision Model (HDM) as a methodology to assess the most efficient, and affordable candidate technologies relevant to all the valid perspectives and criteria.**

I. Introduction

Although the problem of power shortage in Iraq has the root causes since the Gulf war in 1990-1991, where 75% of Iraq's 9,300 MW installed capacity was damaged, leaving only 2,300 MW available at the end of the war [1]. However, the problem itself has been largely augmented after the war in 2003, followed by the civil and political conflict and instability in the entire country. The main causes of the problem augmentation haven't been directly related to the war of 2003 itself, but in fact, it was related to the consequences of that war such as the acts of intentional damages. Despite that, the literature on this complex problem is very limited, however, some of the problem's root causes were diagnosed as an inadequate and very poor planning for rebuilding the country pre and post-the war of 2003[1]. Besides, the lack of the proper preparations of the entire system for the frequent shifts in the strategies, which were considered as the major factors in impeding the rebuilding of the electricity sector even to pre-war levels. In addition, the electricity sector has been facing other major problems such as; the lack of security as it has been a factor for destabilizing the electricity supply. Indeed, both the Coalition troops and Iraqi forces since 2003 have struggled to provide the required guarding for the power plants, while electricity production increased above pre-war levels, with outputs averaging 4,400 MW per day [1]. Albeit the Iraqi ministry of electricity claimed to work on preparing a master plan to improve the electricity system (production, transmission, and distribution) since then, however, demand continued to exceed supply and expected to surpass the production capacity for the next twenty years (or perhaps more). Moreover, according to one of the reports that published on Al-Monitor website, the spending of the Iraqi government to enhance the insecure power system was about $41.5 billion during 2004-2012, including $17 billion were spent on upgrading the existing power stations and setting up new generators [2]. Unfortunately, talking about public money spending on this sector, one should remember that Iraq has been ranked as one of the worst countries based on the corruption perception index for 2016 by transparency international [3]. Iraq was ranked as 166/176 with a score of 17 [3]. Taking into the consideration that Iraqi citizens have spent approximately $80 billion on buying private power generators to provide their homes and small commercial entities with the basic requirements for electricity [1, 2].

In this paper, I suggest a solution that I believe it's going to solve a portion of the problem, particularly the gap between the demand and supply of the electricity in Iraq. This gap has been identified as of 2011 (official report) as a shortage of supplying at least 6000MW [4]. I believe that the Photovoltaic solar panels can play an outstanding potential, quick and relatively smooth solution for this problem. This study will encompass a review of the available literature on both the problem and the proposed solution. Besides, the study will identify the potential criteria as major factors in creating the gaps of the overall situation, analyze these gap(s) to determine the technology candidates (Photovoltaic Solar Panels), and use the expert's panels to help with the basic validation of these criteria, weighting and judging them relatively to a STEEP model perspectives (Social, Technical, Economic, Environmental, and Political). In this research, I'm going to use an open source software of the Hieratical Decision Model (HDM) created by the Engineering and Technology Department of Portland State University. The expected outcome of this methodology is an analysis that facilitates the decision-making process in selecting the most ranked potential technology candidate among the alternatives, as well as framing out the focus on the most ranked perspectives and criteria. Taking into the consideration the wide range of different kinds of photovoltaic technologies available in the market, where the scope of this researcher is to select and evaluate the top three candidates that fit for the situation of Iraq in terms of country solar conditions, regulations and policies, market adoption, environmental aspects and other factors. Basically, the candidate technologies that are going to be ranked would be Crystalline Silicon (C-Si), Cadmium telluride photovoltaics (CdTe), Copper Indium Gallium Selenide (CIGS) [5]. The process of assessing this

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technology would be explained in detail as in the following sections of the research.

II. Literature Review

A. Electricity Shortage in Iraq

The electricity's production, transmission, and distribution in Iraq has been since the beginning till now owned and managed by the government (i.e. the ministry of electricity). It is almost fifteen years today since the war in 2003, while the people of Iraq still forced to live with very limited power supply. Although Iraq is the second largest oil producer in OPEC [6], and one of the world's largest oil reserves, however, the energy sector continues to face serious issues. As shown in Figure 1 below, the demand for power in Iraq was estimated at 15000MW in 2010, but supply had met only 9000MW [4, 7]. Currently, most Iraqis are having electricity that runs five to eight hours a day at best. The problem is clearly insufficient supply rather than excessive consumption. In addition, the electricity situation in Iraq has resulted in massive consequences. It has affected many important aspects of life such as; health, education, and economic. In fact, this persistent shortage of electricity is estimated to have caused around $40 billion in annual losses [1]. However, there are many reasons why there is a huge power shortage in Iraq. In addition to the weak and inefficient infrastructure, there is a massive corruption [8], improper management, poor energy policies, and the lack of appropriate strategic planning [7]. This problem is seeming to continue as the population growth continues, and the demand for electricity continues to increase as well. In fact, Iraq population is expected to reach 55.85 million by 2030 [1,7] and the forecasted demand for electricity is expected to be more than 60000MW [7] during the same year. This increase the need to find another means to generate electricity with higher efficiency, lower cost, shorter time of installation and production, as well as to a cleaner source of energy [9].

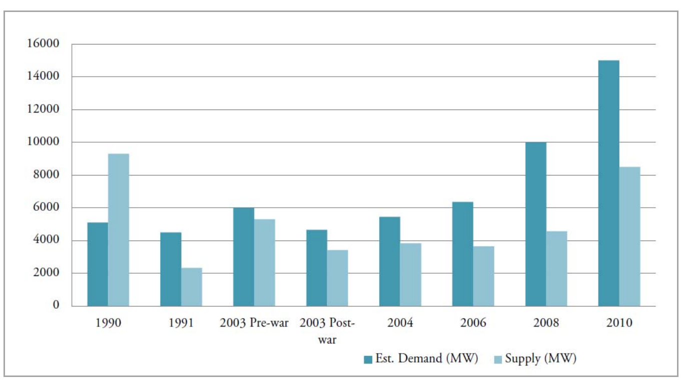

Figure 1-Power Demand and Supply in Iraq (1990-2010), Source [1]

B. Photovoltaic (PV) Technology

Solar energy is a boundless energy source. The sun provides a massive amount of radiation that can be collected and converted to heat and electricity [5, 10]. There are many types of solar energy technology such as hybrid and photovoltaic, where electricity can be produced directly from photovoltaic (PV) cells. It is an increasingly important alternative source of utility power that serves many different applications, and it is expected to make (11%) of the total global electricity by 2050 [11]. PV cells are made from various materials but, the first PVs were made of silicon semiconductors within solar cells that observe sunlight. The photons of light excite the electrons in the cell and cause them to flow, generating electricity [12]. Scientists at national labs are experimenting with organic materials and "quantum dots" to achieve this process, yet most PV panels are still being made with crystalline silicon [13]. Thin-Film Photovoltaic is known as the next generation of PV due to their thinner and lighter weight, and less expensive material [12]. Furthermore, other types of photovoltaic material (amorphous silicon, copper indium selenide (CIS), cadmium telluride (CdTe), and gallium arsenide (GaAs)) can be used. Concentrated Photovoltaic (CPV) is the newer type of electricity production. It uses optics to focus the sun's power on small high-efficiency and multi-junction solar cells [13]. Using high-efficiency, small solar cells paired with less expensive optics made from glass or acrylic allows for a reducing the amount of expensive semiconductor material while detaining higher performance. The resulting solar modules are highly efficient and consent the generation of electricity at a lower cost than traditional silicon solar panels [13].

C. PVs Technologies for the Situation of Iraq

Iraq has in nature an abundant sunshine around the year. Its weather validates the fact that this country is the suitable place for solar energy. As it is known, the output of the PVs solar technologies depends on how much sunlight they get. In any region where sunlight is sufficient enough around the year, the feasibility to use solar technologies is high. In fact, the intensity of solar in Iraq ranges from 416 W/m to 833 W/m between January and June [14], which indicates a high solar intensity. Moreover, solar PVs energy provides a clean and more environmental friendliness energy source, especially that the emission from the consumption of fossil fuel has risen the CO_2 content from 52 MMT in 1980 to around 142 MMT in 2015, noticing that the CO_2 content is taking an upward streaming over time, as shown in figure 2 below.

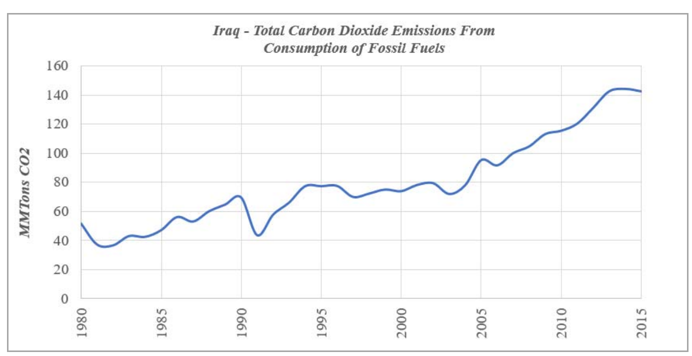

Figure 2-CO2 Total Emissions in MMT-Adapted From [38]

Therefore, considering clean energy sources is crucial to solving both power shortage and other environmental issues in this country.

III. Research Methodology

As graphically illustrated in Figure 3, the research process and design include the use of multiple methods; literature review, expert panels, and gap analysis. However, the Hierarchical Decision Modeling (HDM) is used as the main methodology to conduct the analysis and rank the technology candidates (i.e. assessing the selected perspectives and criteria). Each of these methods including the HDM methodology will be discussed in the following sub-sections.

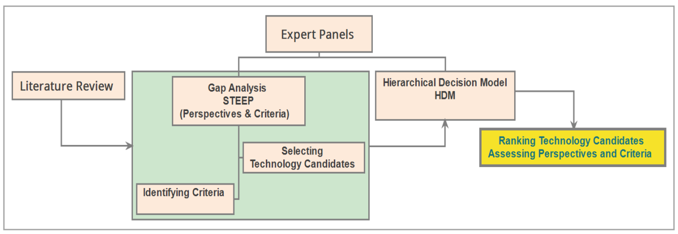

Figure 3 – Research Process and Design

A. Literature Review

The first step in this research is to conduct a literature review on both of the problem of power shortage in Iraq, and the appropriateness of photovoltaic technologies as discussed in the previous sections. Literature review was also used as a foundation in analyzing the gaps (STEEP: perspectives and criteria), selecting technology candidates (PV types), and identifying the criteria required to narrow down the number of alternatives, which will be discussed later in details.

B. Expert Panels

The use of expert panels is for two purposes. First, to validate the outcomes of the literature review in analyzing the gaps, identifying the criteria and selecting the technology candidates. Second, the expert panels are a crucial method in this research in judging and weighing the STEEP hierarchical decision model HDM in ranking the selected technology candidates.

C. Gap Analysis

Gap analysis is a significant method to assess the current situation and define desirable and plausible future plans. Furthermore, gap analysis provides assessment for the current capabilities that help to accomplish the research goals. It covers the requirements that are needed to close the gaps between the current and desired situations [16]. The process of the gap analysis will be discussed in three aspects;

1. Identifying the desired situation.
2. Analyzing the current situation.
3. Defining the gap closure.

The process of selecting the perspectives and technological alternatives is based on the result of the gap analysis. Gap analysis helped in identifying the major criteria and factors in the current situation. These criteria are covered by STEEP. As a result, STEEP perspectives were chosen to have multiple criteria model. Furthermore, the technological candidates were narrowed down based on a comparison of five criteria; technicality, cost, maturity, environmental side effects, and efficiency. Expert panels were used to assure that the selected criteria were valid for comparison. In fact, expert panels reached a consensus to narrow down the technology candidate considering the findings of the gap analysis.

D. Hierarchical Modeling

The third step in this research is to conduct the judgments of the expertise through Heretical Decision Model (HDM) to select the optimal PVs technologies with respect to a given objective. HDM uses multi-criteria that are considered impactable in the alternatives selections process. This tool uses experts' judgment to prioritize the importance or contribution of each perspective with respect to the objective. Moreover, criteria are weighted by experts through a pairwise compression technique with respect to the given perspectives or other criteria [16]. Pairwise comparison is an expert's' judgments estimation technique, by which experts' estimations of the relative importance with respect to the upper level interprets through ranking pair criteria or elements from 0 to 100. Zero means it does not have any relative importance to the upper level, whereas, 100 indicates the absolute relative importance to the upper level [16]. The nature of Heretical structure creates an easily understandable interconnectedness in the impact. However, the qualifying process is complex and difficult to manage. Therefore, using HDM software is crucial to enable experts to perform the ranking process in the most effective and convenient way [16]. Another benefit of this software is to help in calculating and normalizing the weights and providing the inconsistency and disagreement ratios. Disagreement rate indicates how much respondents' weights do not agree with each other. Experts' judgments agreement means that they have the same judgment. In this case, the disagreement ratio is zero. Whereas, one indicates there is huge disagreement between the experts' judgments. When the disagreement rate is more than 0.1, it means that the experts have a considerable disagreement between the importance and relative contribution of the criteria and perspectives regarding the objective [17]. Furthermore, inconsistency rate can be provided, where the standard acceptable rate is less than 0.1. More than 0.1 indicates that the quality of judgment should not be considered or is below the standard acceptable rate [18].

IV. Defining STEEP Perspectives and the Criteria

A. Social Perspective

This perspective consists of the criteria that have positive and/or negative impacts on society, including public perception, employment, health and safety. Each of these criterion is discussed as follows;

1) Public Perception

Public perception can be identified as the aspect of the truth which is shaped by popular opinion, media coverage, or reputation [5]. It represents the social acceptance of the technology. There has been a tremendous amount of studies on reducing the environmental impacts associated with the energy sector. Renewable energy sources such as solar energy have been prompted as solutions to the environmental impacts [19]. Thus, increasing people awareness regarding the solar energy is crucial to the success of such projects [20].

2) Employment

Employment in this context is referring to job creation, availability of workforce, and poverty mitigation [5]. The solar industry, like any new industry is expected to create new job opportunities, especially that the unemployment ratio in Iraq is about (15.01%), which is considered high [7, 15]. Therefore, this criterion can highly influence the decision-making process regarding this technology [21].

3) Health and Safety

Health and Safety characterize the public well-being of the individuals, families, society, and the workplaces, which are a major concern by both governments and societies [5]. The criterion of health and safety plays an important role in assessing any technology, particularly it emphasizes the prevention of long-term hazardous and health effects [22].

B. Technical Perspective

In this context, technical perspective is referring to the accumulated knowledge, skills, experiences, and organizational base, which enable organizations to acquire, develop and use technology to achieve competitive advantage [23]. This perspective consists of; developed R&D, resources, operations, and deployment and maintenance.

1) Developed R&D

This criterion includes the technological position, R&D resources, R&D manpower, and R&D experience. It has a high technical mastery depends on the access to knowledge on needs, ability to acquire technologies, implementation and effective use of technologies, using lessons learned from experience to further technological change capabilities [23].

2) Recourses

Resources is referring to the ttechnical sustainability, which depends on (1) accessibility of component parts, (2) availability of required infrastructure, (3) availability of technical know-how required to accomplish such service, and (4) the elapsed time between repairs [24].

3) Operations

Operations refer to how smooth the operations of manufacturing of renewable energy sources. This can include production capacity, production process complexity, ability to leverage well-known processes, production waste management, line breakage, and production maturity [5].

4) Deployment and Maintenance

Deployment includes field performance, service availability, the effects of power purchase agreements (PPAs), impact on meeting important national energy targets, suitability for installations in buildings, auxiliary storage, transmission, and distribution" [5]. However, maintenance refers to the required frequent, emergent, programmed and preventive maintenance operations.

C. Economic Perspective

This perspective refers to the economic impacts of the target technology in terms of market adoption, product cost, and Tariff cost.

1) Market Adoption

The process of accepting and adopting the PVs technologies in a particular market. Some PVs technologies are rejected, whereas the others have the potential to penetrate the market of Iraq.

2) Product Cost

Product cost is referring to the cost of producing one Megawatt per hour, which varies depending on the type of the used PVs technologies.

3) Tariff Cost

It is the cost of selling a unit of electricity assigned by the government, wherein the case of Iraq, it is defined by the ministry of electricity. The tariff rate in Iraq is currently among the lowest globally, where the collection rates are below 30 percent or less of the billed amounts [1].

D. Environmental Perspective

This perspective seems to be one of the crucial and logical aspects to assess technologies, since there is a growing concern regarding the environment and its sustainability [6]. This perspective includes criteria of pollution, and technology end life cycle.

1) Pollution

Solar energy is an alternative to coal and fuel energy as it is a non-polluting, clean, reliable and renewable source of energy. There's no smokestack or pipe from the solar collectors, so it doesn't pollute the air or water. A major advantage is the fact that solar panels generate no greenhouse gases. According to the National Renewable Energy Laboratory, each household that switches may stop 7.7 tons of toxic greenhouse gases from being released [8]. Making the switch to solar energy has a healthy impact on the environment.

2) Technology End Life Cycle

Recycling is a noteworthy factor in any technology. In many processes of technology assessment, the environmental aspect where the recyclability of technology takes place is a crucial criterion to evaluate whether the technology is green or not. Solar energy is regarded as a green technology, but what happens to solar panels once they reach the end of their lifetime is shaping a thoughtful apprehension. Despite that the positioning of PV technology has grown vividly in recent years and has been resulting in a new form of electronic waste to the planet, there is no program to recover and recycle the precious metals and material that go into manufacturing this technology. Recycling of solar panels suffer because there is a lack of international standards and end-of-life infrastructure, and there aren't enough non-operational solar panels to make recycling them economically attractive [10].

E. Political Perspective

This perspective reflects the acceptation, adoption and impacts of the politics to the photovoltaic technology and includes the criteria of easiness to fit the regulations and political perception of energy.

1) Easiness to Fit the Regulations

Iraq's commercial and civil laws generally fall short of international norms. There are few requirements regarding commercial competition. The National Investment Law (NIL) does not establish a full legal framework governing investment. Furthermore, potential investors still face laws, regulations, and administrative procedures that continue to make Iraq's overall regulatory environment is relatively opaque. The National and Provincial Investment Commissions (NIC) and (PICs) have been active in assisting regional investors. However, NIC and PIC Commissioners and their staffs lack training and expertise and are still building their operations to ease investors' entry into the Iraqi market. As the government continues the path to decentralization, local authorities could gain influence over local tendering and procurement. Local provincial staff similarly lack capacity and training to implement and enforce complex commercial regulations [25]. Additionally, regulatory standards are not clear about renewable energy, including PVs. Therefore, each type of PVs can receive different regulatory conditions to be proven. Therefore, the easiness to meet the regulatory requirements is critical in selecting the PVs technologies.

2) Political Perception for Energy

The poor performance of Iraq's electricity sector is not uncommon with vertically integrated utilities. This is closely connected to Iraq's lack of strong legal, regulatory, political, and economic institutions since the 1990s, particularly since the UN economic sanctions. In addition to the prevalent of the irregularities, bureaucracy, corruption, low efficiency, and unfair policies. These were further augmented post 2003 by the political conflict, which detached any autonomy from the electricity sector, particularly when the ministry of electricity was re-formed in 2004. There is a general view among Iraqi decision-makers that keeping the electricity sector within its authority will serve most people since it has immense social, political, and economic importance. Thus, economic reformation such as removal of subsidies on oil, electricity, and food will be faced with intense opposition among many Iraqis and might cause widespread demonstration or destabilization of the already fragile political progression. Moreover, privatization of the public enterprises, might put hundreds of thousands of public services employees out on the street without jobs [1].

V. Gap Analysis

To analyze the gaps and define the current and desired conditions of the power system in Iraq, a STEEP analysis is used based on the definitions and explanations of the previously discussed perspectives and criteria. The process of the gap analysis is explained in the following sub-sections;

A. Social

The social perspective comprises public perception for PV technologies, employment, and health and safety. Regarding solar photovoltaic technologies, people have a limited understanding and perception, however, through various media, the public awareness can be enhanced. The solar market as an emergent market can open new opportunities for work and therefore can reduce the significant problem of unemployment. Furthermore, generating electricity from solar technologies is expected to improve the health and safety of Iraqi people. Table 1 below summarizes the gaps analysis of the social perspective.

Table 1 - Gap Analysis - Social Perspective

Requirements	Capabilities	Gaps
▪ Public perception	▪ Low	▪ Should be increased through multiple means such as the use of media and social networking platforms
▪ Employment	▪ Low	▪ Opening new jobs
▪ Health & safety	▪ Low	▪ Strengthening the awareness towards health & safety

B. Technical

The technical perspective includes the developed research and development (R&D), operations, and deployment and maintenance. The condition of Iraq in the case of resources is relatively better than other technical factors. In order to improve the R&D, operation, and deployment and maintenance of solar photovoltaic technologies, Iraq must try to invest in R&D, technical training, and development. Table 2 below summarizes the gaps analysis of the technical perspective.

Table 2 - Gap Analysis - Technical Perspective

Requirements	Capabilities	Gaps
▪ Developed R&D ▪ Resources ▪ Smooth operations ▪ Deployment and maintenance	▪ Low ▪ Medium ▪ Low ▪ Low	▪ More R&D works required ▪ Increase technical training, enhance the personal skills, and developments

C. Economic

The economic perspective includes market adoption, product cost, and tariff cost. The market adoption of PV technology is obviously low, which requires more market research and intensive marketing approaches. In addition, power cost is relatively high, which is requiring a plausible reduction to meet the household's affordability in one hand and the make of enough profit margin for the producers on the other hand. Table 3 below summarizes the gaps analysis of the economic perspective.

TABLE 3 - GAP ANALYSIS - ECONOMIC PERSPECTIVE

Requirements	Capabilities	Gaps
▪ Market adoption ▪ Power cost (affordability) ▪ Tariff cost	▪ Low ▪ Expensive ▪ Low	▪ Requiring more focused market research and analysis ▪ Reducing cost of the product to be below the tariff cost ▪ Needs to be increased to ensure a balance of prices

D. Environmental

As discussed before, the environmental perspective includes pollution and technology end life cycle. The pollution rate in Iraq is considered very high, which must be reduced to meet the global standards. To protect the environment, the regulations must enforce people and industries to follow the standardized recycling processes and enforce investors to use recycled materials. Table 4 below summarizes the gaps analysis of the environmental perspective.

TABLE 4 - GAP ANALYSIS - ENVIRONMENTAL PERSPECTIVE

Requirements	Capabilities	Gaps
▪ Pollution ▪ Technology end life cycle	▪ Very High ▪ Low	▪ Needs to be reduced by using eco-friendly power generation sources ▪ Using recyclable or green materials and train people on recycling processes

E. Political

The political perspective encompasses the easiness to fit the regulations and political perception of energy. However, easiness to fit the regulations is not clear, and therefore, not executable and requiring more efforts for clarification. Politicians should have more understanding regarding PV technologies. Table 5 below summarizes the gaps analysis of the political perspective.

TABLE 5 - GAP ANALYSIS - POLITICAL PERSPECTIVE

Requirements	Capabilities	Objective(s)
▪ Easiness to fit the regulations ▪ Political perception of energy	▪ Available, but not clear ▪ Complicated and varies based on each area	▪ Requiring dedicated efforts to establish clear policies and regulations ▪ Increases awareness and encourages the adoption of green and renewable energy sources

VI. TECHNOLOGY CANDIDATES

The research on PV technologies reveals that there are more than 250 different types in the market [5]. The United States National Renewable Energy Laboratory NREL for 30 years has maintained, validated, and updated the PV generation chart. The NREL's chart shows that the research on PVs led to produce multiple technologies and their generation as well. According to the chart, figure 4 below, the trend is directed to the use of efficient, low-cost and environmentally friendly technologies.

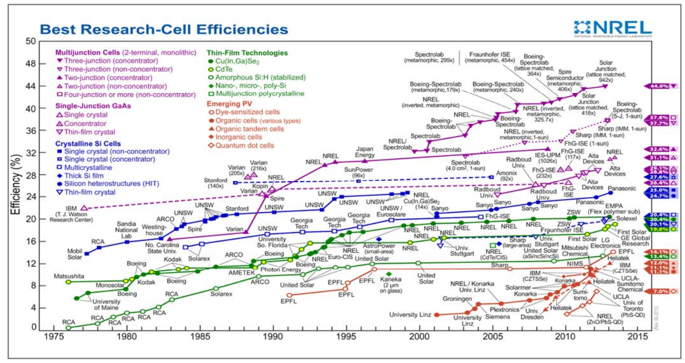

Figure 4-NREL PV chart of Efficiency, source [5]

This research adopts the best five PV technologies based on the higher efficiency [5]. These five technologies are Crystalline Silicon (C-Si), Cadmium telluride photovoltaics (CdTe), Copper Indium Gallium Selenide (CIGS), Amorphous silicon Solar (A-Si), and Organic Solar Cell (OPV). Further on, these five candidates were evaluated considering other criteria including: efficiency, cost, environmental effects, durability, technicality and maturity. The evaluation result reports a low efficiency and high product cost in two of these five candidates, namely Amorphous silicon Solar (A-Si), and Organic Solar Cell (OPV). Therefore, these two PVs were eliminated, and the research thus, assesses the remaining top three PV solar technologies available in the market that suite the goal of building a PV solar farm station; Crystalline Silicon (C-Si), Copper Indium Gallium Selenide (CIGS), and Cadmium Telluride Photovoltaics (CdTe). Each of which is summarized based on the selected criteria as follows.

A. Crystalline Silicon (C-Si)

It is the crystalline forms of silicon and is the dominant semiconducting material used in PV technologies for the production of solar cells. Table 6 below lists the specifications of this type based on the selected criteria.

TABLE 6 - CRYSTALLINE SILICON (C-SI)

Efficiency	Best lab efficiency, up to 25% [5]
Cost	US$0.45-0.55/watt [13]
Environment	Less disposal compared to other alternatives. However, making monocrystalline panels tends to result in more waste, as they are made from slices of silicon ingots [26]
Durability	Durable when compared to other alternatives. Most performance warranties go up to 25 years, but panels last longer [27]
Technicality	Maintaining solar panels is very simple since there are no mobile parts. A few washes a year [28]
Maturity	Matured technology that shares above 85% of the total solar panels [5, 29]

B. *Copper Indium Gallium Selenide (CIGS)*

It is a composition of copper, indium, gallium, and selenium. The material is a solid solution of copper indium selenide (often abbreviated "CIS") and copper gallium selenide. Table 7 below lists the specification of this PV based on the selected criteria.

TABLE 7 - COPPER INDIUM GALLIUM SELENIDE (CIGS)

Efficiency	Between 19-20 % [5]. Germany has been able to raise the efficiency up to 21.7 % [30]
Cost	High production cost. It costs 1.25/ W. TSMC plans to produce CIGS to achieve 28% per watt cost [31]
Environment	90% can be recycled [31]
Durability	30 years (could be more if it is in dry condition) [32]
Technicality	Flexible and lightweight in addition to cheap installation and maintenances [32]
Maturity	Emerging and in early adoption stage.

C. *Cadmium Telluride Photovoltaics (CdTe)*

It is described based on the use of cadmium telluride, a thin semiconductor layer designed to absorb and convert sunlight into electricity. Table 8 below lists the specification of this PV based on the selected criteria.

TABLE 8 - CADMIUM TELLURIDE PHOTOVOLTAICS (CDTE)

Efficiency	17.3% [5]
Cost	Cost US$0.57 per watt in 2013 [33]
Environment	One of the top 6 deadliest and toxic materials known. However, CdTe appears to be less toxic than elemental cadmium, at least in terms of exposure [34]
Durability	10-15 years [35]
Technicality	Easy manufacturing processes [34]
Maturity	Second most common photovoltaic (PV) technology in the world marketplace after crystalline silicon. Currently representing 5% of the world market [36]

VII. HIERARCHICAL DECISION MODEL (HDM)

A. *Objective's Definition and HDM Construction*

The objective of the HDM is to determine the highest ranking of the PVs technologies with respect to the STEEP. The model has four levels as graphically illustrated in figure 5 below, and each level of the HDM is defined in table 9 below. Furthermore, all the definitions, descriptions, and questions of the HDM elements (i.e. perspectives and criteria) are listed in Appendix A. These definitions used to inform the invited experts regarding the meaning of each element in the model.

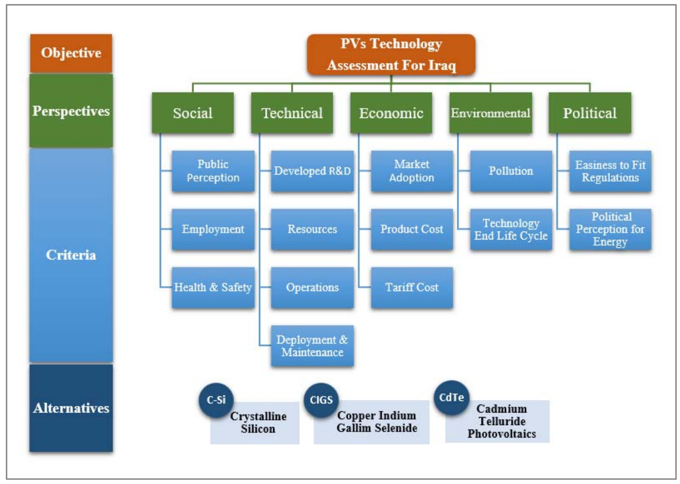

Figure 5-Hierarchical Decision Model (HDM)

TABLE 9 - HDM LEVELS

Level 1	Objective	Assessing the photovoltaic solar technologies to determine the highest ranked technology for the case of Iraq
Level 2	Perspectives	Defined based on STEEP analysis; Social, Technical, Economic, Environmental, and Political
Level 3	Criteria	Defined based on literature review and gap analysis, and validated though the use of the expert panels
Level 4	Technology Candidates	Selected based on the combination of literature review and expert panels

B. *Perspectives Ranking*

The five perspectives were ranked using Pairwise Comparison Method (PCM) software to determine the relative importance of each perspective with respect to the research objective (i.e. PVs technology assessment for Iraq). Table 10 below shows the experts weighting based on their judgments. Indeed, the mean for each perspective's weighting of each expert was calculated, which presents the relative weight for level 2. For more illustration, all the perspectives in level 2 values are shown in figure 6 shown below.

TABLE 10 - PERSPECTIVES RANKING

Level 2	**Social**	**Technical**	**Economic**	**Environmental**	**Political**	**Inconsistency**
Expert 1	0.15	0.18	0.27	0.11	0.29	0.05
Expert 2	0.06	0.24	0.27	0.04	0.39	0.12
Expert 3	0.13	0.16	0.27	0.09	0.35	0.01
Expert 4	0.09	0.13	0.40	0.05	0.33	0.03
Expert 5	0.09	0.17	0.32	0.05	0.37	0.13
Mean	0.10	0.18	0.31	0.07	0.35	0.07

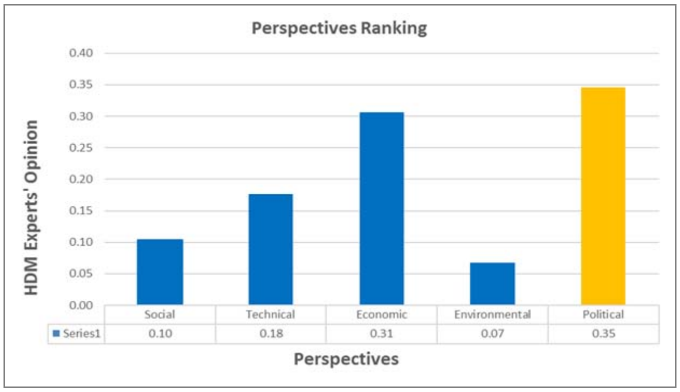

Figure 6-Perspectives Ranking

C. Criteria Ranking

The model has 14 criteria. The experts ranked each criterion with respect to the upper perspective. The higher value that a criterion has, indicates that it has the higher importance or impact on the upper perspective. The pairwise comparison was done by the software to do so. However, the values of the criteria were calculated by the following equation and shown in figure 7 below. Furthermore, figures (10-14) in Appendix B are illustrating the HDM Experts' opinions for each criterion under each perspective (Level 2) [37].

*The value of Criterion = Importance of criterion * The perspective's weight*

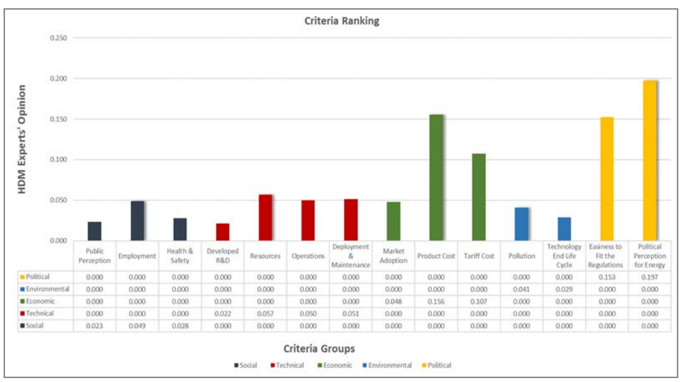

Figure 7-Criteria Ranking

D. Technology Candidates Ranking

The experts weighed a particular technological alternative with respect to the relative importance of each criterion that contributes in its perspective. The higher the value of the ranking the more the significance that a certain criterion has. There are three alternatives and fourteen criteria. The technological alternatives were weighted with respect to the objective. Table 11 shows the weighting values of each expert in regards of each alternative. It is clear that the C-Si has the highest value which means it is more significant than the rest according to experts' judgments. Figure 8 shows the final ranking of the candidates.

TABLE 11 – TECHNOLOGY CANDIDATE RANKING

Experts	C-Si	CIGS	CdTe	Inconsistency
Expert 1	0.47	0.25	0.27	0.02
Expert 2	0.44	0.25	0.31	0.05
Expert 3	0.41	0.27	0.31	0.00
Expert 4	0.35	0.34	0.31	0.01
Expert 5	0.40	0.29	0.32	0.03
Mean	0.41	0.28	0.30	0.02

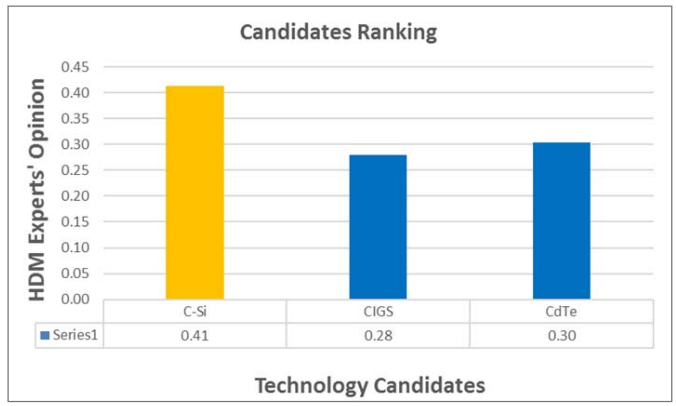

Figure 8- Technology Candidates Ranking

E. Hierarchical Decision Model (HDM) – Final Results

Figure 9 below shows the final results of the HDM. The yellow color indicates that the perspective, criteria, and technology candidate are the highest among the others based on experts' judgments.

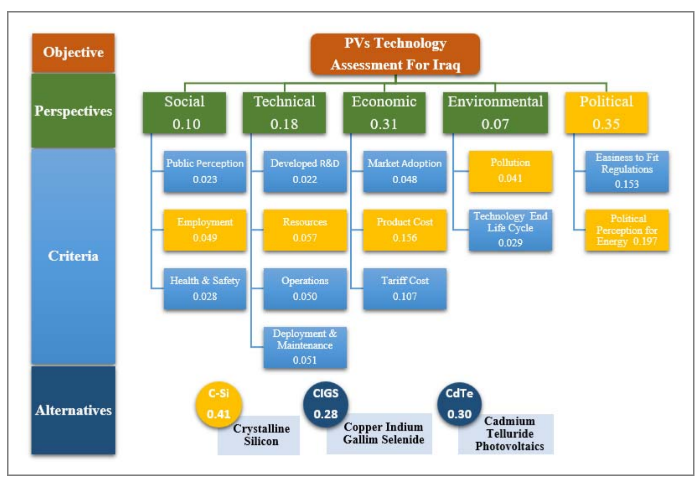

Figure 9-HDM - Final Results

VIII. Discussion of the Results

In this research, Hierarchical Decision Model (HDM) is used to identify the suitable photovoltaic (PV) panel for the situation of Iraq. Five experts participated in this study and gave their judgment using pairwise comparison among the perspectives, criteria, and alternatives (i.e. technology candidates). The results of the experts' judgment indicate that the crystalline silicon (C-Si) is the preferred solar panel by all experts notwithstanding the variance in the degree of preference among experts. There are two traditions to validate the results of the HDM. One way is the degree of inconsistency by the individual expert. The expert's response to each pairwise comparison questionnaire should show an inconsistency level no more than 0.1, otherwise, the expert's judgment would be eliminated. However, as shown in table 11, the five experts in this study have a very low inconsistency (less than 0.1) that varies between a maximum of 0.05 by Expert 2 and a minimum of 0.00 by Expert 3. Hence the results can be considered valid in terms of experts' inconsistencies.

The second way to validate the results is interpreting them with respect to the current and real situation in Iraq. Indeed, at level 1, and based on expert's judgment, the political perspective is weighted more compared to the other perspectives at 0.35. This is not surprising considering the complicated political situation in Iraq (including the easiness to fit regulations and political perception of energy). Furthermore, the economic perspective was ranked second with a weight of 0.31, while the environmental and social perspectives were given the lowest weights by the same experts. Given the environmental perspective the lowest weigh at 0.07 is somehow acceptable since it reflects that both people and the government of Iraq are less concerned about the environmental issues when compared with other perspectives, especially that people' top priority is how to be supplied with a continuous and sufficient power.

However, analyzing the results regarding the higher weight given to the C-Si alternative, it is obvious that the social perspective scored first, particularly the criterion of health and safety at 0.6, while public perception and employment scored second and third respectively. In the technical perspective, C-Si scored higher weight especially in operations criterion, where it scored slightly higher than 0.5. For developed R&D, resources and deployment and maintenance criteria, C-Si was the preferred candidate among the three alternatives with 0.45 weight. In the economical perspective, for market adaption, product cost, and tariff criteria, C-Si scored very close to 0.5 among the three alternatives. Moreover, regarding the environmental perspective, where pollution and end of life use is considered, the result is similar to economical perspective criteria, where C-Si alternative scored close to 0.5 weight among the three alternatives. However, the weights for criteria in political perspective, the three alternatives have very close weights for easiness to fit the regulations criterion, whereas C-Si again has a small edge among the alternatives with 0.4 weight in political perception criteria. Overall, C-Si is the preferred alternative on most of the criteria considered and almost equal weights on only two criteria among the fourteen considered in this study. Table 12 lists the candidates' ranking with respect to each criterion. Moreover, figures (15-28) in Appendix C illustrate this comparison graphically (Level 3).

Table 12 - Candidate Ranking with Respect to Each Criterion

Perspectives	Criteria	C-Si	CIGS	CdTe
Social	Public Perception	0.41	0.35	0.23
	Employment	0.35	0.31	0.33
	Health & Safety	0.60	0.31	0.10
Technical	Developed R&D	0.45	0.32	0.22
	Resources	0.45	0.32	0.22
	Operations	0.51	0.25	0.23
	Deployment & Maintenance	0.47	0.30	0.22
Economical	Market Adoption	0.50	0.30	0.20
	Product Cost	0.46	0.15	0.39
	Tariff Cost	0.48	0.27	0.25
Environmental	Pollution	0.48	0.26	0.26
	Technology End Life Cycle	0.48	0.26	0.26
Political	Easiness to Fit the Regulations	0.34	0.32	0.33
	Political Perception of Energy	0.40	0.30	0.30

IX. Suggested PVs Energy Distribution Method

Since 1980, Iraq has encountered many wars, and therefore, the stability of the country is not obtained yet. These wars delayed or ignored the process of developing the country in all the fields. As unstable country, the national electricity distribution grid is either destroyed or deteriorated. Fixing and rebuilding the distribution grid is problematic too, since the owner of the grid is the government, then it is hard to collaborate with due to the corruption and volatility in the government itself. Also, rebuilding the grid is a costly and risky process besides, it does not assure that the grid would be secured. Therefore, distributing the power generated by the PVs through the national electricity grid is not a feasible solution. Currently, specific, and limited types of solar panels are available in the market, where some Iraqi householders and small commercial entities are using it. However, this approach has some disadvantages. Many householders cannot provide proper maintenance for these panels. Another reason is that Iraqi people cannot afford expensive solar panels. This led many people to favor cheaper types but, most cheap panels often do not meet the need for power supply besides, cheap panels often having a too short lifespan. This has caused a trust issue between customers and solar technologies which led the people to be reluctance to solar panels. Therefore, I suggest that the most feasible method to distribute the power generated by the PVs is building a neighboring community farm. This distribution will assure that the maintenance and operations are halt properly by skilled and specialized people. Also, this will ensure providing an affordable and a reliable source of electricity. Another benefit is that dealing with national grid and its infrastructure will be avoided. Solar energy provider will assure that distributing the power for the community is secured. This option will reduce the risks of this investment and provide a reliable and successful projects.

X. Recommendations

As the security situations on the ground in Iraq improves, the cost structure might be affected, which will tilt favorably towards using fossil fuels for electric generation as the country has the resources of natural gas, which will make this study of evaluating photovoltaic solar panels redundant. However, after the solar energy source expenditure is once established, it will have attractive features in terms of economic feasibility and environmental impact and might endure the onslaught of fossil fuel as a preferred source of energy as the security situation in Iraq improves. Nevertheless, it is worth considering that as long as the initial capital expenditure is in place running solar panels are cost effective as they only use solar energy which is sourced from the sun free of charge which is abundantly available in Iraq. Moreover, Iraq Energy Outlook Special Report has reported that gas alone will not be enough to cover Iraq's projected demand. Therefore, early positioning of solar energy as an alternative source to fossil fuel will be advantageous in the long run. Taking into the consideration, the following concluded recommendations:

1. Political perspective has the highest weight among the five STEEP perspectives considered, suggesting fulfilling regulatory requirements and managing political perception as the important factors in implementing photovoltaic power generation in Iraq.
2. Employment (offering jobs) must be given higher attention since the public perception is highly depending on.
3. The product cost (power prices) must be reduced as low as possible to meet first; the tariff cost, second, the people income, and third, the other means of providing electricity.
4. The resources (including; the lands, technical capabilities and personnel skills) as a criterion under the technical perspective requires more attention to work on in order to ensure the success of the project.
5. Generally, improvement in battery technology will make solar power generation more attractive and this also enhance solar panel use in Iraq in the future.

XI. Conclusion

It is obvious that the problem of power shortage in Iraq is persistent due the accumulation of the factors discussed in this research, causing the country to have a very limited capacity of power supply. This problem is getting worse due to leaving the majority of the issues, particularly the issues of the electricity generation and distribution infrastructure unsolved, in addition to the continuous full dependence of the government facilities, public factories and plants on the national power supply. Therefore, residential houses, and small commercial entities were left to mend for themselves. Some people use private or neighborhoods generators to get power, but most residents do not have financial resources to own generators or operate them, especially that there is an acute shortage of the required fuel to operate them. The current means and most usable power supply is the dependence on the power generated by neighborhoods generators, which are considered pricy, problematic and very low quality. In rare instances, when there is some extra power from the generators, electricity is sold by individual generator owners to their neighbors.

This problem is clearly will continue while the demands on power is continuing to increase. Therefore, the decision to be made in this research was to select the most suitable type of solar panels to use in the case of Iraq as an alternative, and a proposed solution to the problem of power shortage in this country. This proposed solution aims to motivate local and international investors, contractors and householders to consider renewable and green energy sources as an alternative power supply that should take a wider attention and plausible place in the energy production and distribution market in Iraq. Besides, this research aims to point out the most important factors that should be focused on when considering the work on such projects. The photovoltaic solar panels were suggested to fulfill a portion of the demand in residential areas. Since the resource required is sunlight which is in abundance in Iraq, it goes a long way to satisfy the power demand in these areas if the right type of panel is selected for this use.

The use of HDM was to provide pairwise judgments of experts to select the best PVs for the case of Iraq based on STEEP perspectives and fourteen criteria. The result based on experts' judgment indicates that C-Si (crystalline silicon) panels are the preferred type of solar panels since this type is more durable, environmentally friendly, economically feasible, and cost effective among the alternatives. Moreover, from the public perspective, access to electricity with cheaper alternative will be an acceptable development, as long as the supply of electricity is reliable. With the use of C-Si solar panel this can be achievable.

XII. Limitation and Future Research

This research tempted to develop a hierarchical decision model (HDM) to assess and evaluate the top three PV solar technologies, Crystalline Silicon (C-Si), Cadmium telluride photovoltaics (CdTe), and Copper Indium Gallium Selenide

(CIGS). Nevertheless, the literature was very limited and not synthesized well enough to be a purely dependable source for the information of this study. Thus, I used a combination of literature review and expert panels to prioritize the perspectives and criteria, and rank them. Moreover, it was extremely difficult to find experts in both solar technology and the general situation of Iraq. For that, this study used only five experts to rank the prospective and criteria. An important future work would be finding more adequate ranking on the criteria and perspectives by using a larger number of experts in PV solar technology and the critical situation of Iraq. In addition, the experts ranked the whole model, even though they are not specialized in each perspective. Thus, finding specialized experts for each perspective would be an opportunity for future research. Another limitation is that the model was developed to evaluate PV solar technologies in Iraq at the current time, therefore, any change on time or place might change the weights of the criteria and perspectives. Finally, conducting a detailed market research is a chance for future work to ensure the success of the project economically.

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APPENDIX A: DESCRIPTIONS/QUESTIONS - HDM EXPERT PANELS

Objective	Assessing Photovoltaic Solar Panels as a Solution for the Problem of Power Shortage in Iraq
Social	Social impacts of the Photovoltaic solar panels on society
	Public Perception: How likely that the Iraqi people perceive the Photovoltaic technologies as an alternative source of power? Which alternative may be ranked higher than others, or can they be judged equally?
	Employment: Does this type of technology open new jobs and help people to leverage their skills? Which alternative could offer best and more job opportunities?
	Health and Safety: Which of the available alternatives could affect the health and safety of both workers in the fields and people in in general?
Technical	How ready is the country (Iraq) to technically adopt this type of technology as an alternative and how complex or easy this technology could be considered when finally installed, operated, maintained, and upgraded?
	Developed R&D: Which of the alternatives requires more R&D works currently and in the future as well? And how does this criterion weighted when compared with other criteria under the technical perspectives?
	Recourse: Does the country currently has the required recourse for this type of technology? Which alternatives requires more resources? And How important is resources when compared with other criteria under the technical perspectives?
	Operations: How important and smooth are the operations for this type of technology? Which alternative do you think would require more, smooth, complexed operations? How important is this criterion when compared with other criteria under the technical perspectives?
	Deployment and Maintenance: Which alternative do you think would require more efforts to install and maintain? Which alternative would require smother efforts? How important is this criterion when compared with other criteria under the technical perspectives?
Economic	The market readiness for this type of technology besides, the financial success or failure in doing such business (investment) in Iraq
	Market Adoption: Does the market in Iraq ready to adopt this type of technology? Which alternative can be more adoptable? How important is this criterion when compared with other criteria under the economic perspectives?
	Product Cost: Which alternatives do you think would cost more to produce and sell one unit of power using this technology? How important is this criterion when compared with other criteria under the economic perspectives?
	Tariff Cost: When it comes to tariff cost, does it make any difference with respect to each alternative? How do you weight each alternative relatively to the tariff cost? How important is this criterion when compared with other criteria under the economic perspectives?
Environmental	The impacts of Photovoltaic technology on environment
	Pollution: Which alternative has more and worst impact on the environment? How important is this criterion when compared with other criteria under the environmental perspectives?
	Technology End Life Cycle: How important is this criterion in general and which alternative require more effort to recycle the material when the life of its technology ended? How important is this criterion when compared with other criteria under the environmental perspectives?
Political	The political impacts on this kind of technology (Solar Renewable Energy)
	Easiness to Fit the Regulations: Which one of the alternatives fits easier with the regulations on the country in term of alternative source of power? How important is this criterion when compared with other criteria under the political perspectives?
	Political Perception for Energy: Are politicians differentiate among the alternatives in term of perceptions and acceptance? If they do, which one is more preferred? How important is this criterion when compared with other criteria under the political perspectives?
Alternatives	*Crystalline Silicon (C-Si*): It is the crystalline forms of silicon and is the dominant semiconducting material used in photovoltaic technology for the production of solar cells.
	Copper Indium Gallium (di) Selenide (CIGS): It is a composed of copper, indium, gallium, and selenium. The material is a solid solution of copper indium selenide (often abbreviated "CIS") and copper gallium selenide.
	Cadmium Telluride Photovoltaics (CdTe): It describes a photovoltaic (PV) technology that is based on the use of cadmium telluride, a thin semiconductor layer designed to absorb and convert sunlight into electricity.

APPENDIX B: LEVEL 2 - CRITERIA WEIGHTS TO EACH PERSPECTIVE

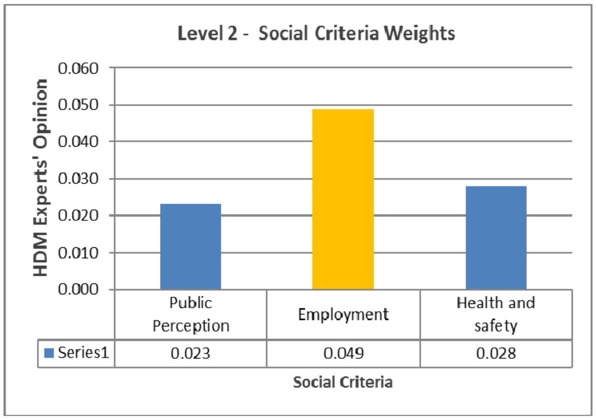

Figure 10-Level 2-Social Criteria Weights

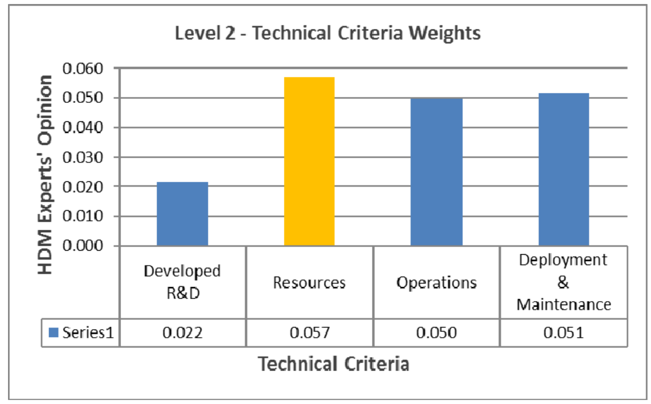

Figure 11-Level 2-Technical Criteria Weights

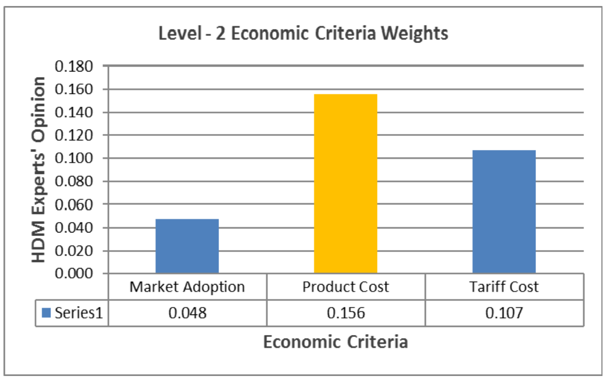

Figure 12-Level 2-Economic Criteria Weights

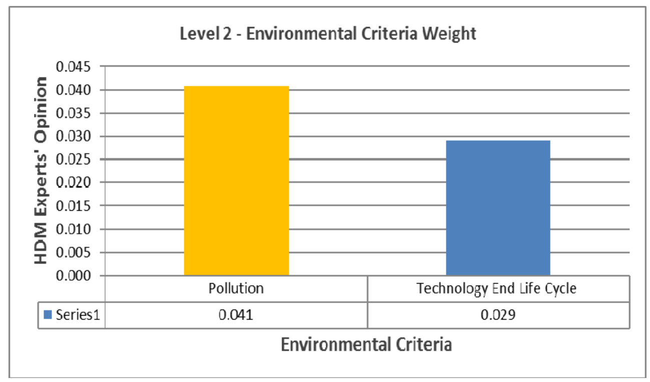

Figure 13-Level 2-Environmental Criteria Weight

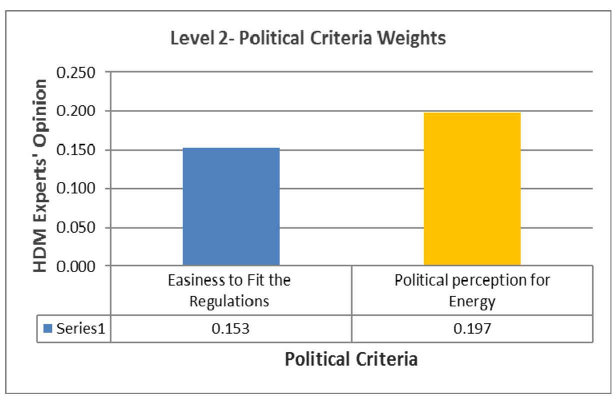

Figure 14-Level 2-Political Criteria Weight

APPENDIX C: LEVEL 3 - CRITERIA WEIGHTS TO EACH ALTERNATIVE

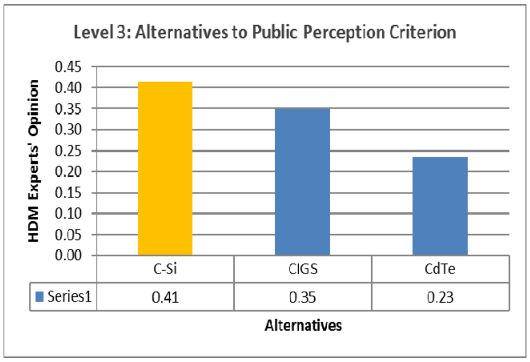

Figure 15-Level 3-Alternatives to Public Perception

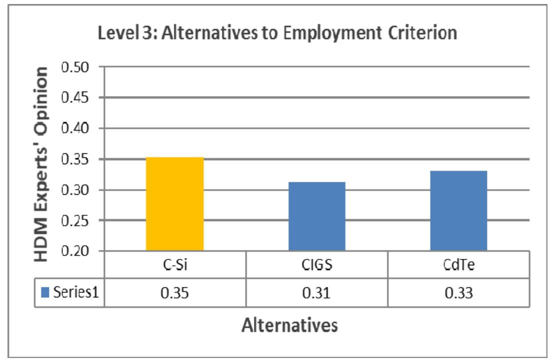

Figure 16-Level 3-Alternatives to Employment

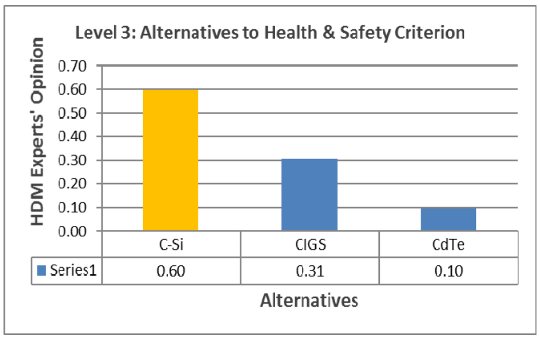

Figure 17-Level 3-Alternatives to Health & Safety Criterion

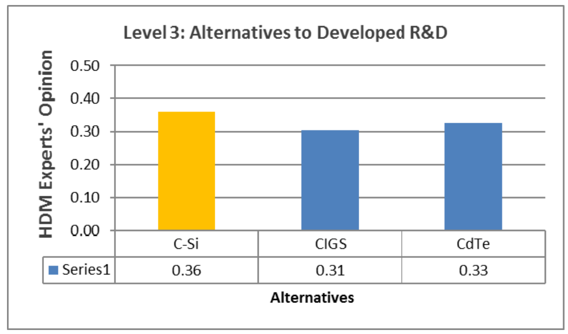

Figure 18-Level 3-Alternatives to Developed R&D

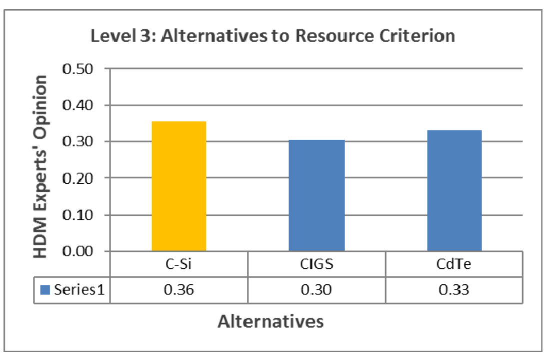

Figure 19-Level 3-Alternatives to Resource Criterion

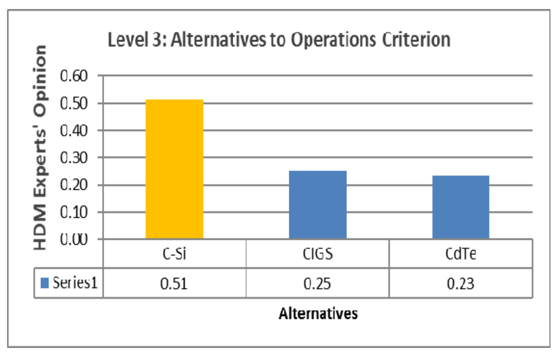

Figure 20-Level 3-Alternatives to Operations Criterion

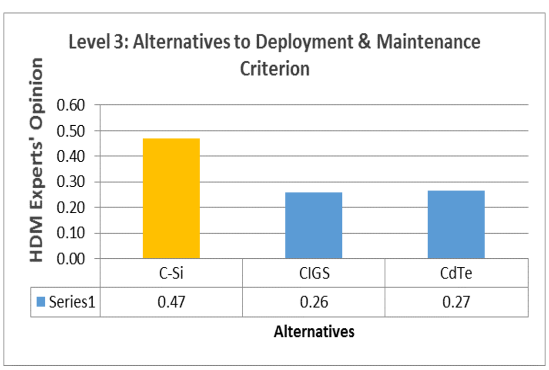

Figure 21-Level 3-Alternatives to Deployment & Maintenance Criterion

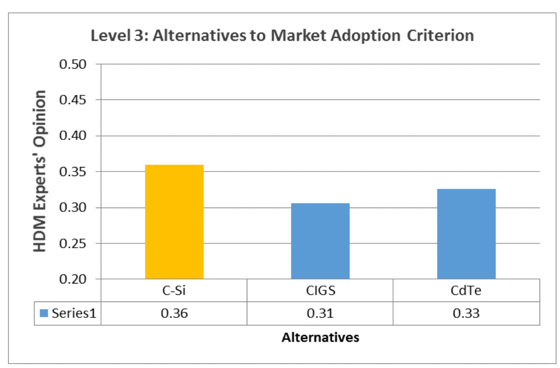

Figure 22-Level 3-Alternatives to Market Adoption Criterion

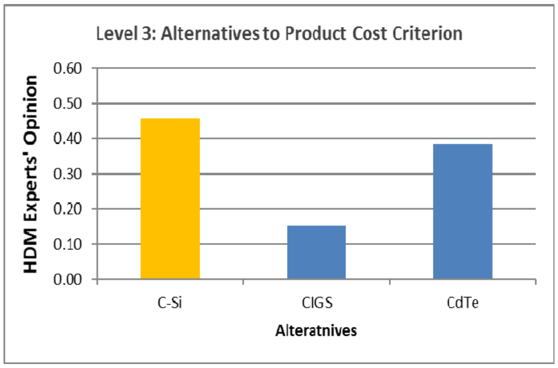

Figure 23-Level 3-Alternatives to Product Cost Criterion

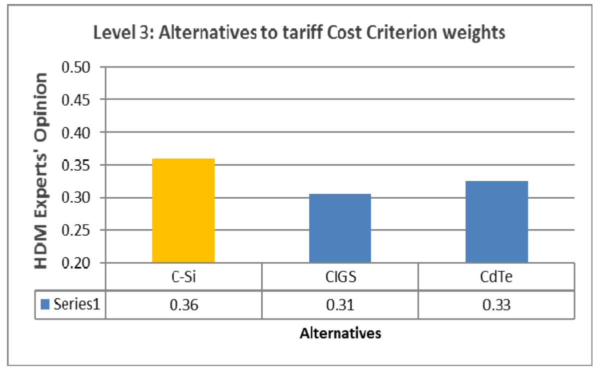

Figure 24-Level 3-Alternatives to tariff Cost Criterion weights

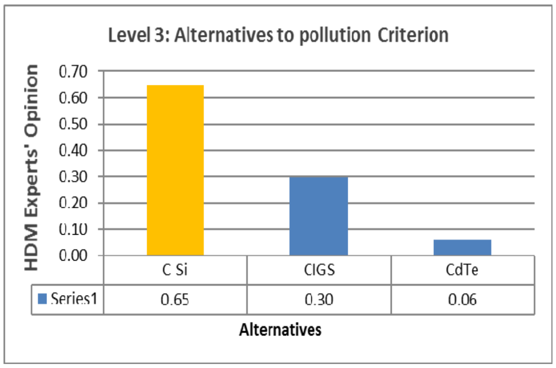

Figure 25-Level 3-Alternatives to pollution Criterion

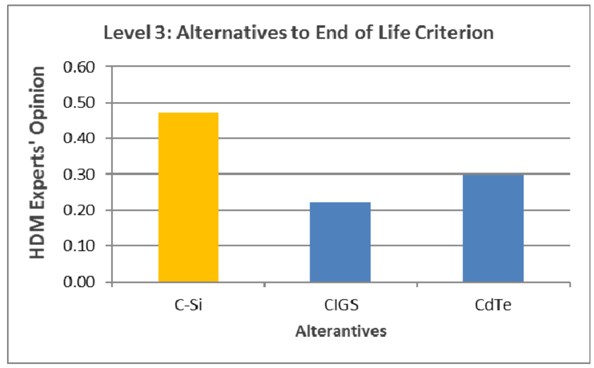

Figure 26-Level 3-Alternatives to End of Life Criterion

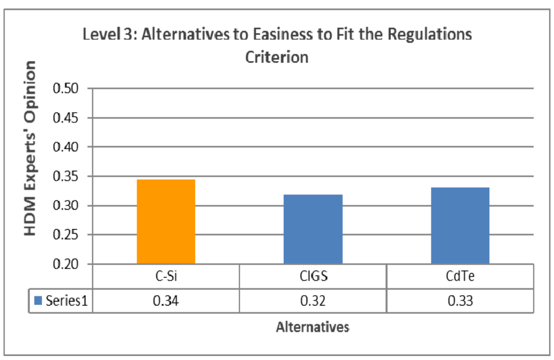

Figure 27-Level 3-Alternatives to Easiness to Fit
The Regulations Criterion

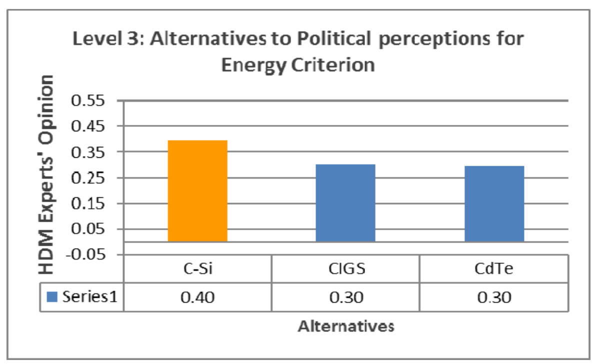

Figure 28-Level 3-Alternatives to Political perceptions
For Energy Criterion