SUPPLIER SELECTION FOR SOLAR PHOTOVOLTAIC (PV) MODULE USING ANALYTICAL HIERARCHY PROCESS: PERLIS SOLAR PLANT PROJECT

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By

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ABSTRACT

The selection of photovoltaic (PV) modules plays an important role in the design of solar power plants. Given that PV module contributes to financial implications, there is a need to review the selection process suppliers to accelerate the implementation of the project. Therefore, the Analytical Hierarchy Process (AHP) has been identified as a decision-making structure that can be used by the solar plant. Basically, AHP uses a structured way for a complex problem with maintaining the simplicity and flexibility of the analysis process. The results obtained in this process can helps in the selection of suppliers to provide a qualitative and quantitative assessment. It can also be used as a reference for other projects in different locations and PV system design. In addition, this study can provide useful information on the performance of the power generation plant for several years with the use of current PV modules. A set of criteria that can be trusted to make decisions that have been identified, namely the financial aspect, the aspect of quality, support resources, capacity aspects, management aspects, and outsourcing aspects. It can be said that by using AHP model can give the rating position and selection of suppliers for Perlis Solar Plant Project. Therefore, the decision making process can be improved and more systematic.

Keywords: Photovoltaic module**, s**upplier selection, analytical hierarchy process, multi-criteria decision-making

ABSTRAK

Pemilihan fotovoltat (PV) modul memainkan peranan yang penting dalam reka bentuk loji kuasa solar. Memandangkan modul PV penyumbang kepada implikasi kewangan, terdapat keperluan untuk mengkaji semula proses pemilihan pembekal untuk mempercepatkan pelaksanaan projek. Oleh itu, Proses Analisis Hierarki (AHP) telah dikenal pasti sebagai struktur membuat keputusan yang boleh digunakan oleh loji solar. Pada asasnya, AHP menggunakan cara yang berstruktur untuk masalah yang kompleks dengan mengekalkan kesederhanaan dan fleksibiliti proses analisis. Keputusan yang diperolehi dalam proses ini boleh membantu dalam pemilihan pembekal untuk menyediakan penilaian kualitatif dan kuantitatif. Ia juga boleh digunakan sebagai rujukan untuk projek-projek lain di lokasi yang berbeza dan reka bentuk sistem PV. Di samping itu, kajian ini dapat memberi maklumat yang berguna kepada prestasi loji penjanaan kuasa selama beberapa tahun dengan penggunaan modul PV semasa. Satu set kriteria yang boleh dipercayai untuk membuat keputusan yang telah dikenal pasti iaitu aspek kewangan, aspek kualiti, sumber sokongan, aspek kapasiti, aspek pengurusan, dan aspek penyumberan luar. Ia boleh dikatakan bahawa dengan menggunakan model AHP boleh memberikan kedudukan penilaian dan pemilihan pembekal untuk Projek Loji Solar Perlis. Oleh itu, proses membuat keputusan boleh dipertingkatkan dan lebih sistematik.

Kata kunci: Modul fotovoltat, pemilihan pembekal, proses hierarki analitik, pembuatan keputuan pelbagai kriteria

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
CI	Consistency Index
CL	Clean
CP	Capacity
CR	Consistency Ratio
CY	Capacity
FN	Financial
IRR	Internal Rate return
MA	Managerial
NPV	Net Present Value
OS	Outsourcing
QSP	Quality System Process
SR	Support Resource
TSR	Technical Support Resources
RI	Random Index
ROI	Return of Investment
QY	Quality

CHAPTER ONE

INTRODUCTION

Chapter one gives an overview of management, project management of solar plant, the importance of selection, and challenges in supplier selection of photovoltaic (PV) module. This chapter also highlights the problem statement, objectives, research questions, and the scope of this study.

1.1 Management

Management in business and organization is the function to coordinate efforts in achieving the goals and objectives using available resources effectively and efficiently. According to Singh and Dixit (2011), it is often considered an aspect of production together with the machines, sources and money. Therefore, management in the business organizations should decide to resolve the issues effectively and efficiently. Management consists of elements such as planning, management, staffing, and controlling an organization in order to achieve the goal and objective. Resources includes the use and manipulation of the human, financial, technological and natural resources (Mabey, Skinner & Clark, 1998). Being excellent in the management of business will permit managers to develop contemporary views along with discovering new methods. However, to have good management, organizations need to have adequate knowledge to enhance their decision-making process. This knowledge, which is known as knowledge management, is a blend of previous experience, insight, and data that forms the organization memories (Zikmund, 2010). It provides a framework that can be considered when assessing a business problem.

One of the prime areas to which this knowledge management approach could be applied is project management (Zikmund, 2010).

1.1.1 Project Management

According to Baker, Murphy, and Fisher (1997), project management is a process and activity such as planning, motivation, and controlling resources, procedures, and protocols to achieve a goal to solve scientific problems. Whilst, project management function is to fulfill the job requirements, the distribution of tasks, and allocation of the necessary resources, work plans, monitoring the work progress and adjusting any deviation from the plan (Cattani, Ferriani, Frederiksen, & Florian, 2011; Meredith & Mantel, 1995). Harrison and Dennis (2004) mentioned that project management has a success criteria from delivery stage up to the implementation. The British Standard Institution (2015) defines project management include in planning, monitoring and regulating all aspects of a project and motivate all parties involved to achieve the project objectives as planned. Meanwhile, Society UK Project Management (APM) has produced UK Body of Knowledge UK (Bok), that defines project management as planning, organised, monitor, and control all aspects of the project and motivate all the parties involved to reach objectives of the project safely and within time criteria, cost, and performance agreed (Kerzner, 2009). According to Kerzner (2009) and Packendorff (1995), project management is also increasingly applied in various fields of industries and organizations. Consequently, the project manager is the person responsible for achieving this goal.

1.1.2 Project Organization

A venture might be flawlessly overseen, yet at the same time, it may be turn out to be a business catastrophe, for instance, because of the changing markets. Rolstadås (2014) reported that the execution of the administration can be accomplished by characterizing two distinct strategies in venture administration: The prescriptive methodology focuses on the formal characteristics of the task association, including administering the documentation and systems, whereas the adaptive methodology concentrates on the procedure of creating and enhancing a venture association, venture culture, and group responsibility.

For the case of power plant project, project development and planning is essential to ensure all valuable assets and project implementation are according to plan. It is due to power plant owner have to secure a power purchase agreement (PPA). Planning process consists of location analysis, technical design authorization process through implementation, design and engineering, project financing and investment, the acquisition component of a system, optimize the system tray, construction project management, operations, and maintenance services (Globerson & Zwikael, 2002). Therefore, project development that is well planned can ensure maximum system safety, reliability, and return of investment.

1.1.2 Project Planning

Studies have identified planning as being one of the critical process factors in a project (James, 2000; Wheelen & David, 2000; Papadakis, 1995). Munns and Bjeirmi (1996) also claimed that one of the successful outcomes of a project management is planning. Arranging a task is the key activity in any venture. However, a lot of people failed to realize that the project planning is valuable in cost saving. Therefore, in order to the project or project management to be successful, project selection activities and planning activities should be integrated (Ko, Lee & Lee (2009); Pinto & Selvin, 1989). Responsibility for planning lies with a project manager who ensures that all activities satisfy the relevant stakeholders (Kerzner, 2008).

1.2 Selection Process

In setting procurement marketing, Lasch and Janker (2004) noted that the supplier procedure is related to the supplier-purchaser connection. Supplier management comprises a multi-level process that has to be well planned. Competitive pressure intensifies the need to enhance delivery performance, quality, and responsiveness, and the same times requires that companies re-evaluate their strategic planning to ensure that costs are reduced (Vijay & Tan, 2003). Therefore, a case of selection of PV modules based on the supplier's capabilities is considered in this study. Photovoltaics (PV) is a method converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon that is often studied in physics, photochemistry and electrochemistry (Globerson & Zwikael, 2002). Photovoltaic cells electrically connected with the composition and or a parallel circuit in order to create higher voltages, streams and the power level. These modules is composed of PV cell circuits and equipment in ecological protection and defence the central building pieces PV framework. The panel incorporates one or more PV modules assembled as a unit can be installed in pre-wired. A group create photovoltaic power unit is ready, which consisted of the number of PV modules and panels. Performance of PV modules and arrays is typically assessed to justify the maximum continuous circuit (DC) power output (watts) under Standard Test Conditions (STC). Standard Test Conditions is defined by the temperature module (cell) Operating 25º C (77º F), and the incidence of solar radiation level of 1000 W / m2 and under Air Mass 1.5 spectral distribution. Therefore this is not always how the PV modules and arrays operate in the field, the real performance is typically 85 to 90 percent of the STC rating (Cell, Modules, & Arrays, n.d). As in many decision-making situations, the selection process is complicated. As a result, a right decision for quantitatively related problems is hard to achieve, whereas making a good guess in qualitative forecasting is comparatively easy (Gungor, Serhadlıog, & Kesen, 2009). The success factors of decision making often focus on objectives, including the facilities necessary technology, key personnel, expertise, technical background and specialized communication skills (Fortune & White, 2006; Mostofi, Nosrat, & Pearce, 2011; Park, 2009; Pinto & Slevin, 1988; Globerson & Zwikael, 2006).

1.3 Importance of Supplier Selections

Supplier selection is an important issue in a decision-making process because unreliable suppliers may cost the organization or the producer (Atkinson, 1999; Ozcan & Suzan, 2011). The producer can set measures in developing the selection criteria to ensuring that the criteria are practical to use suits the need of the projects (Kahraman, Cebeci, & Ulukan, 2003). Therefore, there is a need developing a systematic supplier selection process to identifies and prioritizes criteria which are relevant for technical, economic and performance, and selection time (Tam & Tummala, 2001).

1.4 Challenges in Supplier Selection

According to McAloone and Bey (2009), environment of engineering for product development in a modern organization has changed drastically in decades as the products has become even more complex, especially in knowledge-intensive products. Furthermore, firms functioning in highly uncertain and rapidly evolving situations need to maintain their technologies because their competitiveness depends on product innovation and research and development (R&D) activities (Kelly & Rice, 2002). In this study, the selection of PV module is different according to architectural design, energy consumption and budget allocation. There are several suppliers of PV modules on the market, and if we judge the different characteristics of the PV module, it becomes a challenge to compare different providers and make apples to apples comparisons. Obviously, there are also technical and commercial considerations when selecting a solar PV modules, however, in this section, we will discuss some technical considerations that should be kept in mind when choosing the supplier of PV modules.

1.4.1 Electro Luminescence Testing

Electro Luminescence (EL) is an optical phenomenon which has been used for a long time in lightening applications and recently integrated as an investigation procedure for photovoltaic devices (Dupuis & Krames, 2008). EL tests carried out by most of the companies. However, several manufacturers are doing this module based on random sampling, and some well-known provider conduct this test 100% of the PV modules. EL imaging techniques has been established and can identify faulty modules or modules that are underperforming and allocate separately in different places, EL tests conducted just before packaging PV modules in the overall process. Sample of EL report is attached in Appendix I.

1.4.2 Anti –reflective Coating

An anti-reflective coating (ARC) is known as a very important technique to enhanced the performance of solar cell (Iwahashi et al., 2015). A curve covering the PV module glass diminishes light reflection along these lines, expanding the light that are coupling to the sun-based cells. Normally, about 4% of the occurrence of sun-based radiation is reflected through an ordinary glass and the utilization of ARC covering the PV module glass increases its period up to 4%. Sample of ARC technique is shown in Appendix II.

1.4.3 Bus-bar Design

Normally electricity from the solar cells were taken by bus-bar made of silver foil. A bus-bar on the module surface area diminishes its visible area to the light. Some providers of the PV modules had a back contact materials and may conduct electricity generated by the cells through back contact to make the cells 100% exposed to the solar radiation. Most of the PV module providers had typically two bus-bar. Some of them use the three bus-bar design to increasing the conductive area and increase the cell resistive power losses. A three bus-bar design also reduces the chances of the current generated from getting lost due to the finger interruptions or damages. According to Braun and Skinner (2007), the effectiveness of a sun-based cell ought to be analyzed under interconnected conditions to uncover the maximum capacity of the cell idea. Under those conditions, the multi bus-bar outline exhibits its points of interest in contrast to the best in class. Bus-bar design test is stipulated as in Appendix III.

1.4.4 Module Tolerance

It is desirable to choose the PV modules with positive tolerance. Some phenomena will always occur that would lead to the loss of power during the energy conversion through the PV system. It is important to reduce this power loss. One of the most important parameter module is the power of their good tolerance. It will show in the technical data sheet (Appendix IV) and will be checked during the manufacturing process when the panel is tested based on their production capacity ("Solar sales: Positive tolerance", 2016).

1.4.5 Potential Induced Degradation Free PV Modules

Potential induced degradation (PID) is a new problem that is being studied in India PV module assembly due to high temperatures and operating conditions in high humidity. It is advisable to choose a PID free modules that have been tested for PID test in the temperature of 85^{o} C, 385% relative humidity, 1000V DC, and a duration about 96 hours. Under this condition if the module has passed the PID test, then it is acceptable to work satisfactorily in the Indian conditions. Monetarily, the degradation of a PV module or framework is similarly critical because a higher corruption rate makes an interpretation such as less power generated and reduces future income (Short, Packey, & Holt, 1995). The PV system and environment condition interact to cause PID. PID can significantly reduce yield in PV plants by reductions in shunt resistance (Rsh), maximum power point (MPP) and open circuit voltage (Understanding Potential Induced Degradation, n.d). Illustration of cause and effect of PID is shown in Appendix V.

In technical consideration, it can be conclude that successfully EL test, high thickness of ARC, positive tolerance, minimum of 3 bus-bar design, and PID resistant modules is favourable in choosing the right PV module for the solar plant.

Apart from the five critical factors for the selection of modules that should be considered include aluminium frame, junction box, back-side material, 25 years of warranty, bankability of the technology providers, and other variables.

1.5 The Case Environment

The case study involves Perlis Solar Plant project that have to supply 1.5 MW to Tenaga Nasional Berhad (TNB) for 21 consecutive years by a Fit in Approval Holder (FiAH) company. As this project is new to the company, handling suppliers especially in PV module solar panel is not easy. For the sake of confidentiality, the names of all suppliers involved in this case are concealed and labeled as A, B, C, and D. The supplier selection is based on several criteria, which are finance aspect, quality aspect, support resources, capacity, management, and outsourcing. Project managers are currently using their judgment and experience to choose the best supplier and do not consider the important factors in supplier selection prioritization. The focus of this study is on supplier selection of PV module on a solar project.

1.6 Problem Statement

Lower quality PV modules are argued to enter the emerging solar markets (Runyon, 2013). So, the project manager or project owners have the responsibility for selecting a PV module that meets the standards, price, or quality. There are many modules of PV to choose from. As reported in Photon Photovoltaic Stock Index September 2012, more than 30 manufacturers offer various models of modules related to a long process chain of solar cell manufacturing, including various thermal and chemical treatment steps (Chunduri, 2012). The list of manufacturer or supplier is listed in Appendix VI. But there are also challenges for many PV module manufacturers due to a significant imbalance of supply compared with demand exists, along with the challenges for a lot of manufacturers to produce their products at a cheap price .These factors combined with the usual considerations, such as valuation output modules, power tolerance, efficiency, and price, along with a new inverter, installation, and optional electronic module-level, creating a more complex options module (Amin, Lung, & Sopian, 2009; Hren, 2011). In this situation, how can we guarantee the PV module performance for 20 years or more when most of the module design and advanced technologies has only a few years or less in site? What predictive methods that are available and assessable in order to increase the level of confidence in the prediction of power production? Answers to this question has great implications for all stakeholders in the area of finance, the venture capital for the new products R&D, the original equipment manufacturer's warranty, bank financing PV system, the insurance company system, and user/owner of the system. Considering financial implications are big, there is a need to examine the supplier selection process to accelerate the delivery of the project implementation.

1.6 Research Questions

The key research questions to be addressed in this study are as follows:

1. What are the criteria to be considered in selecting the best and reliable supplier of PV module for the Perlis Solar Plant project?
2. Which PV module supplier should be best selected for the Perlis Solar Plant project?

1.8 Research Objectives

The aim of this study is to recommend to project managers and people involved in making selection decision about the criteria that need to be considered in prioritizing the suppliers so that the best supplier can be chosen. Hence, the objectives of this study are:

1. To identify the criteria for selecting the most appropriate PV module selection.
2. To determine the suppliers who best meet the criteria of the organization.

1.9 Significance of the Study

Limited research has been done on PV module performance, particularly in relation to solar PV supplier selection. This study is carried out with the purpose of providing a structured decision-making method that can be used by a Perlis Solar Plant company. Furthermore, the finding of this study may also be utilized as a reference for other projects in different locations and PV system designs. Additionally, for future study, the findings of this research significantly can inform the plant owner about how the plant performs in generating the solar power annually by using the current PV module.

1.10 Scope

The Perlis Solar Plant project is 100% Bumiputera owned, focusing on the development of renewable energy or any related energy generating activities comprises solar, wind, bio energy, biomass, biogas, hydropower, oil, gas, and coal. This company receives 1.5MW solar quota from Sustainable Energy Development Authority (SEDA), and the solar plant started to commission in 2013. The solar plant consists of other equipment, such as inverters, switchgears, transformers, cables, and other installations. However, this study is particularly dedicated to determining the best criteria for selecting a PV module to be installed in this solar plant which is located at Padang Siding, Perlis. The PV module suppliers are international and local companies.

1.11 Organization of the Thesis

Chapter 1 explains the introduction, background of the study, and research problem. It then outlines the research questions, objectives, significance, scope, limitations, and finally, the structure of this research. In Chapter 2, review of the literature on project selection criteria and research methodology are presented. In addition, selection methods, such as the AHP, are discussed. Chapter 3 elaborates the research methodology applied, research design, and research framework. Results of data analysis are presented and discussed in Chapter 4, and Chapter 5 offers some concluding remarks.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews the literature related to the study of Perlis Solar Plant project. This section appraises project selection criteria, techniques in project selection, and other approaches to group decision making.

2.1 Development of Solar Energy

Currently, the development of solar energy as potential source of energy has been observed tremendously by the industries. In order to achieve good photovoltaic systems, new idea shall be considered: the local production and consumption of solar energy, and the participation of consumers or other related parties (Masson, Latour, & Biancardi, 2012). The photovoltaic business signifies the third important source of renewable energy next to hydro and wind energy, and it is considered as direct source of electricity for consumption in this current situation (Masson et al., 2012). In 2004, a study was conducted to review a new two thin-film PV manufacturing business, however it turns to be unsuccessful job (Braun & Skinner, 2007). The objective of the study was to recognize the choices and costs by evaluating comparable PV technologies and to improve understandings of future developments. It shows that multi-criteria method is suitable tool in gauging the production processes for the second generation of thin film PV. In years of testing and commissioning, PV has been found fit for renewable energy generation due to its simplicity and modularity (Cavallaro, 2010). Additionally, an expert survey was conducted on 26 commercials and new PV technologies in 2008 (Curtright, Morgan, &

Keith, 2008). The results indicated as follow: the average of PV price is forecasted increased by 2030 (China shows that the bid price has already dropped to $0.15/Wp for enormous scale distributions) (Schwartz, 2010). Hence, PV price needs to be at $0.30/Wp for it to be considered as a candidate for large scale power; R&D would increase the efficiency of energy conversion; arrangement of incentives will decrease the price; governments should invest in R&D for PV performance to low the cost and reduce uncertainty; and governments should have allocate certain subsidies. Due to its potential of low-cost materials and standard production (reel-to-reel) processes, Brabec (2004) focused on organic PV (or plastic PV) as a key energy (available energy to produce a product) technology. Furthermore, Alexandra and Horaţiu (2014) conducted a study on the recent and future developments of the photovoltaic business model for Central and Eastern Europe continents. A Delphi method was employed to certify a realistic standpoint of the researched area, appropriately by following the standard phases: selecting and defining the research area and objective; preparing the questionnaires; selecting the experts to be interviewed; implement the first round of online, interviews with the experts personally; analyzing the results; reporting the results to the experts; to run second round of interviews; analyzing the results; reporting the results to the experts; and elaborating the Delphi report (Häder, 2009). They discovered that the photovoltaic system controlled by a company dedicated to the sale of PV energy as their business model has great potential in Romania.

2.2 Application of Selection Method

Policymakers at international, national, regional, local utility, and manufacturer levels would always want to assess and compare the choices of energy technology. Therefore, it is important to develop and update a set of considered criteria to evaluate the technology in relation to the social, environmental, and political perspectives. Arranging a large number of criteria and factors for each perspectives is useful for decision-makers to choose the technology that best fits with the target objectives. Kahraman et al. (2003) mentioned that selection criteria may be applied to various aspects of a supplier's business, such as financial strength, management approach and capability, support resources, technical ability, and quality systems. Prior to award a contract, buyers typically take proactive measures to verify a supplier's qualifications in order to prevent dire consequences of non-performance supplier. Consequently, supplier qualification screening is essential to reduce non-performance suppliers, such as late delivery, non-delivery, or non-conforming delivery (faulty goods). Moreover, the supplier will be ensured to be responsible and responsive partner in the day-to-day business relationship with the buyer. The supplier qualification screening involves in many aspects, which are explained as below.

2.3 Variables Involved in Selection

This section appraises supplier selection criteria, namely, the financial aspect, quality aspect, support resources, capacity, managerial aspect, and outsourcing aspect.

2.3.1 Financial Aspect

Financial benefit is one of the criteria used by Palcic and Lacic (2009) in selecting and evaluating a project. Motta and Quintella (2012) applied non-financial and financial criteria, such as assessment of team and technology, which was the non-financial criteria, and financial area, which was related to assets/property. For the purpose of this study, the financial aspect focuses on the short-term and long-term project physical benefit. In order to calculate the achievement of the project, mostly business organizations develop a standard of Return of Investment (ROI) calculator that uses Next Present Value (NPV) and Internal Rate of Return (IRR) (Palcic & Lalic, 2009). Generally, financial strength can be a good indicator of the supplier's long-term stability. A firm will be convinced if the suppliers have a strong financial position. It also helps to ensure the performance standards of the products and services can be maintained and sustained. Moreover, cash positive firms are much in favour position to weather the ups and downs of an uncertain economy scenarios. From an economic point of view, theoretical problem in all selection models is the potential for making a bad selection. For example, in the construction industry, the problem with value enhancement criteria usually to be the qualitative elements and turn to be costly during the decision process, especially in supplier capability and competence (Meland, Robertsen, and Hannas, 2011). As for solar power generating, Malaysia Building Integrated Photovoltaic Technology Application Project (BIPV) requires any project has to reduce long-term costs as a requirement to apply the BIPV technology (MBIPV Project) in the future.

2.3.2 Quality Aspect

A firm needs a competent technical support from its suppliers in order to provide a consistent high-quality product or services, to encourage positive development efforts and to ensure future improvements. Service and business enterprises sectors emphasizes quality in service especially for the growth and development of their firm (Rahaman, Abdullah & Rahman, 2011). It is significant when the supply and technology firms included in the strategy development of new products or technologies or access to proprietary technologies. Technical criteria may encourage firms to move into the global market. However, sometimes desirable technology may have to develop abroad and will not be given to the local suppliers.

Hren (2011) addressed that the main factors of supplier's quality systems. The processes is to maintain and improve quality and delivery performance. The selection criteria can consider the following: security assurance and the quality control procedures, complaint handling procedures, quality manual, standard registration status such as ISO9000, and internal rating and reporting system. The firm mainly want to check out the supplier's program or processes to assess and address the needs of their customers.

In terms of choosing any PV system equipment, PV module specification sheet needs to be thoroughly investigated to ensure the compatibility and performance. This process can be mirrored as selecting a quality PV module. After identifying and selecting the appropriate modules, the full manufacturer's installation instructions, which are detach from the specification sheet, shall be comply. Specification sheets usually display the module's quality, efficiency, or a special design aspect. It sometimes cover the most important information, such as a technical data. Not every specification sheet follows the same layout, but at least, the information sheet contains the electrical and mechanical data (Hren, 2011).

2.3.3 Support Resources

If necessary, the supplier must have sufficient source to support the development of a product or services, production, and delivery. The criteria should take into account the convenience of suppliers, information systems, and providing appropriate education and training (Kahraman et al., 2014). While considering international suppliers, the firm should pay an extra attention to the industrial infrastructure that supports suppliers. Moreover, the firms also need to create a suitable mechanism in handling financial transactions and product delivery, as well as any matter related to law and regulations. Furthermore, some form of global customer service may be established to support the implementation of projects and daily operations.

2.3.4 Capacity Aspect

Capacity planning is the science and art of estimating space, computer hardware and software and necessary connection resources infrastructure for a period of time. The purpose of capacity planning is to plan well so that the newly added capacity in a timely manner to meet anticipated needs. The successful of capacity planning is balancing between the present and the future, thus reducing operating costs (Rouse, 2006). In the perspective of supplier capacity planning, design capacity is the maximum amount of work that the organization is able to be completed within a certain period. Therefore, the effective capacity is the maximum amount of work that the organization can accomplished within a specified time such as quality problems, delays and material handling (Krajewski & Ritzman, 2005). It is important that suppliers can increase the quantity of delivery within shortest lead time since buyers are not aware of the exact quantity needs over their signed contract. However, it may be effective for long-term contracts in which the buyer can demand for many products tied to unexpected market events. For example, demand for aircraft manufacturers are highly dependent on the overall economy in which the economy depends on growth and retrench period). In addition, surge capacity is available when the supplier has an access to the second or third shifts, overtime, under-utilized facilities and others.

2.3.5 Managerial Aspect

One of the responsibilities of a firm is to maintain a good relationship with suppliers. Firms need to have a particularly good integrated and strategic relationships approach. Therefore, the firm should have confidence in the ability of managing suppliers. Furthermore, supplier management must be committed to the supply base management firm. According to Kahraman et al. (2014), supplier quality level, service and cost is directly proportional to the ability of suppliers to meet its needs.

2.3.6 Outsourcing Aspect

Outsourcing is defined by Yakhlef (2009) as an action of transferring some of the firm's internal activities by selecting external suppliers. Lankford and Parsa (1999) similarly defined outsourcing as an acquisition of a product or service from a source outside of the organization. A firm outsourcing strategy may recognized the advantages or disadvantages of the supplier of a particular region or country. Therefore, firms should have identified the potential risks, such as currency fluctuations, changes in political policy, regulatory changes, and the domestic or international regulations.

2.4 Method in Selection

Many approaches and techniques are available to assist business organizations in select their supplier. In selecting suppliers, a company may approach two main objectives, namely to reduce the cost of purchasing and to increase the overall value of purchases (Monczka, Trent, & Handfield, 1998). With respect to the cost of evaluating suppliers (such as time and travel budget), companies basically evaluate qualified suppliers to buy from them. In this process, the company sent a team of experts to the provider's website, and to assess the criteria and different factors. Hence, they will do a more thorough examination. Eventually, a planned approach is needed by the decision maker to make the best decision, which permits essential trade-offs in a method technique. One of the methodical technique to ensure an effective decision in the selection of a project is Analytical Hierarchy Process (AHP), which employs a simple judgment, namely pair-wise comparison (Saaty, 1980).

2.4.1 Checklist Model

A checklist is a straightforward technique and normally utilized in the screening and selection of a project. A checklist is a criteria inventory that can assess the prospect of the project. It implies a straightforward tool for documentation of point of view, which will enhance discussion and stimulate brainstorm that will promote substitute of ideas (Pinto, 2007).

2.4.2 Direct Scoring Approach

Direct scoring approach requires the decision maker to require numerical values for the expected performance of measured alternatives decision versus multiple objectives. The score for the alternatives given with various maximum points for each criterion is used in this approach. Then, all the points are summed to provide a ranking of an alternatives. Suedal, Kim, and Banks (2009) highlighted that this approach is easy to use, which is commonly used to assess the ecological problems. However, it can give unpredictable results.

2.4.3 Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) usually considered as a strategy to choose a supplier since it permits choice creators to rank suppliers in light of the relative significance of the criteria and suitability of suppliers (Saaty, 1980). AHP offers an approach to determine the position of the master plan is based on a consideration of the choice of decision makers on the importance of the criteria and the extent to which they meet each option. Therefore, AHP is appropriate to determine the issue of supplier selection (Farzad, Mohamad, Aidy, & Rosnah, 2008). These judgments are connected as pair- wise examinations which effect on the following greater amount. In order to meet the objective or a basis, pair-wise correlations can expressed the relative significance of one thing versus another. Each of the pair -wise correlation means about the evaluation of the weights of the thought of those two criteria. Due to AHP uses proportion scale of human judgments, the choice shows the relative importance of the criteria in achieving the objectives of the chain of command (Tam & Tummala, 2001). AHP also is known as a type of multiple criteria decision making (MCDM) (Arbel & Seidmann, 1990). The popularity of AHP started by Thomas L. Saaty. He developed the AHP in the early 1970s in response to allocate limited resources and planning for military purposes. It involves the establishment of a framework consisting of a set of certain elements (Saaty, 1980). Furthermore, AHP process basically deals with complex problems using a structured way to maintain the simplicity and flexibility of the analysis process (Al-Tabtabai, & Thomas, 2004). AHP depends on three broad suppositions concluded from the expression of the method (Mahdi, 2005). They are:

i. Analytic: The use of numbers and logic to explain alternative decisions analytically.
ii. Hierarchy: scores for a basis are obtained from each sub- criterion. Criteria can be extended in a progressive system, and the numerical score at each level of the chain hierarchy.
iii. Process: in any issue including decision making, a procedure is required to accumulate data.

There are several benefits of AHP (Saaty, 1994) as follows:

1. Help to decipher the unstructured problem into a hierarchy of rational decision.
2. Employ pair-wise comparison from the elements of individual groups by stimulate more information from the expert or decision makers.
3. Allocate weights to the elements by setting the computations.
4. Verify the consistency of ratings from experts and decision makers by using consistent measures.

The final result is achieved in the form of weights for each alternative to be compared. Finally, once selected, the factors are arranged in a hierarchic structure, descending from overall goal towards criteria, sub-criteria, and alternatives in successive levels (Saaty, 1990).

2.4.3.1 Strengths of AHP

Is the norm for all modelling methods, AHP is also encounter some strengths and weaknesses. The utilization of the AHP approach offers various advantages. One critical point of interest is its simplicity (Liu & Hai, 2005). The main advantage of the AHP is its capability to organize the rank options in order of their effectiveness in dealing with contradictory objectives. AHP is recognised for its stability and flexibility vis-à-vis changes within and addition of the hierarchy. In addition, the method is able to rank criteria according to the needs of the buyer which also leads to more specific decisions especially concerning with the supplier selection. Therefore, buyers can get a good perspective of the suppliers' performance by using the criteria hierarchy and thus able to assess the appropriate supplier (Omkarprasad & Kumar, 2006).

2.4.3.2 Weaknesses of AHP

Despite the popularity of the AHP, there is certain issues concerning in the AHP methodology. Some cases have occurred in ranking irregularities while AHP or some of its variants are used. Rank reversal may occur when a copy or near copy of the existing option is added to the evaluated alternatives. Triantaphyllou (2001) stated that when a multiplicative variant of the AHP is used, it is not possible to reverse the rank. AHP also requires information in a view of experience, knowledge and some consideration which is sometimes subjective for every decision maker. Moreover, this method does not consider risks and vulnerabilities in regards to the supplier's performances (Yusuff & Poh Yee, 2001).

2.5 Comparison of Selection Methods

The above mentioned selection methods is summarized in Table 2.1.

Table 2.1
Comparison of Selection Methods

Method	Strength	Weakness
Checklist	* Well organized - Time and labour efficient * It is comprehensive * Development of documentation * Clear design of the development scale	* It may be bias by the recorder * It depends on the criteria to be clearly observable * Time consuming - May have many element to inspect
Direct scoring Method	* Allow multiple criteria to be utilized for the assessment * Determines that some criteria are more significant than others * Direct reflection of management strategy * Easily altered to suit changes made by management/ policy	* Output of scoring model is a meticulously comparative measure rather than an absolute measure * May lead to inclusion due too numerous criteria
Analytic Hierarchy Process (AHP)	* Flexibility and simple to employ * It is with weight and can be employ in two distinctive approach	* Great difficulty with too many pair-wise comparison

2.6 Selection and Decision Making in Technological Problem

The explosion of PV movement was said to be an epidemic and get most attention. Even in 2011, the European government incentives has decreased, some experts expected that the growth will be continued around the world, driven by the strategic placement (Bowden, Honsberg, & Schroder, 2010). A study showed that the importance of PV production. Basically, PV uses unlimited sunlight to produce electricity, although nowadays its contribution is still low than the total electricity consumption. Therefore, PV must maintain a growth rate greater than 40% with production of 4 magnitude to maximize its capability. (Bowden et al., 2010). By using Moore's Law, PV indicates that it has the potential to achieve the required growth rates similar to related integrated circuits (ICs) (Nelson, 2010). Degroat, Morabito, Peterson, and Smestad (2009) conveying a systems analysis approach can be adopted for solar energy. It seemed to be an element that is useful to the decision makers and the public. There are three important characteristics of acceleration of solar: solar electricity generation through the electricity grid (enabled by infrastructure which is called as "Smart Grid"); reduction of production costs and continuous uses; and development of capability. It is important to check the results that have been used in the decision making process and evaluation of energy. These approach will be identified any gaps in the literature. Any model applicant must have the ability to be flexible with respect to a variety of perspectives, individuals (decision-makers, stakeholders, practitioners, end users and others), a variety of criteria, and the ability to provide guidance to practitioners and operational management. Thus, the model may help in both evaluation and direction position. For example, the functions of the wish (or value) criteria may offer guidance for R&D (or policy makers) to focus on the criteria that have a high gap with respect to the optimum benefit (Degroat et al., 2009). Whereas, the method of multi-criteria decision making (MCDM) is a systematic method of combining various criteria in the process of evaluating, comparing, and evaluating different alternatives. It has been wildly used in engineering, such as in the field of industrial and manufacturing systems, (Chiou & Tzeng, 2002; Kahraman et al., 2007; Karsak, 2002; Li, 2012; and Sari, 2013), energy engineering (Boran, Genç, & Akay, 2012), aerospace mechanical engineering (Hsia, Chen, & Chang, 2008), construction engineering (Hsieh, Lu, and Wu, 2004), and chemical engineering (Jia, Tong, Wang, Luo, & Jiang 2004; Pirdashti, Tahmasebi-Sarvestani, & Bahmanyar, 2009). However, many aspects of engineering seems to be failed to assess in a quantitative form but relatively successful in a qualitative way because of the imperfect understanding of the terms used. For example, in airline safety evaluation, linguistic labels such as “high”, “medium”, “low” are used (He, Zhou, & Gong, 2010). In these circumstances, decision makers often give their assessments in language form and decisions need to be made in an unclear environment. Therefore, the method of MCDM become a popular method for an order of preference by similarity to ideal solution (TOPSIS).

Besides AHP, there are a number of multi-criteria methods can be utilized to facilitate individual or group decision making, such as:

1. AHP Combined Method
2. Fuzzy AHP
3. Fuzzy AHP Combined
4. Fuzzy AHP Group
5. Group Evaluation Method
6. Weighted Sum Method (WSM)
7. Weighted Product Method (WPM)
8. Delphi Method
9. Voting System.

2.7 Importance of Supplier Selection

The selection of the right PV modules may provide high impact for solar plant projects; however, there are several obstacles such as evaluation index system, the problem of loss of information, and lack of objective in the selection process may reduce the rationale of decision-making. With the necessary technology, appropriate key personnel, sufficient expertise, good technical background and communication skills commonly considered as the success factors based on the intended objectives (Belassi & Tukel, 1996; Fortune & White, 2006; Pinto & Slevin, 1988; and Zwikael & Globerson, 2006). This can also be said as “competence” (Meland et al., 2011). Project managers shall pay attention to current and future situation that may affect the projects. Therefore, managers have to organize and put a plan in place on how to deal with these situations and making it to be positive or negative. In this case, Delphi technique is preferable. Cantrill, Sibbald, and Buetow (1996) mentioned that Delphi technique is a method used to estimate the prospect and outcome of future situations. It is noticeable that Delphi and AHP technique commonly used as a tool to provide criteria weight and position of the selected technologies in the early stages. Kim (2013) used Delphi-AHP method as a decision-making tool for selecting recyclable wastes in the waste management of major electrical and electronic equipment (WEEE). Delphi and AHP methods are also used in the PV and power generation industries. For the first time, Pakistan has used the AHP model proposed by Amer and Daim (2011) which in his study is about selection of renewable energy technology consists of solar PV and solar thermal particularly for developing countries. Additionally Ma, Chang, and Hung (2013) provided a reference for the government and companies using Delphi and fuzzy AHP method in selecting the outdated technology in smart energy photovoltaic industry. This reference is useful to guide the acquisition of industrial technology and the resource allocation. Besides, Mattiussi, Rosano, and Simeoni (2013) presented a framework model that includes multiple objectives for a sustainable energy supply and been evaluated by four CHP plants and two photovoltaic plant which consists of mono-crystalline and poly–crystalline. Furthermore, there is a study on the selection of key technologies by the silicon PV industry by Yong, Honghang, Qiang, and Yibo (2014). They comprise a Delphi-AHP based methodology to create a qualitative and quantitative measurement system when selecting and prioritizing main technologies amongst the six links of the silicon PV industry. Utilizing the knowledge and experience of experts' evaluation and Delphi-AHP is an effective method when making scientific decisions (Yong et al., 2014).

2.8 Criteria for Technological Products

In defining sustainable technological energy priorities, several approaches have been developed, for example to assist policy makers by using a multi-criteria decision-making method by linguistic variables in fuzzy logic (Doukas, Andreas, & Psarras, 2007), and a scenario analysis with participatory decision analysis that emphases on the challenges in the methodology (Madlener, Kowalski, & Stagl, 2007). Whilst, multiple criteria decision making (MCDM) is a set of models, methods, and systems developed to assist decision makers in creating multifaceted decisions in a methodical and structured manner. Numerous methods are proposed to resolve different problems. One of them is done by Pablo, Fidel, Juan-Pascual, and Andrea (2014), by using AHP/ANP-based decision analysis method on solar-thermal power plant projects investment.

Their main reasons for using this approach were:

(a) Permit the decision makers to analyze complex decision problems using a systematic approach by outlining the main issues to be easy and appropriate sub-problems.

(b) ANP shall be used if there are interdependencies among the elements (criteria and alternatives), and detailed analysis of primary and interdependence between the elements of the group. This will force the decision makers to reflect carefully on their approach in the project priorities and problems solving.

2.9 Discussion and Summary

This section appraised the pertinent literature on supplier selection criteria, which are the independent variables in this study. There are the financial aspect, quality, support resources, managerial aspect, capacity, and outsourcing. The literature highlights the importance of using appropriate procedures for decision-making and evaluation criteria can reflect that a quantitative and objective must be integrated before the selection process. AHP approach is more effective in decision making than other approaches as it has both quantitative and qualitative substances (Cheng & Li, 2002). Since the project is a multi-criteria decision-making problem, AHP appears to be a suitable approach for this study. The next chapter discusses the application of AHP in PV module selection for a solar plant project.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter explain about the research methodology adopted in this study. It starts with a discussion on research design and research framework, followed by the development of questionnaire, survey implementation, and data analysis using AHP.

3.1 Research Design

This study combined qualitative and quantitative approaches for the data collection where the respondents (decision makers in supplier selection) were asked about their position and their role as a decision maker in the company. This research used AHP to determine the criteria for choosing and prioritizing suppliers. Before the present study was carried out, prior permission from the organization was asked. A preliminary survey was conducted to identify decision maker requirements using a structured interview method. A total of four decision makers were asked regarding their organizational status and role as a decision maker in the organization. There were 3 company directors and design consultant. Initially, the interviews with the decision-making process was conducted through face to face. Data were collected using an open-ended project selection survey form (Appendix VII). Position, department, years of services, educational qualification, and experience in decision making were collected. Then, the collected data is analysed and a few of criterion is identified. The researcher allow the decision maker to discussed and argued on each criteria related to their experience and knowledge. Finally, consensus has been made and the decision maker has short listed the supplier criteria to be considered as the most reliable and important to the Perlis Solar plant project. Based previous researchers used a quantitative method to examine the supplier selection criteria such as financial aspect, quality, support resource, capacity, managerial aspect, and outsourcing. These criteria were used in this study to meet the research objectives. To determine which supplier to be identified, the researcher explained and guided to the decision maker about the four suppliers, namely, Supplier A, B, C, and D.

3.2 Research Framework

Six supplier selection criteria were used in this study. They were the financial criterion, quality, and support resource, capacity, managerial dimension, and outsourcing.

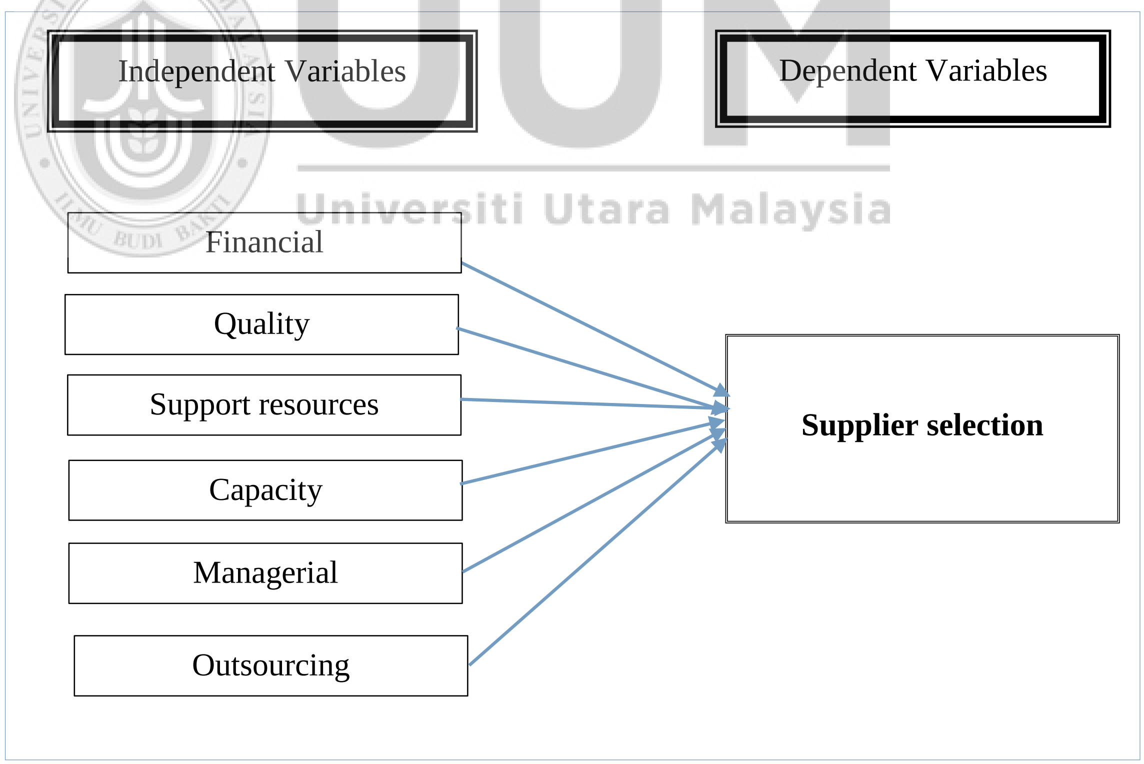

Figure 3.1
Project selection criteria

The six major selection criteria were as follows:

i. Financial aspect - A group of criteria with the objective of capturing the financial reimbursement of the project. The criteria are explicitly related to cost, productivity, and earnings measures.

ii. Quality aspect - Includes the supplier's quality assurance and control procedures, complaint handling procedures and quality manuals.

iii. Support resources - Involves the level of risk tolerance that an organization accepts to execute a project.

iv. Capacity aspect - The supplier's capacity to increase the delivery quantities within short period is necessary as the buyers may be unsure about their exact quantities needs over the life of the contract.

v. Managerial aspect - A group of criteria specifically related to the strategic organizational objective.

vi. Outsourcing aspect - The advantages or disadvantages associated with choosing the suppliers in a particular region or country.

These selection criteria are shown at level one in Figure 3.2 of the decision hierarchy structure.

3.2.1 Selection of Alternatives

Four suppliers were to be chosen who were shortlisted based on the pre-screening criteria set by the upper management. They were:

a. Supplier A

b. Supplier B

c. Supplier C

d. Supplier D

The upper management has considerable knowledge about the projects. These decision alternatives are shown at level three in Figure 3.2.

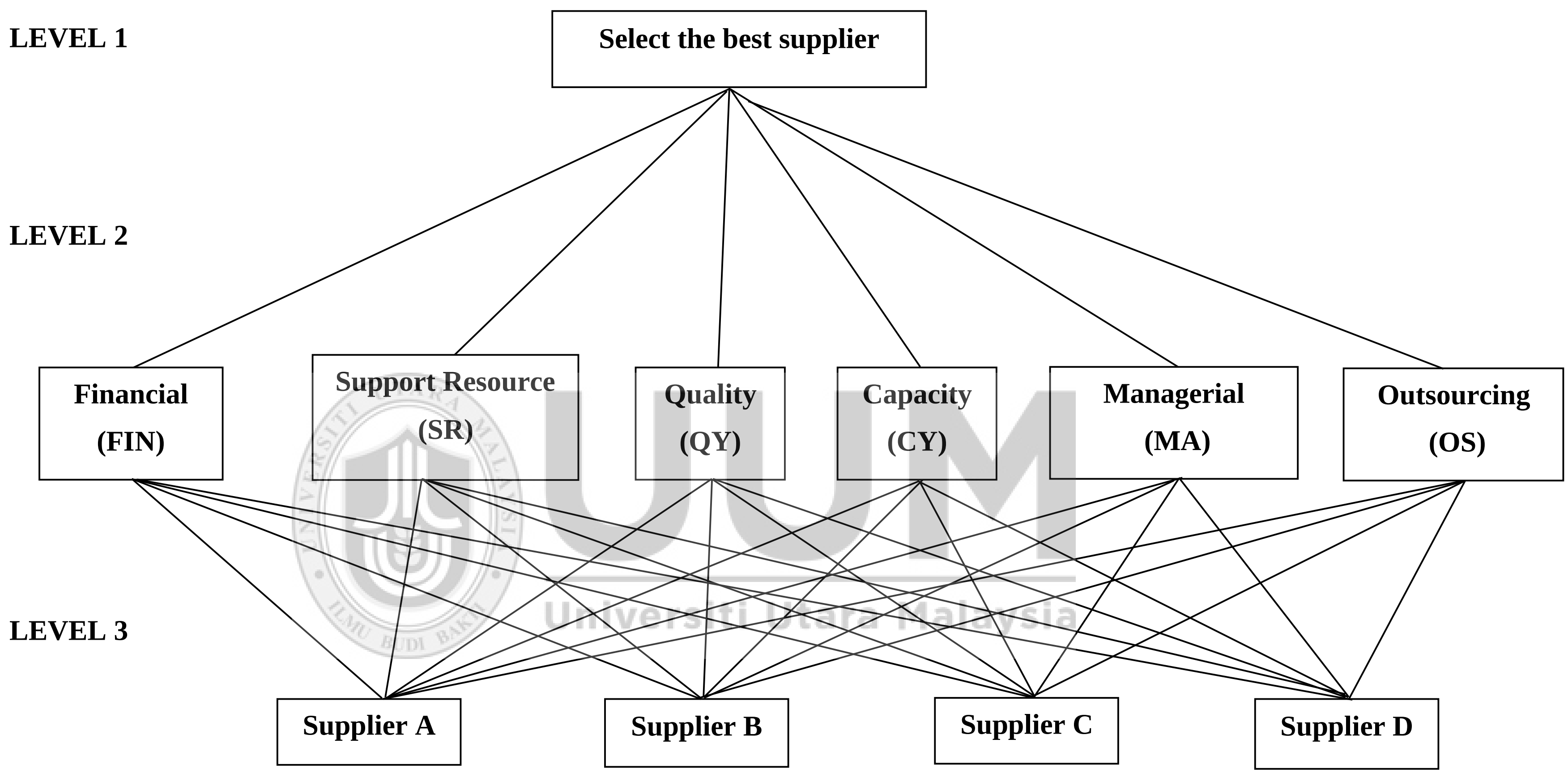

Figure 3.2
Decision hierarchy structure

3.2.2 Development of Questionnaire

A set of questionnaire (Appendix VIII) was prepared to collect data. The respondents of the decision maker were required to make a pair-wise comparison for indicating appropriate degree of the importance of each pair of the selection criteria. After that, they were asked for indicating a preference of the alternatives set against the respective selection criteria. The respondents compared the selection criteria shown on the left with another indicated at the top. The comparison scale (Saaty, 1977), as depicted in Table 3.1, ranged from 1 = equally preferred/important to 9 = extremely preferred/important.

Table 3.1
Comparison Scale

Value	**Definition**	**Explanation**
1	Equally preferred/important	Two activities contribute equally to the objective
3	Moderately preferred/important	Experience and judgment slightly favor one activity over other
5	Strongly preferred/important	Experience and judgment strongly favor one activity over other
7	Very strongly preferred/important	An activity is strongly favored and its dominance is demonstrated in practice
9	Extremely preferred/important	The evidence favoring one activity over another is of the highest possible order
2,4,6,8	For compromise between the above values	When a compromise needed

Source: Saaty (1977)

The data collected were then used for AHP analysis (details in Chapter 4).

3.3 Interview Implementation

Prior to the supplier evaluation, the respondents were briefed about the purpose of the questionnaire and how it should be answered. The respondents were then requested to respond one day after the distribution of the questionnaire to allow sufficient time for them to understand the instruction. It was also to allow them to seek clarification before answering the survey.

3.4 Data Analysis

The next step is to estimate the relative weight (priority) element of the results using data collected. These weights represented a decision maker for any judgment on the relative importance or preferences of the elements in the hierarchy (Saaty, 1994). This is a called pair-wise comparison. The eigenvector and the weighted a score of each alternative were computed with the help of Microsoft Office Excel programme before supplier selection was made. The detailed data analysis is described in Chapter 4. When using AHP, the first step is to establish priorities as guidance for the interviewer and ranking.

The following was carried out:

i. To measure how much more important a criterion than the other criterion, AHP used a scale with the values from 1 to 9. Table 3.2 shows how a decision maker's verbal descriptions of the relative importance of the two criteria was converted into a numerical rating

Table 3.2
Preference Scale of AHP Technique

Verbal judgment	**Numerical rating**
Extremely more important	9
	8
Very strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

ii. Next, a structured interview with the respondents was carried out to understand the preferences to rank the priority of the criteria.

iii. The arithmetic mean of a set of values is the ratio of their sum to the total number of values in the set. The disadvantage of the mean is that it is a sensitive to the extreme values especially when the sample size is small. Is therefore, it is not an appropriate measure of central tendency for the skewed distributions (Swinscow & Campbell, 2003). As the interviews were conducted amongst a team of decision makers and as a group, the geometric mean was used (Forman & Peniwati, 1998). The geometric mean in AHP enables aggregating individual judgments and ranking decision criteria based on its weight (Subramaniam, 2010).

iv. A different AHP matrix was formulated for the main criteria to determine their corresponding weights. The same approach was used to solve the entire formulated matrix.

v. Next, a consistency test in AHP was used to measure the degree of inconsistency in pair- wise comparison (Kwiesielewicz & Uden, 2004).

vi. Later, the importance of criteria was determined based on their weights. The criterion with the highest weight was more important than other criteria. The main criteria were compared to each other and ranked based on their weight.

3.5 Summary

This chapter explained the research methodology applied in this study. It described the research approach adopted, providing details of the research subjects, the questionnaire, and its administration. The data collected then were analysed using pair-wise comparison or AHP method. Results are explained in Chapter 4.

CHAPTER FOUR

DATA ANALYSIS AND RESULTS

In this chapter, the findings of analysis data are discussed. The method of data analysis was carried out by using the AHP approach. The results of the study present the prioritization in the selection criteria of the supplier, as well as the supplier that best fulfilled the requirements of the organization.

4.1 The Respondents

Four respondents were involved in this study. They were key decision makers of project selection. Table 4.1 presents their background. The decision makers from the top management were the Project Manager, Project Owner and Company Director, which is the top management and the key person in making any decision involved in selecting the supplier of PV solar module. The company appointed a Design Consultant for this project because it requires a specific consultant to advise on the requirements for running and commissioning the project. With regards to educational qualification, 75% of the respondents had a doctoral degree, suggesting that they were qualified in evaluating and selecting the most appropriate supplier to be prioritized in the company. In addition, all the respondents considered the criteria when choosing the supplier.

Table 4.1
Background of respondents

Position	Department	Length of service	Educational level	Experience in making decision (decision maker)	Consideration of selection criteria
Project Manager	Top Management	15 years	PhD	Frequently	Yes
Project Owner	Top Management	10 years	PhD	Frequently	Yes
Company Director	Top Management	9 years	Master	Frequently	Yes
Company Director	Top Management	8 years	PhD	Intermediate	Yes

4.2 AHP Analysis

The AHP technique were mainly employed allocating weights to the six selection criteria identified.

4.2.1 The Selection Criteria

An AHP method was used to analyze the six selection criteria. These include a pair-wise comparison, and calculate the relative weights, eigenvector, and the consistency ratio.

4.2.1.1 Pair-wise Comparison

The establishment of priority among all the criteria was based on pair-wise comparisons. Data were tabulated into a pair-wise comparison matrix for assessing the criteria. In the pair-wise comparison matrix, the diagonal elements are normally equal to one, and the lower triangle elements of the matrix are the reciprocal of the upper triangles elements

(Zahedi, 1986). The following example of the calculation is based on the data collected from a decision maker and is used to demonstrate the AHP calculation.

Table 4.2
Pair-wise comparison for criteria – Project Manager

Criteria	**FN**	**QY**	**SR**	**CY**	**MA**	**OS**
Financial (FN)	1.000	5.000	3.000	4.000	4.000	5.000
Quality (QY)	0.200	1.000	2.000	2.000	0.500	2.000
Support resource (SR)	0.333	0.500	1.000	3.000	2.000	3.000
Capacity (CY)	0.250	0.500	0.333	1.000	0.500	0.500
Managerial (MA)	0.250	2.000	0.500	2.000	1.000	2.000
Outsourcing (OS)	0.200	0.500	0.333	2.000	0.500	1.000

Table 4.2 shows the data collected from the Project Manager. In the first row, he ranked five for the Financial criterion, which means that this dimension is more important to the Quality criterion. Ranked three, the Financial criterion is moderately more important to Support resource criterion and ranked four means the Financial criterion is moderately strongly more important to the Capacity criterion. When Financial and Quality criteria are compared, the former is five times more important than the latter. One always enters the whole number in the appropriate position, and its reciprocal is automatically introduced in the transposed position. Appendix II shows the questionnaire on the selection criteria in the matrix where the respondents did the integer part while the blank matrix was completed by the researcher.

4.2.1.2 Calculate the relative weights and eigenvector

Next, the normalized matrix was computed from the pair-wise comparison matrix for the selection criteria. Therefore, the eigenvector was calculated. For matrix normalization, the column totals were first determined based on the data collected in Table 4.2. Table 4.3 demonstrates the computed column totals.

Table 4.3
Pair-wise comparison for criteria – Column Total

Criteria	FN	QY	SR	CY	MA	OS
Financial (FN)	1.000	5.000	3.000	4.000	4.000	5.000
Quality (QY)	0.200	1.000	2.000	2.000	0.500	2.000
Support resource (SR)	0.333	0.500	1.000	3.000	2.000	3.000
Capacity (CY)	0.250	0.500	0.333	1.000	0.500	0.500
Managerial (MA)	0.250	2.000	0.500	2.000	1.000	2.000
Outsourcing (OS)	0.200	0.500	0.333	2.000	0.500	1.000
Column Total	2.233	9.500	7.166	14.000	8.500	13.500

Once the column totals were determined, each number or entry in the matrix were divide by its respective column total to produce the normalized matrix as shown in Table 4.4. Once the matrix is normalized, the numbers in each column will sum up to one.

Table 4.4
Normalized Matrix

Criteria	FN	QY	SR	CY	MA	OS	Total
Financial (FN)	0.447	0.526	0.419	0.286	0.470	0.371	2.519
Quality (QY)	0.090	0.105	0.280	0.143	0.059	0.148	0.825
Support resource (SR)	0.149	0.053	0.139	0.214	0.235	0.222	1.012
Capacity (CY)	0.112	0.053	0.046	0.071	0.059	0.037	0.378
Managerial (MA)	0.112	0.210	0.070	0.143	0.118	0.148	0.801
Outsourcing (OS)	0.090	0.053	0.046	0.143	0.059	0.074	0.465
Total	1.000	1.000	1.000	1.000	1.000	1.000	6

Subsequently, the averages of the various rows from the matrix of numbers were calculated to determine the eigenvector (priorities) as shown in Table 4.5. For example, in the case of the Financial criterion, the sum of this row was 2.519. This value was divided by 6 to get the average value of 0.419. Larger values of the eigenvector indicate the greater importance of the criteria to the decision maker.

Table 4.5
Eigenvector for the criteria

Criteria	Priority	Ranking
Financial (FN)	0.419	1
Quality (QY)	0.138	3
Support resource (SR)	0.169	2
Capacity (CY)	0.063	6
Managerial (MA)	0.133	4
Outsourcing (OS)	0.077	5

In summary, the Project Manager rated the financial criterion as the most important in the supplier's selection, followed by support resources, quality, managerial criterion, outsourcing, and capacity.

4.2.1.3 The consistency ratio

Considering how that humans are error-prone and often inconsistent, the AHP allows a degrees of errors and inconsistencies in the decision maker for judgments (Min, 1992). During the interview process, the researchers interviewed the decision makers and enquire about their decision at least 2 times to get the certainty and firmness of their erection. Therefore, finding the consistency ratios will show us how we are consistent with our rankings. A higher value of CR means the decision makers are less consistent, whereas the lower value means they are more consistent. According to the rule of thumb suggested by Saaty (1980), a consistency ratio (CR) of 0.10 (10%) or less is considered as acceptable margin; otherwise, the decision maker should then revaluate his/her ranking scores. The formula and calculation of the consistency ratio is as below:

$$CR = \frac{\text{Consistency index (CI)}}{\text{Random index (RI)}}$$

Where;

$$CI = \frac{\lambda - n}{n - 1}$$

n = number of decision elements in the consideration

λ = the average value of consistency vector

RI = mean CI of a randomly generated reciprocal matrix from a ratio scale of 1 to 9, as in Table 4.6 (Render & Stair, 2000).

Table 4.6
Random Index

n	Random Index
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41

First, the weighted sum vector was calculated (see Table 4.7), i.e., to determine the eigenvector number (see Table 4.5), the first criterion was multiplied by the first column of the original pair- wise comparison matrix (see Table 4.2). Second, the eigenvector number was multiplied by the second column and so forth. Finally, the values in the rows were summed up.

Table 4.7
Weighted Sum Vector

Criteria	FN	QY	SR	CY	MA	OS	Priority	Wt. Sum Vector
Financial (FN)	1.000	5.000	3.000	4.000	4.000	5.000	0.419	2.785
Quality (QY)	0.200	1.000	2.000	2.000	0.500	2.000	0.138	0.906
Support resources (SR)	0.333	0.500	1.000	3.000	2.000	3.000	0.169	1.064
Capacity (CY)	0.250	0.500	0.333	1.000	0.500	0.500	0.063	0.398
Managerial (MA)	0.250	2.000	0.500	2.000	1.000	2.000	0.133	0.878
Outsourcing (OS)	0.200	0.500	0.333	2.000	0.500	1.000	0.077	0.479

Next, the consistency vectors were determined by dividing a weighted sum vector with the respective eigenvectors determined previously (see Table 4.8).

Table 4.8
Consistency Vector

Criteria	Priority	Wt. sum vector	Consistency vector
Financial (FN)	0.419	2.785	6.647
Quality (QY)	0.138	0.906	6.565
Support resource (SR)	0.169	1.064	6.295
Capacity (CY)	0.063	0.398	6.317
Managerial (MA)	0.133	0.878	6.601
Outsourcing (OS)	0.077	0.479	6.221

Subsequently, the value of lambda (λ) was computed by taking the average value of the consistency vector, i.e., 6.647 + 6.565 + 6.295 + 6.317 + 6.601 + 6.221) / 6 = 6.441. Therefore,

$$CI = (\lambda - n)/(n-1)$$

$$= \frac{(6.441 - 6)}{6 - 1}$$

$$= 0.088$$

$$CR = \text{consistency index (CI) / random index (RI)}$$

$$= 0.088 / 1.24$$

$$= 0.071$$

In this case, the CR of 0.071 shows that the pair-wise comparison was deemed consistent within the acceptable random variations for this particular decision maker. The above steps were repeated for the data collected from all decision makers. Table 4.9 summarizes the relative weights of criteria and rank order of importance of the respective decision makers.

The AHP technique always allows a decision makers to meaningfully synthesize their priorities in the order to derive an overall prioritization in and rankings which includes the application of the geometric mean (Lai, Wong & Cheung, 2002). Thus, the mean weight for each supplier selection criteria was obtained by dividing the sum of all the individual weights by four respondents. From Table 4.9, based on the geometric mean (Subramaniam, 2010), it can be concluded that the ranking of supplier selection criteria in the company was Financial, Support Resources, Managerial, Quality, Capacity, and Outsourcing.

Table 4.9
Relative weights of selection criteria

Selection criteria	Rep. PM		Rep. PO		Rep. Purchasing		Rep. DC		Mean Weight	
	Wt	**Rank**	**Wt**	**Rank**	**Wt**	**Rank**	**Wt**	**Rank**	**Wt**	**Rank**
Financial (FN)	0.419	1	0.470	1	0.448	1	0.421	1	0.44	1
Quality (QY)	0.138	3	0.064	4	0.073	6	0.108	4	0.10	4
Support resource (SR)	0.169	2	0.220	2	0.137	2	0.261	2	0.20	2
Capacity (CY)	0.063	6	0.061	5	0.095	4	0.044	6	0.07	5
Managerial (MA)	0.133	4	0.143	3	0.151	3	0.112	3	0.14	3
Outsourcing (OS)	0.077	5	0.043	6	0.095	5	0.053	5	0.07	6
Consistency Ratio (CR)	0.071		0.081		0.070		0.092			

Figure 4.1 shows the mean weight and its correspondent ranking of the supplier selection criteria.

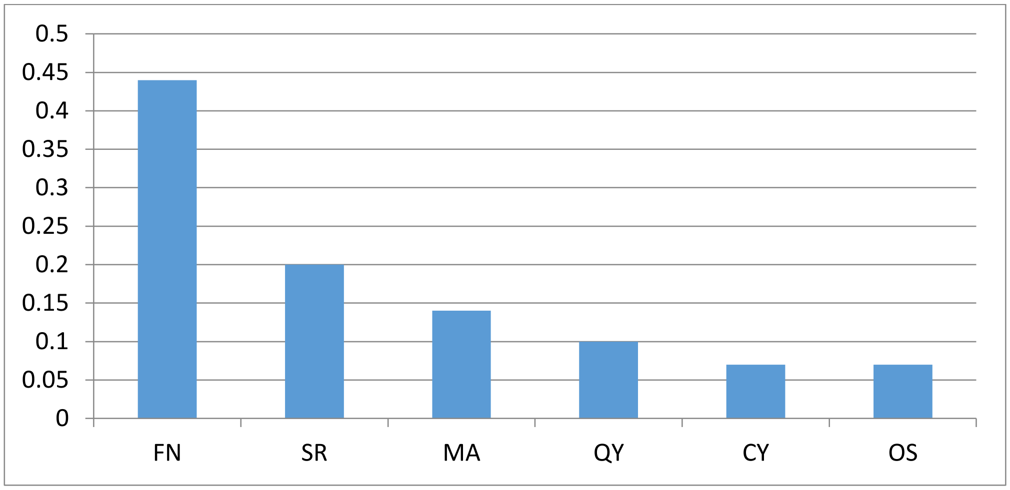

Figure 4.1
Mean weight and its correspondent ranking of the supplier selection criteria

Throughout the evaluation process, the group members were given the opportunity to discuss and seek clarification on their perspective ranking before they could agree and accept the mean weight calculated and its correspondent ranking. The Financial aspect was the most important criterion to the group members since cost is the most crucial part in selecting the supplier criteria. Capacity and Outsourcing were equal in terms of mean weight, but most decision makers agreed that Capacity is more important than Outsourcing because the PV module solar requires correct timing and compliance with delivery terms. Overall, the decisions makers were reliable with their decisions as the CR are closely to “0” which below the prescribed 10% satisfactory level as recommended by Saaty (1980). Figure 4.2 shows the calculated CR for each decision maker.

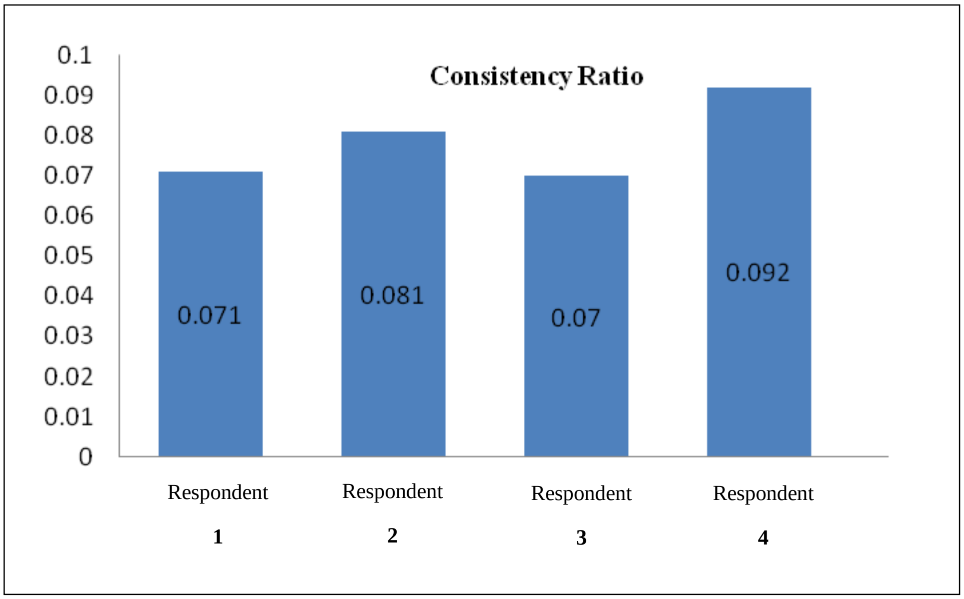

Figure 4.2
Consistency ratio of decision makers

4.2.2 The Alternatives

The second part of the analysis was to produce a normalized matrix from the pair-wise comparison matrix to determine how the four choices (suppliers) address each criterion followed by using the weight vector. The same strategy was utilized to compute the four alternative which is the suppliers against every criterion. Figure 4.3 to Figure 4.8 depict the mean weight and the corresponding rank of the four alternatives by addressing the respective criteria. Table 4.10 summarizes the results of the mean weight and the rankings of the alternatives against each criterion.

Figure 4.3 : *Financial*

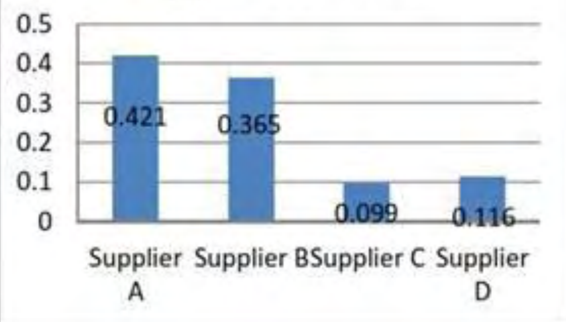

Figure 4.4 : *Quality*

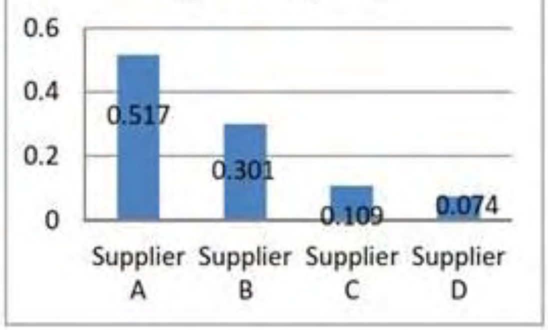

Figure 4.5 : *Support resources*

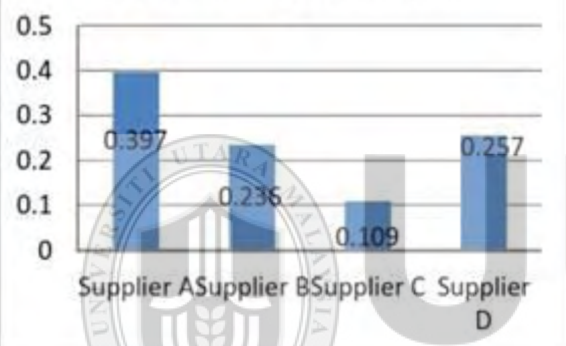

Figure 4.6 : *Capacity*

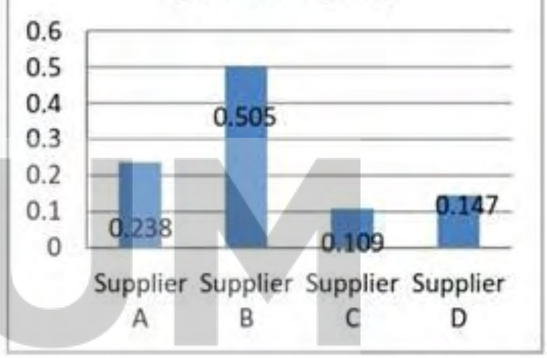

Figure 4.7 : *Managerial*

Figure 4.8 : *Outsourcing*

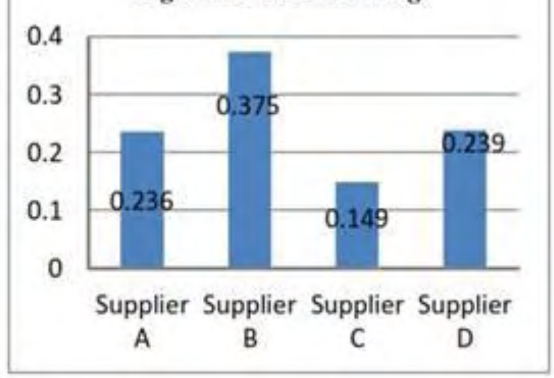

Table 4.10

Mean Weight and Ranking of Alternative against Each Criterion

	FN	Rank	QY	Rank	SR	Rank	CY	Rank	MA	Rank	OS	Rank
Supplier A	0.421	1	0.517	1	0.397	1	0.238	2	0.341	2	0.236	3
Supplier B	0.365	2	0.301	2	0.236	3	0.505	1	0.346	1	0.375	1
Supplier C	0.099	4	0.109	3	0.109	4	0.109	4	0.148	4	0.149	4
Supplier D	0.116	3	0.074	4	0.257	2	0.147	3	0.165	3	0.239	2

Table 4.10 shows that in terms of the financial aspect (FN), Supplier A was ranked first as it offered value in terms of cost, profit, and return. On the other hand, Supplier C was the least preferred as it offered limited value in terms of profit and cost (Figure 4.3). For the Quality (QY) criterion, Supplier A was ranked first because of technical and operational criteria while Supplier D was the least preferred in terms of quality. As a PV module solar project lasts more than 20 years, quality is key (Figure 4.4). In terms of the Support Resource (SR) criterion, Supplier A was ranked first because it offers support resource and support services. As a PV solar module is common in a solar technology project, technical support is necessary. Supplier C has a few support resources, and hence the least preferred choice (Figure 4.5). With respect to the Capacity criterion, Supplier B was the most preferred choice because it is committed to on-time delivery. Supplier C was the least preferred (see Figure 4.6). For the Managerial aspect (MA), Supplier B was ranked the most preferred because it a good relationship with the company while Supplier C was ranked the least preferred due to a lack of such relationship (Figure 4.7). For the Outsourcing (OS) criterion, Supplier B was ranked the most preferred because they give

lower price, although the currency exchange and duty and tax included (at that particular time), compared to Supplier C, which is a local product (Figure 4.8).

4.2.3 Aggregate and compute the overall weighted score for each alternatives

In this step, the overall weighted score was computed for the each suppliers. The overall rankings of the suppliers against each respective criterion was calculated by multiplying the rankings of the suppliers against each criterion with the ranking of the criteria. The respective selection of the group members and the calculated mean weight of the group are illustrated in Table 4.11. The results from the AHP method shows that Project Manager (PM) chose Supplier B as his first choice with the highest ranking of 0.362, followed by Supplier D (0.296), Supplier A (0.234), and Supplier C (0.108). The same interpretation applied to the rest of the decision makers. The overall mean weight of the group indicated that Supplier B was their first choice with the highest mean weight of 0.36, trailed by Supplier A (0. 35), Supplier D (0. 17), and Supplier C (0. 13).

Table 4.11
Summary of Results for AHP Analysis

Selection criteria	**Rep. PM**		**Rep. PO**		**Rep. Purchasing**		**Rep. DC**		**Mean Weight**	
	Wt	**Rank**	**Wt**	**Rank**	**Wt**	**Rank**	**Wt**	**Rank**	**Wt**	**Rank**
Supplier A	0.234	3	0.492	1	0.263	2	0.410	1	0.35	2
Supplier B	0.362	1	0.311	2	0.410	1	0.344	2	0.36	1
Supplier C	0.108	4	0.132	3	0.109	4	0.165	3	0.13	4
Supplier D	0.296	2	0.065	4	0.219	3	0.082	4	0.17	3

4.3 Summary

Based on the results from the AHP method and the objectives of this study, the financial (FN) criterion is identified as most appropriate and relevant in supplier selection, with the highest mean ranking of 0.44. This means that the financial aspect was the most relevant in supplier selection. On the other hand, Outsourcing (OS) was the least preferred selection criterion. In determining which supplier that best meet the requirements of the project, Supplier B, which had the highest mean ranking of 0.36, should be selected. It means that the management must focus on this supplier in their prioritization of their projects.

CHAPTER FIVE

CONCLUSIONS

Choosing a supplier is always a challenging task for a firm as it may involve many selection criteria. In many instances, cost is used to determine the choice of a supplier. However, nowadays, other parameters are also beginning to be considered, such as quality, on-time delivery, and professionalism. The AHP method was used to identify the project selection in this case study.

5.1 Summary

As a quantitative decision support tool, the AHP method allows the organization to prioritize its supplier based on certain criteria. This tool d enables the decision makers to justify their choices, as well as generate possible results. In general, the two objectives set were achieved as follows:

i) From the literature review, six selection criteria were used by this group decision makers and analysed using AHP method. They were prioritized as follows:

1. Financial aspect
2. Quality aspect
3. Support resources
4. Capacity aspect
5. Managerial aspect
6. Outsourcing aspect

ii) By using the AHP method, Supplier B was identified to be the most preferred supplier. Furthermore, all decision maker agreed that Supplier B was chosen to be the best amongst the four suppliers and fits the requirement of the organization.

5.2 Contribution of the Study

The main contribution of the present work is the identification of the important criteria for PV module supplier selection for Perlis Solar Project. A set of reliable criteria in making decision has been clarified. Thus, the first objective of the research was satisfied. The second contribution is the development of multi-criteria decision model for the evaluation and selection used in PV module supplier selection. As a result, the model for supplier evaluation and selection was successfully developed by using the AHP method. Thus, the second objective of the research was met. Using the AHP model, the present study clearly identified systematically the criteria for supplier selection and structured the problem. The suggested five-point rating system of assessing the supplier helped the decision makers reduce the time that could have spent if the pair-wise comparison judgments were used. The system also enabled the decision makers to determine the strengths and weaknesses of the supplier classifications by comparing them against the set criteria and sub-criteria. Additionally, the findings of this study can be transferred to a worksheet/database for simple computations. It is also uncomplicated for the appraisal team to achieve the consensus decision. From the results, the AHP model developed can be used as a basis for implementing supplier selections of PV module systems. The present study can be replicated to select suppliers in a PV module company. It can be said that by using AHP model in the selection of suppliers for Perlis Plant Solar Project could enhance the company's decision-making process.

In conclusion, this study may be the first attempt developing a model for PV module supplier selection. The results showed that the models are able to assist decision makers in examining the strengths and weaknesses of supplier selection by comparing them against the set criteria, sub-criteria, and sub sub-criteria. Furthermore, the model is applicable to any supplier selection problem in a PV module company in the world. In other words, the proposed AHP model is more effective when it can be used as an aid in decision-making process.

5.3 Limitations

There are some limitations in this study as discussed below, and each limitation should be addressed in future works. The selection criteria in this study were based on literature review, so they may be limited and may not hold true for other companies. For future research, other selection criteria should be taken into account. Secondly, the decision makers in this company were limited to top management people. Thirdly, the results may not be applicable to supplier selection process in other industries such as manufacturing or construction. The project has successfully implemented the AHP method in the supplier selection process and proposed the best choice. However, better choices outside the candidate pool could have been considered. There are also limitations in the AHP method. For example, Min (1994) addressed that AHP can be considered as relative importance which affect the performance of the suppliers, moreover it will effectively take into risk and uncertainty in assessing the supplier’s potential.

5.4 Recommendations

For a successful group decision-making process, the following recommendations are worth considered:

a. Commitment from decision makers is required to apply the AHP technique in making selection decisions. Supportive top management will enhance its effectiveness.

b. Broaden the usage of AHP to other functions of group decision making in the organization, such as in the selection of a supplier for sourcing functions.

c. Training is to be provided to potential decision makers in the organization to appreciate the AHP application.

d. Invest in appropriate software to ease computation of AHP such as Expert Choice.

e. Apply AHP to other selection criteria.

Solar energy has become a matter of global attention in the past few years, especially in Malaysia. This is evidenced by the warm welcome received by Sustainable Energy Development Authority Malaysia (SEDA) when a 20 MW solar quota is depleted within 1 hour (SEDA Portal, 2 April 2013). Solar can be one of the main renewable sources for electricity generation in Malaysia with the many sources of funding for R&D and support government policies in Malaysia.

The paper has discussed the selection process using the AHP model and its ability to embrace both qualitative and quantitative data through the assignment of numerical values to qualitative data. This paper has also discussed the significance of its role as a decision-making tool. The use of generic selection criteria in many studies highlighting the need to identify the evaluation criteria, although there will always be a special case of the criteria for assessing suppliers. This is important for many industries and in the context of the acquisition to estimate the relative importance of the criteria (Arbel & Seidmann, 1990). Other studies have also discovered supplier selection criteria may be different if using regression-based approach. However, it is important to note that the methodology based on regression cannot estimate the relative importance of these criteria as there will be deterministic linear option and also less effective in alleviating human preferences and subjectivity (Arbel & Seidmann, 1990). Thus, to meet the objective of the study while addressing this limitation, the HP for group decision making was used.

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