



CEMENT INDUSTRY PREFERENCES FOR CAPTIVE POWER PLANTS IN PERSPECTIVE OF CURRENT ENERGY CRISES OF PAKISTAN

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Abstract

In the current wake of energy deficiency, it is pretty reasonable for the senior management of Pakistan Cement Industry to look for non-conventional sources for electricity generation. Comparative study of captive power plant (CPP) options may help the top management in decision making and highlight the industry preferences for installation of new CPPs. This paper presents an Analytical Hierarchy Process (AHP) based multidimensional approach to select the CPP's for cement industry and to prioritize the factors affecting this selection. The CPP's shortlisted for this analysis include; Coal Fired CPP (CF-CPP), Refuse Derived Fuel CPP (RDF-CPP) and Waste Heat Recovery CPP (WHR-CPP). The AHP routines are modelled in commercially available AHP software. Data specific models are solved using the data collected from top management of different cement plants in Pakistan. The quantitative data for alternative power plants with respect to each criterion has been collected from different data bases. AHP results show that Pakistan cement industry has a strong demand for non-conventional CPP's and the top management is giving high priority to factors like 'Automation' and 'Performance' while installing the CPP's. Management is not much sensitive about the associated initial costs. The paper concludes with a ranking list in which WHR-CPP is at the top while RDF-CPP and CF-CPP are at the second and third place respectively. The results may help the policy makers of international CPP manufacturing firms and national cement industries in their future strategic decisions.

Keywords: Multi-Criteria Decision Making (MCDM), Captive Power Plants (CPPs), Analytical Hierarchy Process (AHP)

1. INTRODUCTION

Energy is a very crucial element for the growth and sustainable development of any society in this modern era. Economy of a country requires useable, reliable, affordable and uninterrupted supply of energy to sustain the development momentum. The per-capita consumption of energy is considered an important aspect of economic growth of a country.

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Developing countries are facing serious challenges to meet their increasing energy needs and Pakistan is amongst those countries where there is a need to find a solution for the energy deficiency. The primary energy supply of Pakistan mainly consists of oil, natural gas, coal, hydro and nuclear electricity. Source wise major shareholders of the primary energy mix (in Metric Tonnes of Oil Equivalent (MTOE)) and their trend from year 2010 to year 2014 is shown in Figure 1[1].

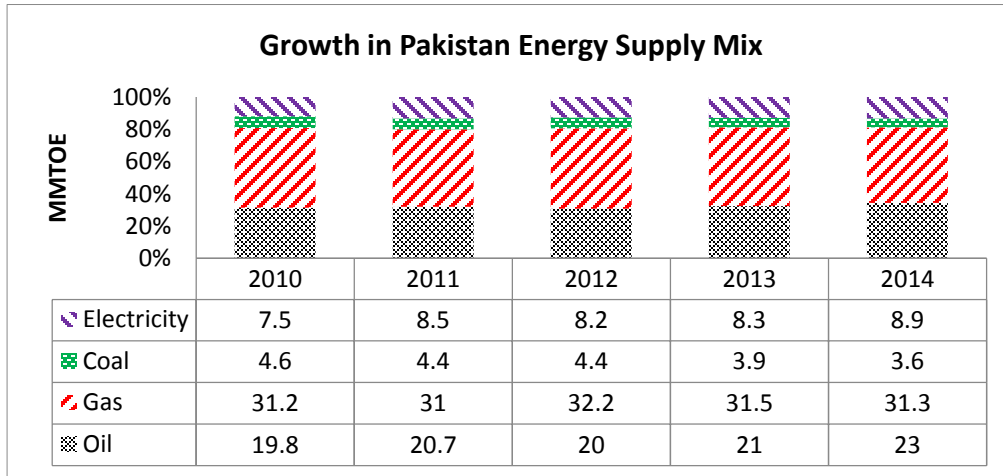


Figure 1: Source wise Primary Energy Supplies (MTOE) of Pakistan [1].

Although electricity is a secondary source of energy, it has become indispensable for domestic as well as for other applications such as industry, transport, agriculture etc. Total installed capacity of electricity (less the supply by Karachi Electricity Supply Company (KESCO)) in the country was 22,104 MW at the end of June 2014 as compared to 20,850 MW in June 2013. With increased industrialization and urbanization, the growth in supply of electricity could not keep pace with the rising demand and the shortfall reported in 2013 has been about 5000 MW [2]. This gap in demand and supply is expected to prevail in the country by year 2020 [1].

Cement industry is one of the major entities in industrial sector playing vital role in the development of infrastructure in Pakistan. Being tenth major export item, it also contributes a considerable share in the national exports. Pakistan is placed among top twenty cement producing countries of the world and it is the eighth largest exporter of cement. Although total installed production capacity of Pakistan's cement industry is about 44,768,250 tons per year, currently only 75~85% of this capacity is being utilized. The construction sector has witnessed growth of 11.3% during year 2014 and domestic industry dispatches have also increased by 9% during the first five months of the year 2015 resulting in rapid increase in the consumption of cement [3]. As Pakistan is moderately heading towards economic stability, construction and development activities are expected to further improve in the coming years. Even if the infrastructure projects envisioned by the present government partially materialize in their five year term, the resulting demand growth (~8% pa) will tempt the cement industry to bring additional capacities online [4].

Production of cement is amongst the highly energy-intensive processes. Average consumption of electricity is in the range of 110~120 kWh per ton of cement which depends on the age of a cement plant and technology used for cement manufacturing [5]. The combined cost of fuel and power make up 74% of the total expenditures whereas power accounts for 50~60% of direct

production cost [6]. In order to cope with the prevailing energy crises, the cement industries of Pakistan need to generate their own electricity using captive power plants.

While coping with the challenges of energy shortfalls, the cement industries in Pakistan are now striving for installing more and more independent CPP's. However they are still mostly depending on the conventional fuels like oil and gas as discussed earlier. On the other hand world's oil and gas reserves are declining very rapidly and are suspected to be finished in the second half of this century. Many alternative fuels and technologies are available for the purpose of power generation to meet the in-house energy requirements of cement industries. Based on these arguments, it is reasonable for the top management even in Pakistan to consider non-conventional options of CPPs. There is a very close competition among the alternatives short listed by experts for the current analysis including coal-fired, RDF and waste heat. Prioritization of factors affecting the selection decision of these CPP alternatives is the main focus of this study in perspective of developing countries.

Coal is the second largest source of energy having about 27.3% share in the global primary energy mix [7]. The existing known coal reserves of the world are approximately 929 billion tons, 40% of which is used for power generation. A coal based power plant having up to 50 MW generation capacity costs about 1.2~1.5 million US\$ per MW (most economical) and can be installed within 1.5~2 years. According to Rauf, et al. [2], Pakistan has approximately 186 billion tons of coal reserves (equivalent to 400 billion barrels of oil) which are considered to be sufficient for 20,000MW electricity generation for 40 years. Despite the fact that these reserves are sixth largest in the world, these contribute only 6% in the total energy mix of the country and 0.1% in electric power generation [7]. However it is a debatable and complex issue due to sulphur content in local coal which is harmful to the environment.

Cement industry has great potential to generate its own power using heat (of exhaust gases produced from cement manufacturing processes) by waste heat recovery system (WHRS). These plants are estimated to improve overall operating efficiency and decrease power consumption cost by 30% resulting in big financial support by making their production costs even more competitive [8].

Refuse derived fuel (RDF) is obtained by efficiently removing inert fractions from the waste and turn out a valuable fuel which can be used in waste-to-energy power plants as alternative fuel. Huge potential of electricity generation from solid waste exists in the country as large amount of municipal waste (approximately 56,000 tons) is produced on daily basis in urban areas of Pakistan only which is annually increasing at 2.4% rate [9].

2. Multi-Criteria Decision Making in Energy Decisions

A lot of research is reported in literature on different aspects of energy solutions to cope with the current energy crisis observed particularly in developing countries. The current solutions have many attributes which are multidimensional. While selecting energy solutions we must take into account all of these influencing parameters. Analytical Hierarchy Process (AHP) is one of the most widely utilized multi-criteria decision making (MCDM) tools applied in many fields of research. In AHP, the experts are asked to compare the parameters by considering two of them at a time. Then the alternatives are compared with respect to each parameter by using the same pairwise comparisons or by incorporating the quantitative data available in some other authentic form. Thus a prioritized list of influencing parameters as well as the alternatives is prepared by performing the recommended mathematical procedure which is explained in modelling section.

Despite the fact that research on the issue of coping with the global energy crisis has rapidly increased in recent past, the multi-criteria decision making for captive power plants of the cement industry are pretty rare. Some authors have applied MCDM techniques like AHP for comparative evaluation of renewable energy power plants [10, 11] while some others emphasize on the energy policy making issues and strategic decision making. A few examples of the MCDM based decision making in energy policy making are: Madadian, et al. [12] evaluated four waste management policies including RFD with a focus on energy solutions for the society. They prioritized eight parameters to select the best strategy using AHP. Hughes [13] also utilized AHP to establish an energy security index to have a prioritization of energy sources making up a theoretical jurisdiction's energy mix. Erol and Kılıç [14] also assessed an energy source policy making using the AHP. A unique study had been reported in literature on said issue by Hong, et al. [15] which addresses the hydrogen energy production. The alternatives for this research work include Natural Gas Reforming, Coal and Biomass gasification, Water electrolysis, thermo chemical production, Photo-electro Chemical hydrogen production, and biological hydrogen production. Eight criteria's are taken under consideration. Strategic energy planning and decision making has also been addressed by some researchers under the umbrella of AHP based MCDM analysis. These include an energy education framework for Taiwan proposed by Chen, et al. [16] and setting a performance criterion for energy projects on national level by Fu and Lin [17].

The literature review depicts that MCDM based decision making in national and international level problems of the energy sector is still not a much saturated area from the point of view of available research potential. However these authors are yet unable to find a comprehensive and comparative analysis of the captive power plants in literature particularly those which are not depending on the conventional fuels like oil and gas.

3. Materials and Methods

In this section the AHP modelling and research methodology for selection and ranking of captive power plants is presented. As per standard AHP modelling procedure developed and recommended by Thomas L. Saaty, it is first needed to define our variables and alternatives for comparison matrices. Then the experts/decision-makers from the concerned industry would be able to compare all the parameters with respect to each other and the alternatives. Once the variables are defined for pairwise comparison the problem is graphically modelled in the form of hierarchy having the goal at top most level and the alternatives at the lowest level.

Once the variables are defined and the hierarchy is constituted, the analysis involves three main steps: a) Constituting the comparison matrices between sub-criteria, main criteria and the alternatives at each level of the constructed AHP hierarchy b) Calculating the weights for each member of the matrices and hierarchy c) Having an estimation the inconsistencies in calculated values using the consistency ratio equations. The output would be in the form of rankings and weights for all sub-criteria, the main criteria and the alternatives. Let 'A' be a square comparison matrix with 'n' number of rows and column and ' a_{ij} ' be the relative value of criteria 'i' with respect to 'j' as shown in Eq. (1).

$$A = [a_{ij}]_{n \times n} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \cdot & \cdot & \dots & \cdot \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \quad (1)$$

The pairwise comparisons of all the problem elements at each level of hierarchy would be done using the recommended Saaty's 1-9 scale having values from one to nine.

Once all the concerned pairwise comparison matrices are prepared, the *vector of weights*, $w = [w_1 \ w_2 \ \dots \ w_n]$, will be calculated using Saaty's Eigenvector procedure. The calculation of these weights involves the following two steps. The comparison matrix 'A' is normalized using Eq. (2) while the final priority weights are calculated using Eq. (3).

$$a_{ij}^* = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad (2)$$

where $j = 1, 2, 3, \dots, n$.

$$w_i = \frac{\sum_{j=1}^n a_{ij}^*}{n} \quad (3)$$

where $i = 1, 2, 3, \dots, n$.

The models involved in estimation of inconsistencies were adopted from the relevant literature on AHP. The alternatives considered for this MCDM based comparative evaluation of the CPP's for cement industry of Pakistan include Coal Fired Power Plants, Waste Heat Recovery Power Plants and Refuse Dried Fuel (RDF) Power Plants as discussed in previous section. An initial list of main and sub-factors affecting the decision of power plant selection had been extracted through literature and presented to the experts. The panel of experts included about fifteen experts in different cement industries from different regions of Pakistan. All of them had an in-depth knowledge and experience of dealing with energy related issues of the cement plants. After a few modifications and recommendations the experts agreed on an initial un-prioritized list of factors to be included in upcoming AHP analysis. They excluded many factors like different turbine and generator specifications which are believed to be equally important for all of the captive power plant alternatives and have almost no effect on comparative evaluation of the alternatives. The hierarchy shown in Figure 2 not only provides the different levels of our problem but also a complete initial list of affecting parameters and the alternatives.

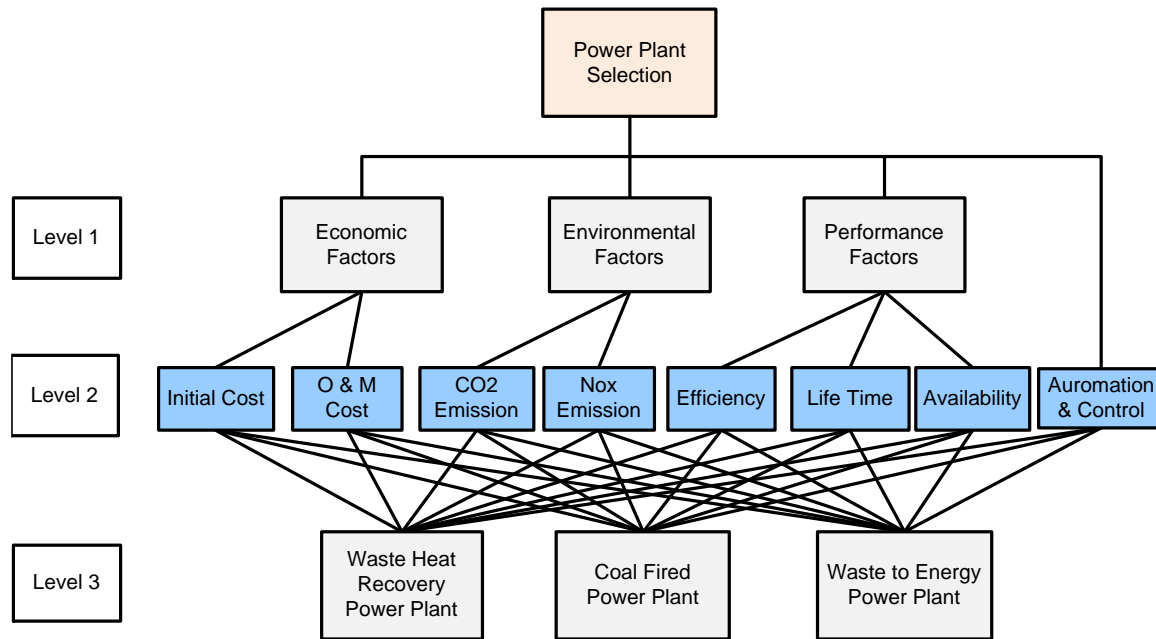


Figure 2: AHP Hierarchy of Power Plant Selection

A questionnaire has been designed for the pairwise comparisons and presented to the experts. The geometric mean of values obtained through pairwise comparisons by all experts has been then calculated to have a combined and aggregate prioritization of factors. In order to minimize the computational effort and to have a comprehensive representation of results, the AHP software package Expert Choice® has been utilized.

After completion of pairwise comparisons of all main and sub factors, the next AHP step is about comparing all the alternatives with respect to each sub-factor. However for most of the factors accurate data about the alternatives can be explored from different data sources. The reliance on human approximations can, therefore, be minimized by making use of the available quantitative data. Appendix shows the quantitative values and respective data sources of the sub-factors with respect to three CPP's alternatives. According to available data, the factors can be divided into two categories; 1) desirable factors when decision makers are interested in higher values like performance factors and 2) undesirable factors when the decision makers are interested in lower values like the costs. To bring all the desirable and undesirable factors at par, the data grid feature of software has been utilized. By making use of defining the decreasing and increasing utility curves we can define whether we are interested in higher values or the lower ones. Thus, in this way, direct inputs have been provided to AHP model in Expert Choice®. However, for the factor named 'Automation and Control', no directly quantifiable measurement was possible. The conventional AHP pairwise comparisons have been, therefore, performed by seeking expert opinions using questionnaires for this particular factor.

5. Results and Discussions

This section provides the solved models and discussion on results. The values assigned by cement industry experts constitute the comparison matrices which were combined and the models solved in the software. Figure 3 shows the results in the form of rankings of the factors.



Figure 3: Overall rankings of the main factors

The factors like ‘Automation and Control’ and ‘Performance’ are at the top of list while ‘Economic Factors’ have attained the lowest priority. This result is quite interesting and really fascinating from the view point of global investors. The results indicate that due to the present energy crisis in Pakistan, there is a pressure on the top management and policy makers in the cement industry to even consider alternative CPPs rather than restricting themselves to the conventional CPPs based on cost alone. They really don’t care about the economic factors like costs and are more interested in performance and automation of the power plants. This means that the cement industry demands are apparently strong enough to attract the investors who can provide sophisticated, highly efficient and environment friendly power plants. A more detailed information about calculated priorities for all the main and sub factors can be seen in AHP hierarchy shown in Figure 4. Here the alphabets ‘G’ and ‘L’ in parenthesis denote the global and local priorities respectively.

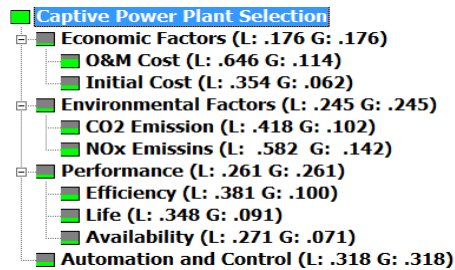


Figure 4: The priority details of all main and sub factors in AHP hierarchy

The results in hierarchy suggest that though economic factors are lowest in the overall ranking, the calculated priority weight of ‘Operations and Maintenance Costs’ is much higher than the initial investment cost. The sub-factors of ‘Environmental Factors’ and the ‘Performance’ have no substantial differences in terms of local priority weights.

Using the collected data presented in Appendix 1 and the pairwise comparisons, the AHP models have been solved in software. Figure 5 shows the overall final rankings of all power plant alternatives.



Figure 5: AHP Rankings of Alternative

It can be observed from Figure 5 that Waste Heat Recovery CPP has got the highest ranking while the RDF and Coal Fired CPP’s are second and third in the list. The Waste Heat Recovery CPP is much stronger than its competitor alternatives in Environmental Factors and Automation and Control. Its weight is almost similar to RDF CPP in case of Economic Factors while it is only marginally lower than Coal Fired CPP in ‘Performance’.

The RDF CPP has lowest value of ‘Performance’ while it is higher than Coal Fired CPP and lower than Waste Heat Recovery CPP in all other factors. The Coal Fired CPP is lowest in

ranking because it is weaker in most of the factors and worst in case of the environmental factors.

6. Conclusion and Recommendations

The current energy crisis in Pakistan is demanding the strategic managers to switch over to non-conventional alternatives of power generation to cope with the prevailing energy shortfalls. The country is among top cement producing nations of the world. However, like other industries, the cement sector is also facing the challenge of coping with the ever increasing energy needs. It is inevitable for the decision makers and the global investors to define and analyse the priorities for power plant selection decisions particularly in current perspective of industry requirements. This study presents a structured and scientific analysis of the criteria affecting this decision. Results show that currently the top management of Pakistan cement industry is keen about the sophisticated, efficient and highly automated CPP's and they are not much sensitive about the initial investment costs. Environmental factors have secured third position in the ranking list. Though the economic factors are at the bottom most location in the rankings, the operations and maintenance cost is a critical sub-factor of the economic factors. Based on these defined priorities, the Waste Heat Recovery CPP has emerged as the most suitable power plant among the selected three alternatives for the cement industry while RDF and Coal-based are second and third choices. This is because of its dominance in factors like automation, environment and the economy. Coal-based CPP is lower in the list mainly due to its environmental issues and the competitive sophistication.

The study can be extended by applying some hybrid multidimensional approaches which handle the real world ambiguities. It is a country and industry specific research and is applicable in current energy perspective. However, the same approach can be applied to calculate preferences of other industries. Moreover, it is strongly recommended that factors like 'power quality', maturity of technology' and 'ability of meeting energy needs of the plant' should be included in future studies.

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Appendix: Quantitative Data for Alternatives

Factors	Alternatives	Values (Estimated)	Data Sources
Initial Cost (USD)	Waste Heat Recovery	60M	Calculated from Financial and Technical Reports of renowned cement firms of Pakistan, [18], Reports from Confederation of European Waste-to-Energy Plants (CEWEP) URL:http://www.cewep.eu/ , [19], Data collected from different reports available at Ekokem URL:http://www.ekokem.com/en/
	Coal Fired	65M	
	RDF	31M	
O & M Cost (USD)	Waste Heat Recovery	1875	Reports provided by Alternative Energy Development Board of Pakistan, URL:http://www.aedb.org/
	Coal Fired	4000	
	RDF	2100	
Life Time (Years)	Waste Heat Recovery	25	Calculated from Financial and Technical Reports of renowned cement firms of Pakistan Reports from Confederation of European Waste-to-Energy Plants (CEWEP) URL:http://www.cewep.eu/ , [19], Data collected from different reports available at Ekokem URL:http://www.ekokem.com/en/ , [20]
	Coal Fired	25	
	RDF	25	
Availability	Waste Heat Recovery	99%	www.wikipedia.org/wiki/Availability_factor
	Coal Fired	90%	
	RDF	99%	
Efficiency	Waste Heat Recovery	30	Calculated from Financial and Technical Reports of renowned cement firms of Pakistan Comparison of power plant efficiencies extracted from information available at http://www.brighthubengineering.com/power-plants/ , [21]
	Coal Fired	48	
	RDF	35	
CO ₂ Emission (Gg)	Waste Heat Recovery	0	Calculated from Financial and Technical Reports of renowned cement firms of Pakistan, http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions
	Coal Fired	2249	
	RDF	837	
NO _x Emission (Gg)	Waste Heat Recovery	0	Calculated from Financial and Technical Reports of renowned cement firms of Pakistan, www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions
	Coal Fired	6	
	RDF	5.4	