Assessment of Environmental and Operational Performance of Thermal Powerhouses in Pakistan by Employing Data Envelopment Analysis Technique

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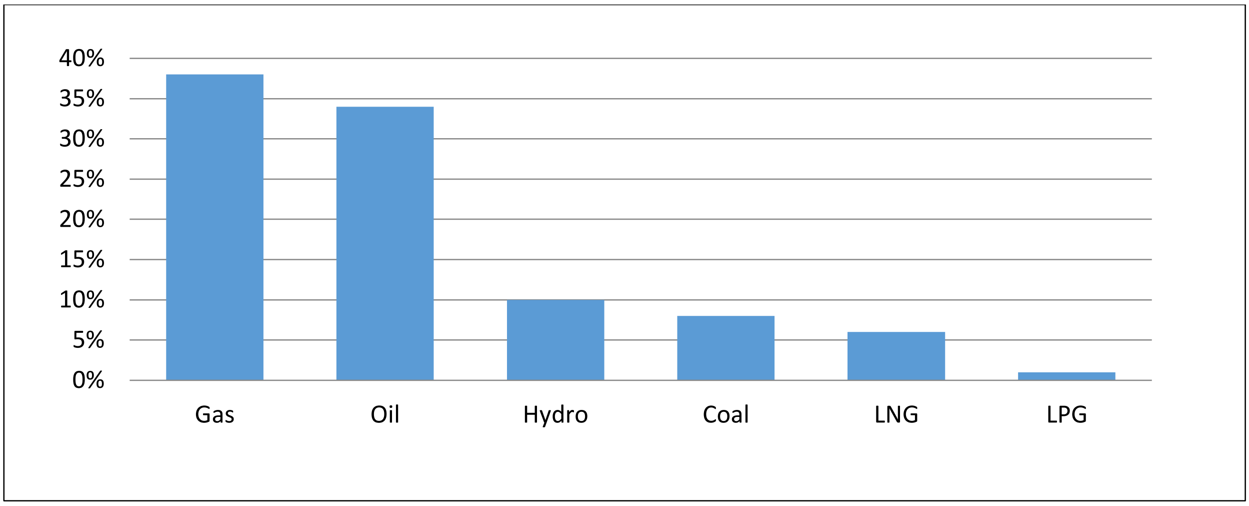
Abstract: In this paper, the operational and environmental efficiencies of twenty-one natural gas and eleven residual furnace oil thermal powerhouses using DEA (Data Envelopment Analysis) are presented. In the computation of the operational conduct, important generation factors are utilized as input, and fuel-cost/actual generation (Y) is taken an output in Model-01. At the same time, estimation of the performance of the environmental parameters such as gases discharged into atmosphere are taken as yield in Model-02. DEA technique is the key tool used for the calculation of the relative performance of the policy making units with various outputs and inputs. CRS/CCR (Constant Return to scale) and VRS/BCC (Variable Returns to scale) type models of DEA are applied in the analysis. Relationship among the score (Efficiency) and Output/Input variables are examined. Based on the analytical results the four most efficient powerhouses for each model are identified and one with the worst performance is also recognized.

Keywords:

1. Introduction

The energy plays a key role in all types of development, including economic development[1]. The energy demands of Pakistan and around the globe have increased exponentially due to socio-economic growth[2]. As per a report by NEPRA (National Electric Power Regulatory Authority) of Pakistan; the energy gap between the consumption and generation of Pakistan is about 6000MW, and the energy consumption in the country increased by 4.96% in 2016 excluding the K-electric. In order to meet the future demands either new powerhouses should be installed or the efficiency of existing powerhouses should be optimized[3].The most of the powerhouses in Pakistan use natural gas and the residual furnace oil fuels. 85% of both the fuels are imported from the other countries. These fossil fuels impart burden on the national budget and have a negative impact on the environment. Pakistan possesses very low energy resource capitals (Oil/Natural Gas). Pakistan totally relies on the other countries for fossil fuels like (oil and gas). Pakistan Bureau of Statistics said that the country invested $7.6 billion worth of fuel in the fiscal year ending 30th June 2016. This accounted for 17% of the total import bills of the year of 44.76 billion US dollars [4]. As they cost too much for the developing country like Pakistan, it is of prime importance to estimate the efficacies of existing powerhouses. The other alternatives from which, Pakistan can generate electricity through renewable resources such as solar, wind, hydropower and biomass, but the utilization of these resources needs technology as well as a high installing cost. Unfortunately, Pakistan cannot afford them at the moment[4].

According to NEPRA Report 2016, the total generation of Pakistan was 25,374MW in the country among these, the generation on the gas 38%, oil 34%, LNG (liquefied natural gas) 6%, LPG 1%, Hydro 10% and coal 8%. This shows that the major contribution of the electricity in Pakistan is dependent on the thermal powerhouses, which contributes 65.50% in the total share of electricity, on the second number Hydro powerhouses which contributes 28.04% in the generation of electricity, Renewable energy (solar, wind and bagasse) share the generation of electricity 3.36% and the Nuclear power contributes 3.10% in the electricity. This shows that still, the thermal powerhouses are dominant in Pakistan the major share of electricity comes from the thermal powerhouses. In this study, we have investigated twenty-one natural gas and eleven residual furnace oil powerhouses to check their Operational (Model-01) and Environmental (Model-02) performance. Theses thermal powerhouses generate about 65.5% of total generation (25,374MW) of the electricity[3][5].



'Figure 1'.Resource used for the electricity generation in Pakistan[3]

The number of researchers has tried to evaluate the Operational and, Environment efficiency of the thermal powerhouses in the various countries of the world by applying the Non Radial Data Envelopment Analysis[6], DEA SBM model[7], DEA [8], Data-Envelopment-analysis(DEA) Porters hypothesis[9], and Data Envelopment Analysis Classical model[10].In this paper, we have used the technique of DEA to analyze the Operational and, Environmental efficacy of Pakistan's thermal powerhouses which has never been done before. This study will give the direction for the future policy making for thermal powerhouses houses in the Pakistan.

2.Methodology

Rhodes, Cooper, and Charnes introduced the DEA method in 1978. DEA is used to compute the DMU (Decision Make Units') relative efficiency in an organization.[11][12] Here, a DMU is a particular unit inside an organization that has the authority regarding a portion of the choices it makes, yet not total opportunity concerning these choices. DEA can be applied to [Schools, Hospitals, University departments, Police stations, Prisons, Army, Navy, Air force, Banks, tax collection, thermal powerhouses, and many other places]. The benefits of DEA, include, it can be practically used in the non-profitable organization. DEA allows efficiency measurements on numerous outputs, inputs without assigning any weightage and stipulating any functional system, which are the major advantages of the DEA approach. Thermal Powerhouses' energy efficiency is termed as the power generated per energy input unit. The model can to solve the numerous inputs and outputs and need not any scientific type of work in correlating inputs and outputs. The DEA technique helps to detect the cause of inefficiency, concerning the dearth of outputs and overuse of inputs[13]. By employing the DEA technique, to recognize the source of inefficiency, concerning the dearth of outputs and overuse of inputs. The other advantages of the DEA are it focuses on discrete observations rather than means of population. It can utilize the exogenous and, dummy variables.

Model has ability to solve various inputs and outputs at the same time. However, disadvantages of DEA are it starts to converge gradually to Absolute Efficiency. In can also be influenced by, low inputs and huge outputs[10].Moreover, in this study we use two common models known as Cooper, Charnes and Rhodes (CCR) or (CRS) and, Bankers, Cooper and Charnes (BCC) or (VRS).The constant return to the scale (CRS) model is defined as if we increase the input there will be a proportional change in the output[12]. The Variable return to the (VRS) scale model is defined as if we increase the input there will be no proportional change in the output[14]. Scale Efficiency is termed as the ratio of CRS/VRS.

Constant return to scale = $\theta_{CCR} = P_{A1}/P_A$(1)

Variable return to scale =$\theta_{BCC} = P_{A2}/P_A$ (2)

Scale efficiency = $\theta_{CCR}/\theta_{BCC} = P_{A1}/P_{A2}$ (3)

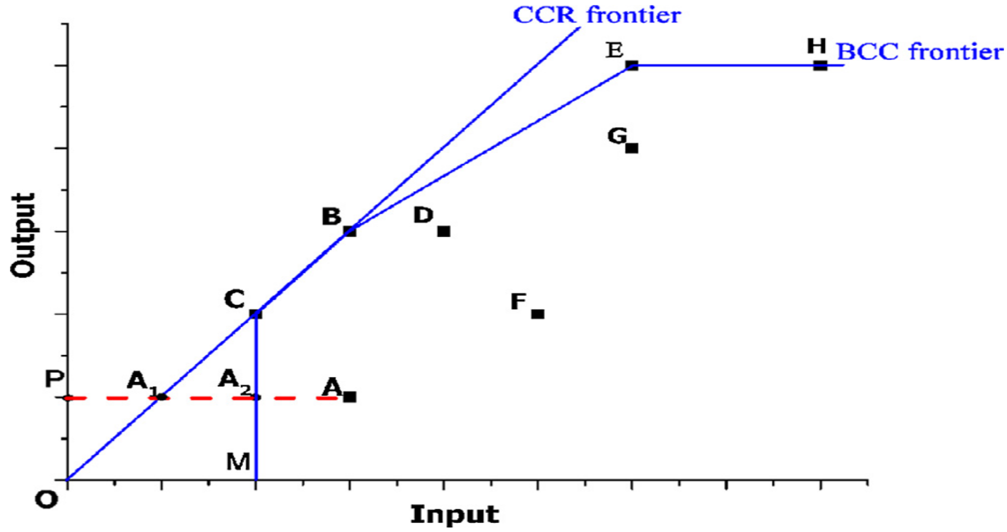
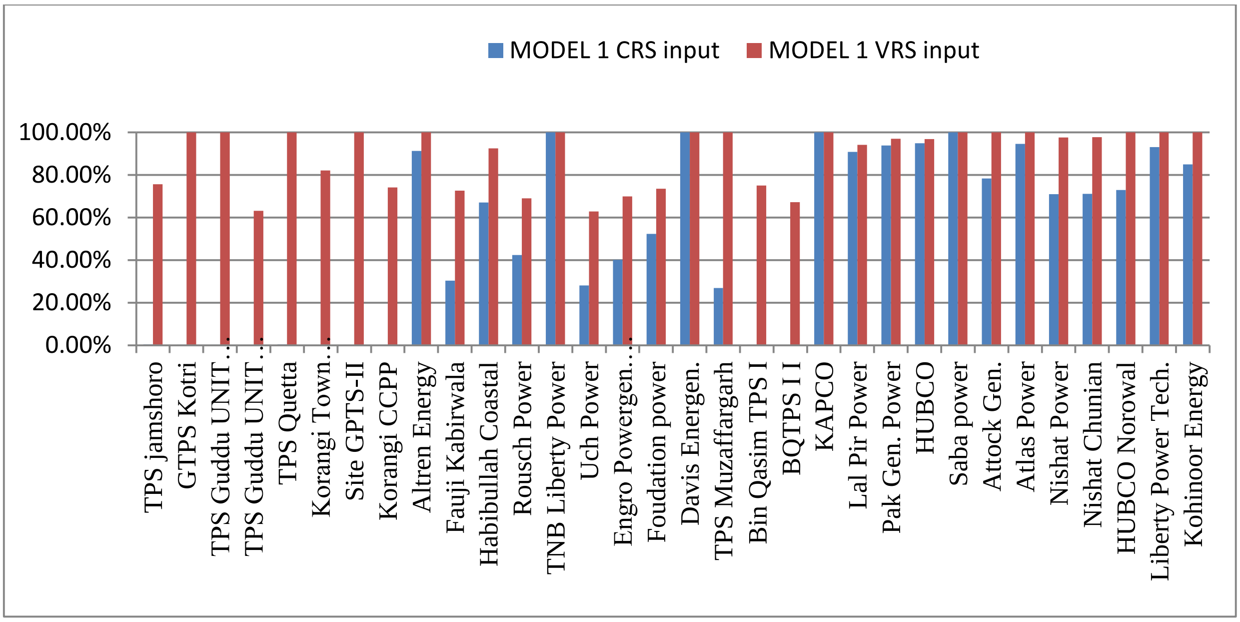


Figure 2.Graphical representation of data envelopment analysis.

In Model-01, we have checked the operational performances of the powerhouses using CRS and VRS methods and have compared their efficiencies computed using CRS and VRS. Major generation indications are selected as Input parameters, while fuel-cost/actual production of electricity is selected as Output parameters. While in Model-02, we have checked the Environmental performance of the thermal powerhouses. Environment waste from thermal powerhouse (CO_2 , SO_2 and N_2O) will be considered as output. The efficient and inefficient powerhouses are determined by using the results of the calculations. Furthermore, the inputs of inefficient powerhouses are compared with the inputs of those efficient powerhouses to make them efficient.

3.Results and Discussion

The results of model1 (operational efficiency) are given in Fig3. GTPS kotri, TPS Guddu(1-4), TPS Quetta , Site GTPS-II , Altren Energy , TNB Liberty power , Davis Energen , TPS Muzaffargarh, Kapco, Saba power , Attock gen , Atlas power , HubcoNorowal , Liberity power tech , Kohinoor energy powerhouses are found the most efficient in the variable return to scale (VRS). TPS Jamshoro, Korangi town GTPS-II, Korangi CCPP,Faujikabirwala, Habibullah coastal, Foundation power, Bin Qasimtps-I , Lal pir power, Pak gen power, Hubco, Nishat power and Nishat chunian are found the high performer powerhouses in the VRS, remaining are considered as the low performer powerhouses in VRS model 1 .On the other hand TNB liberty , Davis Energen, Saba and Kapco powerhouses are found the most efficient in the constant return to scale (CRS) in model 1.Altern Energy, Lal pir,power, Pak gen power, Hubco, Attock gen , Atlas power , Nishat power , Nishat Chunian , Hubco Norway , Liberity power tech and Kohinoor energy are found high performer in the CRS in model 1, remaining are considered as low performer powerhouses in the model 1. So as to make the non-efficient powerhouses efficient the inputs of the powerhouses must be decreased as per the obtained results of the CRS and VRS. The outcomes of both the model show that TPS Guddu unit (5-13) power house has most terrible performance.



'Figure 3' VRS and CRS efficiencies of the powerhouses (for Model 1)

The terms which are used in the following tables, their details are given below.

Thermal efficiency (%η)

Capacity usage factor (%)(CUF)

Average operational time (t)

Project production capacity (GWH) (PPC)

Fuel cost/actual generation (Y) (output in Model 1)

Carbon dioxide (CO_2) (output in Model2)

Powerhouses efficiency (%)

Slack analysis of Model 1.

Table1. Increase in Inputs and outputs according to the CRS analysis results of the model 1.

List of the powerhousesNumber of being reference (for efficient houses)

	CRS	Peers and weight for inefficient house.	% η	CUF	PPC	t	y
TPS jamshoro	.439%	0.12874267 TNB Liberty Power (0.16248191)	0	0	0	0	1967.27
GTPS Kotri	0.25%	TNB Liberty Power (0.16248191)	0	0.099	0	0	1314.33
TPS Guddu (4)	0.29%	TNB Liberty Power (1.0)	0	0	0	0	0
TPS Guddu (13)	0.07%	TNB Liberty Power (0.94196988)	0	0	0.3211	475.3426	64.1767
TPS Quetta	0.33%	TNB Liberty Power (1.0)	0	0	0		0
Korangi Town	0.06%	TNB Liberty Power (01682837)	0	0	0	1126.338	45.1034
Site GPTS-II	0.11%	TNB Liberty Power (1.0)	0	0	0	0	0
Korangi CCPP	0.05%	TNB Liberty Power (0.15009206)	0	0	0	682.7616	34.1649
Altren Energy	91.30%	TNB Liberty Power (1.0)	0	0	0	0	0
Fauji Kabirwala	30.40%	TNB Liberty Power (0.00626279)	0	0	0	2335.815	0
Habibullah Coastal	67.12%	TNB Liberty Power (0.08801295)	0	0	0	526.2155	0

Rousch Power	42.41%	TNB Liberty Power (0.30375685)	0	0	0	716.2258	0
TNB Liberty Power	100%	12(1.0)	0	0	0	0	0
Uch Power	28.11%	Davis Energen (0.42138431)	0	0	0	1814.934	0
Engro Qadirpur	40.16%	Davis Energen (0.05690061)	0	0	0	1072.604	0
Foudation power	52.32%	Davis Energen (0.39259802)	0	0	0	1351.632	0
Davis Energen.	100%	6(1.0)	0	0	0	0	0
TPS Muzaffargarh	26.895 %	(1.0) Davis Energen (0.39259802)	0	0	0	0	0
Bin Qasim TPS I	0.264%	0.45437 Davis Energen (0.39259802)	0	0	0	0.271144	1462.81
BQTPS I I	.0371%	0.82518 Davis Energen (0.39259802)	0	0	1736.6	0.006463	307.163
KAPCO	100%	3 (0.2458115)	0	0	0	0	0
Lal Pir Power	90.80%	KAPCO (0.39202156)	0	0	0	2623.918	0
Pak Gen. Power	93.93%	KAPCO (0.40122844)	0	0	0	2404.295	0
HUBCO	94.97%	KAPCO (0.62069487)	0	0	0.5674	2148.861	0
Saba Power	100%	7(1.0)	0	0	0	0	0
Attock Gen.	78.33%	Saba Power (0.98309710)	0	0.121	0.1156	3994.098	0
Atlas Power	94.59%	*Saba Power* (0.17143288)	0	0	0.0568	2734.236	0
Nishat Power	70.92%	*Saba Power* (0.13523047)	0	0	0.0551	2916.519	0
Nishat Chunian	71.08%	*Saba Power* (0.11043061)	0	0	0.0698	2853.166	0
HUBCO Norowal	72.98%	*Saba Power* (0.24622704)	0	0.024	0	2608.475	0
Liberty Power Tech.	93.17%	*Saba Power* (0.97847860)	0	0	0.1388	2634.106	0
Kohinoor Energy	84.97%	*Saba Power* (0.12818047)	0	0	0	3006.536	0

Table2. Increase in Inputs and outputs according to the VRS analysis results of the model 1.

List of the powerhouses	VRS%	Number of being reference (for efficient houses) Peer and weight (for inefficient houses)	% η	CUF	PPC	t	y
TPS jamshoro	75.63%	TPS Guddu (4) (0.12874267)	0	0	0	0	1967.27
GTPS Kotri	100%	(0.16248191)	0	0.0990	0	0	1314.33
TPS Guddu (4)	100%	(2) 1.0	0	0	0	0	0
TPS Guddu (13)	63.18%	TPS Guddu (1-4) (0.94196988)	0	0	0.3211974	475.342	64.1767
TPS Quetta	100%	(1) 1.0	0	0	0	0	0
Korangi Town	82.12%	TPS Quetta (0.1682837)	0	0	0	1126.33	45.1034
Site GPTS-II	100%	(1) 1.0	0	0	0	0	0
Korangi CCPP	74.20%	Site GPTS-II (0.15009206)	0	0	0	682.761	34.1649
Altren Energy	100%	(3) 1.0	0	0	0	0	0
Fauji Kabirwala	72.58%	Altren Energy (0.00626279)	0	0	0	2335.81	0
Habibullah Coastal	92.48%	Altren Energy (0.08801295)	0	0	0	526.215	0
Rousch Power	68.98%	Altren Energy (0.30375685)	0	0	0	716.225	0
TNB Liberty Power	100%	3 (1.0)	0	0	0	0	0
Uch Power	62.82%	TNB Liberty Power (0.42138431)	0	0	0	1814.93	0
Engro Qadirpur	69.94%	TNB Liberty Power (0.05690061)	0	0	0	1072.60	0
Foudation power	73.57%	TNB Liberty Power (0.39259802)	0	0	0	1351.63	0
Davis Energen.	100%	1.000000	0	0	0	0	0
TPS Muzaffargarh	100%	2 (1.0000000)	0	0	0	0	0
Bin Qasim TPS I	75.07%	TPS Muzaffargarh (0.45437894)	0	0	0	0.27114	1462.81
BQTPS I I	67.19%	TPS Muzaffargarh (0.82518956)	0	0	1736.622	0.00646	307.163
KAPCO	100%	3 (0.2458115)	0	0	0	0	0
Lal Pir Power	94.11%	KAPCO (0.39202156)	0	0	0	2623.91	0
Pak Gen. Power	97.04%	KAPCO (0.40122844)	0	0	0	2404.29	0
HUBCO	96.90%	KAPCO (0.62069487)	0	0	0.5674872	2148.86	0
Saba Power	100%	1.00000000	0	0	0	0	0
Attock Gen.	100%	0.98309710	0	0.1215	0.1156960	3994.09	0
Atlas Power	100%	0.17143288	0	0	0.0568919	2734.23	0
Nishat Power	97.72%	*Saba Power* (0.13523047)	0	0	0.0551017	2916.51	0
Nishat Chunian	97.81%	*Saba Power* (0.11043061)	0	0	0.0698125	2853.16	0
HUBCO Norowal	100%	0.24622704	0	0.0241	0	2608.47	0
Liberty Power Tech.	100%	0.97847860	0	0	0.1388792	2634.10	0

Kohinoor Energy	100%	0.12818047	0	0	0	3006.53	0

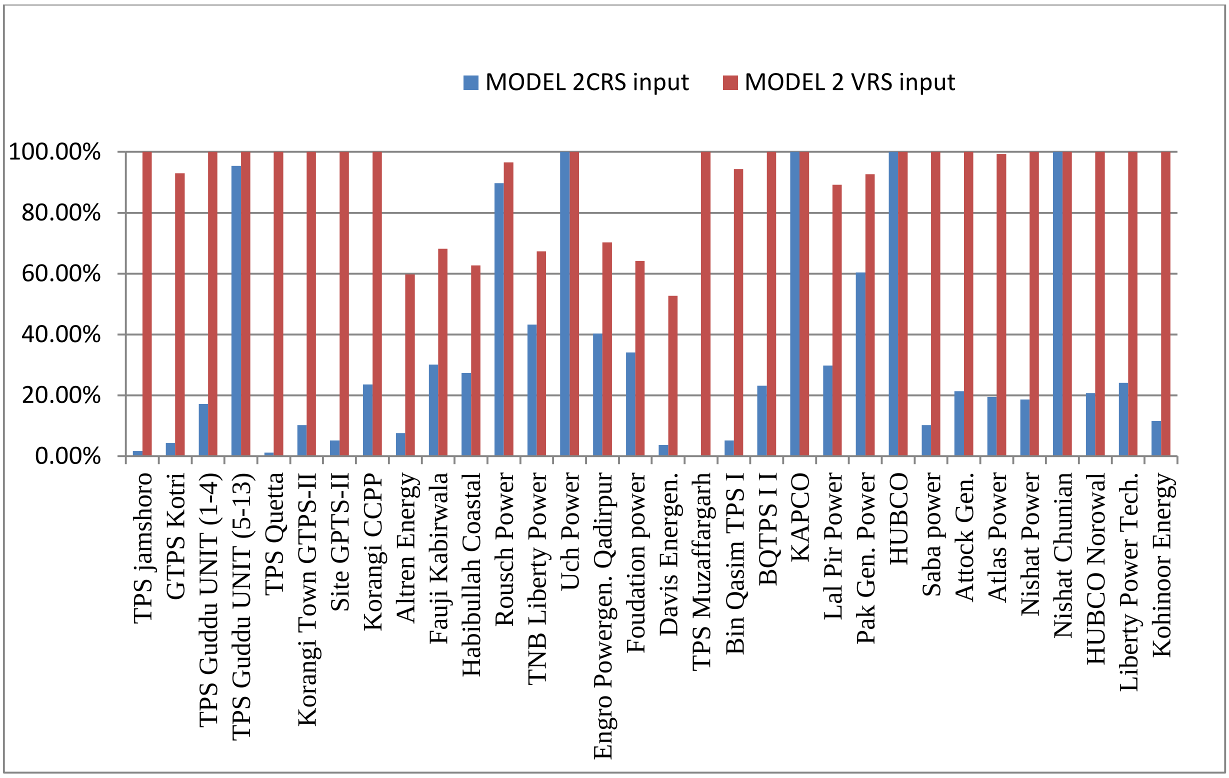


Figure 4.VRS and CRS efficiencies of the powerhouses (for Model 2).

Figure 4 shows the analysis results of the negative impact (model 2) of powerhouses on the environment. TPS Jamshoro ,TPS Guddu unit(1-4), TPS Guddu unit(5-13), TPS Quetta, Korangi Town GTPS-II, Site GPTS-II, Korangi CCPP, Uch Power, TPS Muzaffargarh , BQTPS II , Kapco , HUBCO, Saba power, Attock Gen, Nishat Power, NishatChunian, HUBCO Norowal, Liberty power Tech and Kohinoor Energy powerhouses are found the most efficient in the variable return to scale (VRS) in model 2. GTPS Kotri, Rouschpower , Engro powergen qadirpur , Bin Qasim TPS- I , Lal pir power , Pak gen power and Atlas power are found the good performer in the VRS model 2, remaining are considered as bad performer powerhouses in model 2.UchPower,Kapco , HUBCO,NishatChunian powerhouses are found efficient in the constant return to scale (CRS) in model 2. TPS Gudduunit(5-13) and Rousch power are found the good performer in the CRS model 2 and remaining are considered as the low performer powerhouses in the model 2. So as to make the non-efficient powerhouses efficient the inputs of the powerhouses must be decreased as per the obtained results of the CRS and VRS. Davis Energen has most terrible performance in the model 2.

Slack analysis of Model2.

Table3. Increase in Inputs and outputs according to the CRS analysis results of the model 2.

List of the powerhouses Number of being reference (for efficient houses)

CRS % Peers and weight (for inefficient houses) % η y t

CO_2

TPS jamshoro	1.6851 %	Uch Power (1.00000000)	0	0	0	0
GTPS Kotri	4.31%	Uch Power (0.8670589)	0	0	0	661304 .
TPS Guddu (4)	17.16%	Uch Power (1.0)	0	0	0	0
TPS Guddu (13)	95.37%	Uch Power (1.0)	0	0	0	0
TPS Quetta	1.15%	Uch Power (1.0)	0	0	0	0

Korangi Town	10.15%	Uch Power (1.0)	0	0	0	0
Site GPTS-II	5.17%	Uch Power (1.0)	0	0	0	0
Korangi CCPP	23.51%	Uch Power (1.0)	0	0	0	0
Altren Energy	7.58%	Uch Power (0.94178422)	0	42200.784	487.7	0
Fauji Kabirwala	30.11%	Uch Power (0.74800681)	0	11788.452	981.5	0
Habibullah Coastal	27.38%	Uch Power (0.5875060)	0	34258.601	0	0
Rousch Power	89.75%	Uch Power (0.2410622)	2.9870	22832.467	0	0
TNB Liberty Power	43.27%	Uch Power (0.6253988)	0	67888.738	0	0
Uch Power	100%	13(1.0)	0	0	0	0
Engro Qadirpur	40.27%	KAPCO (0.63616059)	0	19228.060	273.4	0
Foudation power	34.13%	KAPCO (0.67403668)	0	27064.839	415.1	0
Davis Energen.	03.66%	KAPCO (0.8966283)	0	46844.364	0	0
TPS Muzaffargarh	0.1134 %	KAPCO (1.00000000)	0	0	0	0
Bin Qasim TPS I	5.1651 %	KAPCO (0.1086917)	0	0	0	0
BQTPS II	23.10%	KAPCO 0	0	0	0	0
KAPCO	100%	5 (1. 000000)	0	0	0	0
Lal Pir Power	29.81%	HUBCO (0.4591761)	0	2949.4701	0	0
Pak Gen. Power	60.40%	HUBCO (0.4055376)	0	2014.7553	0	0
HUBCO	100%	2(0.4115171)	0	2160.1262	0	0
Saba Power	10.23%	*Nishat Chunian* (0.2648932)	0	270.4037	0	0
Attock Gen.	21.33%	*Nishat Chunian* (0.7079379)	0	6683.668	0	0
Atlas Power	19.45%	*Nishat Chunian* (0.3779411)	0	4950.4506	0	0
Nishat Power	18.65%	*Nishat Chunian* (0.8618964)	0	5441.2226	0	0
Nishat Chunian	100%	7(0.9144940)	0	4345.9063	0	0
HUBCO Norowal	20.75%	*Nishat Chunian* (0.8195152)	0	4776.0232	0	0
Liberty Power Tech.	24.11%	*Nishat Chunian* (0.4081281)	0	5062.0029	0	0
Kohinoor Energy	11.58%	*Nishat Chunian* (0.5671905)	0	5347.6459	0	0

Table4. Increase in Inputs and outputs according to the VRS analysis results of the model 2.

List of the powerhouses Number of being reference (for efficient houses)

VRS% Peers and weight (for inefficient houses) % η y t

CO_2

TPS jamshoro	100%	1.0	0	0	0	0
GTPS Kotri	92.99 %	TPS Quetta 0.8670589	0	0	0	661304
TPS Guddu (4)	100%	1.0	0	0	0	0
TPS Guddu (13)	100%	1.0	0	0	0	0
TPS Quetta	100%	6(1.0)	0	0	0	0
Korangi Town	100%	1.0	0	0	0	0
Site GPTS-II	100%	1.0	0	0	0	0
Korangi CCPP	100%	1.0	0	0	0	0
Altren Energy	59.78 %	TPS Quetta (0.94178422)	0	42200.8	487.7	0
Fauji Kabirwala	68.21 %	TPS Quetta (0.74800681)	0	11788.5	981.56	0

Habibullah Coastal	62.74 %	TPS Quetta (0.5875060)	0	34258.6	0	0
Rousch Power	96.58 %	TPS Quetta (0.2410622)	2.98	22832.5	0	0
TNB Liberty Power	67.35 %	TPS Quetta (0.6253988)	0	67888.7	0	0
Uch Power	100%	5(1.0000000000)	0	0	0	0
Engro Qadirpur	70.28 %	Uch Power (0.63616059)	0	19228.1	273.40	0
Foudation power	64.21 %	Uch Power (0.67403668)	0	27064.8	415.10	0
Davis Energen.	52.67 %	Uch Power (0.8966283)	0	46844.4	0	0
TPS Muzaffargarh	100%	1.0	0	0	0	0
Bin Qasim TPS I	94.40 %	TPS Muzaffargarh (0.1086917)	0	0	0	0
BQTPS II	100%	0	0	0	0	0
KAPCO	100%	0	0	0	0	0
Lal Pir Power	89.17 %	KAPCO (0.4591761)	0	2949.47	0	0
Pak Gen. Power	92.66 %	KAPCO (0.4055376)	0	2014.75	0	0
HUBCO	100%	1(0.4115171)	0	2160.12	0	0
Saba Power	100%	0.2648932	0	270.403	0	0
Attock Gen.	100%	0.7079379	0	6683.66	0	0
Atlas Power	99.33 %	*HUBCO* 0.3779411	0	4950.45	0	0
Nishat Power	100%	0.8618964	0	5441.22	0	0
Nishat Chunian	100%	0.9144940	0	4345.90	0	0
HUBCO Norowal	100%	0.8195152	0	4776.02	0	0
Liberty Power Tech.	100%	0.4081281	0	5062.00	0	0
Kohinoor Energy	100%	0.5671905	0	5347.64	0	0

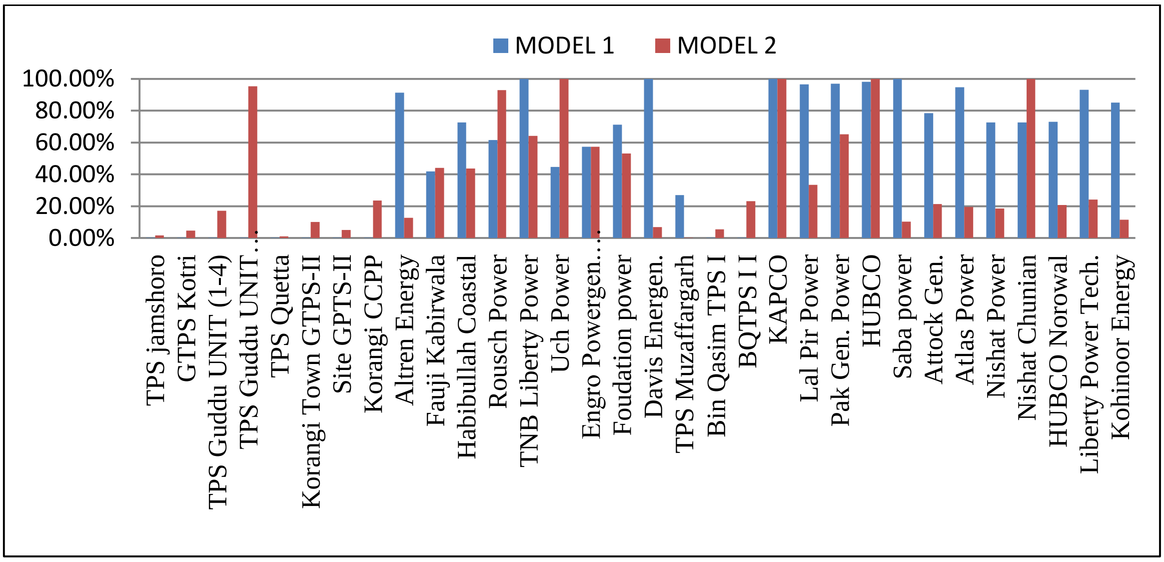


Figure 5.Scale efficiency of the powerhouses of both the models.

Figure 5 shows the scale efficiencies of the both the models (model 1 & model 2). The figure illustrates that the TNB Liberty Power, Davis Energen, Saba powerandKapcopowerhouses are the most scale efficient in the model 1, where asKapco and Nishat Chunian are found the most scale efficient in model 2.

4.Conclusion

As indicated by the results, only KAPCO powerhouse is found to be the most efficient powerhouse in both the models and no other powerhouse is efficient in both the models. KAPCO, TNB Liberity power and Davis Energen powerhouses are found efficient in the natural gas fired powerhouses in model 1.KAPCO and Uch power house is found efficient in the natural gas fired powerhouse in the model 2. Saba powerhouse is found efficient in the residual furnace oil in model 1. Hubco and Nishat Chunian are found efficient in the residual furnace oil in model 2. We believe that the outcome of this paper can be taken as one of the resources for making guidelines, recommendations and setting up the executives' strategies for Pakistan.

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