

Cost Modeling for Thermal Energy Storage in Hybrid Power Generation from CSP and Biomass Resources in Turkey - Southeastern Anatolia and Eastern Anatolia Region

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Abstract

Usually hot springs spa and evaluation of district heating Southeastern Anatolia and Eastern Anatolia between 45 ° C and 125 ° C, less dense the population is not economically in the region. there is a great need for storage of excess energy which is cleaner than the energy produced from the fossil fuel power plants. This storage has facilitated the increasing penetration of storage technologies and primarily from renewable energy sources (RES). The efficient use of excess energy sources in today's electricity networks may minimize the threat of global warming and climate change. However, the cost of power output and storage of these energy sources should be considerable and easy to adjust to changing demand cycles as the current and future energy storage technologies used for energy.

Model data trends observed in the average of approaches were examined and evaluated as a very well-parametric analysis of costs. It has been expanded by recent model costs. This risk analysis and plant construction, investors can provide insurance companies for risk assessment and decision-makers geothermal wells. Thus, the risk analysis will help in calculating the correct budgeting and insurance premiums.

The overall objective of hybrid the parabolic dish CSP solar panels and geothermal energy is the presence of a hybrid geothermal system can be produced economically. Geothermal energy was started in the vast area to be searched, amended as a result of the research data, the field is narrowed down to investigate to direct heating of regional area. At the same time studies in the cost-benefit criterion it has been considered, and thus became the economic research work.

Keywords: energy storage, risk assessment, stochastic cost estimation, simulation, direct heating simulation

I. Introduction

Lignite consumption in energy production is increasing in parallel with growing energy needs today. In terms of reserve and production quantities of high quality lignite, natural resources are limited. The significant amount of electricity is produced primarily from coal in the world (TKİ 2009, TTK 2009).

The almost 211TWh total electricity in 2011, Turkey were produced primarily from imported natural gas and domestic coal (Fig 1) (EIA, 2013). The total amount of asphaltite resource in reserves and production in Şirnak City are over 82 million tons of available asphaltite reserve and 400 thousand tons per year, respectively (MTA, 1987). Turkish coal industry needs noble gasification technologies and high gasification performances at lower cost with various types of local coals regarding researches. The most effective and cost-effective combustion or gasification technologies are needed for clean coal products in today's modern technologies (Bell et al, 2011, Shadle et al, 2001, Sharma et al, 2008, Jess et al, 2009, Kajitani et al, 2006). Turkish coal industry needs specific tests (Çakal et al, 2007) in order to measure gasification performances of various types of local coals regarding standard qualification tests. There are lots of signs for the waste yield of biomass in industrial many fields even using regular high capacity biomass of cellulosic wastes (Anonymous, 2009, Karakaya, 2008, TAM 2009, TSI 2009). Processing technologies using biomass should be under contribution to the fuel side producing high

value cleaned products, pyrolysis and gasification of lignite.

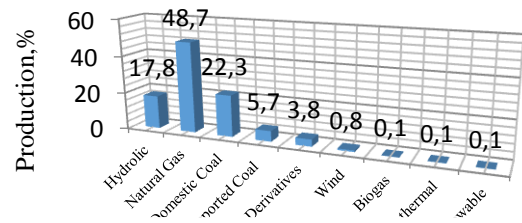


Fig 1. Primary Electricity production vs resources in Turkey regarding 2013.

II. Biomass Waste Potential of Turkey

In Turkey, the Ministry of Agriculture and Rural Affairs declared the statistics that the amount of waste generated from annual and perennial crops received from local authorities; the amount of production and acreage of each product is calculated using the data for 2012-2013. In our country, agricultural production waste is commonly left in the field. Cereal straw is used for various purposes, for example, used as animal feed, and fertilizer. The main waste in the field following the agricultural sawed products, plantations is allowed to rest. These kinds of waste cotton stalks, corn stalks, sunflower stalks, hay and tobacco stalks are waste, etc. Total amount of waste products are divided into theoretical and actual values given in the Table 1[3]. The total annual production of field crops in Turkey and waste quantities are given in Table 2.

Tab 1. Total amount of Municipal waste divided into actual values in Turkey and Eastern Anatolian Region in 2012.

Waste Type	Waste Statistics		
	Heat Value, kJ/kg	Country, Actual million ton/year	Eastern Anatolian Region Actual, 1000tons/year
Textile, Rubber, Plastics	18200	0,6	2,1
Wood, Cardboard, Paper	17600	2,4	1,6
Organic Municipal Waste	13500	2,2	29
Animal Waste	13500	1,9	21
Forestry and Agricultural Biomass	18500	2,8	63
Total	18000	9,9	116,7

Total heat value of approximately 16,8 kJ/kg for corn stalk and 20,2 kJ/kg for peanut shell waste. According to the total thermal value, basic products are corn 33.4%, wheat 27.6% and cotton 16.1 %, respectively. In Table 1, the total annual production of horticultural crops waste in Turkey is given. Its total thermal value is approximately 21.5 kJ/kg, respectively. Within the total calorific value of the product with the biggest 56.3% nut shell and olive seed 25.2%. According to the number of animals in Şırnak, the calorific value of the amount of waste and animal waste are as given in Table 2, about 13, 30 and 26,5 million in Turkey for cows, sheep and poultry, and approximately the amount of annual waste capacity are 0.2, 0.1, 0.008 million tons, respectively. The total annual amount of forest, bush and wood waste, are 6, 0.6 and 0.49 million tones, respectively. The total available 65 % solids content of 3% and 99% values were determined by the availability of forest, bush and wood waste, respectively [TSI, 2013, TAM, 2013]. Thus, Şırnak's cows, sheep and poultry waste calorific value of the annual total was found to be of about 48, were 3 and 0.7 MJ, respectively.

Today in Şırnak, including biomass in terms of research and development in renewable energy incentive researchs are carried out and the agricultural and forest wastes in cellulosic form are investigated in power generation. In recent times the output of the power of free licence laws before energy prices, energy-producing companies buy the energy of the states were determined through interviews. Now renewable energy prices will be forced to comply with market conditions.

Tab 2. The total annual production of biomass waste in Şırnak and Eastern Anatolian Region.

Waste Type	Waste Statistics		
	Heat Value, kJ/kg	Eastern Anatolian Region Actual 1000ton/year	Şırnak Actual, 1000ton/year
Plastic	17200	2,1	1,3
Agricultural waste	17600	2,8	1,6
Cow, Sheep Poultry Wastes	13400	21	11
Forest Waste	18600	60	33
Total	17000	85,9	46,9

This situation of renewable energy sources in order to better compete and market additional policy tools need to emphasize that EU energy policy and law by examining the conclusions drawn from Turkey according to the potential policy instruments include: the country, the purpose specified deviation from the guarantees to domestic targets , including renewable energy sources , given up to one year , domestic gross energy consumption a certain share have to target (about 10%) should be determining policy and legislation. These are obtained from renewable resources and electric power for heating may comprise separate but integrated objectives. These policies and laws only for biomass separate, but can also include an integrated target. All use of renewable sources in the EU target of achieving 12% market share for the biomass should be increased up to 300%. The country, the purpose specified deviation from the guarantees to domestic objectives including, biologically-based fuels, specific to a year, used in transport petrol and diesel fuel market, a certain share to have a target for determining the policies or laws should be removed. Regard to the energy in Turkey appropriate potential market instruments include: biomass -generated electricity, heating and / or used in transport fuels, tax reductions or exemptions, flexible loans, low interest loans, loan guarantees , property first operating subsidies and / or grants and related service for consumers willing to use discounts as well as other financial support mechanisms. A potential market instrument of state support is not required to continue forever. They just won and sustaining investor confidence during development and may be important.

III. Combustion of Biowaste, Oil and Char in Fluidized Bed

Considerable research on coal pyrolysis and gasification has been conducted over the years, but the pyrolysis results are widely dispersed because of the complex chemistry of coal (Wei-Biao et al, 2001, Liu et al 2002). Time related coal-pyrolysis modeling assumes basically first-order kinetic equations, or less

sensitive for heating rate (Shale et al 2001, Sharma et al 2008). The other distributed activation model is dependent on the heating rate. The last two more advanced models need three and four constants, respectively, which basically depend on the coal properties but also cover to some extent, the effect of heat-and-mass transfer phenomena (Donskoi et al, 1999, Wictorsson et al, 2000).

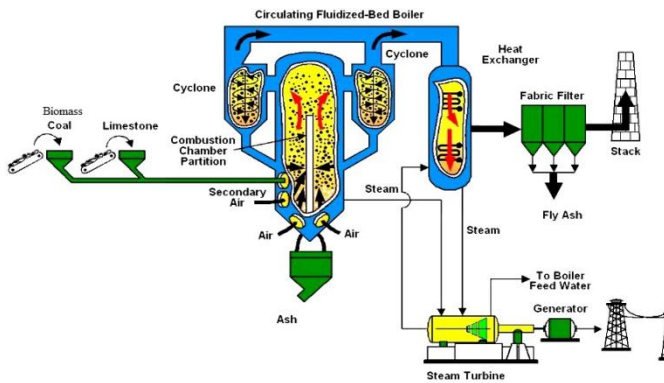


Fig 2. Fluidized Bed Combustion of Coal and Biomass for combustion

Tab 3. The Proximate Analysis of Şırmak Biomass Types.

Weight(%)	Wood Waste	Trash	Cow Waste	Poultry Waste	Corn Waste
Moisture	41.26	29.26	24.2	21.6	10.26
Ash	1.07	9.7	4.25	3.34	1.07
Fixed Carbon	25.08	25.08	25.08	25.08	45.08
Volatile Matter	74.59	74.59	64.59	64.59	54.59
Calorific Value (kcal/kg)	1430.1	1630.5	1760.8	1930.2	3780.2

Tab 4. The total annual production of animal waste in Şırmak and waste quantities.

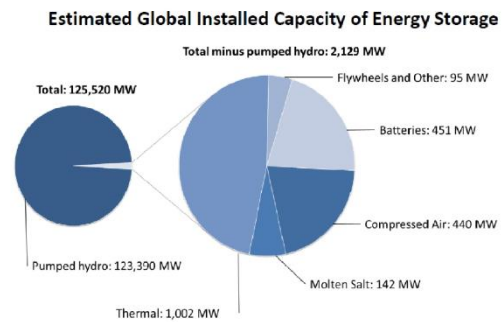
Waste Type	Waste Statistics		
	Heat Value, kJ/kg	Theoretical, 1000ton/year	Actual, ton/year
Cow	15200	25,4	12,3
Sheep	14600	2,3	1,6
Poultry	13700	0,7	0,4
Total	14200	28,4	13,3

That is the reason for the different values of the activation energy and pre-exponential factor cited in the literature and the lack of generally valid data. The same situation exists in the case of coal-char gasification. The reaction rate of char is influenced mainly by chemical and physical factors, which include coal type, catalytic effect of the ash and the

specific surface area of biochar, which changes during the reaction course with the development of internal pores.

IV. The Energy Storage

The energy storage provide the main support to the renewable energy production. The commercial successes in electric power storage Technologies mentioned and its ability were described some of the emerging applications in power storage like wind farm power stabilization, steam, hydro, wind, etc. (Anonymous f,h, 2013, Ibrahim et al 2007) The figures of statistical potential of storage in the world is defined as seen in Fig 3. The use of different techniques in energy storage are classified as seen in Fig 4 regarding discharge time. Some cost evaluations covering security of supply and environmental impacts, climate change evaluations, and technical and economic analysis, may be discussed in energy planning and activities.



Source: StrathGen Consulting, LLC research; thermal storage installed and announced capacity estimated by Ice Energy and Calmac. Note: Estimates include thermal energy storage for cooling only. Figures current as of April, 2016.

Fig 3. The Compressed air and Thermal Storage Use Distribution in Energy Storage.

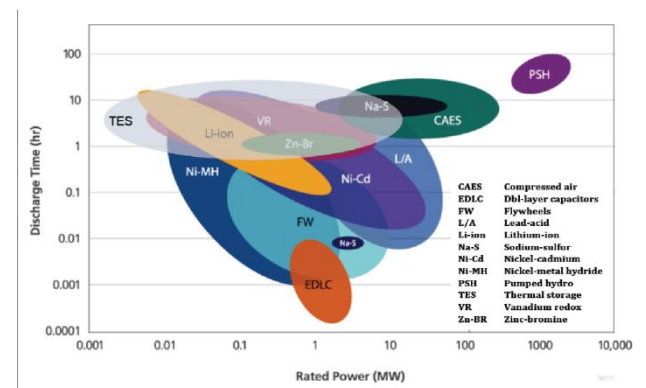


Fig 4. The Discharge rates of Different Types of Energy Storage Units vs Power.

Natural power output cannot be controlled. The power from these generators varies according to the availability of the resources (for example in case of Solar heat or wind turbine, it depends on the availability of wind or sun) (Anonymous a,b,c, 2013, Ibrahim et al 2007). During the non-availability of the power the storage technologies manage a vital role in

improving the overall stability and reliability of power system (isolated/grid connected/systems with large share of renewable sources) and improve the controlled electricity distribution capacity to meet ever growing power demand. The internal grid circulation with the energy storage in renewable sources may stabilize power level in heap and 50-60% yield recoveries were provided at the end of year. As seen in Fig 5 the power consumption can be supplied by stored earlier day time. (Anonymous d,e, 2013, Poullikkas et al 2007)

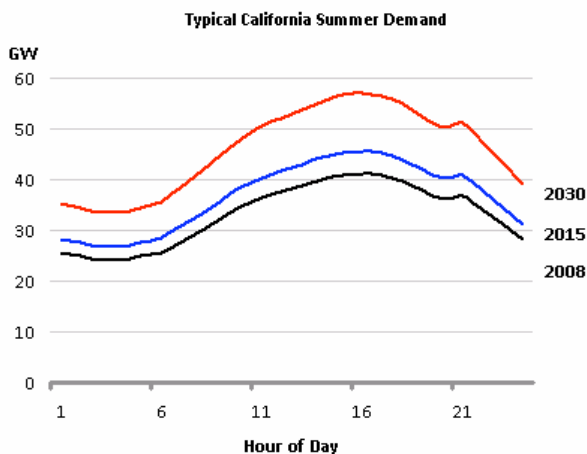


Fig 5. The power demand of California on daily period in summer

A. Compressed Air Storage

The special thing about compressed air storage is that the air heats up strongly when being compressed from atmospheric pressure to a storage pressure of approx. 1,015 psia (70 bar). Standard multistage air compressors use inter and after coolers to reduce discharge temperatures to 300/350°F (149/177°C) and cavern injection air temperature reduced to 110/120°F (43/49°C) (Anonymous g,h, 2013, Ibrahim et al 2007). The heat of compression therefore is extracted during the compression process or removed by an intermediate cooler. The loss of this heat energy then has to be compensated for during the expansion turbine power production phase by heating the high pressure air in combustors using biogas, fuel. Alternatively using the waste heat of a combustion gas turbine exhaust in a recuperator is able to heat the incoming air before the expansion. Even the heat of compression can be thermally stored before entering the cavern and used for adiabatic expansion

extracting heat from the thermal storage system.

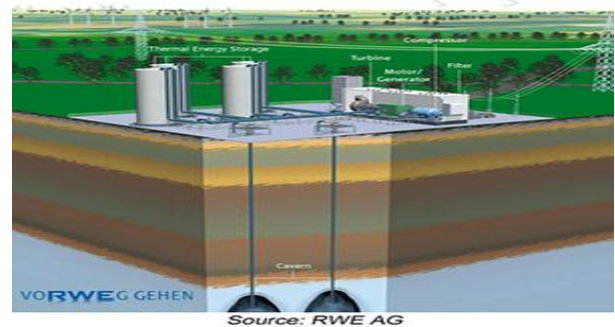


Fig 6. CAES Method

The only two existing CAES plants in Huntorf, Germany, and in McIntosh, Alabama, USA, as well as all the new plants being planned regarding the diabatic method. The compression stage normally uses up about 2/3 of the turbine capacity, the CAES turbine – unhindered by the compression work – can generate 3 times the output for the same natural gas input. This reduces the specific gas consumption and cuts the associated CO₂ emissions by around 40 to 60%, depending on whether the waste heat is used to warm up the air in a recuperator. The power-to-power efficiency is approx. 42% without, and 55% with waste heat utilization.

B. Hydrogen Storage

Electricity can be converted into hydrogen by electrolysis. The hydrogen can be then stored and eventually re-electrified. The performance today is as low as 30 to 40% but could increase up to 50% if more efficient technologies are developed. Despite this low efficiency the interest in hydrogen storage is growing due to the much higher storage ability compared to batteries (small scale) or pumped hydro and CAES (large scale). (Anonymous f,h, 2013, Ibrahim et al 2007)

Small amounts of hydrogen (up to a few MWh) can be stored in pressurized vessels at 100~300 bar or liquefied at 20.3K (-423 deg F). Alternatively, solid metal hydrides or nanotubes can store hydrogen with a very high density. Very large amounts of hydrogen can be stored in man made underground salt caverns of up to 500,000 m³ at 200 bar (2,900 psi), corresponding to a storage capacity of 167 GWh hydrogen (100 GWh electricity). In this way, longer periods of flaws or of excess wind / PV energy production can be leveled. Even balancing seasonal variations might be possible.

C. Liquid Air Energy Storage

Liquid Air Energy Storage (LAES) is sometimes referred to as Cryogenic Energy Storage (CES). The word "cryogenic" refers to a gas in a liquid state at very low temperatures. The working fluid is Liquefied Air or Liquid Nitrogen (78% of air). The systems share

similar performance characteristics to pumped hydro and can harness industrial low-grade waste heat/waste cold from co-located processes, converting it to power. Size range extends from around 5MW/15MWh to >50MW/250MWh and with capacity and energy being de-coupled, the systems are very well suited to long duration applications.



Fig 7. Linde Liquid Air Storage Tanks

V. Projected Tests for Hybrid Power and Capital Model for Energy Storage

A fluidized bed reactor was used in coal combustion heated till 600 °C with a rate 7-10°C/min by fuel. The process was tested at a scale of 2–3 kg/h; collecting operational and design data to build an industrial installation. A technological diagram of the coal gasification-pyrolysis process developed unit is made. Thermal destruction almost observed at temperature Heat exchanger oil temperature increase from 350 °C to 400°C with storage and performance of 60-70% and also simultaneous dilution of waste oil products by condenser distillate may be used. it is necessary to optimize the storage conditions of oil circulation without the heat loss transported to heat exchanger, where the average heat conductivity per oil amounts changes 20 - 30 kW/m³, so enhancing ORC heat transfers.

VI. Cost Model for Energy Storage

Compressed air storage for large scale installation of coal combustion was planned simply. Porous shale beds in Southeastern Anatolian region, in Batman was planned with fine coal burned with oil and biowaste at 0,2 m/s. In order to achieve this, it is necessary to create gaseous conditions of internal circulation without the transported coal and char in the fluidized bed, where the average concentration of solids amounts to 0.1- 0.2 m³/m³, i.e. the conditions for residence time are long enough for the thermal oil storage of combustion units(Dinçer and Rosen 2011, Cabeza, 2015) and intensive gas firing so enhancing mass and heat transfers.

The cost of underground compressed air storage will greatly depend on drill cost. The parameters are defined in Table 5 below.

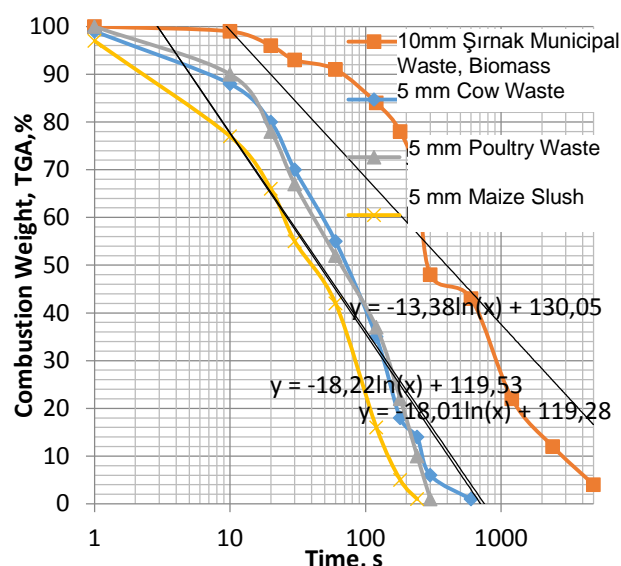


Fig 8. The rates of Combustion of biowastes used in coal combustion at 600°C in fluidized bed.

Thermal oil storage may greatly concerned by combustion using power plant systems, due to heat loss in echanger and recupator use in the heat recovery.

Tab 5. Correlation and variable values in Drilling depth with the cost of investment.

RiSK Point	Weak Rock	Mid Rock	Hard Rock	500m	1500 m	2500 m
	s					
Depth,m	1	3	6	1	4	8
Advance Rate	0.071	0.21	0.71	0.71	0.11	0.071
Drilling Period	12	59	112	42	122	333
Investment	121	145	223	222	678	2311
Risk	1	3	6	1	4	8
Risk Error	-0.26	-0.24	-0.29	-0.21	-0.344	-0.41
	6	5	8	3		
Correlation Coefficient	-0.26	-0.14	-0.57	-0.25	-0.679	-0.053
	6			6		

Compressed air use was investigated in the projected study due to the regional potential of Southeastern Anatolian region of Turkey. Espeially oil reservoirs was thought as storage field, in the mean time the natural gas using power plants may advantageously evaluate the compressed air or liquidified air. However liquidified air was not considered in ths projected study due to costly compression units was needed.

Gaussian normal distribution of risk probability values defines the value of the compressed air plant investment in data-intensive midpoint. It is obtained as given below section. As given in Tab 6 the compressed air storage unit cost reached high levels. Time became the main parameter in the evaluation.

Tab 6. The Capital costs of Compressed air storage in the region into the used oil reservoirs

Unit Cost, \$	10.000 m3/y	100.000m3/y
Compression units: 4 stage	600.000	1.600.000
Surface Storage Tanks: \$	400.000	1.000.000
Drilling well	1.000.000	4.000.000
Water oil seperators	30.000	300.000
Combustion Fan	60.000	600.000
Filter bag units : \$	60.000	600.000
Dust Collector Units: \$	50.000	150.000
Automation Control System	200.000	1.200.000
Field Cost	500.000	4.500.000
Engineering Project	1.400.000	4.400.000
Power Plant	5.900.000	28.000.000
TOTAL :\$	10.200.000	46.350.000

For the integrated plant, the capital investment cost of 500 thousand tons/year capacity was determined as 53 million \$, while 1 million tons/year capacity the investment value was doubled. Already region for high-capacity incinerators could not considered due to the impossibility of sources and the obtaining funds and logistics were not feasible. Mobile 25000 tons/year capacity plant, depending on the companies' unit costs is determined as 11 million \$ (as given in Table 6).

Mobile plant and integrated plant operating costs were calculated based on the present prices. As Table 6 also given mobile plant labor, it will provide advantages in terms of reactive maintenance. Mobile plant operating cost was calculated as approximately 25 TL/ton for defined biowaste. This integrated facility cost rose to 63TL/ton.

Mobile plant and integrated plant operating costs and energy production (70% and 60% thermal efficiency fuel efficiency) was calculated to be connected. mobile plant as given in Figure 8, while in a period of their capital investment in 22 months, after a period of 36 months will generate more revenue for the integrated plant operating costs will be advantageous investment capital back to paying (Figure 8).

$$u(x; t; \rho) = 100 \cdot \frac{1}{N} \sum_{i=0}^n \frac{u(x,t) - u(x; t)^-}{u(x,t)} \quad (1)$$

VII. Investment Modeling of Compressed Air Storage from Coal and Biomass Combustion

Thus, the installed capacity of the planned plant was about 2 million kWh/year and the entire unit energy yield was 22 MWh/year and 15% storage capacity was used in cost estimations.

The costs of drilling equipment such as maintenance costs

General Pareto distribution of the cumulative risk the possibility of failure depth is closer to the discovery and exploration of geothermal resources available well data. Figure 9, as determined in the MATLAB software risk probability value is above 5% probability of 60-90.

$$u(x, \sigma, c) = (1/\sigma) (1 + k/\sigma (x - \Theta))^{-1-1/k} \quad (2)$$

while exponential distribution $k = 0$, where u is the cost function, σ is the variance, k is hybrid distribution parameter, Θ is the tim parameter, x is the flow rate by the following equation.

TV_C is the total cost, T_x is tax, F is the interest, $O_{m\&o}$ is maintenance cost, D is share rate, c_m is capacity factor, K is the unit capacity. As given below;

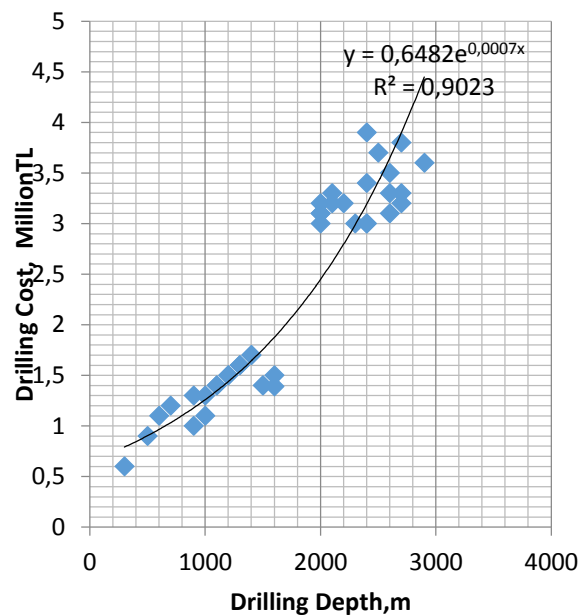


Fig 9. Change of the Cost of Drilling for Compressed Air Storage.

$$TV_C = T_x + F + O_{m\&o} + D \quad (3)$$

$$Q(n) = 8760 \times CF(n) \times K \quad (4)$$

The cost calculation of the plant,

- Calculation of unit cost of the facility,
- Calculation of the investment costs of the facility at which it will go into production,
- Plant operating costs and the calculation of the annual income,

$$R(n) = Q(n) \times P(n) \sum_{m=1}^M 1/(1-r)^{M-m} \quad (5)$$

$$E(0) = (1-f) \sum_{m=1}^M C_m(1+r)^{M-m} \quad (6)$$

$$L(0) = f \sum_{m=1}^M C_m(1+r)^{M-m} \quad (7)$$

The capital cost for compressed air storage and thermal oil storage may greatly affected by the cost of storage material and process units complexity. The proposed cost of investment depending on flow rate of stored material and conversion to heat or energy as given below.

$$u(x; t; \Theta) = \sum_{i=0}^n u(x, t) + \phi(x; t; \Theta) \cdot e^{-ti\theta} \quad (8)$$

where R is the revenue, Q is the capacity, P is the sale price, r is the interest rate, m is month, n is the integer of month, E is investment cost, f is debt rate, c_m is

capacity factor, L is the debt, u cost function, t is time, Θ is the time unit parameter.

As given Tab 7 the cost distribution changed by time of storage well drilling and time. Risk point was similar to geothermal well drilling. As shown in Fig 10 risk parameters occurred in the projected cost risk analysis. As seen in Fig 11 the capital cost was ranged up to 180 million \$ for 100.000 m³/y compressed air storage.

Tab 7. Normal distribution Cost variable values in Compressed air Storage Well Drilling with the cost of investment regarding depth.

RISK Point	Wea k Rock s	Mid Roc k	Har d Roc k	500 m	1500 m	2500 m
Depth,m	1	3	6	1	4	8
Advance Rate	0.071	0.21	0.71	0.71	0.11	0.071
Drilling Period	12	59	112	42	122	333
Investmen ts	121	145	223	222	678	2311
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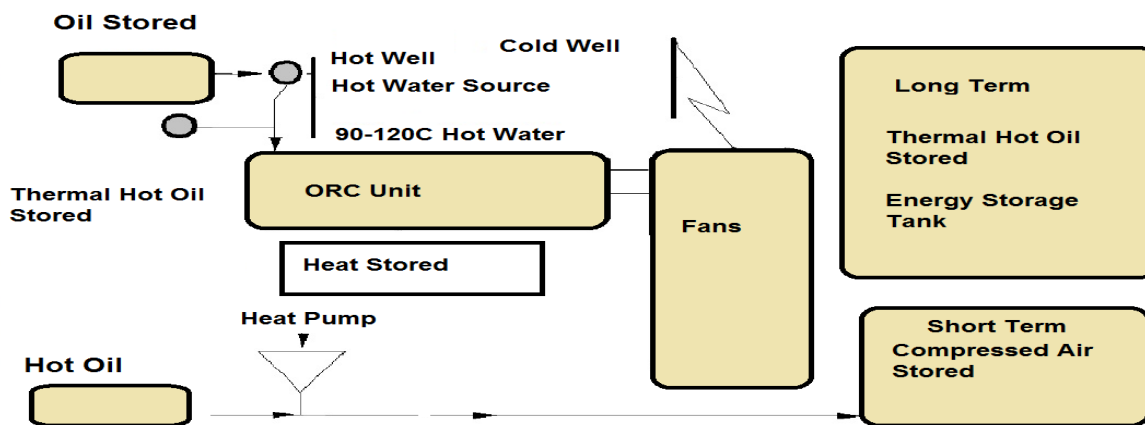


Fig 10. ORC Use for Low Heat Geothermal and Biomass sources in energy and risks of Capital Investment costs in Turkey

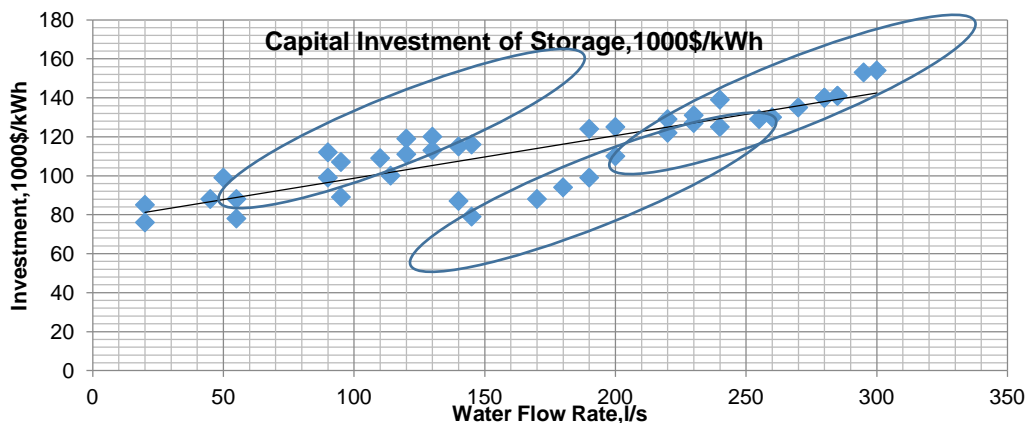


Fig 11. The Investment rates of Compressed Air Storage in Combustion Power Plant.

Tab 8. Compressed Air Storage Cost Variables on Coal and Biomass energy capital cost risk

Projected Cost and Revenues	Batman Without Storage	Siirt Without Storage	Batman With Storage	Siirt With Storage	Cost Risk Batman	Cost Risk Siirt
Net Electricity kWh	137,000,000	132,000,000	167,000,000	162,000,000	3	3
Average Annual Sale TL	0,26	0,26	0,26	0,26	6	6
Production Cost nominal	0,21	0,21	0,26	0,26	6	6
Production Cost actual	0,11	0,11	0,15	0,15	6	6
Return rate ,%	42	40	33	34	6	6
Annual Net Profit	22,000,000.TL	21,000,000.TL	12,000,000.TL	11,000,000.TL	6	6
Calculated Sale price change,%	14	14	14	14	6	6
Calculated debt rate,%	22	21	22	21	6	6
Capacity factor	1	1	1	1	2	2
Land cost	1,6	1,6	1,6	1,6	2	2
System performance factor	21	19	21	19	3	3
Toatal field, acre	4	4	4	4	1	1
Cogeneration	Sellective	Sellective	Sellective	Sellective	1	1
Average Risk					6	6

VIII. Conclusions

This project approach assumes basically that the thermal oil storage units are much feasible instead of compressed air units, so that is a decisive factor for the path of the storage method and heat exchanger units. Therefore a model of hot oil storage may be supported by biogas combustion, too. The gas temperature and fluid bed combustion and pyrolysis oil use for coals and biomass may provide clean combustion and oil storage. Combustion rates were lower higher at the high temperatures over 900 C so that heat conduction loss to boiler materials might be fundamentally low enthalpy yield. The main conclusions are as follows:

- ❑ Time uncertainties are taken into account by adding a contingency factor. This approach is simple and it is advantageous to be close to the real projected cost data.
- ❑ Storage by compressed air was efficient but also requires more equipment for compression needed.
- ❑ The liquidified air storage system needs subsequent high cost compression units.

However, time variable and uncertain application of parametric variables makes possible reliable risk analysis. This research has examined various risk models for energy production. The most appropriate model is determined by comparison. The compressed air was efficient in natural gas combustion turbines but also requires optimization. The liquidified air storage system needs high cost stage by stage compression units.

The used oil fields will be suitable for compressed air storage. The capital cost of thermal oil storage will be suitable for industrial combustion systems at small scale and shorter time concern.

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