Original Article: Simulation and Optimization of Urban Energy System Based on Combination of Technologies and Energy Production and Distribution Network

Hamidreza Nasiri[1], **Fariborz Ahmadi Daryakenari**[1]

[1] *Department of Energy Systems Engineering, Mahmood Abad Faculty of Marine Science, Petroleum University of Technology, Iran*

Citation: H. Nasiri, F. A. Daryakenari. Simulation and Optimization of Urban Energy System Based on Combination of Technologies and Energy Production and Distribution Network. *J. Eng. Indu. Res.* 2021; 2(3):129-148.

10.22034/jeires.2021.281603.1036

Article info:
Received: 16 January 2021
Accepted: 28 March 2021
Available Online: 30 April 2021
Checked for Plagiarism: Yes
Peer Reviewers Approved by:
Dr. Amir Samimi
Editor who Approved Publication:
Professor Dr. Mohammad Haghighi

Keywords:
Cogeneration Systems, Urban Energy Consumption, Air Pollution

ABSTRACT

Cogeneration systems have potential limitations. Because the heat recycled in these systems is a function of mechanical load (electricity), mismatch between power and heat consumption can lead to energy loss and reduced efficiency. On the other hand, partial loading of the engine or turbine reduces its mechanical efficiency and exergy of the exhaust gas. Therefore, meeting a specific consumer demand, requires optimization of the system in order to maximize the efficiency of the entire energy system of the city as well as a system management model. The performance of the cogeneration system in cities is limited for several reasons. For example, restrictions on the release of air pollutants and noise pollution may allow equipment to be installed in the suburbs instead of city centers, or to use smaller, more limited-capacity equipment. Similarly, the lack of space (land for installation of equipment) creates constraints in areas where the population and building texture is dense. Such restrictions may lead to the use of smaller power plants and equipment, which are less efficient than large equipment and require more initial investment (cost relative to MW output). In this paper, the effect of such constraints on the urban energy system is quantitatively investigated and the optimal model for the sample city is presented.

Introduction

The models chosen for the simulation presents the optimization of the urban energy system based on the combination of technology and the network of energy production and distribution to meet the needs of consumers, which is a function of place and time [1]. The method used for optimization is from whole to part. The pattern used is based on the train pattern [2]. By dividing the city into specific areas, based on the population and the number of buildings located in each area, the need for different resources is extracted. Naturally, the variable of need is a function of time and place. The demand function is seen in Equation 1.

$$D_{rit} = f(i,t) \qquad \textbf{Equation (1)}$$

***Corresponding Author:** *Hamidreza Nasiri, (hamidreza.nassirii@gmail.com)*

In this regard, the source demand r in the geographic region at time t is input to the template as input data. For ease of numbering, the city is divided into squares, but the numbering is done as a single index. The time interval is considered as a function of time and as an input variable. The time interval can be different for different times, for example, for winter and summer days when the pattern of peak electricity, cold and heat consumption is different, but in one of the best methods, each day is divided into three-time intervals: Low load interval, normal time interval and peak time interval. Reducing time intervals increases computational volume but can provide more accurate results. Due to the limited volume of calculations in the software, there are usually limitations to reduce the time interval [2]. Any equipment or technology marked with a P symbol takes resources as input and delivers resources to the area in which it is located. For example, a gas-fired power plant receives air and natural gas as inputs and delivers electricity and heat, in the form of hot water or hot air. In this way, the total source r produced in each region is calculated from Equation 2.

$$P_{rit} = \sum_{p} \alpha_{rp}.\rho_{pit} \quad \forall rit$$

Equation (2)

For each source r and equipment p is assumed to be constant and presented as an input variable. But in reality, this coefficient is a function of several factors, including equipment loading. For example, the mechanical efficiency of the motor at different loads is shown in Figure 1 1. In this form, the conversion factor (efficiency) varies between 28% to 42% in loads of 10 to 100%. But for ease of calculation, this coefficient is assumed to be constant and it is tried to load the systems in such a way that they do not work at partial loads [3].

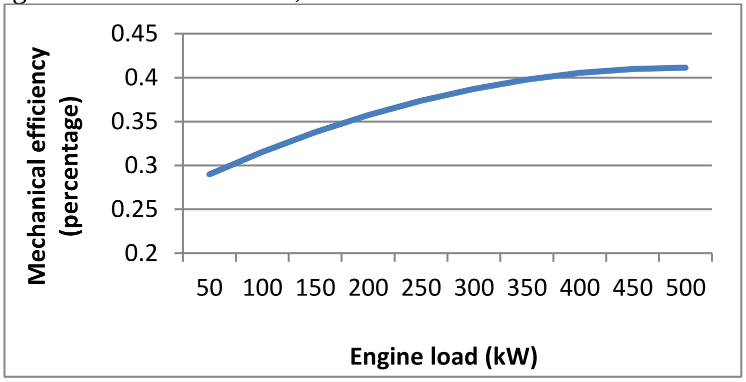

Figure 1. Relationship between efficiency and mechanical power of gas engine D87 [9]

If a source enters it from some areas and sources leave it from some areas, for each region, two variables are defined that indicate the number of imports and exports from and out of the city, which are introduced with variables. These variables are zero for areas not bordering the city and zero for border areas greater than or equal to zero. If city operates as an island, it provides its source. For example, if this condition applies to electricity, it indicates that at time t, the city has generated all the electricity it needs without the need for a national grid. Of course, they may be greater than zero, in which case the city's power grid is used to transfer this source to the national grid [4]. The small size indicates the degree of independence of the city from foreign sources, and the higher it is, the more dependent the consumers outside the city are on the sources of poetry. The simultaneous large size of these two variables also indicates the role of the city in resource transfer. In practice, the city imports and exports resources only in some border areas. Therefore, it will be zero for all regions except them. In places where and are zero, the input data and in places where their optimal value is calculated, are considered decision variables, indicating the load rate of the resource transfer equipment from region i to i ’at time t. Greater is always assumed to be equal to zero. If the source current is from region i 'to i, it will be greater than zero and zero [5].

The source output coefficient r is the load rate unit of the transmission equipment from the source area and the source input factor r is the unit load rate of the transmission equipment to the destination area. So, at time t, the whole resource r coming out of region i to direction i 'is equal to, and the total resource r coming out of region i to region i' is equal, and we are going to waste that. In the ideal state, which becomes equal, the transmission loss becomes zero. But if the transmission equipment has losses, these values will differ from each other, and are independent of the distance of origin and destination and depend on the technology or equipment of the transmission, for example, a heat exchanger and a power transformer have this type of drop. If the source drop due to transmission is a function of the distance between the source and the destination, another coefficient is used: The source drop coefficient r is the unit of load rate of the transmission equipment and the distance unit [6]. It is also the same coefficient for entering the destination area. This drop is used for cases such as power transmission through the network or heat transfer through hot water in the pipe. By defining these variables, we can write the output of the source r from region i at time t as equation 3:

$$Q_{rit}^{OUT} = \sum_{\tau i'} (\beta_{r\tau}^{src} + \gamma_{r\tau}^{src}.l_{ii'}) q_{\tau i' it} \quad \forall rit$$

Equation (3)

The entry of this source into region i at time t is also in equation 4:

$$Q_{rit}^{IN} = \sum_{\tau i'} (\beta_{r\tau}^{dst} + \gamma_{r\tau}^{dst}.l_{ii'}) q_{\tau i' it} \quad \forall rit$$

Equation (4)

From the combination of Equation 3 and Equation 4 we have:

$$Q_{rit} = -Q_{rit}^{OUT} + Q_{rit}^{IN} = -\sum_{\tau i'} (\beta_{r\tau}^{dst} + \gamma_{r\tau}^{dst}.l_{ii'}) q_{\tau i' it} + \sum_{\tau i'} (\beta_{r\tau}^{src} + \gamma_{r\tau}^{src}.l_{ii'}) q_{\tau i' it} \quad \forall rit$$

Equation (5)

It is one of the decision variables that is obtained as the output of the template. If technologies that have the ability to store the resource are used in the regions, another decision variable is defined. It means saving the resource in time t and it means consuming the resource stored in the past time intervals. In any case, resource consumption should not exceed the total amount stored in previous periods. This constraint is stated in Equation 6.

$$\sum_{t=t_0}^{t_t} S_{rit} \geq 0 \quad \forall \mathrm{rit}_t$$

Equation (6)

There are two other limitations to energy storage:

A) The limitations of the equipment installed for resource storage obtained from Equation 7:

$$S_{rit} \leq \sum_{\sigma} N_{\sigma i}.C_{\sigma}^{MAX} \quad \forall rit$$

Equation (7)

B) The amount of residual resource at the end of each time period (assuming one day in this pattern) is zero. This constraint can be seen in Equation 8.

$$\sum_{t} \Delta t_t.S_{rit} = 0 \quad \forall ri$$

Equation (8)

Equation 9 shows the dependence of production, consumption, transmission, input, output, and resource storage in each time period for each region:

$$P_{rit} - D_{rit} + Q_{rit} + I_{rit} - E_{rit} = S_{rit} \quad \forall rit$$ **Equation (9)**

Objective function

The objective function is defined as the weighted sum of the effects of each of the variables in Equation 9 on key performance indicators:

$$\min Z = \sum_{\mu} W_{\mu} (C_{\mu}^{p} + C_{\mu}^{q} + C_{\mu}^{I} + C_{\mu}^{E} + C_{\mu}^{S})$$ **Equation (10)**

In this regard, key performance index, weighting index, total share of resource production equipment on key performance index, share of total transmission equipment on key performance index, and total share of import and export of resources on key performance index and total equipment share Resource storage is a key indicator of performance. The key performance indicator can be cost, emissions, energy consumption or any other key factor that is targeted. Several key factors can be defined for each city and their effect on the objective function can be combined through weighting [7]. For example, the effect of resource generation equipment on the key performance index can be seen in Equation 11:

$$C_{\mu}^{p} = A \sum_{Pit} C_{\mu OP}^{p} . \rho_{Pit} . \Delta t_{t} + \sum_{Pi} C_{\mu IP}^{p} . N_{Pi} \quad \forall \mu$$ **Equation (11)**

The first part is the effects of operation and the second part is the effect of creating or installing equipment. In this regard, the effect of the load rate of the P equipment unit and the effect of the number of P tools installed on the key performance index and the coefficient of conversion of current costs to the base rate [8].

For example, it can be the cost of repairing and maintaining an engine per kilowatt hour of its operation and the cost of the initial investment for the construction of each power plant. The coefficient is a function of the average bank interest rate and in multi-year analyses, its effect is very significant, but in short-term (for example, several months) or non-dynamic analyses, this coefficient can be assumed to be "one". If the life of the equipment is longer than the analysis period, the investment cost should be considered in proportion to the analysis period as well as the equipment life period. For example, in a one-year city analysis, the initial investment cost for a 20-year-old power plant should be considered linearly. If linear depreciation is assumed, the one-year effect of this investment would be one-twentieth of the total investment. The share of resource transfer equipment in the key performance index is calculated from Equation 12.

$$C_{\mu}^{q} = A \sum_{\tau i' it} C_{\mu I \tau}^{q} . N_{\tau i i'} \quad \forall \mu$$ **Equation (12)**

The effect of resource imports and exports on the key performance index is obtained from Equation 13 and Equation 14, respectively:

$$C_{\mu}^{I} = A \sum_{rit} C_{\mu r}^{I} . I_{rit} . \Delta t_{t} \quad \forall \mu$$ **Equation (13)**

$$C_{\mu}^{E} = A \sum_{rit} C_{\mu r}^{E} . I_{rit} . \Delta t_{t} \quad \forall \mu$$ **Equation (14)**

In these equations, the effect of imports and exports of the source unit r on the key performance index are depicted. For example, the price per cubic meter of natural gas or per kilowatt hour of electricity to buy or sell can be the effect of "gas" and "electricity" sources on the key performance indicator of "cost" [9].

Selection of power generation tools

In general, commercial tools of labor production can be divided into several categories:

- A set of internal combustion engines including gasoline, diesel, gas, dual fuel engines.
- Steam cycle set including steam power plants and steam engines.
- Gas turbine set includes gas turbine, combined cycle (combined with steam cycle) and microturbines.

Reciprocating internal combustion engines

Most internal combustion engines use a four-speed reciprocating mechanism called a crankshaft to generate power. The components of this mechanism in the engine include mandrel, handle, crankshaft and cylinder. As the mandrel moves back and forth inside the cylinder, its motion through the handle becomes the rotational motion of the clamp. The force applied to the mandrel is due to the increase in volume and pressure of the combustion fuel-air mixture inside the combustion chamber, and the rotation of the crankshaft causes the mandrel to return from the lower pause point upwards and perform the discharge or compression process. This relatively simple mechanism is the basis of the predominant design of existing internal combustion engines. During engine operation, fuel consumption is measured as flux [10].

The performance index for comparing the capabilities of motors is obtained by dividing this value by the output power. The concept of the obtained index indicates the extent to which the engine can use fuel optimally to produce power. This index is called specific consumption. It is clear that smaller amounts of specific consumption are the goal of the design. Specific consumption is a dimensional indicator. A dimensionless index that shows the relationship between engine output (output work per cycle) and input required to produce this work (fuel energy consumption) will be more valuable. This index is called return. Efficiency is the result of dividing the output of the engine from the input energy of the engine (fuel). Although different fuels such as gas, diesel, gasoline, etc. are used in internal combustion engines, in general, these engines are based on the iron or diesel cycle or a combination of the two [11].

Gasoline engine

Almost all gasoline engines run on an ironing cycle. In these engines, the fuel and air are mixed homogeneously before entering the combustion chamber or inside it to start the combustion with the spark plug. Of course, there are special and limited designs of these motors that use layered or inhomogeneous mixtures. Direct injection of gasoline into the combustion chamber is also a new design that is not expensive.

Therefore, spraying fuel and preparing the fuel-air mixture in most gasoline engines begins before air enters the combustion chamber. To maintain a good level of pollution and combustion, it is necessary to keep the mass ratio of fuel to air within a certain range. If the amount of fuel is less than a certain amount, combustion will not start, and if the amount of fuel is more than a certain amount, carbon monoxide and unburned hydrocarbons will increase in combustion products. In these motors, the output power of the motor is managed by adjusting the amount of incoming air. As the throttle valve opens and closes, the pressure drop in the inlet air path changes and the amount of inlet air in the suction or respiration process is adjusted. The intelligent management system also adjusts the amount and timing of fuel injection according to the amount of air entering the engine by sprays [12].

Diesel engine

Diesel engines are based on the diesel cycle. In these engines, only air enters the combustion chamber during respiration or suction. The fuel injection nozzle is located inside the combustion chamber and starts spraying the fuel at the right moment, usually just before the high pause point (end of compression). After spraying, diesel becomes very small droplets, which ignite in contact with hot air. The amount of air entering the diesel engines is constant and the output power in these engines is adjusted by managing the amount of fuel injection. The combustion mechanism in diesel engines is very complex, but for a certain range of fuel amount, the combustion is complete and no pollutants such as unburned hydrocarbons (seen as black smoke) are produced. Although the main fuel for diesel engines is diesel, heavy diesel engines can be designed and built to consume lower fuels as well.

Many marine, power plant, and industrial heavy-duty diesel engines, especially in the military sector, are designed to run on fuels such as fuel oil and even crude oil. Of course, furnace oil has a high viscosity and in order to be injected into the combustion chamber, it must be smoothed in some way. Sometimes the burn is heated to lubricate. In some cases where the viscosity of the fuel is very high, superheated steam is mixed with the fuel to heat it up and pump the water-fuel mixture more easily [13].

Gas engine

Natural gas, the main component of which is methane, is commonly used in engines that run on an iron cycle. Of course, this fuel can also be used in diesel engines, but the shape of the cycle changes to a state between the ironing cycle and diesel, constant volume combustion and constant pressure. However, in both cases the gas is mixed with the inlet air to the engine and is rarely injected directly into the combustion chamber. If the engine is based on an ironing cycle, the gas-air mixture will ignite with a spark plug, and the engine will perform similarly to gasoline engines. In this case, the mass ratio of gas to air must be within a certain range to start with the spark of the combustion candle and the flame propagation is stable.

Engine power output management is the same as for gas-fired gasoline engines. That is, by creating a pressure drop in the air inlet path, the amount of air entering the engine and thus its power is adjusted. Because these engines are very similar to conventional gasoline engines, it is possible to make a two-burner engine with minor modifications to the engine so that it can run on both natural gas and gasoline. Of course, it is not possible to use two fuels at the same time, and in the gas-fired mode, the engine produces less power than in the gas-fired mode due to the reduction in the volume of incoming air. If you need to use gas in the engine and to avoid power reduction, the engine is designed gas base. That is, from the beginning of the design, the main fuel is gas and gasoline is considered as an alternative fuel by the designer.

There is another way to ignite the gas-air mixture. In this method, the amount of gas mixed with air has a wider range than the previous method. This means that thinner mixtures can also be used in the engine. The amount of air entering the combustion chamber is constant in this method and power management is possible by changing the amount of fuel. As the mixture dilutes, there is a risk of ignition as the spark plug may not have the energy to ignite the dilute gas-air mixture. To start the combustion, the ratio of gas to air around the candle, like the first method, must be a certain value to ignite the mixture.

As combustion begins, the flame expands to a thinner range. There are several ways to prepare the right gas and air mixture around the candle. Sometimes a pre-combustion chamber is used. In this method, independent sprays are used in the front of the room to keep the gas-to-air ratio constant. The mixture is easily ignited by a spark plug and the flame is propagated from the pre-chamber to the main combustion chamber where the dilute mixture is located. In the other method, the pre-chamber is not used and the candle is placed in the main combustion chamber. But independent sprays are placed around the spark plug to inject fuel to prepare the mixture to start combustion. The intelligent engine management system will adjust the fuel injection and spark plug timing.

Dual combustion engine

A dual-burner engine is an engine that burns two different fuels at the same time. Usually, one of these fuels is natural gas and the other is diesel. The base cycle of a dual-burner engine is also the diesel cycle. Of course, because two fuels are used in the combustion process, the combustion process in a dual-burner engine is slightly different from a conventional diesel engine. The operation of a dual-burner engine is similar to that of a conventional gas-fired engine. Only ignition instead of spark plugs, like a diesel engine, starts with direct injection of diesel into the combustion chamber. In these engines, the gas is mixed with air and then enters the combustion chamber. The gas-air mixture is usually thinner than normal (true richness).

At the end of the compaction phase, the diesel is injected into the combustion chamber in very fine droplets, each of which acts like a spark plug and ignites the gas-air mixture. The ratio of natural gas to diesel depends on the design and load of the engine. In these methods, the ratio of diesel can be from small amounts to more than ninety percent [14].

Spraying method

In this method, 1 to 3% of the fuel consumption is diesel. Combustion of gas provides engine power, and diesel is used only to ignite a mixture of fuel and air. In this method, the output power of the engine is adjusted by changing the dilution of the gas-air mixture. Most diesel engines will be converted to dual-fuel engines with modifications. Of course, there will be some power loss in the conversion process that if the engine is considered dual-burner in the design phase, there will be no problem in using the engine. Because gas is cheaper than diesel in many countries, in many cases, users of heavy-duty diesel engines are reluctant to use dual-fuel engines, especially when gas is easy to access. Dual-combustion of heavy engines is more economically justified than lighter engines, and therefore light (automotive) diesel engines are rarely dual-fuel, but many heavy-duty diesel engines, especially in power plant and ground use, are designed and used as dual-fuel.

Steam power plant

The steam engine was the first production tool used to propel ships and kill trains. Small steam engines were also used in trains and city buses (known in Iran as the smoky car). Today, the steam cycle is the most important power generation cycle to run power generators in the world. The steam power plant operates on a steam cycle basis. The fluid pressure of this cycle, which is water, is increased by a pump. High pressure water enters the boiler and after evaporation it turns into superheated steam. This superheated steam is then used to drive the steam turbine. The steam turbine is built in stages. Each stage of the turbine is made up of a row of fixed blades and a row of moving blades. High pressure steam accelerates as it passes through the blades of a fixed row and rotates them when it strikes the moving blades.

The steam usually cools down after passing through several stages of the turbine, but it still has a good pressure. To increase cycle efficiency, this steam is sent back to the boiler to be heated and returned to the turbine. In this process, the vapor pressure does not change and the vapor energy increases only by increasing the temperature. Steam turbines are divided into two or three sections of high pressure, medium pressure and low pressure based on the inlet steam pressure. Between the two sections, steam is sent to the boiler to increase its energy. Figure 3 shows a steam turbine made by Siemens. As shown in Figure 3, this turbine consists of two parts, high pressure and low pressure. The front is high pressure and the rear is low pressure [15].

Journal of Engineering in industrial Research

Figure 2. Steam turbine manufactured by Siemens [6]

After the last stage of the turbine, the water vapor becomes saturated steam. This steam enters the condenser to become saturated water. A condenser is a type of heat exchanger in which a fluid changes state from vapor to liquid. In some cycles, the coolant in the condenser is part of the steam cycle fluid (direct contact condenser), and in some cyclists, the fluid in the vapor cycle transfers heat indirectly to the cooling fluid. In other words, the separate water cycle cools the condenser. Water in this cycle takes heat from the water vapor of the steam cycle and gives it to the environment. The heat exchange of the condensing water cycle with the environment can be by means of a dry cooling tower, a wetter cooling tower, air-cooled or water-cooled. In cool air condensers, steam enters a converter similar to the engine water heat exchanger in a car. The fluid in this converter is cooled by the air flow created by the fan to change state. In a dry cooling tower, condensate cycle water enters heat exchangers located at the bottom of chimney-like structures. Air enters from the bottom of the tower and by passing through the converter, the water heats up the condenser cycle and heats up. Hot air is less dense than ambient air and moves upward to exit the upper opening of the tower. In the cooler tower, a mechanism similar to water coolers is used. The water energy of the condenser cycle is used to evaporate the water that is sprayed onto the heat exchanger. Cooler towers have very good efficiency, but the water consumption of a 1000 MW power plant, such as the Shahid Mofteh power plant in Hamadan, which has a cooler tower, is over 30 million liters per day.

In a cold-water system, the water in the condensing cycle is cooled by the flow of ambient water, such as seawater or river water. This system also has good efficiency, but in addition to the limitations at the construction site of the power plant, due to the heating of sea or river water, it poses serious risks to the water ecosystem in the power plant area. Two factors affect the efficiency of the steam cycle: The temperature of the steam entering the turbine and the condensing pressure. The temperature tolerance of the first row of the turbine limits the maximum steam temperature at the inlet to the turbine and usually the maximum steam temperature does not exceed 655 degrees Celsius. Ambient temperature also limits the condenser pressure. That is, the cooler the ambient temperature, the lower the condenser operating pressure and the higher the steam cycle efficiency. In the steam cycle, as the fluid is not in direct contact with the combustion products, different types of fuel can be used. Thus, the inherent advantage of the steam power plant is the extensive use of heat sources. These heat sources can be energy from fission or nuclear fusion, burning solid fuels such as coal, liquid fuels such as furnace oil and diesel, natural gas and hot air from a gas turbine or diesel engine, and even geothermal energy.

Gas turbine

Most gas turbines are built axially. After passing through the strainer, air enters the compressor. The compressor is designed and built-in stages. At each stage of the compressor there is first a row of moving blades and then a row of fixed blades. The air accelerates due to the impact on the moving blades, and after passing through the fixed blades, its speed decreases and instead, its pressure increases. In this way, in each step, some air pressure is added. Eventually, high-pressure air enters the combustion chamber. In a combustion chamber, fuel (gas or diesel) is mixed with air and then ignited. The mechanism of combustion of fuel in the combustion chamber of a gas turbine is similar to that of a domestic boiler burner, in that, unlike reciprocating engines, it is a continuous combustion engine. High-pressure, hot air exits the combustion chamber and enters the turbine. Like a compressor, a turbine is built in stages. But unlike the compressor, the turbine first has fixed blades and then moving blades.

The air reduces its pressure by passing through fixed vanes, but instead accelerates and rotates them when it strikes moving vanes. Gas turbine blades are much smaller than steam turbine blades, so it is more common to use better correlations, which are naturally more expensive, in making these blades. These correlations are usually able to withstand hotter temperatures than the metals used in steam turbines. But it is still difficult to cool the turbine blades and therefore they are covered with special materials to make them more resistant to heat. However, due to the limited tolerance of very hot temperatures by metals, the air temperature entering the turbine should not exceed a certain limit. Intermediate cooling may be used between stages of the compressor. In this method, the air passes through the heat exchanger and cools down a bit. In this way, the air that leaves the compressor and enters the combustion chamber will be cooler and as a result, the air that leaves it will be cooler. Although in this method, the blades of the first stage of the turbine are placed in a safer margin in terms of operating temperature, due to the drop in air pressure when passing through the central cooler, the total efficiency of the gas turbine is somewhat reduced. The 340-megawatt turbine is one of the largest gas turbines in the world. The knowledge and technology of designing and manufacturing compressor blades is complex. The sensitivity and importance of the geometry of the turbine blades is not as great as that of the compressor blades, and these blades, even if they do not have a perfectly optimal design, still rotate due to high-speed air collisions with them. But if the compressor blades are not properly designed, they simply blow the air and cannot increase the pressure. Much of the work that the turbine does to the gas turbine shaft is spent running the compressor; if the mechanical efficiency of the compressor and turbine is low, the net output of the gas turbine will be negligible. That is why the proper design of the compressor is so important. The number of solid particles and impurities in the fuel consumption of gas turbines is also very important. Because these particles are associated with the hot air coming out of the combustion chamber, they eventually erode when they collide with the turbine blades. For this reason, gas turbines use only high-quality fuels such as diesel and natural gas.

Although the efficiency of the gas turbine is lower than other production tools, its high power-to-weight ratio has created unique conditions for it. This feature has led to the expansion of gas turbines as aircraft propellants. Other disadvantages of gas turbines are the high cost of periodic repairs and the short interval between repairs. Gas turbine operating conditions, type of fuel consumed, amount of load, etc., are the factors that multiply the coefficients in the actual operating hours of the gas turbine.

Items such as how many times it is turned on or off, emergency stop, etc. also add equivalent operating hours to the actual operating hours of the gas turbine. The basis for calculating the operating hours of a gas turbine for major repairs is the total operating hours equivalent. In cases such as power supply during peak hours, tools are needed that turn on quickly and their generated electricity in a short time to reach conditions that can be synchronized with the network. Although the time interval between turning on the gas turbine from the cold state and reaching its maximum power is usually less than 30 minutes, due to high depreciation, turning on the gas turbine at peak consumption and turning it off after reducing the load is not cost-effective. And usually by combining gas turbine and steam cycle, they produce the base load with it. The sum of a gas turbine and a steam cycle is called a combined cycle [16].

Combined cycle

As mentioned in the steam power plant section, due to the closed fluid cycle and the technical characteristics of the boiler, a variety of heat sources can be used to supply the heat required by these power plants. On the other hand, the efficiency of gas turbines is not very good and the exhaust gases with a temperature in the range of 450 to 650 degrees Celsius waste a lot of energy. Because the maximum steam temperature in steam power plants usually does not exceed 650 degrees Celsius, the hot gases from the gas turbine can also be used as a steam cycle heat source. With this in mind, the exhaust gases from the gas turbine enter the boiler, which is called the steam generator from the recycled heat. In this system, the power of the turbine and the steam cycle are usually selected in such a way that a gas turbine and a steam cycle together form a combined cycle. But in cases where gas turbines are small, two or more gas turbines provide steam cycle energy.

The efficiency of gas turbines is usually less than 35% and in very good working conditions their efficiency can hardly reach 40%. Thus, it is not cost-effective to use them to generate the necessary power to generate the base load of the grid, but by converting it to a combined cycle, the efficiency has increased to more than 50%, and in a power, plant built by General Electric in Wales, the efficiency it has also reached about 60%. The hybrid cycle is very difficult to manage and adjust, and its optimal performance is possible under certain conditions. Changing the load or operation of the gas turbine affects the temperature and flux of the exhaust gases.

The temperature and flux of these gases will also directly affect the conditions of the steam cycle and its production capacity. At partial loads of the gas turbine, the temperature and flux of the exhaust gases are reduced and the necessary energy is not provided for the optimal operation of the steam cycle. Despite all these problems, due to the very good efficiency of this cycle, almost no gas turbine power plant in the world can be built without a combined cycle.

Microturbine

Small reciprocating engines are very cost-effective, and spare parts and repair services are readily available worldwide. But these engines are relatively polluted and expensive to maintain. Although many efforts have been made to improve these two issues for reciprocating engines, microturbines are in better condition in terms of maintenance and pollution compared to heavy engines. Microturbines are small generators that burn gaseous or liquid fuels and spin the generator very fast. Microturbines operate on the thermodynamic cycle of large gas turbines, which is the Brighton cycle. In this cycle, the compressor (usually radial) compresses the incoming air, then the air is preheated using the heat of the turbine exhaust gas.

The preheated exhaust air in the combustion chamber is mixed with the fuel and ignited. Combustion hot gas expands through the expansion turbine and power turbine. The expansion turbine drives the compressor and, in uniaxial models, the generator and generate direct current electricity. This power is first converted to alternating current by alternating current and then to alternating current at a frequency of 50 or 60 Hz. Of course, a precise definition of a microturbine has not yet been provided, but the term is usually used for high-speed gas turbines in the 15 to 300 kW power range. The microturbine industry has been introduced in several sections, including: Small gas turbines, auxiliary generators and turbo vehicles. The determining indicator for reducing friction is the use of air bearings, or in other words, gas bearings, which, while reducing friction, also increase the life of the bearing and allow a faster speed.

In general, microturbines have two major advantages, one is the reduction of pollutants into the environment and the other is the reduction of repairs compared with conventional motor-generators. Table 1 shows the number of pollutants produced for several generators. As can be seen, the number of particles in the output products of the microturbine is the lowest. In connection with repairs, experience has shown that microturbines need very little repair. For example, a microturbine unit in Tulsa only needs to replace the air filters after 20,000 hours of operation. [8] In addition, microturbines are light and small, and their performance is associated with low vibration and low noise production [17].

Table 1. The number of pollutants produced (other than SOx) in different units (parts per million) [8]

THC	CO	NOx	Generator type
150	340	2100	**500 kW diesel engine**
10	50	25	**4500 kW gas turbine**
250	120	200	**Steam turbine with coal fuel 500 MW**

Journal of Engineering in industrial Research

Another problem for microturbines is how to connect to the national grid. This issue has been largely addressed by electronics and microprocessors and is still evolving. The cost per unit of a microturbine is up to $ 1,100 per kilowatt.

Although this is less than the cost of similar units such as wind turbines and fuel, it is higher than diesel units. If microturbines are used in large numbers, some costs will be reduced and they will compete with diesel generators, especially since they are much better in terms of repairs.

Exhaust engines

An external combustion engine is an engine in which the cycle fluid does not come into direct contact with the combustion products. The steam engine described is one of the most widely used external combustion engines. In this engine, the boiler, like a heat exchanger, transfers the hot air energy from the combustion of the fuel to the cycle fluid. Gas turbines can also be built to operate externally. The Stirling engine is one of the most famous extraneous engines. The four processes of the Stirling engine theoretical cycle are like the four main processes of all production tools. In the first process, the fluid is heated at high pressure. In the second process, as the fluid exerts on the working environment, its pressure is reduced to the initial pressure. In the third process, at low pressure, the temperature of the fluid is reduced to the initial temperature. In the final process, the environment works on the fluid and the fluid is compressed to reach a strong pressure. At the end of this stage, the fluid has the initial pressure and temperature and is ready to repeat the first process.

The theoretical cycle of this engine is similar to the ironing cycle, but its practical mechanism is slightly different. There are two popular types of Stirling engines. Type A has two cylinders and two pins. One of the cylinders of this engine is in contact with the cold environment and the other cylinder is in contact with the hot environment.

Components of the system of simultaneous generation of electricity and heat

Among the power generation tools introduced, the use of two categories in simultaneous production systems is more common: Reciprocating engines and gas turbines. The power actuator (motor or gas turbine) whose output shaft is connected to the power generator shaft provides the work required to generate electricity. The heat recovery system absorbs heat dissipated from the power actuator and transmits it to the heat consumer. If heat absorbed in the heat recovery system is used in absorption chillers, cold is generated. To manage and optimize the performance of the cogeneration complex, a monitoring and management system is needed. This system regulates and manages the mechanical and thermal load according to the objectives defined for the set.

The exhaust temperature of the gas turbine in the full load state is about 600 degrees Celsius, so its energy can be used to produce superheated steam. Superheated steam can convert its energy into work, and electricity into a generator, in a steam turbine. In cases where thermal energy is required more than electricity, the energy of the smoke can be recovered for thermal use by using heat recovery boilers or suitable heat exchangers. The advantages of using gas turbines in the system of simultaneous production of electricity and heat are:

- Exhaust smoke is high in energy and has a high efficiency.
- The gas turbine does not require an independent cooling system, and if the heat recovery system goes out of circuit, the turbine can continue to operate and power generation will not stop. The advantages of using gas turbines in this system are:
- The efficiency and power output of the gas turbine is sensitive to the pressure drop in the flue outlet path, and to reduce the pressure drop in the heat recovery converter, its size is increased.
- Microturbines are typically built in capacities of less than 500 kW and gas turbines in the tens of megawatts and stronger ranges, and a variety of gas turbines are not available for 1 to 10 MW capacities.
- The temperature of the smoke coming out of the gas turbine is very hot compared with the temperature of hot water required in residential applications; therefore, its heat recovery system will be more expensive due to the use of heat-resistant pipes.

Calculations and Research Findings

The key indicator selected is cost. In fact, the ultimate goal is to minimize the cost of providing the resources needed by the city. Assuming demand is stable, supply system management can reduce costs. The selected sources are natural gas, electricity and heat [18].

Pattern assumptions

Due to the software processing limitations, the city was divided into 25 regions as shown in Table 2. The length and width of each area was considered to be one kilometer. It is necessary to determine the electricity, heat and gas consumption of each of these areas in each time period.

Table 2. How to number city areas

Y/X	***1***	***2***	***3***	***4***	***5***
1	1_1	2_1	3_1	4_1	5_1
2	1_2	2_2	3_2	4_2	5_2
3	1_3	2_3	3_3	4_3	5_3
4	1_4	2_4	3_4	4_4	5_4
5	1_5	2_5	3_5	4_5	5_5

Y/X	***1***	***2***	***3***	***4***	***5***
1	1	2	3	4	5
2	6	7	8	9	10
3	11	12	13	14	15
4	16	17	18	19	20
5	21	22	23	24	25

The area of Tehran is 686.3 square kilometers and the average population density is about 12039 people per square kilometer. This index was the basis of population density in the hypothetical city. Assuming that the population density in the central areas is higher than the margins, using a random index and distance from the center, the population distribution in the hypothetical city was assumed as in Table 3. The average population density in this case is 12040 people per square kilometer and the total population of the city is 301 thousand people.

Table 3. Population distribution in each area of the hypothetical city

Y/X	**1**	**2**	**3**	**4**	**5**
1	8550	8980	8530	9770	7840
2	7860	10680	13620	13980	11700
3	11060	10610	18680	20350	11060
4	9490	14810	16350	16780	12750
5	8550	12020	11430	14740	10810

In order to obtain the amount of electricity, heat and gas consumption, the statistics of the energy balance in 2009 as well as the information of the Statistics Center of Iran in 2009 were referred to.

Table 4. Amount of electricity sales by type of consumption in Tehran province [18] (MWh)

Commercial	**industry and Mining**	**Agriculture**	**General**	**Home collection**	**Total**	**Year**
2442037	4222221	330788	2097571	6011570	15677853	**1375**
2359158	4904096	394704	3363864	7658759	20136066	**1380**
3360365	6462496	598202	4836103	10318479	26450828	**1384**
3625788	6745245	674362	5062140	10775102	27865291	**1385**
3745523	7244611	653054	5768577	10792463	29174100	**1386**
3855758	6229653	747257	5288224	10891860	27700559	**1387**
4077690	7753879	724858	5577256	11139965	29996386	**1388**

However, because in the model developed in this paper, direct consumption of natural gas for non-heating and heating uses is separated and it is assumed that on average, 90% of gas consumption is for heating purposes and 10% for non-heating uses such as cooking. The time periods are considered for four seasons and two consumption periods in each season (normal and peak consumption). The duration of each of these eight periods is presented in Table 5. At peak consumption intervals, power consumption is multiplied by a random function between 1.3 and 1.5.

Table 5. Time periods and duration of each of them

Time	**Delta_t (hour)**	**Delta_t %**
Spring-Normal	1767	0.201712
Spring-Peak	465	0.053082
Summer-Normal	1860	0.212329
Summer-Peak	372	0.042466
Autumn-Normal	1710	0.195205
Autumn-Peak	450	0.05137
Winter-Normal	1602	0.182877
Winter-Peak	534	0.060959
Total (hour)	**8760**	**1.00**

Table 6. Average annual demand for heat, electricity and natural gas in each region (MW)

Heat	**1**	**2**	**3**	**4**	**5**
1	11.7	12.54	11.54	14.14	11.45
2	10.77	15.54	19.72	19.77	16.22
3	16.09	14.65	25.77	28.82	15.72
4	13.27	20.18	23.93	23.77	17.67
5	11.94	15.89	15.7	20.3	15.1
Elec.	1	2	3	4	5
1	2.391	2.66	2.478	3.007	2.295

2	2.41	3.303	3.816	4.074	3.513
3	3.201	3.245	5.66	5.948	3.308
4	2.835	4.279	4.925	5.054	3.751
5	2.551	3.383	3.324	4.44	3.131
NG	1	2	3	4	5
1	1.343	1.34	1.301	1.532	1.207
2	1.169	1.554	2.036	2.116	1.672
3	1.667	1.649	2.812	3.211	1.559
4	1.472	2.223	2.46	2.539	1.936
5	1.256	1.917	1.745	2.113	1.638

Four resource generation technologies were considered:

1- Small household boiler that consumes natural gas and generates heat required for a building.

2- Large boiler that consumes natural gas and generates heat required for several buildings.

3- Small cogeneration unit (one megawatt) that consumes natural gas and generates heat and electricity.

4- Medium cogeneration unit (sub-megawatt) that consumes natural gas and generates heat and electricity.

The pattern was simulated for five different scenes:

1- Main Scene: All technologies, i.e. small and large boilers, small and medium cogeneration units, can be used in this scene and the optimal answer is obtained based on minimizing equipment and fuel costs;

2- Small boiler scene: Small boiler technologies, small cogeneration unit, medium cogeneration unit;

3- Small generator stage: Small boiler and small cogeneration unit;

4- Ideal Scene: All equipment is used except large boiler. The capacity of the generators is optimal; and,

5- Current scene: Use only a small boiler. The result of the main scene is examined in detail and for other scenes it is only introduced and compared with the main scene. In the main scene, there will be all four defined technologies.

Table 7. Number of equipment installed in each area in the main stage

SMALL_CHP	**1**	**2**	**3**	**4**	**5**
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
				Total	0
MEDIUM_CHP	1	2	3	4	5
1	1	0	0	0	0
2	1	1	1	1	0
3	1	0	1	1	0
4	0	1	1	1	0
5	0	0	0	1	0
				Total	12
SMALL_BOILER	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
				Total	0
LARGE_BOILER	1	2	3	4	5
1	2	4	4	5	4

2	2	4	5	6	6
3	4	5	8	9	5
4	4	5	7	7	6
5	4	5	5	6	5
				Total	127

According to the hypotheses described, the key performance indicator is cost. Therefore, the variables that directly target the problem, which is to minimize this index, are: The effect of installation and operation of resource production equipment, resource transfer equipment, as well as the import and export of resources to the city.

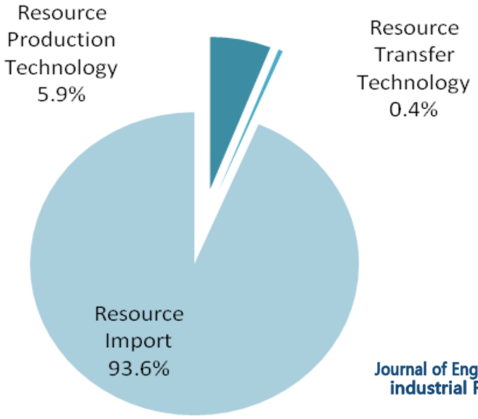

Figure 3. The share of each cost decision variable in the main scene

Table 8. Average consumption and production of production equipment resources during the year (main scene)

HEAT	**1**	**2**	**3**	**4**	**5**
1	13.38	11.89	11.33	12.94	10.38
2	12.54	16.25	20.13	20.39	15.49
3	16.82	14.07	26.65	28.86	14.65
4	12.51	21.50	23.57	24.07	16.88
5	11.37	15.83	15.11	21.10	14.07
ELECTRICITY	1	2	3	4	5
1	9.94	0.00	0.00	0.00	0.00
2	9.94	7.87	7.66	5.45	0.00
3	8.07	0.00	6.07	6.22	0.00
4	0.00	5.83	5.69	5.38	0.00
5	0.00	0.00	0.00	4.78	0.00
NG	1	2	3	4	5
1	-28.66	-13.21	-12.59	-14.37	-11.53
2	-27.73	-28.99	-33.00	-30.23	-17.21
3	-29.89	-15.64	-38.05	-40.70	-16.27
4	-13.90	-31.98	-34.10	-34.22	-18.76
5	-12.63	-17.58	-16.45	-30.08	-15.64

Table 9. Average holding rate of production equipment during the year (main scene)

SMALL_CHP	**1**	**2**	**3**	**4**	**5**
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00
MEDIUM_CHP	1	2	3	4	5
1	11.18	0.00	0.00	0.00	0.00
2	11.18	9.75	9.56	6.77	0.00
3	9.90	0.00	7.44	7.47	0.00
4	0.00	7.11	6.51	5.83	0.00
5	0.00	0.00	0.00	5.21	0.00
SMALL_BOILER	1	2	3	4	5
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00
LARGE_BOILER	1	2	3	4	5
1	2.69	10.38	9.89	11.29	9.06
2	1.96	6.63	10.18	12.56	13.52
3	6.97	12.28	17.48	19.35	12.78
4	10.92	13.20	13.33	14.36	12.99
5	8.75	12.17	11.62	12.67	11.01

Table 10. Average cost and balance of import, demand, production, consumption and transfer of city resources in a one-year period, in the main scene

Import (MW)		**Demand (MW)**	
Heat	0.00	Heat	425.47
Electricity	1.65	Electricity	83.37
NG	638.75	NG	41.04
Produced / Consumed (MW)		**Transferred (MW)**	
Heat	421.77	Heat	12.78
Electricity	82.90	Electricity	148.41
NG	-583.43	NG	13576.29
Production Units		**Costs**	**258.5 M$**
Small CHP	0	Production Technology	5.9%
Medium CHP	12	Transfer Technology	0.4%
Small Boiler	0	Resource Import	93.6%
Large Boiler	127		

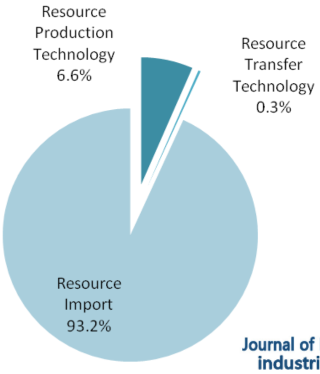

Figure 4. The share of each of the cost decision variables in the small boiler room

Table 11. Average cost and balance of import, demand, production, consumption and transfer of city resources in a one-year period, in the boiler room

Import (MW)		**Demand (MW)**	
Heat	0.00	Heat	422.19
Electricity	1.30	Electricity	88.98
NG	661.78	NG	45.47
Produced / Consumed (MW)		**Transferred (MW)**	
Heat	429.07	Heat	9.83
Electricity	90.02	Electricity	38.48
NG	-601.91	NG	2618.16
Production Units		**Costs**	**269.60** M$
Small CHP	2	Production Technology	6.6%
Medium CHP	12	Transfer Technology	0.3%
SMALL_BOILER	26652	Resource Import	93.2%

Table 12. Arrangement of resource production equipment in the field of small generators

SMALL_CHP	**1**	**2**	**3**	**4**	**5**
1	3	3	3	4	3
2	3	4	4	5	4
3	4	4	7	7	4
4	3	5	6	6	4
5	3	4	4	5	3
				Total	105
MEDIUM_CHP	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
				Total	0
SMALL_BOILER	1	2	3	4	5
1	666	768	646	934	708
2	587	1031	1311	1279	1077
3	1013	947	1529	1863	1050
4	878	1352	1571	1502	1108
5	792	970	914	1373	908
				Total	26777

Table 13. Average cost and balance sheet of import, demand, production, consumption ity resources in a one-year period, in the field of small generators

Import (MW)		**Demand (MW)**	
Heat	0.00	Heat	422.19
Electricity	2.88	Electricity	88.98
NG	663.90	NG	45.47
Produced / Consumed (MW)		**Transferred (MW)**	
Heat	429.17	Heat	0.01
Electricity	86.33	Electricity	3.79
NG	-603.08	NG	2792.34
Production Units		**Costs**	**272.16** M$
Small CHP	105	Production Technology	6.4%
Medium CHP	0	Transfer Technology	0.3%
SMALL_BOILER	26777	Resource Import	93.3%

The number of generators installed in each region is a decision variable that belongs to the range of integers.

Table 14. Arrangement of resource production equipment in the ideal scene

SMALL_CHP	**1**	**2**	**3**	**4**	**5**
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
				Total	0
MEDIUM_CHP	1	2	3	4	5
1	0.268	0.31	0.283	0.367	0.259
2	0.281	0.39	0.422	0.433	0.431
3	0.347	0.384	0.695	0.743	0.396
4	0.347	0.51	0.602	0.613	0.468
5	0.293	0.381	0.394	0.508	0.366
				Total	10.491
SMALL_BOILER	1	2	3	4	5
1	684.8	792.8	651.6	940.4	723.2
2	601.2	1037.6	1319.2	1287.2	1073.2
3	1020.4	953.6	1545.6	1874.4	1056
4	884.4	1358.8	1580.4	1509.6	1115.2
5	801.2	985.6	924.8	1380.8	914
				Total	27016

Table 15. Average cost and balance sheet of import, demand, production, consumption and transfer of city resources in a one-year period, in the ideal scene

Import (MW)		**Demand (MW)**	
Heat	0.00	Heat	422.19
Electricity	2.89	Electricity	88.98
NG	655.76	NG	45.47
Produced / Consumed (MW)		**Transferred (MW)**	
Heat	427.73	Heat	0.00

Electricity	86.27	Electricity	2.91
NG	-595.08	NG	2767.19
Production Units		**Costs**	**267.98** M$
Small CHP	0	Production Technology	6.1%
Medium CHP	10.491	Transfer Technology	0.3%
SMALL_BOILER	27016	Resource Import	93.6%

The significant distance between the total costs in the ideal and main scene means that the capacity of the resource production equipment is not optimal. As it turns out, with the use of large boilers, the costs in the main stage are lower than in the ideal scene.

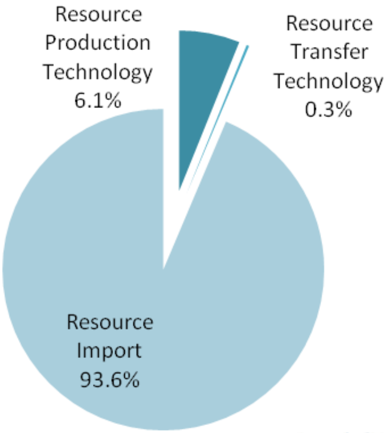

Figure 5. The share of each variable of cost decision in the ideal scene

In the current scene, the production equipment of the city heating source, only the boiler and electricity are supplied only through imports. This scene is very similar to the current state of the city's resources. Therefore, comparing it with other scenes can be used to evaluate the performance of the scene.

Table 16. Arrangement of resource production equipment in the current scene

SMALL_BOILER	1	2	3	4	5
1	792	894	765	1059	827
2	712	1148	1477	1448	1245
3	1157	1078	1823	2087	1178
4	993	1563	1774	1755	1257
5	918	1138	1082	1584	1026
				Total	30780

Because there is no electricity generation equipment in the city at this stage, all electricity consumption is provided through imports from outside the city.

Table 17. Average cost and balance of import, demand, production, consumption and transfer of city resources in a one-year period, in the current scene

Import (MW)		**Demand (MW)**	
Heat	0.00	Heat	422.19
Electricity	94.46	Electricity	88.98
NG	526.79	NG	45.47
Produced / Consumed (MW)		**Transferred (MW)**	
Heat	422.20	Heat	0.01
Electricity	0.00	Electricity	89.39
NG	-469.11	NG	2221.61
Production Units		**Costs**	**324.77** M$
Small CHP	0	Production Technology	1.6%
Medium CHP	0	Transfer Technology	0.2%
SMALL_BOILER	30780	Resource Import	98.3%

Conclusion

The average heat generated in cogeneration units is about 429 MW and the total heat produced in these units during the year will be about 3.75 million MWh. Considering the energy price in Iran in 2009 and comparing this scene with the main scene, about $ 163 million a year will be generated from energy savings, which results in a 1.5 year of payback period on investment of about $ 240 million for the installation of cogeneration plants.

References

[1]. K. Lo Han, *Journal of Engineering in Industrial Research.*, **2021**, 2, 123-133

[2]. A. Ahmad, A. Sadrodin Reyazi, *Journal of Engineering in Industrial Research.*, **2021**, 2, 134-160.

[3]. B. Barmasi, *Journal of Engineering in Industrial Research.*, **2021**, 2, 161-169.

[4]. M. Amirikoshkeki, *Journal of Engineering in Industrial Research.*, **2021**, 2, 170-178.

[5]. M. Bagherisadr, *Journal of Engineering in Industrial Research.*, **2021**, 2, 179-185.

[6]. F. Zare Kazemabadi, A. Heydarinasab, A. Akbarzadeh, M. Ardjmand, *Artificial cells, nanomedicine, and biotechnology*, **2019**, 47, 3222-3230.

[7]. A. Samimi, M. Samimi, *Journal of Engineering in Industrial Research.*, **2021**, 2, 1-6.

[8]. A. Bozorgian, P. KHadiv Parsi, M.A. Mousavian, *Nashrieh Shimi va Mohandesi Shimi Iran*, **2009**, 27, 59-68.

[9]. A. Bozorgian, P. KHadiv Parsi, M.A. Mousavian, *Iranian Journal of Chemical Engineering*, **2009**, 6, 73-86.

[10]. A. Bozorgian, S. Zarinabadi, A. Samimi, *Journal of Chemical Review*, **2020**, 2و 122-129.

[11]. S. Nozariamini, R. Rahimiyan, S. Miryousefi ata, *Progress in Chemical and Biochemical Research*, **2020**, 3, 377-389.

[12]. A. Samimi, *Progress in Chemical and Biochemical Research*, **2020**, 3, 140-146.

[13] R. Rahimiyan, *Advanced Journal of Chemistry*, **2020**, 2, 239-246.

[14]. Y. Kamyabi, M. Salahinejad, *International Journal of Advanced Studies in Humanities and Social Science*, **2020**, 9, 50-62.

[15]. R. Rahimiyan, S. Zarinabadi, *Progress in Chemical and Biochemical Research*, **2020**, 3, 251-268.

[16]. R. Rahimiyan, *Progress in Chemical and Biochemical Research*, **2020**, 3, 329-339.

[17]. R. Rahimiyan, *Advanced Journal of Chemistry*, **2020**, 2, 247-253.

[18]. S. Salehi-Kordabadi, S. Karimi, M. Qorbani-Azar, *International Journal of Advanced Studies in Humanities and Social Science*, **2020**, 9, 21-36.

[19]. M.R. Rahnama, M. Ajza Shokouhi, A. Heydari, *International Journal of Advanced Studies in Humanities and Social Science*, **2020**, 9, 37-49.

[20]. A. Bozorgian, *International Journal of Advanced Studies in Humanities and Social Science*, **2020**, 9, 229-240.

[24]. Gabriel A. Ayeni, *Journal of Engineering in Industrial Research.*, **2021**, 2,17-21.

[25]. F. Zare Kazemabadi, A. Heydarinasab, A. Akbarzadehkhiyavi, M. Ardjmand, *Chemical Methodologies*, **2021**, 5, 135-152.

[26]. S. Hashem, *Journal of Engineering in Industrial Research*, **2021**, 2, 44-55.
[27]. A. Bozorgian, Z. Arab Aboosadi, A. Mohammadi, B. Honarvar, A. Azimi, *Eurasian Chemical Communications*, **2020**, 2 (3), 420-426.
[28]. Akhtarian zand, *Journal of Engineering in Industrial Research.*, **2021**, 2, 22-27.
[29]. K. Malmal, N. Shiri, *Journal of Engineering in Industrial Research.*, **2021**, 2, 28-35.
[30]. Z. Torabi, *Journal of Engineering in Industrial Research.*, **2021**, 2, 36-43.
