Original Article: Management of Urban Energy System Based on the Use of Train Model in CHP Systems

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Citation: F.A. Daryakenari, H. Nasiri. Management of Urban Energy System Based on the Use of Train Model in CHP Systems. *J. Eng. Indu. Res.* 2021; 2(3):119-128.

10.22034/jeires.2021.281537.1035

Article info:
Received: 16 November 2020
Accepted: 30 March 2021
Available Online: 29 April 2021
Checked for Plagiarism: Yes
Peer Reviewers Approved by:
Dr. Amir Samimi
Editor who Approved Publication:
Professor Dr. Mohammad Haghighi

Keywords:
Energy Consumption, Train Model, Cogeneration.

ABSTRACT

Prior to the use of fossil fuels, urban energy was supplied through biomass sources, mainly wood and coal. The sources of these materials had to be located in a certain area around the city. The limitations of these resources, along with the limitations of water and food, limited the size of the city and its potential for expansion. The required electricity was generated regionally and sporadically. The first generators of electricity were steam engines, but gradually they were replaced by internal combustion engines. Over time, with the development of distributed networks, problems arose. Researches and reports were published that expressed the disadvantages of this method and suggested that the national network be constructed and all local networks be connected to it. Cooling of power plants, their construction inside the cities were not cost-effective, so the power plants were moved to areas with easier access to fuel and water, and centralized power plants were developed. Therefore, the electricity reached the end consumer through the global electricity transmission and distribution network. The fuels used for transportation were transported in the same way that they are used today, that is, using tanks and being delivered to the consumer at gas stations. This paper proposes using new technologies to produce power. In this paper, the train method has been used to simulate the energy consumption in cogeneration systems. The results of the analysis indicated that the use of small sized steam boilers reduce the overall cost of small-sized as well as average-sized generators.

Introduction

With the development of the national gas and electricity grid, cities that were previously independent islands became members of the national energy grids, so that a change in the consumption pattern of each of them could affect the energy supply in other cities [1-5]. One of the most important proposed technologies is the cogeneration of power and heat. The share of energy carriers in final energy consumption is shown in Figure 1 and a summary of the per capita change in energy consumption throughout history and the effect of the development of cities and electricity networks on it is shown in Figure 2.

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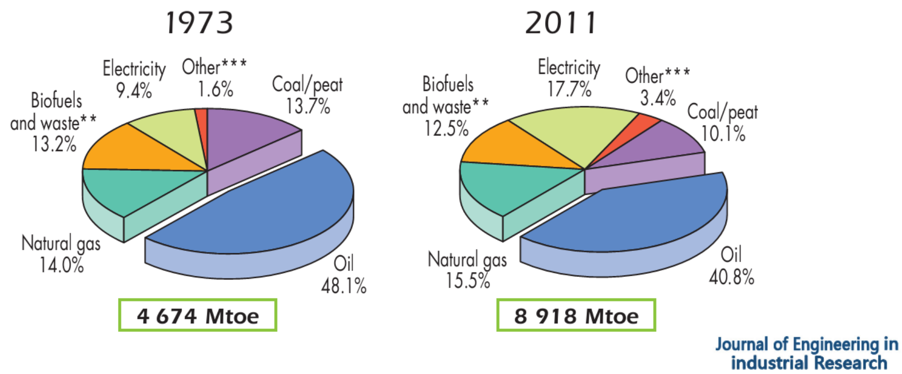


Figure 1. The share of energy carriers in final energy consumption in 1973 and 2011 [6]

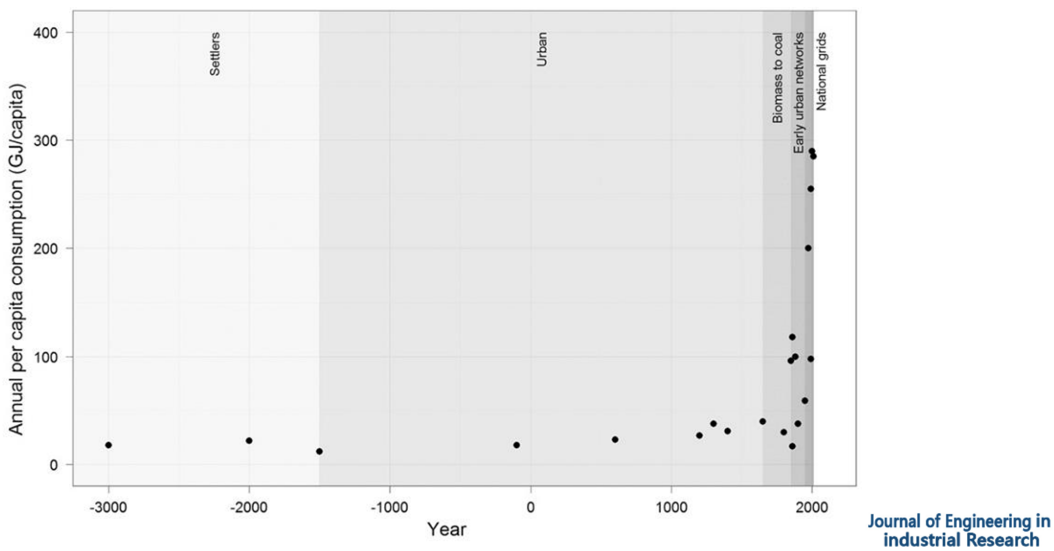


Figure 2. Per capita change in energy consumption throughout history and the effect of urban development and electricity networks on it [7]

None of the changes were resource-dependent alone, and social and technological change played a key role in the transition from one era to the next. For example, cars and other transportation systems made it possible for many people to make daily commutes of tens of kilometers or even hundreds of kilometers between their place of residence and work, making this a pattern of social life change compared to centuries ago. As a result, with increasing demand for longer trips, the need for fast transportation systems along with higher energy consumption has emerged [8-11].

Resource constraints and environmental impacts

As shown in Figure 2, the closer we get to the current period, the faster the changes. Given the development of many power plants and power grids in recent decades, the life of many of the equipment now used to generate power is coming to an end, and investing in similar complexes requires careful consideration. Rising consumption, limited fossil fuel resources and rising prices on the one hand, and adverse side effects of their use, especially carbon dioxide emissions and rising global temperatures, have forced governments to take steps to reduce their dependence on these resources [12]. Along with the development of technologies for the use of renewable sources such as sunlight and wind in the long run, increasing the energy efficiency of fossil fuels, especially in the urban energy system, is a sensible solution that will be effective in the short and medium term. Research shows that by optimizing the urban energy system with current technologies, it is possible to reduce carbon dioxide emissions by 20% compared with the current level [13-15].

One of the most widely used technologies in recent years is the simultaneous generation of electricity and heat (and cold). Although several decades have passed since the introduction of this technology, the practical optimized use of this technology in the urban energy system has just been considered in recent years [16].

Technologies for simultaneous production of electricity and heat

Co-production involves the use of a set of technologies that simultaneously generate electricity, heat and, if necessary, cold near the point of consumption, by a single process from fossil fuels or renewable sources, including biomass. In cogeneration systems, engines, gas turbines, or other devices usually convert some of the fuel energy into work (electricity), and some of the fuel energy that is wasted in normal operation is used for thermal purposes. Cogeneration systems typically convert up to 85% of primary fuel energy into usable energy. While in separate generation of electricity and heat, the efficiency of electricity generation does not exceed 60% while the efficiency of boilers is about 90% [17].

Thermodynamic Principles

From a thermodynamic point of view, all power-generating cycles have a similar structure. In all cycles, the processes are performed on the fluid and finally the work is obtained from the fluid. In the first process, the environment works on the fluid and the fluid is compressed. In the second process, the fluid is heated at high pressure. In the third process, as the fluid exerts on the working environment, its pressure is reduced to the initial pressure. In the final process, the temperature of the fluid is reduced to the initial temperature. At the end of this stage, the fluid has the initial pressure and temperature and is ready to repeat the first process. The main difference between various power cycles is in the type of fluid and the type of processes that are performed on it.

Internal Combustion Engines

Internal combustion engines, are one of the oldest power production systems after the steam cycle. The fuel used in this cycle is gasoline or natural gas. Of course, other fuels that have the necessary physical properties and have an octane number of more than 85 can be used in this cycle [18].

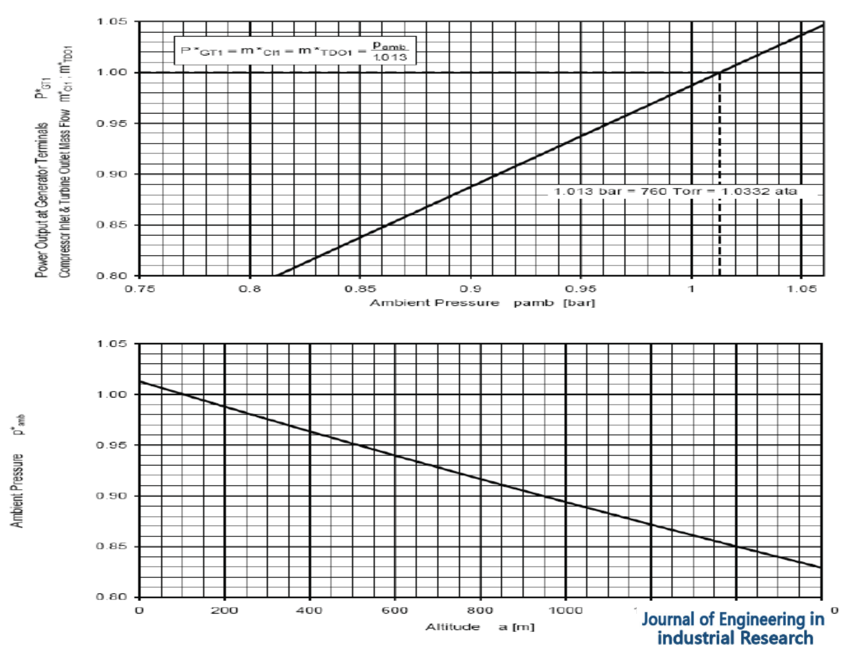


Figure 3. Effect of ambient pressure and altitude on the performance of V94.2 gas turbine [5]

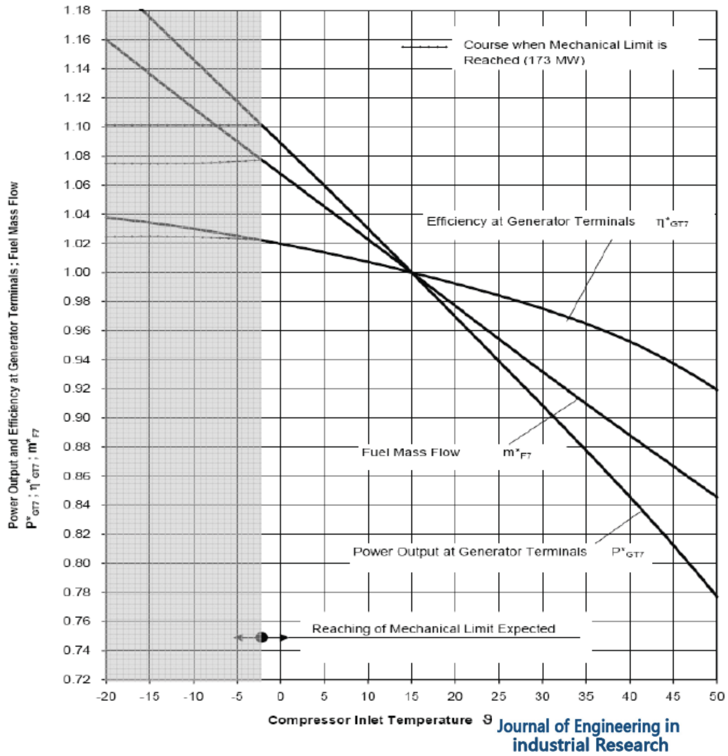


Figure 4. Effect of ambient temperature on the performance of V94.2 gas turbine [5]

In some cases, exhaust fumes from a gas turbine, which also has a high thermal energy, are used as the evaporator of Rankine cycle. This type of cycles is called combined cycles [19].

Rankin Cycle (Steam Power Plant)

The Rankin cycle, or steam cycle, is the main cycle of steam power plants. Unlike the previous three cycles, where the fluid was gaseous in all processes, this cycle uses water (infrared and saturated) and steam (saturated and superheated). Of course, the processes of this cycle are still the same as the four main processes of all productive cycles. Figure 1 shows a view of Rankin's theoretical cycle in the entropy-temperature diagram [20].

Cogeneration systems

One of the strategies that play a significant role in reducing the consumption of primary carriers to meet the energy needs of cities is the integration of energy systems. Exergy analysis of large cities such as London and Vienna show that only 10 to 20% of fuel energy is extracted as work (electricity) and the rest is wasted or consumed as non-hot (low exergy) heat. Simultaneous production technologies reduce the consumption of primary energy carriers in three ways:

1- Increasing efficiency in power generation tools,

2- Reducing transmission and distribution losses, and

3- Recovering heat dissipated to the environment in the engine or gas turbine for heating purposes. The power generation tools introduced can be used in cogeneration systems.

In the thermodynamic process of these instruments, the fluid uses part of its energy from combustion and transfers another part of the energy to the environment as heat loss. The goal of cogeneration systems is to recover this waste heat and use it to meet heat (or cooling) needs. Simultaneous generation of electricity and heat is one of the solutions that have been used for years to increase the energy extracted from fossil fuels. In this method, the first priority is to produce high quality energy (electricity) from fuel, and the heat that is produced at the same time as the work is extracted and must be transferred to the environment is used for heating purposes, especially those that do not require hot temperatures [21].

In a cogeneration system, a power plant must be built near the point of consumption of heat, so these plants are classified as distributed generation plants. The heat of this system is recovered from fumes, engine cooling fluid, oil, etc. and is transferred to the place of consumption through the interface fluid [22].

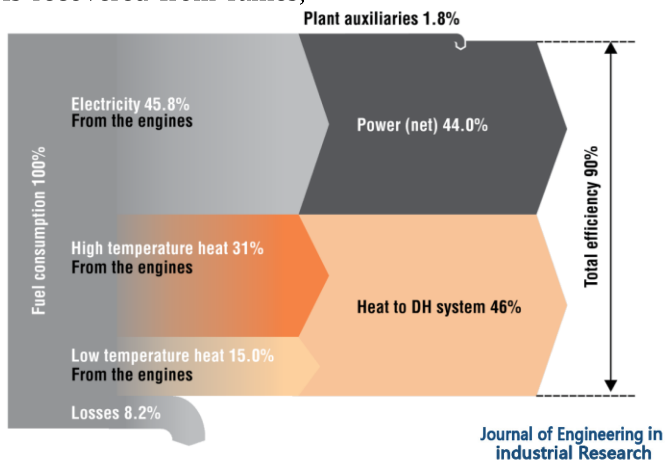


Figure 5. Thermal balance of the system of simultaneous production of electricity and heat for the production of hot water for residential heating applications [23]

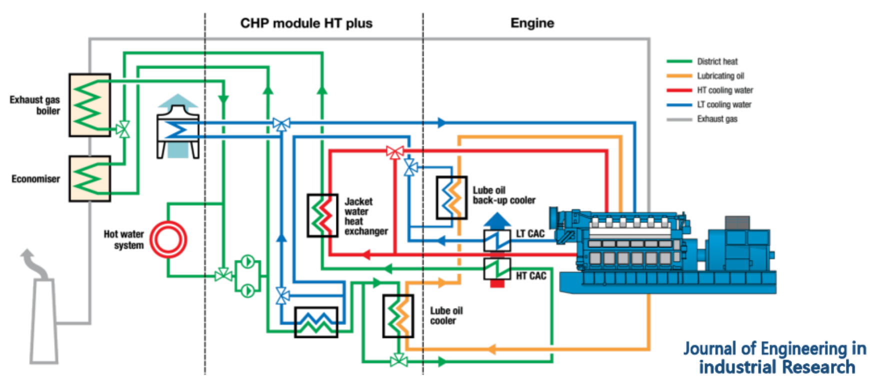


Figure 6. Simultaneous generation of electricity and heat for the production of hot water for residential heating applications [24]

Numerous simultaneous production centers have been set up and operated in Iran. Kashan University co-production power plant (which was built with the investment of Fuel Consumption Optimization Company) is one of the power plants that has been implemented as a model. Tarasht power plant in Tehran is another example that transfers its generated electricity to the national grid and the heat of the engine cooling system to the pool of Tarasht sports complex. The power plant provides the Ministry of Energy with electricity for the building and part of the heat required for the complex. In factories owned by Paxan Company, electricity and heat of simultaneous production power plants are used in different parts of the factory [25]. In many countries, cogeneration systems are fully commercialized. In 2007, for example, the Netherlands provided 30% of its electricity production and 20% of its heat needs through the simultaneous production of electricity and heat. Germany also supplies 13% and 14% of its electricity and heat needs from these units, respectively, and according to the plan, by 2020, the share of electricity production from these systems reached 25% [24].

In Denmark, which is one of the leaders in the simultaneous generation of electricity and heat, electricity generation from centralized to large power plants has been steadily declining for 25 years from 1980 to 2005, with a negative growth of 99.4%. Also, large units of simultaneous production of electricity and heat have a decrease of 7.19 percent in this period. Instead, small units of electricity and heat production at the same time had a growth rate of 2068%, i.e. more than twenty times in this period [24-26].

Also, self-consuming electricity and heat generators grew by 392%. Literature and research background for concentrated consumers, such as factories or out-of-town settlements, production optimization is performed simultaneously with various well-known methods, and there are usually fewer restrictions on the use of this system. [27]

However, in cities, with various constraints such as lack of space for power plant construction, emission and noise limitations, disproportion in the simultaneous consumption of electricity and heat, the need to redesign the urban energy system to achieve optimal efficiency, etc., has faced difficulties in a comprehensive urban system based on cogeneration [28].

Simulation of the Energy System

The models developed for energy systems fall into seven general categories: Simulation, scene evaluation, balancing, top-down, bottom-up, performance optimization, and investment optimization. Patterns such as markers are scene-oriented and are used in many countries. Its purpose is to study the various scenes in a single energy system that are defined in a small to national geographical range and a maximum period of 50 years. The basis of this group of models is the framework of economic balance and they are used in energy policy-making at the national level. Deco software is a tool that is used to optimize the energy supply. This software optimizes the use of predefined tools and technologies based on the criteria that the user chooses. The time intervals in this software can be very short. For example, for a one-year analysis, one-hour intervals can be defined. The solution method is also linear programming [9].

Other models, such as Modest, are used to minimize the cost of investing and operating in a situation where the entire demand is being met. In this method, because the linear programming model is used, it is possible to solve big problems [14]. In this model, the initial investment costs are considered as a linear function of the installed capacity, so in the answers obtained from the analysis, sometimes unattainable or very small capacities are presented, which is one of the weaknesses of this model. Another limitation of this method is that it does not take into account the storage technologies and spatial distance [31].

Analysis of CHP Systems

GIS along with hybrid integer linear programming equations is used in order to design heating and cooling networks. Annual demand for heating, hot water, cooling and electricity is extracted from building information in the GIS. The reciprocating fluid temperature is then selected to meet the total need, as well as the communication paths of the different regions that exchange energy with each other. This model can also use various technologies in its analysis such as cogeneration systems [2]. Extensive research has been conducted to optimize the cogeneration system of buildings. For example, linear integer programming has recently been used to design the layout and optimize the simultaneous generation of electricity, heat and cold to minimize annual costs and meet the needs of heating, hot water, cold and electricity. Other researches have examined the preference of technologies for minimizing energy consumption or cost in a cogeneration system. For example, the use of absorption or compression chillers in residential complexes independent of the national grid has been compared in a study [9]. Various studies have been conducted in the country to determine the optimal operation strategy and optimal design of cogeneration systems. For example, two computer programs have been developed to provide heat and electricity consumption of the residential complex. With the help of these programs, sensitivity analysis related to changing system parameters have been conducted [23].

In another study, the technical and economic feasibility of using small production systems with nonlinear integrated integer programming to determine the optimal capacity for the five climates of Iran have been investigated and the results have been analyzed [4]

Energy demand simulation is one of the most important issues in the accuracy of the results for real cases. In a study, household energy demand based on socio-economic model and Nemes model has been simulated in three sections: Electrical appliances, hot water consumption and required cooling-heating [2].

Some research has also been conducted for real residential complexes. For example, the optimal strategy of managing the power production system simultaneously with the use of electrical management for the complex has been investigated [3]

The difference between the global price of fuel and its price in Iran leads to different solutions to the same issue. In a study, the determination of the optimal dimensions of the unit of cogeneration of electricity and heat for the sample residential complex has been investigated using stochastic optimization. Finally, the output results are presented for the two current situations of the price of energy carriers in Iran and the global price of energy carriers [7].

Simulation of systems that work with multiple energy carriers has its complexities and usually different methods are used to analyze these systems. For example, the hierarchical decision-making method has been used to optimize capacity and performance in systems with multiple energy carriers [8].

Also, energy poles, which are defined as nodes of energy production, play a major role in the analysis and modeling of these systems [9].

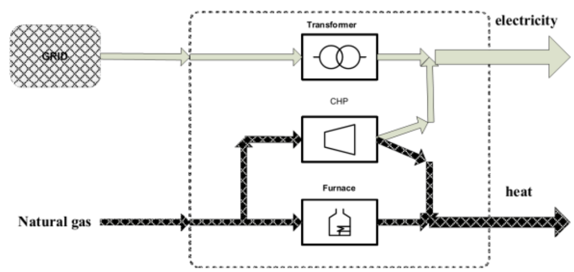


Figure 7. An example of the definition of energy pole [4]

Simulation of the energy system of the city

A new model for comprehensive urban energy planning is being developed by BP at Imperial College London. The model developed in this project can be used for metropolises such as London, Vienna, Sydney, Paris, etc.

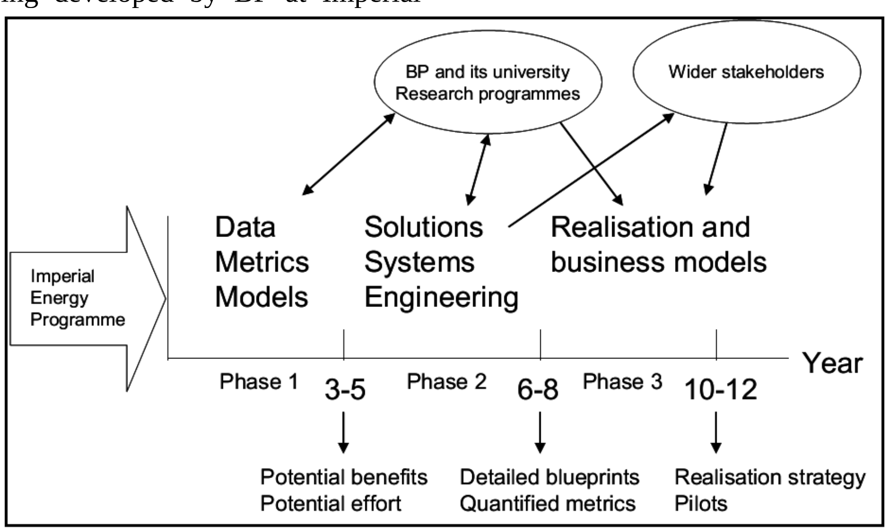


Figure 8. General plan and objectives of the urban energy system plan of BP and Imperial College London

The model used in this design is called Train, which considers resources and technologies as a network. In the train model, the city is divided into sections, each with a specific amount of demand for each resource over a period of time (Demand is a function of time and place).

The proposed template for this paper is very similar to this template. In addition to the inherent complexities of energy systems, urban energy systems also have specific issues in the social and cultural fields, as well as limitations in the production of pollutants, allocation of space for power plant construction within the city, and changing existing structure and infrastructure to the optimal structure.

As can be seen from this diagram, in the small boiler scene, there is about 17% savings in total costs and about 21% savings in energy import costs compared to the current scene. In the main scene, there is about 24% of savings in fuel costs and a total of 20% savings compared with the current scene. The saving mode in other scenes relative to the current scene is shown in Figure 9.

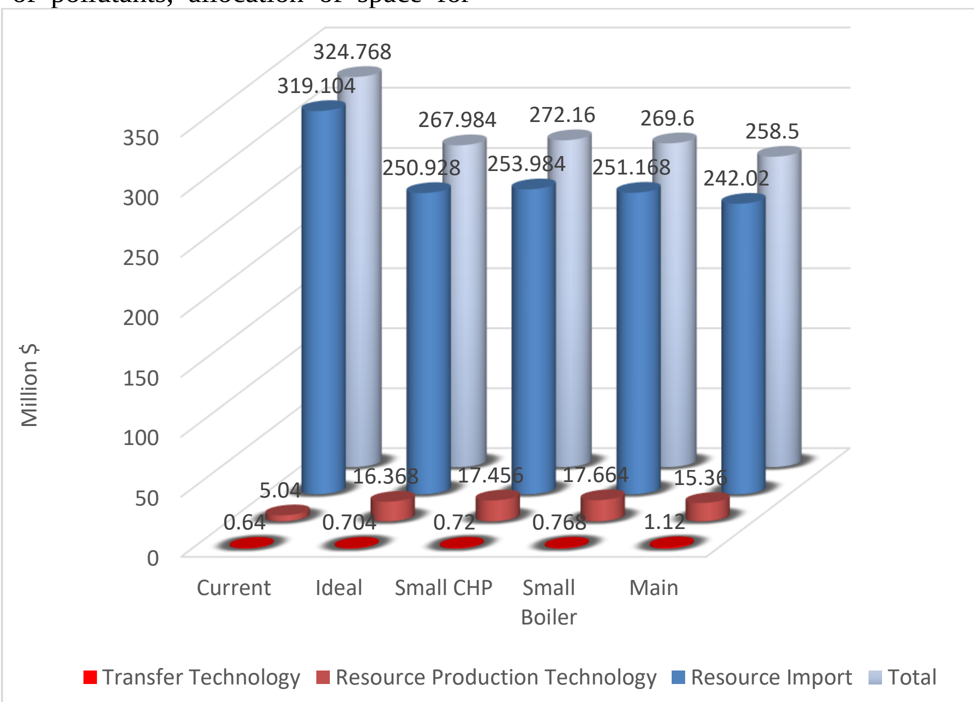
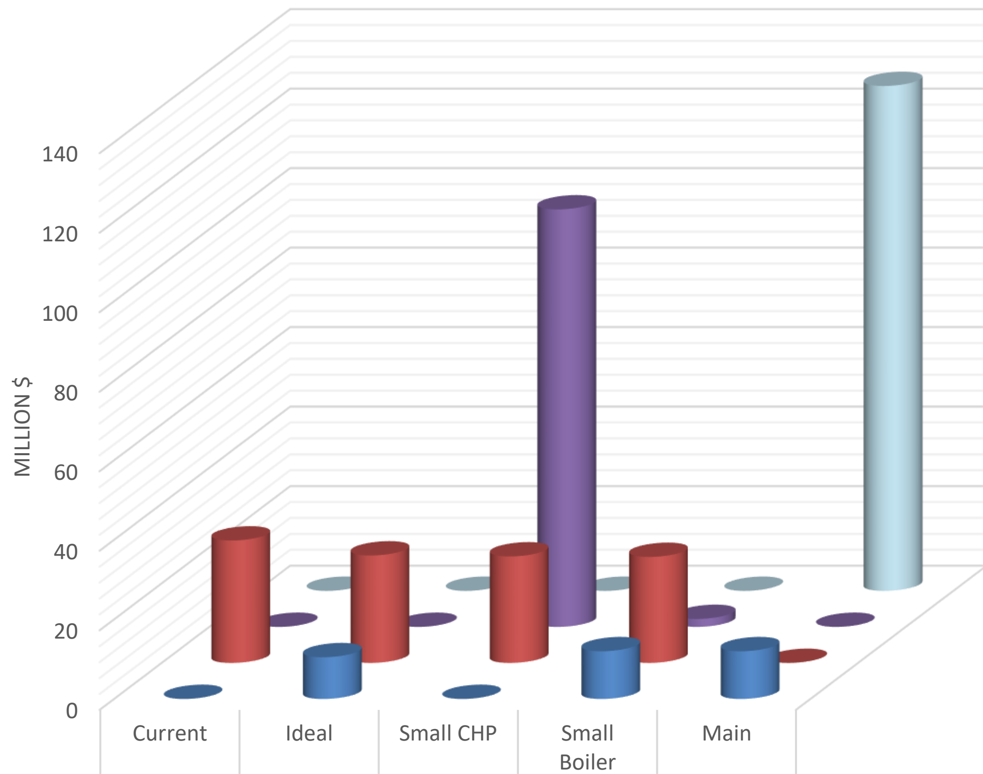


Figure 9. Comparing cost details in each scene

Table 1. The amount of cost savings in each scene compared with the current scene

	Main	Small Boiler	Small CHP	Ideal
Fuel Cost Reduction	24%	21.3%	20.4%	21.4%
Total Cost Reduction	20%	17.0%	16.2%	17.5%

The close proximity of the small boiler stage and the ideal stage shows that the selected capacity is suitable for small and medium generators. A comparison of the number of installed equipment also shows a 13.4% reduction in the need to install a boiler in the boiler room of a small boiler compared with the current stage. The number of equipment installed in each scene is shown in Figure 10.



	Current	Ideal	Small CHP	Small Boiler	Main
Medium CHP	0	10.491	0	12	12
Small Boiler×1000	30.78	27.016	26.777	26.652	0
Small CHP	0	0	105	2	0
Large Boiler	0	0	0	0	127

Figure 11. Number of equipment installed in each scene [46]

Conclusion

Urban energy system has an integrated structure and energy management in one part can affect the other parts. Different technologies are used to produce power such as gas turbines and steam cycles. However, the use of cogeneration systems has become more common. Various models such as Deco and Modest have been used to analyze urban energy systems that optimize investment and operational costs. In this study, the Train model has been used to simulate energy consumption in cogeneration systems. The results of the analysis indicate that utilizing small-sized boilers would bring 21 percent of reduction in fuel costs and 17 percent reduction in total cost.

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