Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Decarbonization Transformation Model of Multi-Energy Demand for Textile Manufacturing Processes

M. Ziya Sogut

mzsogut@pirireis.edu.tr

Piri Reis University

Artūras Kilikevičius

Vilnius Gediminas Technical University

Research Article

Keywords: Industry, Cogeneration, Energy Demand, Efficiency, Sustainability

Posted Date: August 24th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10397338/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

DECARBONIZATION TRANSFORMATION MODEL OF MULTI-ENERGY DEMAND FOR TEXTILE MANUFACTURING PROCESSES

M.Ziya Sogut[1]*, Artūras Kilikevičius[2]

[1] Maritime Faculty, Piri Reis University, Istanbul, Türkiye
[2]Vilnius Gediminas Technical University, Vilnius, Lithuania
* E-mail: mzsogut@pirireis.edu.tr; mzsogut@gmail.com

ABSTRACT

The responsibility of efficient management in multi-energy production of industrial processes using multiple energy should develop measures to ensure economic and environmental sustainability. For processes that manage multiple heat needs, such as textiles, resource efficiency can be seen as a direct optimization problem. Especially in fossil fuel-based consumption of businesses, management strategies can be evaluated together with a carbon purification perspective. This study aimed to improve the multiple energy use optimization developed under the responsibility of energy management in a textile enterprise and to reduce its environmental impact. In this context, multiple consumption data were taken as a basis and the cogeneration outputs supported by the process were investigated as well as their environmental impacts. In the study, it was seen that the need for operational heat loads in the enterprise was optimized with multiple heat management and the efficiency model could be improved. In the analyzes, it was seen that the average overall efficiency potential of the cogeneration process, which is approximately 59%, can lead to a cumulative reduction of approximately 76% in fossil fuel consumption as a result of approximately 17% improvement with low thermal processes with optimization. At the end of the study, a holistic thermal management model was developed to improve the operational performance of cogeneration processes, and recommendations targeting environmental sustainability were also presented.

Keywords: Industry, Cogeneration, Energy Demand, Efficiency, Sustainability

Introduction

Global decarbonization strategies are shaped by actions based on reducing fossil fuel consumption and preventing their environmental impacts. Industrial buildings, which are an important stakeholder of energy consumption, have to increase their consumption efficiency and develop effective resource management in order to fulfill this responsibility in multiple energy consumptions. (Chen et al., 2024). In such business structures, the manageability of energy should be developed together with the production dynamics in an institutional framework. (Daneshvar et al., 2025). Although this process depends on operational business parameters, business management tools must also be considered to improve energy and environmental sustainability. Although this develops as a disciplinary process directly as a requirement of energy management systems such as ISO 50001, improving resource efficiency is a step that needs to be developed together with business demands (Fitzgerald et al., 2023). It is unfortunate that, despite the continuous improvement approaches that are based on national targets, a significant number of organizations, businesses, and buildings still have problematic energy management systems. Nevertheless, energy management constitutes a pivotal component within the overarching framework of continuous improvement, playing a pivotal role in facilitating change. This issue is to feel primarily within a manageable organizational infrastructure within institutional structures. Today, business structures characterized by legal consumption limits demonstrate limited potential in terms of energy consumption. Unfortunately, a considerable number of businesses are not subject to legal obligations as a result of these limitations and thus continue to consume energy in an inefficient manner (Gonzalez-Torres, 2023). The enhancement of competitive dynamics and the escalating emphasis on quality have contributed to the evolution of a robust framework that integrates production quality with ISO 9001 standards. Since the close of the 19th century, there has been a notable increase in global awareness, which has in turn led to the development of ISO 14001 environmental awareness. This, in turn, has been accompanied by an increase in sustainability expectations on the part of businesses, which has resulted in the spread of ISO 50001 energy management systems (Bernardo et al.,2009). Indeed, the ISO 50001's fundamental objective is to raise awareness among enterprises and advocate for the monitoring of continuous improvement and the development of savings. Nevertheless, the limited institutionalization in contemporary business structures, coupled with the challenges inherent in process monitoring, constitutes a

problematic domain. While this situation hinders the development of corporate culture, it is an important problem in the development of a corporate behavior based on an energy efficiency approach. These challenges have been addressed from different perspectives in the literature. For example, Sousa Lira et al. (2019) and Fiedler and Mircea et al. (2012) examined the difficulties arising in the global spread and implementation of ISO50001. This is seen to affect unbalanced distribution and resource sharing, especially along with regional differences. On the other hand, ISO 50001 evaluates the relationship between energy and finance and also addresses effective management tools. Indeed, Reis et al. (2020) and Marimon and Casadesús (2017) examined the effects of financial, fiscal, social, and operational barriers in their studies. ISO50001 also reveals a structural problem due to cultural differences. Herce et al. (2020) and Fuchs et al. (2020) examined the socio-ecological motivations and internal cultural challenges for businesses and revealed the role of top management in solutions. The manageability of consumption intensities and efficiency structures is a choice as a significant milestone, particularly for enterprises not encompassed by the purview of ISO 50001. ISO 50001 facilitates the establishment of an institutional and dynamic roadmap for the creation of an effective and efficient energy management infrastructure and the development of direct implementation processes in terms of corporate goals.

However, managing energy demand sustainably in industry remains a major challenge due to infrastructure fluctuations and inefficient technologies. Significant energy losses occur in electricity transmission and distribution lines. This type of problem area is exemplified by the control challenges related to intensive energy demand in textile enterprises, which are the subject of this study. In this process, which starts with resource management in reality, system choices come to the fore. In terms of energy efficiency, cogeneration and trigeneration systems that simultaneously meet electricity and heat needs are an important development(Akhbari et al., 2025). These systems increase efficiency and reduce environmental impact by lowering energy costs. Disseminating these technologies in industry is critical for sustainable energy management based on energy efficiency. Cogeneration systems are technologies that enable heating and cooling energy to be produced at the same time using the same device, primarily based on electrical energy. In addition to generating electricity, these systems provide the heating and hot water required by the process and, with an additional unit, provide cooling, meaning that the process can easily be transformed into trigeneration. Cogeneration systems have been widely studied in the literature(Cui et al., 2026). For instance, Imal et al. have contemplated the potential of cogeneration and trigeneration systems in a hospital context and have conducted an economic evaluation of such a system. In their study, the payback periods were defined as 3.9 years for the cogeneration system and 4.15 years for the trigeneration system (Sivrioglu et al., 2011). Sivrioglu et al. have conducted a study on the economic viability of implementing a cogeneration system in a shopping mall. In the course of the analyses conducted, it was determined that the life cycle processes were subject to direct influence by electricity prices (Imal et al., 2016). Pirmohamadi et al. (2019) defined back-pressure steam turbines and their multiple arrangements and determined the most suitable heat and energy cogeneration systems—teams design from an exergy point of view. Caglayan and Caliskan (2018) have examined the gas turbine cogeneration model in a ceramic factory and made energy, exergy, and sustainability analyses. In their study, the exergy efficiency was found to be 89.46% for 10 °C, while this value was determined to be 29.98% for 30 °C.

Energy management can be defined as a planned organizational development aimed at minimizing or eliminating environmental problems arising from energy resources while concomitantly reducing energy consumption and costs without compromising quality in service and production (Luboff et al., 2016). Consequently, effective energy management in enterprises is a significant benefit. Nevertheless, the effective management of energy in production should be regarded as a disciplinary process that necessitates a multidimensional approach. While energy management is practiced in a variety of ways in many enterprises, there are inefficiencies in this area. Indeed, in systems devoid of an effective design and optimization capability, the manageable challenges of energy production give rise to inefficiencies (Nath and Ramanathan, 2016). This study is an evaluation of a textile company using a modeled triple-source system, focusing specifically on heat management issues and the impact of energy and environmental sustainability. This study developed solutions based on the derived data. This study specifically identified the inefficiency impact of the process, based on the energy audit study defined as the impact assessment of the reference cogeneration process.

Sustainability and Cogeneration Technologies

The development of institutional solutions within the scope of energy efficiency and management has been shown to have a significant impact on the competitive power of businesses. This, in turn, has led to an increased importance of today's global competition. In production-oriented business cultures, the underlying structural

problems are frequently productivity issues that are either ignored or postponed. The utilization of the capacity of commercial enterprises is generally managed based on market shares, and this is comparatively low for a significant number of enterprises. In such circumstances, the assurance of uninterrupted energy supply and the maintenance of energy quality are integral to the preservation of production continuity (Çomaklı et al., 2015). Substantial financial losses are predominantly attributable to technological limitations inherent in infrastructure, wherein each energy source is utilized through a distinct source or system employing conventional technologies. The utilization of combined power technologies assumes paramount importance in ensuring the continuity of resources and the effective management of energy for such structures (Hai et al., 2023; Na et al., 2025). These systems, also defined as combined power systems, cogeneration, or trigeneration, are energy production technologies that have become widespread in many structures, especially in the industry, since the 2000s. The fundamental functionality of these technologies is predicated on the generation of electrical and thermal energy within a unified structural framework, contingent on a primary energy source. These processes can be categorized as follows: i) electricity-first processes and ii) heat-first processes. However, when considered in conjunction with traditional structures, integrated power generation produces significant advantages in terms of sustainable energy transfer for both cases (Haghghi et al., 2019; Mohtaram et al., 2024). This is particularly pertinent in structures characterized by high consumption continuity, where the efficiency of traditional structures in terms of high system losses must be taken into account to ensure energy continuity. As demonstrated in Figure 1, the resource energy usage values of traditional applications and cogeneration applications are shown.

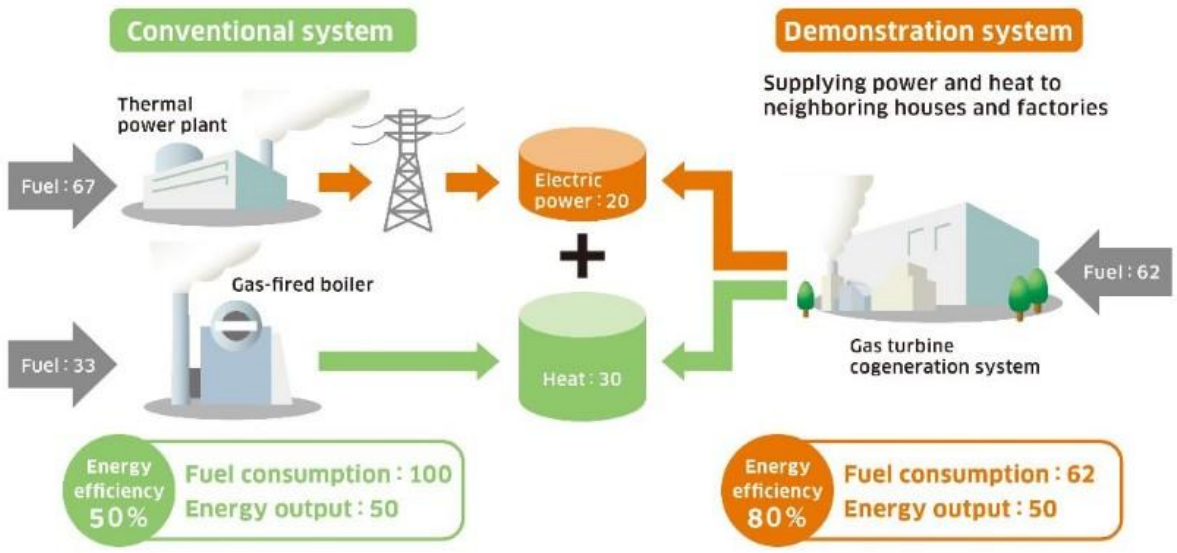


Fig.1 Conventional and cogeneration system comparison (Kawasaki, 2017)

The prevailing concerns regarding energy efficiency and conservation, heightened environmental consciousness due to climate change, and mounting international obligations have underscored the imperative for high-efficiency energy production facilities that prioritize reduced fossil fuel consumption. In this context, the European Union published the Cogeneration Directive in 2004, intending to encourage high-efficiency energy production facilities, such as cogeneration and trigeneration applications. Furthermore, a high-efficiency microcogeneration incentive system has been developed for cogeneration applications. In Germany, for instance, in addition to tax reductions in microcogeneration applications, an incentive price is applied for excess electricity transferred to the grid. Despite the increased utilization of cogeneration applications in industry and integrated building applications, there has been a decline in sector preferences in recent years, attributable to supply issues experienced in natural gas. Nevertheless, it is employed in particular to satisfy the requirement for multi-purpose energy sources. For instance, the Federal Republic of Germany has set itself the objective of increasing its share in total production to 25% by the year 2020. Within these systems, it is encouraging (see: İGDAŞ, 2014). However, like Figure 2, depending on its technological development, cogeneration preferences, based on many opportunities such as solar energy and waste energy use, have found application areas in recent years.

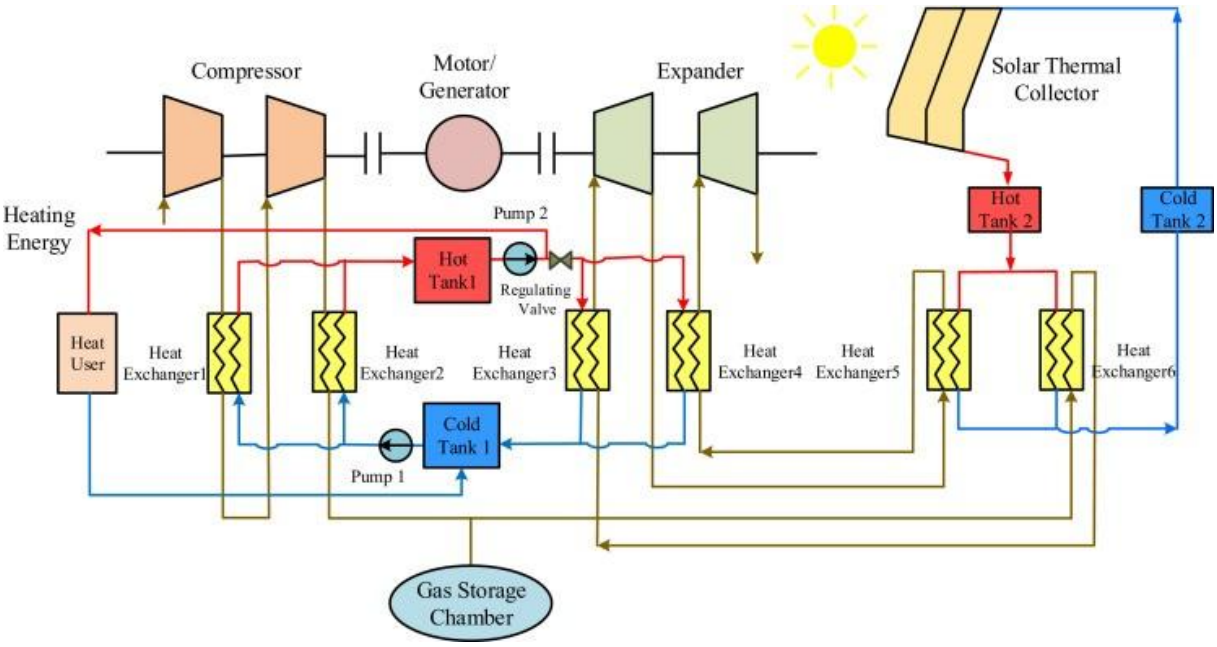


Fig.2 Schematic diagram of the cogeneration system based on AA-CAES coupled with solar auxiliary heat (Peng et al,2021)

In addition to the building sector, cogeneration systems, which are increasingly used in industrial and commercial structures, are seen as power systems. These structures, defined as power plants, can be evaluated within the scope of low-carbon technologies with high efficiency potential. In particular, cogeneration power plants can be divided into three categories: small-scale applications, micro-cogeneration applications, and macro-cogeneration applications. These systems, which are preferred due to multiple energy demands, have developed as effective tools in energy demand management, especially as combined power units. These system preferences can produce continuous and dynamic energy with demand process optimization as combined heat and power generating systems. Engine preferences in power technologies: gas turbines can have 3 different structures. These are gas engines, diesel engines, or combined engines. The performance of gas turbines stands out among these structures (Ezeamama, 2016). These engines work on the principle that the turbine compresses the air and generates electricity from high-temperature gases through the turbine. The heat energy of the high-temperature exhaust gases coming out of the turbine is converted into usable heat energy with the help of a waste heat boiler, and the engine efficiency is maximized. The preference for gas turbines in cogeneration and trigeneration systems is increasingly popular and is mostly valid for applications of 1 MW and above. In these engine applications, the heat capacity is approximately 2.5-3 times the turbine output power (Figure 3).

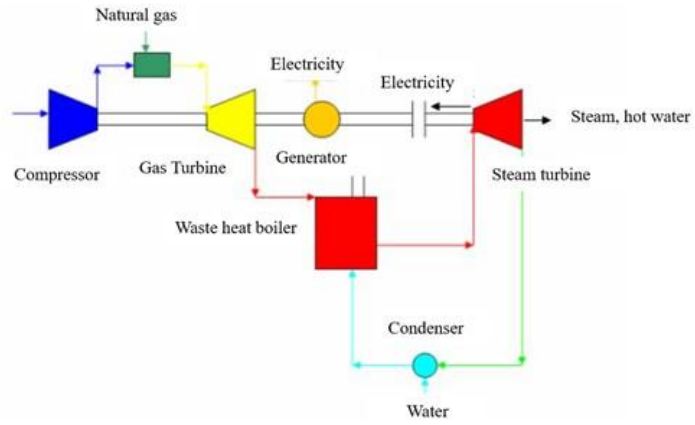


Fig.3 Flow chart of the cogeneration plant (with gas turbine) (IGDAS,2014)

Today, while the electricity demand of enterprises is predominantly met by local grid systems, the heat demand requirement is primarily met by conventional boiler systems. In such structural load distributions, there is considerable potential for significant electricity demand loss and high input cost for existing grid systems, in conjunction with distribution line and transformer load losses. In contrast, the efficacy of boiler technologies is contingent upon the type and characteristics of the requested heat, as well as the boiler's performance. Operating at an average efficiency level ranging from 55 to 95%, these technologies demonstrate high inefficiency in meeting the requisite heat demands. There is considerable potential for the enhancement of the performance of combined power technologies to achieve a demand optimization that will facilitate the utilization of these two distinct energy demands, thereby ensuring that the performance exceeds 90%. In the context of power system preferences, the efficiency of the combined system is enhanced through the direct conversion of waste heat into useful heat energy. Energy optimization for combined power systems must be considered in conjunction with consumption price optimization. The environmental impacts of these enterprises are contingent on their operating performance, with sustainability being influenced by operating costs. However, for structures utilizing multiple energy sources, such as the textile enterprise examined in the study, an integrated design should be developed, and an effective optimization should be implemented.

Energy Efficiency Management for Industry

The industrial sector, which has approximately 29% of total energy consumption among energy-consuming structures, is an energy-efficient structure with a multi-faceted and multi-source structure. Together with its sub-sectors, it has a very dynamic structure with different management tools and a chain related to different disciplines of the sector. Although increasing competition processes reveal a structure that increases production in the sector, input parameters, including energy, directly affect the sustainability of enterprises. This consumption demand, which is mostly dependent on fossil fuels, affects the sustainability of enterprises in terms of their environmental effects. In this respect, the increasing environmental pressures on enterprises have turned into a situation that affects competition, which has pushed enterprises to new searches in policies regarding energy and environmental sustainability. Today, the increasing energy management demand of enterprises has also developed as a result of this perspective. Indeed, especially when developing applicable actions, enterprises have needed an institutional framework. Energy management is a management organization structure that ensures that the output or service produced for institutional structures is fulfilled most efficiently with the lowest and cleanest energy(Fan and Su, 2024). In this respect, the target definition of this structure, which aims to develop action frameworks in enterprises, is also developed together with the policies of the enterprise. Today, the structural characteristics of the industry necessitate a holistic view, together with the main sectors. Sectoral priorities can be indicated as petrochemicals (~33%), the iron and steel sector (~33%), the cement sector (~9%), and the paper sector (~5%). However, energy management is expected to be addressed with an institutional framework that also develops a cultural change. Indeed, the increase in global temperature caused by environmental pollution originating from fossil fuels has directed countries to a strategic approach and to produce policies in this regard. National energy efficiency strategies in many countries have developed targets in this regard, and a holistic proposal has been provided for all sectors (Brian et al, 2024). In addition to these main sectors, leading sectors such as textile and automotive, which have developed in the country, have also gained value in this context. It is recommended that the industrial sector should control the increasing fossil fuel consumption for 2050 strategies, including structures that provide global reports such as the International Energy Agency (IEA), and that businesses should reduce energy intensity in their sustainability strategies (IEA, 2008). Of course, these structural limitations require the development of energy management awareness in institutions, the development of energy efficiency targets for energy-intensive processes, and the definition of manageable criteria. In this context, the industrial sector has a structure that needs to be examined from every perspective to develop energy and environmental sustainability. Some sub-sectors in the sector can be seen in this context because they have high energy density as well as high energy efficiency potential. It can be said that there is a need for dynamic and effective energy management, energy efficiency, and the reduction of energy costs for these sub-sectors.

The environmental sustainability targets that have emerged today, which have gained a national or international dimension, such as the EU, have limited fossil fuel consumption while also highlighting applicable actions in the energy transition. These strategies, which are included in frameworks such as carbon management and green call,

have assumed a new role in supporting the energy transition in the decarbonization process. For example, the EU's 30% reduction of emissions in its 2030 targets and the zero-carbon approach in its 2050 targets reveal this directional change. Policies that support this, such as Turkey's national energy efficiency action plan, reveal an effective sharing (Orhan, 2021). Of course, the development of possible structural mechanisms for the change of the sector, the definition of sectoral priorities such as incentive systems, and, above all, the sustainability of energy efficiency and its gaining of institutional value are expected processes. However, the development of sectoral targets and the inclusion of a potential of 80% in scope are important steps. In this context, the establishment of an energy management infrastructure for enterprises over 1000 TEP defined in Turkey, and the development of a method that can be followed in enterprises have also been regulated. In countries such as England, Türkiye, and France, where this is tied to legal processes, these processes are also secured following national policies (Orhan, 2021).

The dissemination of energy management in the industrial sector and the development of institutional models primarily occur when they find a place in business organizations. The climate change problem in the world since the 19th century has introduced people to the negative effects of fossil resource inefficiencies. Energy management models must be viewed within a management organization, and that change must be supported within this framework, particularly in structures that use a variety of energy sources (Fahad et al., 2017). The textile sector, which is taken as a reference in this study, should also be evaluated along with the measures that support the operational efficiency of the business, together with its multiple energy demands. In this respect, energy management systems such as ISO 50001, which have become prominent and widespread in recent years, have facilitated corporate management. Sustainability, which is an important applicable area, especially for businesses, has gained an institutional feature. Although energy management stands out within this structure in some businesses, the corporate responsibility of energy management refers to interrelated areas. However, the originality of energy management and the steps it reveals should be addressed in an independent structure, along with the organizational charts. This situation should also be seen as an important step for textile businesses. It is seen that it includes an application process depending on the flow form given in Figure 4.

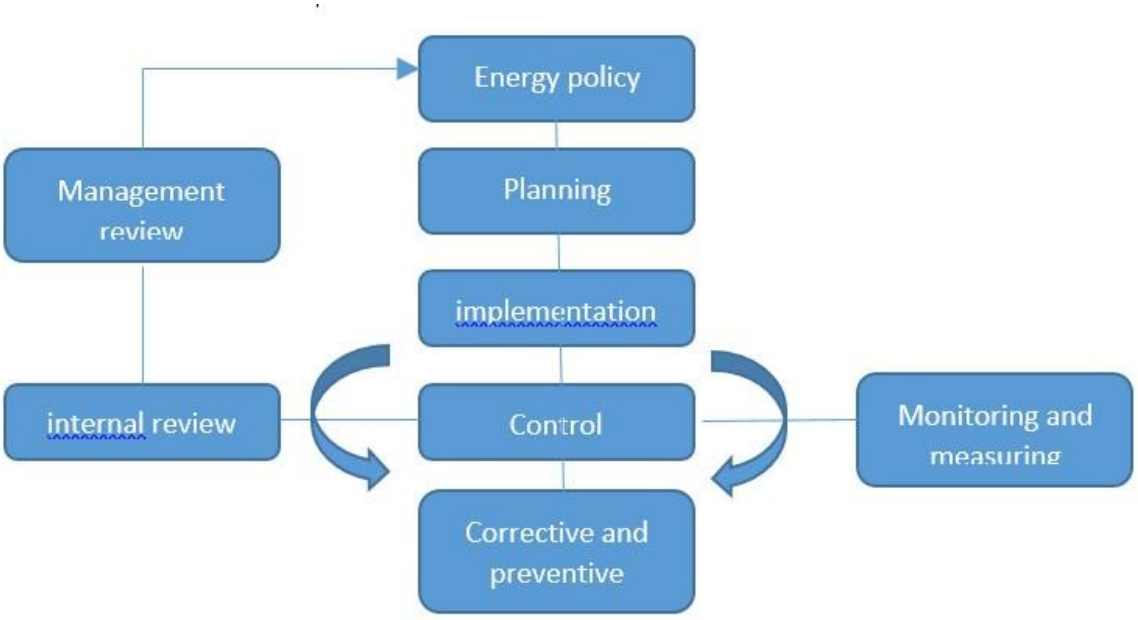


Fig. 4 The energy management system (EMS) cycle (ISO, 2011)

ISO 50001 Energy Management System requires a preliminary study for the defined businesses. In businesses that want to implement ISO 50001, the first step is to reveal and analyze the current status of the business. Another situation expected in businesses is to define the institutional responsibilities of energy management and to develop an action plan based on policy. In this planning process, it is recommended to conduct survey studies for the scope

and limits of energy efficiency studies. This process, which is often neglected in most businesses, serves especially to define possible criteria. The survey study is also defined as a holistic energy scan for energy-using processes and is related to the definition of a possible target potential. Although energy scanning varies according to the nature of the business, it should be addressed separately for the important energy users determined according to the scope and limits, from the whole to the specific. The referenced textile business has a production flow that includes a disciplinary process from yarn to dye production and has energy-intensive processes in all stages. Energy is a parameter that directly affects the target processes of the business and the unit costs of production. The sustainability steps expected in textiles have affected corporate targets, and the reduction of possible high energy costs, together with consumption, has come to the fore in global markets. ISO 50001, suggested above for the management of energy for the operational processes of the business, has supported corporate development at a sustainable rate and also contributed to the development of corporate targets. Energy is also addressed and modeled within this scope, along with the sustainable and environmental production targets expected in textiles. In this respect, it is expected that consumption points are defined, a criterion is developed for each of them, and consuming processes are monitored in this respect.

In textiles, production efficiencies or operational processes are mostly considered through possible consumption data. This situation is shaped by the production data, and the energy consumption is shaped depending on an estimated value. In reality, the measurement values of energy are directly formed by shaping the parameters for each user. Especially for heat processes, it is directly addressed with thermodynamic data. However, for textile companies, along with environmental conditions, binary data also directly affects energy consumption. In analyses, production balance includes processes that need to be examined together with thermal performance conditions of the processes. Energy manageability in companies is shaped by continuous improvement opportunities that directly take into account production and consumption performances.

Methodological Framework

Energy efficiency directly indicates a change that targets the reduction of consumption in services and production. It is a process that is expected to become an applicable behavior for institutional structures. Ensuring institutional continuity of energy primarily depends on the establishment of a management framework. In every business with such service features, a management responsibility and management structure should be established first. Energy management expectations for textile applications are mostly based on standard analyses. In reality, the efficiency processes of businesses are shaped by the development of individual awareness in the institution, the provision of technological competence, and the provision of top management support. Energy efficiency is a fundamental process that energy management should plan as a goal, and an effective road map should be shaped. The road map is a strategic step of energy management and defines the steps to be followed in the business. In this context, the development of action continuity is also related to the effectiveness of the defined road map. The energy efficiency road map presented in Figure 5 in this study is an applicable tool for such businesses.

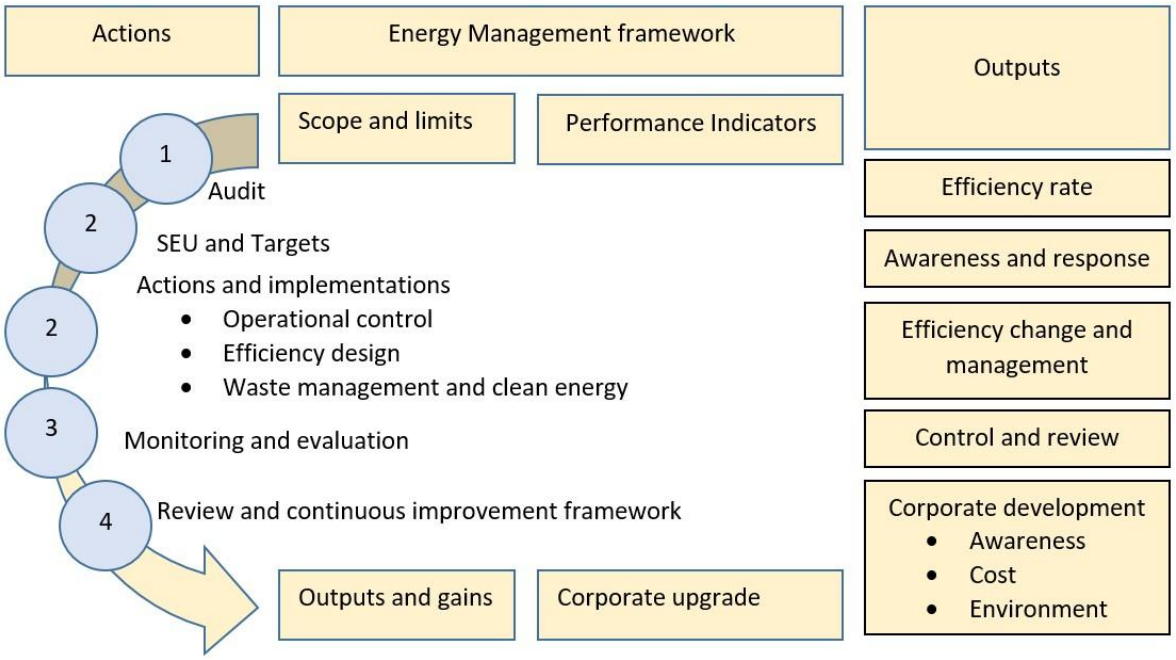


Fig. 5 Energy efficiency road map (Sogut and Karakoç, 2023)

The institutional roadmap proposed in the study includes the defined action steps. The potential for energy efficiency is defined by the expected outputs, and the most crucial action step created in this process identifies the elements that demonstrate the company's consumption patterns. The study to be developed in the businesses directly provides the behavior of energy users and the development of possible efficiency targets. The success of the energy study is an effective data collection process, depending on the energy users. This stage requires effective planning and a measurement plan. The energy management team defined in this context determines the framework, scope, data types and collection types, and measurement points of the study. It also defines the processing method, data criteria, attributes, measurement time, and collection periods in data types (Hepbasli, 2011; Bojana and Filipović, 2016). In sectors where such energy impacts are intense, continuous process data can be obtained with the established monitoring systems. However, although it is possible to design a separate method for low-energy-consuming structures with non-production energy consumption data, this is a neglected situation. Therefore, preliminary studies should be seen as a process evaluation.

In collecting data according to the source type of the enterprise, it is necessary to pay attention to the total method first. For example, it is important to define a common unit for electricity and liquid fuels. In this context, it is necessary to read the enterprise data first and create the effect parameters. The primary application for energy studies is to define regression analyses depending on the data and variables. These analyses are expected to develop the energy efficiency potential according to the standard and target equations and to create a cumulative total value graph. This study collects consumption data depending on the consumption types of the textile enterprise defined. The demand consumption of important energy users in the enterprise is also evaluated, and the performances are evaluated according to the targets. The cogeneration process defined in the study has also been examined together with the consumption behaviors of the resource usage. In fact, in such energy studies, variables affecting consumption are developed, and standard and target equations are developed for such variables. The direct relationships of these variables with energy consumption are evaluated. The specific variable or variables found appropriate are examined about the energy consumption of the enterprise. The energy and variable relationship is a parametric value depending on the deviation from the standard line equation (Onaygil, 2015). The controllable variables defined in the business are the variables that affect energy consumption in the business and are recorded. The standard equation produced for businesses is the linear equation that defines a correlation between energy and the defined variables. The linear equation was developed.

$$E = a + b(P) \quad (1)$$

Here, a and b are equation constants, and P is the variable/variables related to energy. However, these variables can define more than one parameter (x, y, z). In this context, the developed line equation;

$$E = a + \sum b(x) + c(y) + d(z) \quad (2)$$

A line graph is developed for the distributions produced by the developed line equation, and a target line with the same characteristics is created over the data under this graph. The target equation defining this target line is also related to the defined variable(s). This equation also shows the potential related to the variable with energy data depending on the regressions made. The accuracy of both equations or the validity for the business is tested with the R^2 value, and this value is expected to be over 90%. Different methods can also be used in standard and target definition. Especially in conditions where there is data that does not comply with the energy consumption data, the lowest consumption for the defined variable or the consumption depending on the experience value is also an acceptable criterion. In these conditions, the energy efficiency potential of the business is defined by the defined target values or equation (Sogut, 2009). Combined power technologies are generally evaluated according to thermodynamic principles. When the business structures are considered, they can be expressed as thermodynamic heat engines in their holistic aspects, and the general energy efficiency for these systems can be expressed as follows:

$$\eta = \frac{W_{net}}{\dot{Q}_{in}} \quad (3)$$

Where, ηi s thermal efficiency, $\dot{W}_{net}$ express the net electricity consumption obtained from the system, and $\dot{Q}_{in}$ express the fuel energy transferred to the fluid circulating in the system. Güç teknolojileri, termodinamik makineler olarak, güç üretimi ve faydalı iş olarak tanımlanan elektrik enerjisinin dışında, egzoz, ceket suyu ve ara soğutucu ünitesi gibi farklı ısı transferlerine sahiptir. Bu bağlamda, sistemin toplam enerjisi şu şekilde ifade edilebilir:

$$\dot{Q}_{in} = \dot{W}_{net} + \dot{Q}_{losses} \quad (4)$$

Where, $\dot{Q}_{losses}$ refers to the losses in their systems. The energy supplied to the system directly depends on the amount of fuel. In this case, the energy given to the system can be expressed as:

$$\dot{Q}_{in} = \dot{m}_{fuel}.\,\mathrm{LHV} \quad (5)$$

Where, $\dot{m}_{\mathrm{fuel}}$ represents the amount of fuel supplied to the system, and *LHV* is the low heat value of the fuel. The amount of fuel *Mfuel* needed for the total energy load in a system can be calculated as follows;

$$M_{fuel} = \frac{Q_{in}}{LHV_{fuel}} \quad (4)$$

Here, η_{engine} expresses the thermal efficiency of the engine (Imal et al., 2014).

Results and Discussion

This study includes an energy audit based on multiple steam production and related energy efficiency engineering solution recommendations based on derived data from a modeled textile company. The modeled textile company is formed with a local structure and is connected to a triple heat source.The energy efficiency and framework of the company were first evaluated together with the energy efficiency culture of the company. The consumption distributions of the company with an average annual energy consumption potential of 8500 TOE in total were electricity (produced), electricity (steam received), natural gas, and coal at 9%, 5%, 45%, and 41%, respectively. The distributions of electricity and natural gas consumption in this consumption are given in Figure 6.

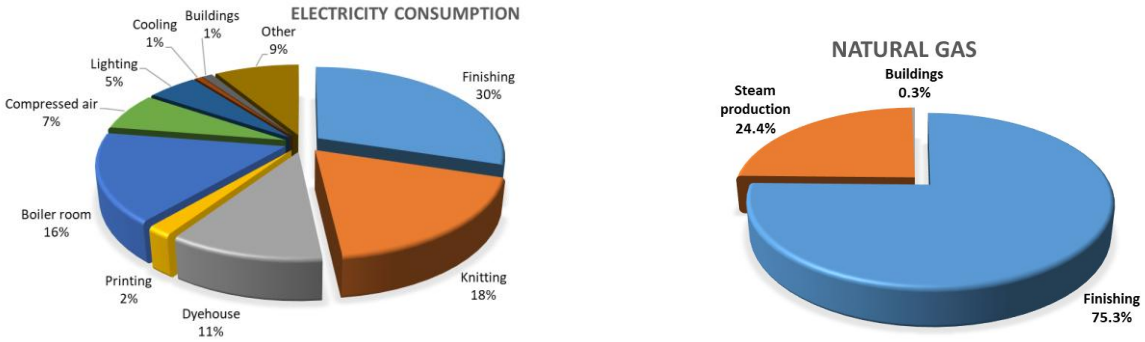


Fig.6 Electricity and natural gas consumption

Considering the energy management culture of the business, a high and inefficient distribution is observed, especially in heat management, due to local system solutions. Especially the steam used as an energy carrier is produced from three cogeneration, natural gas boiler, and coal power plants, respectively. The usage area is distributed as finishing, paint shop, washing, and other sections. Steam production and distribution are given in Figure 7.

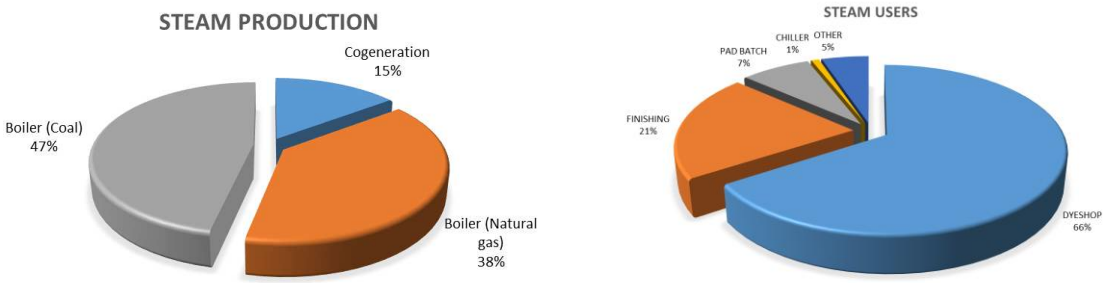


Fig.7 Steam production and usage distributions

The company prioritizes production costs in an energy management culture based on steam production. It is observed that the highest steam production is achieved in the coal plant with flame and smoke pipes. In this context, an energy efficiency assessment has been made. According to the plant consumption taken from the company, the operating efficiency of the coal plant has been determined as 74.8%. On the other hand, the operating efficiencies were found to be 37.81% for the coal plant on the heat side, 38.3% for the natural gas boiler, and 23.3% for the cogeneration process. However, the energy efficiency of the coal boiler is 73.4%, the efficiency of the natural gas boiler is 74/74, and the total efficiency of the cogeneration process is 85%. It is observed that the heat-generating processes in the company show a very low performance. The primary reason for this is the high cycle losses in heat consumption and the inadequacy of heat recovery. In this context, a system proposal (Figure 8) has been developed, and an integrated structure has been suggested for all heat sources of the company.

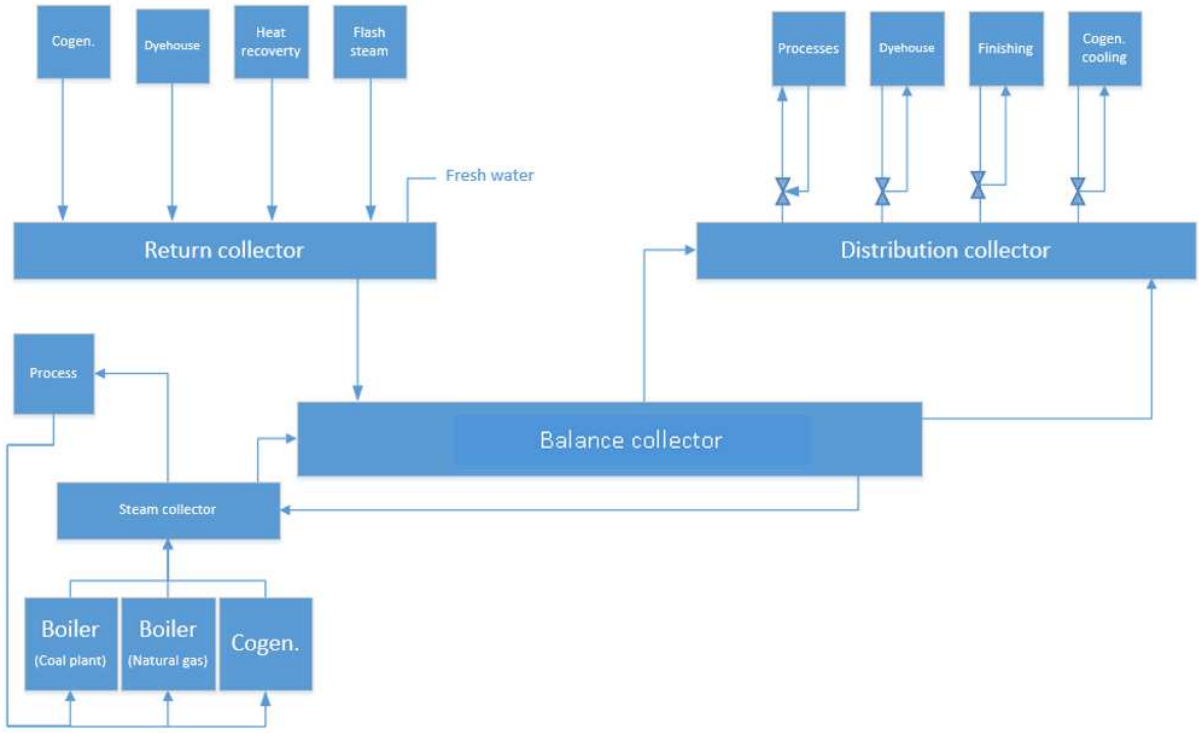


Fig.8 Holistic heat management process

The problem area of the enterprise is the operation of cogeneration, and in this context, the operation efficiency directly shows that the low operation efficiency in the cogeneration process needs to be improved. The full-load operation performance of such processes has a process that will directly affect the life cost as well as the efficiency. In this context, first of all, the load curves were examined based on the defined three-year data of cogeneration. There is a 4.48 MW GE Jenbacher J612 GS gas engine in the enterprise. According to the catalog data, the engine's electricity production efficiency is 43.3%, thermal efficiency is 44.4%, and it is seen that it is 87.7% in total. Again, according to the catalog data, the NOx value of the engine is 500 mg/Nm³ (5% O_2). The energy production data based on the cogeneration study data are given in Figure 9.

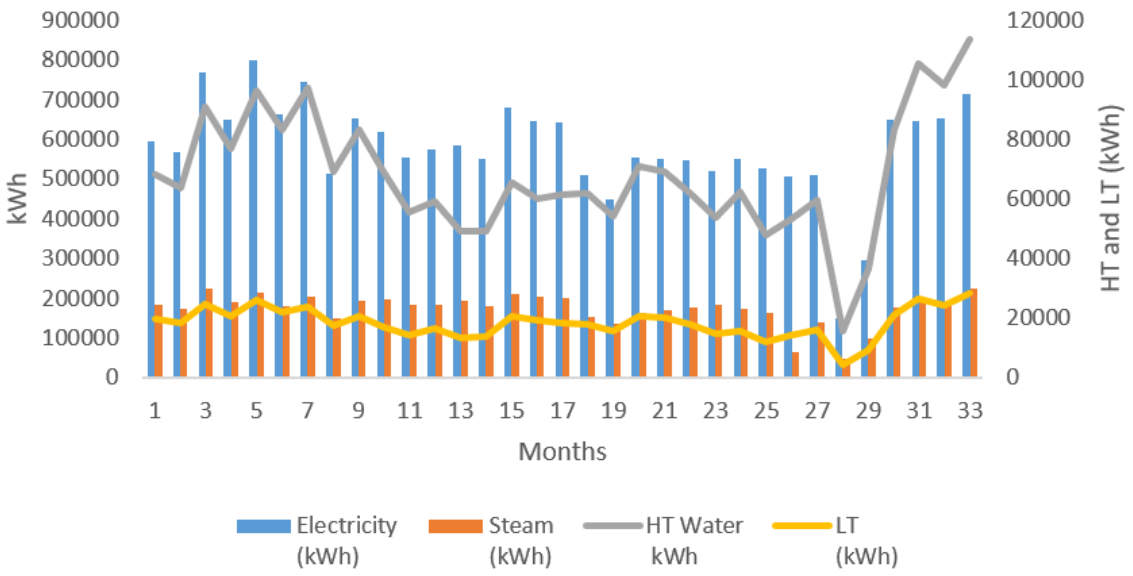


Fig.9 Energy production of the Cogenration process

The performance analysis of the cogeneration process was evaluated separately for the three years of measurement. However, in the total energy consumption, electricity was 69.97%, steam 20.02%, HT 7.89%, and LT 2.12%. These values were evaluated together with the total fuel consumption, and the average efficiency of the cogeneration process was evaluated. According to the performance distributions given in Figure 10.

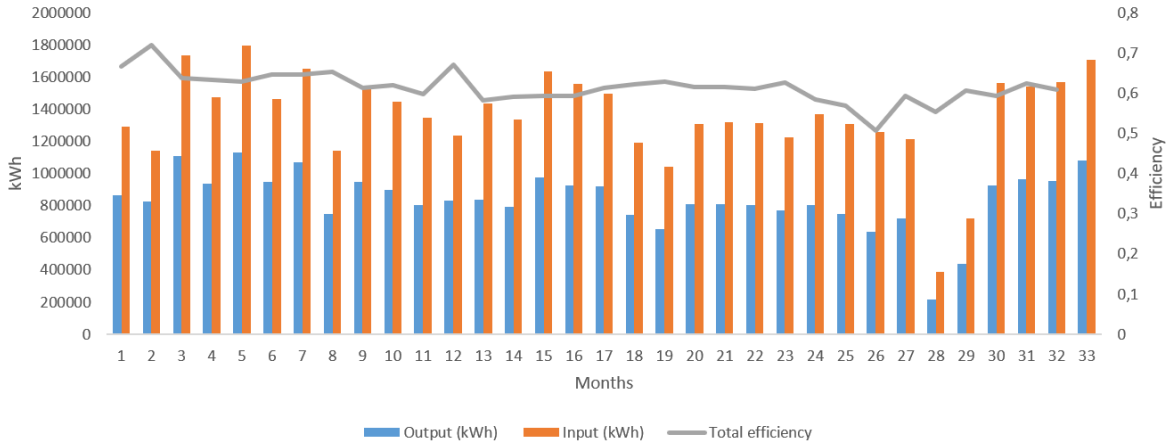


Fig. 10 Energy performance distributions of cogeneration process

Based on data from three years of cogeneration, the process's average efficiency was 61.58%. The efficiency distributions of the process have a fluctuation between 57% and 74%. According to this data, 20 of the 33 datasets have an average performance of 62%. According to this data, especially electricity production efficiency and heat production efficiency were evaluated. The distributions according to the analysis are given in Figure 11.

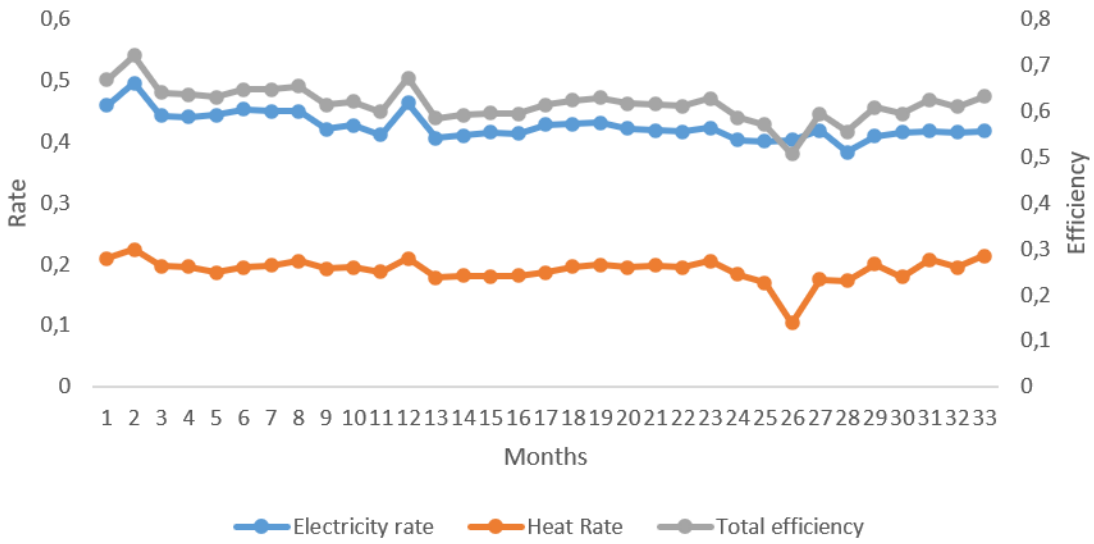


Fig.11 Energy efficiency and production rates in the cogeneration process

When these distributions are examined, the average electricity production is 44.31%, while this value is found to be 19.03% in heat production. When these data are compared with the capacity production values of the cogen, a potential of 1.72% is seen for electricity, while this value shows a potential of 57.14% on the heat side. Depending on these data, it is seen that there is an important problem affecting efficiency, especially in heat load. Since the heat side of the cogeneration is produced with waste resources, the performance is quite low. The electricity usage potential of the enterprise within this structure is also examined. Since the electricity effect of cogeneration production is also an important parameter in optimization. Accordingly, the distributions are given in Figure 12.

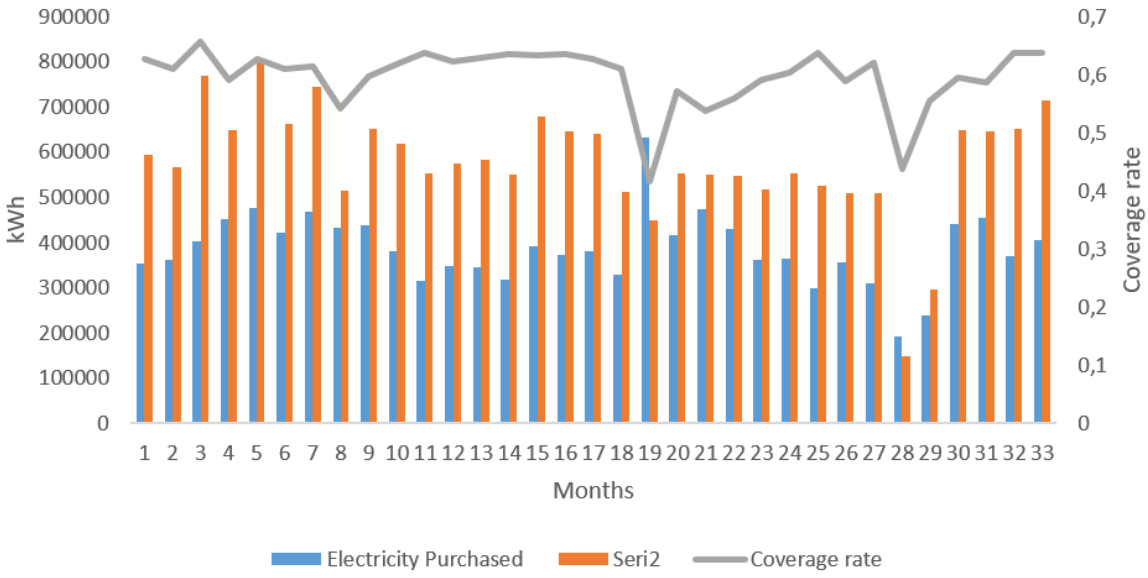


Fig.12 Distribution of electricity consumption of the business

While the electricity produced by the company in the cogeneration is actively consumed in the system, the coverage ratio varies between 54% and 64%, while the production average is 59.68%. These values show that cogeneration has limitations in heat production capacity. In this case, steam production in particular has supportable criteria. The study is addressed by comparing the outputs in cogeneration production with the cogeneration capacity. Accordingly, the heat usage behaviors of the company are evaluated, and the cogeneration

effect is questioned. The heat production distribution of the cogeneration with a load potential of 14.76% is given in Figure 13.

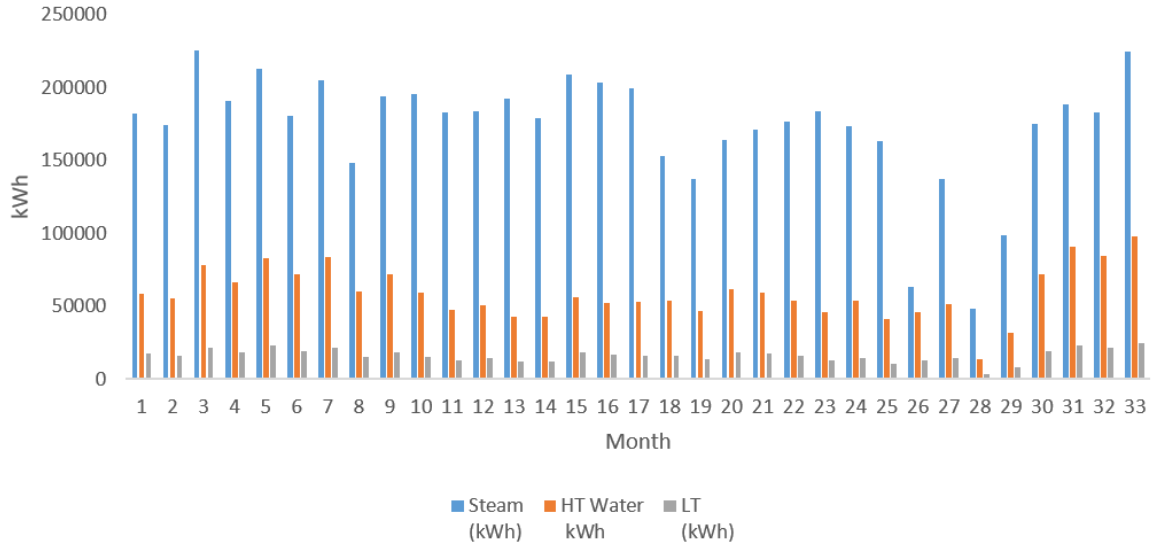


Fig.13 Heat production distributions in the cogeneration process

In the cogeneration process, the evaluation of the current capacity was first made for the producible potential of the steam line. In the current production, it was seen that the steam ratio of the total heat was 0.70, the HT ratio was 0.24, and the LT ratio was 0.06. However, considering that the total heat capacity of the cogeneration is 44.4%, the current capacity represents a potential of only 29.49% of the total capacity. The natural gas and coal potential that the enterprise can meet through the proposed common use process of this effect on the waste potential of the cogeneration was examined. According to these data, the distribution of natural gas and coal savings is given in Figure 14.

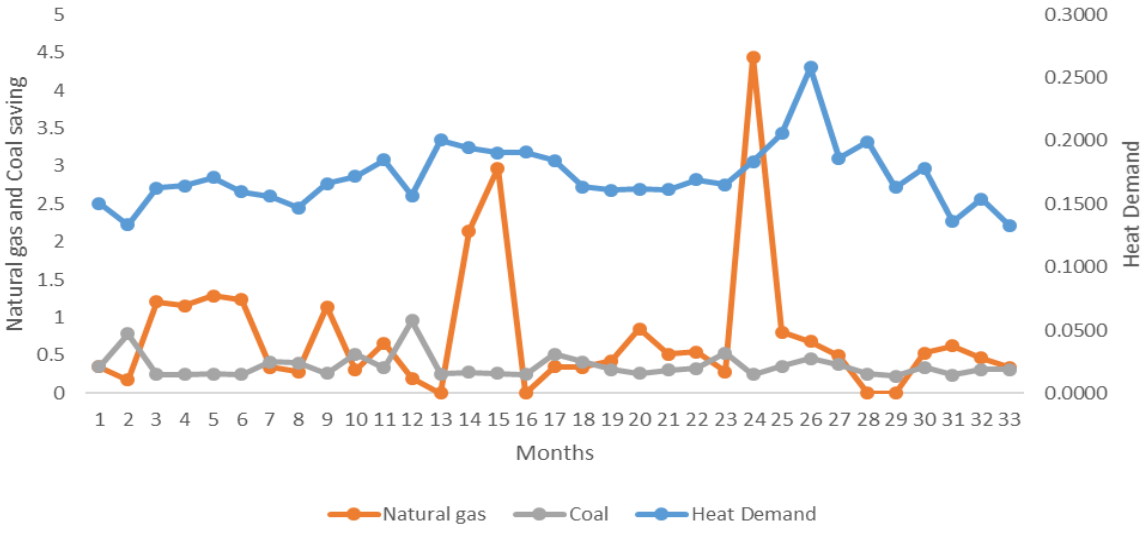


Fig.14 Heat optimization of cogeneration process

When the potential that can be produced in the waste heat of cogeneration is taken into consideration, an average of 17.17% effect is seen in the heat demand. This value has been examined by considering both the natural gas boiler consumption data and the coal plant consumption data. While it is seen that there is no continuous full operation in the natural gas plant, the potential that emerges in some months has shown that there can be significant savings in boiler consumption. Depending on this data, it is seen that a 76.35% saving can be achieved in natural

gas consumption. On the other hand, if coal is taken as a reference, it can be said that a 36.05% potential can be met in the plant. The company must first make a system change in terms of the suggested process. It indicates a high potential for consumption points connected to cogeneration.

It has been evaluated that the most important change in businesses is the development of a visionary roadmap with a decarbonization strategy. Along with this process management, the action process of decarbonization needs to be defined. In this context, a logical framework for the action steps of decarbonization has been developed with a new perspective according to the available data and is given in Table 1.

Table 1 The logical framework of decarbonization

Strategic Objective	**Study Findings**	**Responsibility of Energy Management**	**Decarbonization process**	**Monitoring Indicators (KPIs)**	**Expected Result**
Reducing fossil fuel dependence	86% of energy comes from coal and natural gas.	Creation of fuel hierarchy	Coal → Cogeneration waste heat → Natural gas → Electrification → Renewable energy ranking	Coal consumption (TOE), natural gas consumption (Sm^3)	Reduction in total fossil fuel consumption
Removing coal from the system	The coal boiler meets 41% of the total energy.	Operating the coal boiler only at peak loads	Increasing steam generation with cogeneration waste heat	Coal boiler running time (hours/year)	Reducing CO_2 emissions from coal
Making cogeneration the main heat source	The total efficiency of cogeneration is 61.58%, well below the catalog value (87.7%).	Full-load operation strategy according to heat demand	Waste heat recovery and centralized load management	Cogeneration total efficiency (%)	Reduced need for natural gas boilers
Reducing natural gas use	With waste heat optimization, a 76.35% saving potential in natural gas consumption has been determined.	Using waste heat as a primary energy source	Recovery of exhaust gas, HT-LT and condensate heat	Natural gas consumption (Sm^3/year)	Reduction in fuel cost and carbon emissions
Integrated steam management	Three different steam sources are operated independently.	Central steam management system	Dynamic load sharing and automatic control	Share of cogeneration in steam generation (%)	Operational data optimization
Electrification	Developing fossil fuel-fired heat process alternatives	Plan for transition to electricity-based heat generation models	Heat pump, electric steam generator and electrical system preferences	Electrification rate (%)	Reducing the use of fossil fuels
Integration of Renewable Energy	Creation of the operation plan of the entire generation system according to the	Increasing the use of renewable electricity	Solar power plant, electricity supply plan	Renewable energy rate (%)	Reduction of indirect (Scope 2) emissions

	electricity demand .				
Carbon-based energy management	Monitoring energy performance with carbon indicators and creating a model	Conducting energy management through carbon intensity	Energy-Carbon dashboard, ISO 50001 and ISO 14064 integration	kg CO_2e/ton of product	Continuous decarbonization model and system integration

The operating obligations to be developed according to these data should be handled into a new concept and the energy usage competence of the enterprise should be reshaped according to the KPIs to be defined. KPIs have been developed to support the decarbonization strategy for energy Management based on the energy use behaviors of the existing business. The target year of the enterprise has been taken as 2035 and the energy efficiency targets of the enterprise have also been developed. Table 2. In this context, decarbonization targets have been established together with the efficiency strategy of the enterprise.

Table 2 Target tracking framework for decarbonization strategy

Monitoring framework	KPIs	Current Situation (Audit)	Years		
			2028	2030	2035 Vizyonu
Energy Data	Total energy consumption (TOE/year)	8.500	≤8.000	≤7.600	≤7.200
	Carbon intensity (tCO_2e/tonne of r)	Reference	−20%	−45%	−90% and above
Energy consumption shares	Coal's energy share (%)	41	<20	0	0
	Energy share of natural gas (%)	45	<35	<20	<5 (backup only)
Energy monitoring indicators	Waste energy recovery rate (%)	≈29,5	>50	>70	>85
	Total efficiency of cogeneration (%)	61,58	>75	>82	>85
	Cogeneration heat utilization efficiency (%)	19,03	>30	>38	>42
	Fuel substitution rate (%)	0	>30	>60	>95
	Renewable energy rate (%)	Low	>20	>40	>80
	Electrification rate (%)	Very low	>15	>40	>%90
	Biofuel utilization rate (%)	0	Pilot application	>20	Transition fuel / depending on requirement

In the study, a four section program was proposed for the business. The flow logic that energy management should follow was planned as 2026-2028, 2028-2030, 2030-2035 and after 2035 within the scope of the logical framework

of the program. The main process management that stands out in the study was envisaged as improving efficiency, reducing the fossil fuel impact, increasing the electrification potential and renewable energy potential. However, it is envisaged that the first stage will increase efficiency, especially in the cogeneration facility, to be developed with transition technologies for 2030, and that it will only be operational with carbon-free fuel or low-carbon fuel after 2035. First of all, the transition process, which aims to remove the need from steam with a process engineering of the enterprise and develop a hot water production model, has been proposed as the main priority goal. In this context, 2035 has been taken into account as a full electrification target for the enterprise. In this context, it is envisaged that the 2035 target will be to make electrification the dominant energy system and to maintain the supporting role of biofuels as alternative fuels for transition and special processes, which will offer a more flexible and feasible strategy.

Traditionally, most of the process heat in the plant is met by central steam systems. It is expected that the need for energy management in this direction will be supported by real data and the results will be controllable. The energy audit carried out in this context showed that a significant part of the high-pressure steam used in the plant was consumed in dyeing, washing and finishing processes that require low temperatures. It has been shown that this situation increases inefficiency in the enterprise and causes unnecessary exergy destruction for the processes. According to the process data of the cogeneration system, the heat recovery potential stated as 44.4% according to the heat recovery potential actually used in the operation is only 19.03% and the total cogeneration efficiency remains at 61.58%, revealing that the current steam management strategy is not compatible with the process requirements. In addition, only about 29.5% of the waste heat potential can be utilized, indicating that the use of high-temperature steam as the primary energy carrier for every process is not technically and economically sustainable.

The primary responsibility of energy management is to develop energy demands with sustainable and renewable resources in accordance with the heat demands required by the processes in production processes, together with the decarbonization approach developed, together with fuel conversion. First of all, it is planned to develop more efficient technological transformations in the use of steam of processes suitable for low temperature solutions in process needs and heat management. In this context, it is to develop more effective resource management with both waste hot water conversion and heat pump. As a matter of fact, it has been observed that only 2 fuel tanks require more than 100 C heat. In this context, the development of the washing program has been developed as a priority hedf. However, in this context, reducing distribution losses by using modular low-pressure steam generators operating on a process basis instead of high-pressure central steam generation and producing steam only at necessary points has also been presented as an evaluated solution. Within the framework of this transformation, it is prioritized to completely eliminate coal from the system in the short term, to significantly reduce natural gas consumption in the medium term, and to consider biofuels or other sustainable carbon-free fuels as transition fuels.

Conclusion

This study examines the energy management framework in the industry while examining the energy efficiency potential. Depending on the energy studies of the enterprise, the efficiency of the direct cogeneration system was first evaluated, and its performances were calculated. The energy optimization of the cogeneration process was evaluated in the study, and the results are presented below. Accordingly.

a. The cogeneration share in the electricity consumption of the enterprise has an average of approximately 59%. However, the main energy source in thermal load is the coal power plant, with 46.64%.
b. Local studies, not integrated, were observed in the resource consumption of the enterprise. This situation creates an imbalance, especially in thermal resource management. For this purpose, it was seen that the mechanical system should be revised.
c. In the heat load distributions in the cogeneration process, the total heat was found to be 0.70, the HT ratio was 0.24, and the LT ratio was 0.06.
d. The energy efficiency potential in the cogeneration process was found to be 2.58% in electricity and 17.17% in heat load on average.
e. It has been observed that approximately 76.35% gas savings can be achieved with thermal optimization in the cogeneration unit. In this context, the carbon footprint of the business will also be affected.
f. It has been observed that an energy management that will support cost-effective environmental sustainability can be developed with the integrated management of the business.

g. The decarbonization strategic model of the enterprise has been developed and the electrification transformation and logical framework for 2035 have been presented.

The analyses conducted have shown that a disciplined system preference in businesses will directly reduce energy use and environmental pollution due to possible entropy loads. In addition, the primary task of energy management is to develop an energy efficiency roadmap in a business, as suggested in the study. The proposed decarbonization model has been developed as a management framework for a direct multi-energy management strategy, especially for textile enterprises. This study directly presents the energy study and planning framework. It is recommended that target criteria be developed for each user, along with the life cycle analyses of the efficiency suggestions to be proposed for the future.

References

Akhbari H., Eslami S., Gholami A.(2025) Long-term performance evaluation of hybrid solar thermal and desalination Systems: Heat transfer fluids and advanced configurations insights, Case Studies in Thermal Engineering, Volume 73, 106601, ISSN 2214-157X, https://doi.org/10.1016/j.csite.2025.106601.

Bernardo M., Casadesus M., Karapetrovic S., Heras I. (2009) How integrated are environmental, quality and other standardized management systems? An empirical study, Journal of Cleaner Production, Volume 17, Issue 8, Pages 742-750, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2008.11.003.

Brian S., Hatem M., Sekiguchi H., Hassan H. (2024) New approach for zero energy industries via integrating energy management and renewable energy system: Enviro-economic investigation, Energy and Buildings, Volume 319, 114573, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2024.114573.

Bojana J. and Filipović J. (2016) ISO 50001 standard-based energy management maturity model – proposal and validation in industry, Journal of Cleaner Production, Volume 112, Part 4, 20 January 2016, Pages 2744–2755
IEA, World Energy Outlook (2008) World Energy Agency, Paris, France, https://www.iea.org/media/weowebsite/2008-1994/WEO2008.pdf

Caglayan H., Caliskan H.(2018) Energy, exergy and sustainability assessments of a cogeneration system for ceramic industry, Applied Thermal Engineering, Volume 136, Pages 504-515

Chen W., Wei C., Sun L., Dong H., Hijioka Y., Nakajima K., Fujii M. (2024) Carbon-neutral heat supply strategies for industrial decarbonization: A critical and systematic literature review, Cleaner and Responsible Consumption, Volume 15, 100244, ISSN 2666-7843, https://doi.org/10.1016/j.clrc.2024.100244.

Çomakli K., Çakir U., Çokgez A. K., Şahin E. (2015) Contribution of the Cogeneration Systems to Environment and Sustainability, World Academy of Science, Engineering and Technology, International Journal of Humanities and Social Sciences, Vol:9, No:6

Cui Z., Wang Y., Xie S.(2026) Optimizing integrated energy systems with a virtual energy station framework: Exergy-based scheduling and multi-energy integration, Case Studies in Thermal Engineering, Volume 79, 2026, 107799, ISSN 2214-157X, https://doi.org/10.1016/j.csite.2026.107799.

Daneshvar M., Mohammadi-Ivatloo B., Zare K. (2025) An innovative sustainable multi-energy management framework for full renewable grid-tied microgrids under the transactive energy paradigm, Sustainable Cities and Society, Volume 120, 106167, ISSN 2210-6707, https://doi.org/10.1016/j.scs.2025.106167.

Ezeamama Anayo A. (2016) Micro Combined Heat and Power Systems – Evaluation of a Sample Application, ACEEE Summer Study on Energy Efficiency in Buildings. https://www.aceee.org/files/proceedings/2016/data/papers/1_8.pdf

Fahad,M. S. A. AliNaqvi, M.Atir, M.Zubair, M.M.Shehzad, Energy Management in a Manufacturing Industry through Layout Design, Procedia Manufacturing, Volume 8, 2017, Pages 168-174

Fan L., Su Z.(2025) Simultaneous multi-objective optimization of a biogas-based power generation and brine desalination system for using in sport facilities, Case Studies in Thermal Engineering, Volume 69, 105958, ISSN 2214-157X, https://doi.org/10.1016/j.csite.2025.105958.

Fiedler, T., Mircea, P.-M., 2012. Energy management systems according to the ISO 50001 standard: challenges and benefits. In: IEEE International Conference on Applied and Theoretical Electricity, vols 1–4. Craiova, Romania. https://doi.org/10.1109/ICATE.2012.6403411.

Fitzgerald P., Therkelsen P., Sheaffer P., Rao P. (2023) Deeper and persistent energy savings and carbon dioxide reductions achieved through ISO 50001 in the manufacturing sector, Sustainable Energy Technologies and Assessments, Volume 57, 103280, ISSN 2213-1388, https://doi.org/10.1016/j.seta.2023.103280.

Fuchs, H., Aghajanzadeh, A., Therkelsen, P., 2018. Using Industry's Own Words to Quantify the Benefits and Challenges of ISO 50001. ECEEE Industrial Summer Study 2018, Berlin, Germany. https://eta.lbl.gov/publications/using-industry-s-ownwords-quantify.

Gonzalez-Torres M., Bertoldi P., Castellazzi L., Perez-Lombard L.(2023) Review of EU product energy efficiency policies: What have we achieved in 40 years?, Journal of Cleaner Production, Volume 421, 138442, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2023.138442.

Halkos G., Nomikos S. Corporate social responsibility: Trends in global reporting initiative standards, Economic Analysis and Policy, Volume 69, Pages 106-117, ISSN 0313-5926, https://doi.org/10.1016/j.eap.2020.11.008.

Haghghi M. A., Shamsaiee M., Holagh S. G., Chitsaz A., Rosen M. A.(2019) Thermodynamic, exergoeconomic, and environmental evaluation of a new multi-generation system driven by a molten carbonate fuel cell for production of cooling, heating, electricity, and freshwater, Energy Conversion and Management, Volume 199, 112040, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2019.112040.

Hai T., Ali M. A., Alizadeh A., Sharma A., Metwally A. S. M., Ullah M., Tavasoli M.(2023) Enhancing the performance of a Novel multigeneration system with electricity, heating, cooling, and freshwater products using genetic algorithm optimization and analysis of energy, exergy, and entransy phenomena, Renewable Energy, Volume 209, Pages 184-205, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2023.03.088

Herce, C., Biele, E., Martini, C., Salvio, M., & Toro, C. (2021). Impact of Energy Monitoring and Management Systems on the Implementation and Planning of Energy Performance Improved Actions: An Empirical Analysis Based on Energy Audits in Italy. Energies, 14(16), 4723. https://doi.org/10.3390/en14164723

Hepbasli A., 2011, Energy Efficiency and Management System: Approaches and Practices, Schneider Electric, Bayraktar Street. Ayyıldız Plaza 16/B, Küçükbakkalköy/Ataşehir, 34750, Istanbul – Turkey(TR)

İGDAŞ, (2014), Cogeneration and Trigeneration Systems, İstanbul, http://cdn.igdas.com.tr/Web/Content/KojenerasyonVeTrijenerasyonSistemleri.pdf

İmal M., Kısakesen T. , Kaya A.(2016) Analysis of Heating - Cooling Capacities of Cogeneration and Trigeneration Technologies in Terms of Energy Economy: The Case of KSU Health Application and Research Hospital, KSU Journal of Engineering Sciences, 19(2).(TR)

ISO 50001: Energy Management Systems Standard Natıonal Semınar on Standards for Qualıty and Empowerment 22 Nd And 23 Rd June, 2011 K. K. Chakarvartı Energy Economıst Bureau Of Energy Effıcıency New Delhi. https://present5.com/iso-50001-energy-management-systems-standard-national-seminar/?frp=aHR0cHM6Ly9wcmVzZW50NS5jb20vaXNvLTUwMDAxLWVuZXJneS1tYW5hZ2VtZW50LXN5c3RlbXMtc3RhbmRhcmQtbmF0aW9uYWwtc2VtaW5hci8-&instream=

Kawasaki(2017) Gas Turbine Cogeneration System, https://global.kawasaki.com/en/energy/equipment/gas_turbines/cogeneration.html?wovn=pl

Luboff, J., Legett, R., Jangra, V., Firme, R.(2016) Commercial Strategic Energy Management Programs: Best Practices and Approaches. In: Behavior, Energy, and Climate Change Conference. https://beccconference.org/wp-content/uploads/2016/10/Luboff_presentation.pdf.

Mohtaram S., Aryanfar Y., Ghazy A., Wu W., Kaaniche K., Alcaraz J. L. G.(2023) An innovative approach for utilizing waste heat of a triple-pressure cogeneration combined cycle power plant by employing TRR method and thermodynamic analysis, Case Studies in Thermal Engineering, Volume 49, 103198, ISSN 2214-157X, https://doi.org/10.1016/j.csite.2023.103198.

Marimon, F., Casadesús, M., 2017. Reasons to adopt ISO 50001 energy management system. Sustainability 9 (10), 1740. https://doi.org/10.3390/su9101740.

Na S., Shuai Z., Nan L., Zijian L., Meng H., Zhengchun S., Ke W., Xiaoyong G., Wen-Quan T.(2025) Adaptive optimization decision system for plate-fin heat Exchangers: An integrated approach to enhancing efficiency and performance, Case Studies in Thermal Engineering, Volume 73, 106619, ISSN 2214-157X, https://doi.org/10.1016/j.csite.2025.106619.

Nath, P., Ramanathan, R., (2016) Environmental management practices, environmental technology portfolio, and environmental commitment: a content analytic approach for UK manufacturing firms. Int. J. Prod. Econ. 171 (3), 427–437. https://doi.org/10.1016/j.ijpe.2015.09.040.

Onaygil S.(2015) Efficiency in Industry, Energy Management and Savings, 5th National Efficiency Congress, Ankara, 6-7 October (TR)

Orhan A. (2021) Outlook of Energy in the World and Turkey 2021, Turkish Informatics Association "Human and Technology" Events 2, Workshop on Environment and Natural Resources in a Human Focus in a Digitalizing World, Sustainable Energy Policies, May 30. https://enerji.mmo.org.tr/wp-content/uploads/2021/05/TBD-_%C3%87al%C4%B1%C5%9Ftay_27.04.2021_Sunum_OrhanAyta%C3%A7.pdf

Peng Li, Qingya Hu, Ye Sun, Zhonghe Han(2021) Thermodynamic and economic performance analysis of heat and power cogeneration system based on advanced adiabatic compressed air energy storage coupled with solar auxiliary heat, Journal of Energy Storage, Volume 42, 103089, ISSN 2352-152X, https://doi.org/10.1016/j.est.2021.103089.

Pirmohamadi A., Ghazi M., Nikian M.(2019)Optimal design of cogeneration systems in total site using exergy Approach, Energy 166-1291-1330.

Sivrioğlu M., Yurdakul M., Aydoğan A. and İç Y. T.(2011) Economic Comparison of Cogeneration Systems to be Installed in Large Commercial Buildings with Alternative Systems, Çankaya University Journal of Science and Engineering Volume 8 (2011), No. 1, 135–151 (TR)

Sogut Z. (2009) Energy Audit in Buildings and Example Application, Journal of Defense Sciences, No.8, P.1, P.127, 2009.

Sogut, M.Z., Karakoç, T.H. (2024). Investigation of Energy Efficiency Road Map of Industrial Facility. In: Zhao, J., Kadam, S., Yu, Z., Li, X. (eds) IGEC Transactions, Volume 1: Energy Conversion and Management. IAGE 2023. Springer Proceedings in Energy. Springer, Cham. https://doi.org/10.1007/978-3-031-48902-0_30

Sousa L. J. M., Salgado E. G., Luiz A. B.(2019) Which factors does the diffusion of ISO 50001 in different regions of the world is influenced?, Journal of Cleaner Production, Volume 226, Pages 759-767, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2019.04.127.