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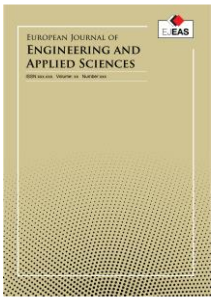

Review Article

Industrial Energy Efficiency Technologies and Management Applications in Turkey

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Abstract. Efforts to ensure sustainability in energy, reduce foreign dependency and combat climate change require efficient use of energy and energy resources in Turkey as well as in the rest of the world. Implementing environmentally friendly policies and methods in energy production/consumption and creating resource alternatives, and increasing efficiency by avoiding waste has been a policy that has been emphasized in Turkey. Energy efficient technologies in the industry is to use energy with high efficiency and savings without sacrificing production quality. The application of benchmarking methodologies to determine the efficiency of the industrial plant in terms of energy consumption and to compare it with similar enterprises in the same industry will provide a solid basis for the steps to be taken according to the current situation of a particular industrial plant. Therefore, for such a comparative analysis a set of criteria should be determined and applied. For this purpose, there are two main types of criteria that can be used by grouping them as general and sector-specific criteria. In this study, considering both criteria, energy efficiency technologies and management practices that can be applied for different sectors in Turkey have been compiled. Studies conducted in the literature within the scope of good practices in energy efficiency and management for the Textile, Iron-Steel, Cement and Glass sectors were examined, and policy and strategy proposals for the dissemination of these studies to the locomotive sectors in Turkey were discussed.

Keywords: *Energy policy and strategy, Industrial energy, Energy efficiency, Energy management.*

Türkiye'de Endüstriyel Enerji Verimliliği Teknolojileri ve Yönetim Uygulamaları

Öz. Sanayilerin enerji tasarruf potansiyelinin yüksek olması ve tükettikleri enerjinin büyük kısmının ticari enerji olması nedeniyle enerji tasarrufu çalışmalarında ele alınması gereken önemli bir sektördür. Sanayi sektörü, Türkiye'de birincil enerjinin %24'ünü ve elektriğin %47'sini kullanmaktadır.Enerjide sürdürülebilirliğin sağlanması, dışa bağımlılığın azaltılması ve iklim değişikliği ile mücadele çabaları, tüm dünyada olduğu gibi Türkiye'de de enerji ve enerji kaynaklarının verimli kullanılmasını gerektirmektedir. Enerji üretimi/tüketimi konusunda çevre dostu politika ve yöntemlerin uygulanması ve kaynak alternatiflerinin oluşturulması, israftan kaçınılarak verimliliğin artırılması Türkiye'de üzerinde önemle durulan bir politika olmuştur. Sektörde enerji verimli teknolojiler, üretim kalitesinden ödün vermeden enerjiyi yüksek verim ve tasarrufla kullanmaktır. Endüstriyel tesisin enerji tüketimi açısından verimliliğini belirlemek ve aynı sektördeki benzer işletmelerle karşılaştırmak için kıyaslama metodolojilerinin uygulanması, belirli bir endüstriyel tesisin mevcut durumuna göre atılacak adımlar için sağlam bir temel sağlayacaktır. . Bu nedenle, böyle bir karşılaştırmalı analiz için bir dizi kriter belirlenmeli ve uygulanmalıdır. Bu amaçla genel ve sektörel kriterler olarak gruplandırılarak kullanılabilecek iki ana kriter türü bulunmaktadır.Bu çalışmada her iki kriter dikkate alınarak Türkiye'de farklı sektörler için uygulanabilecek enerji verimliliği teknolojileri ve yönetim uygulamaları derlenmiştir. Tekstil, Demir-Çelik, Çimento ve Cam sektörlerine yönelik enerji verimliliği ve yönetimi konusunda iyi uygulamalar kapsamında literatürde yapılan çalışmalar incelenmiş ve bu çalışmaların Türkiye'deki lokomotif sektörlere yaygınlaştırılmasına yönelik politika ve strateji önerileri tartışılmıştır.

Anahtar kelimeler: *Enerji politikası ve stratejisi, Endüstriyel enerji, Enerji verimliliği, Enerji yönetimi.*

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1. Introduction

After the first oil crisis in 1973, the problem of energy security emerged as a prominent issue mostly for developed countries. However, later on, energy security has become a more global issue due to the increase in energy consumption and supply groups and the international agreement of the world energy industry, political turmoil and wars, and continued volatility in energy supply [1].

In order to achieve a sustainable growth, many countries have made meeting their energy demands and needs at the most appropriate scale. If countries cannot meet these needs within their borders, they become dependent on foreign energy. Empirical research conducted in recent years also attributes one of the most important obstacles to industrialization and growth to the high dependence on foreign energy. These studies show that there is a directly proportional relationship between growth and energy consumption, and that growth can be realized with the precondition of energy supply, minimizing foreign dependency [2]. The primary energy supply and the change in primary energy consumption by sectors on the basis of resources in the world and Turkey are shown in Fig. 1 and Fig. 2, respectively. Within the scope of primary energy supply, while the energy supply increased from 544.3 EJ to 612.19 EJ in the period from 2010 to 2019, it decreased to 588.1 EJ in parallel with the slowdown in economic activities with the pandemic period in 2020 [3].

Today, although fossil fuels have a dominant share of 83.4% on the basis of the amount supplied in 2020, it is understood that this trend continues in energy consumption.The energy of fossil fuels, which have a dominant share among the fuels consumed, is supplied by 34% oil, 30% coal and 24% natural gas resources [4].

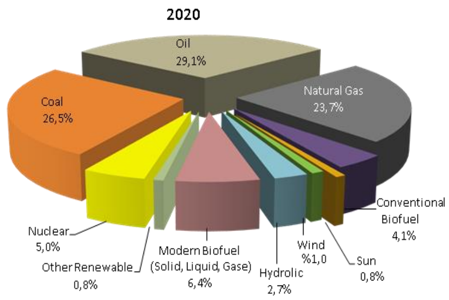

Fig. 1. *Sources of World Primary Energy Supply in the world [3]*

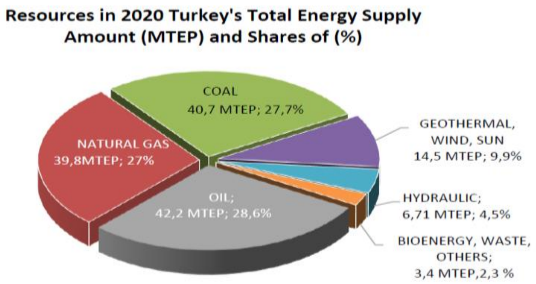

Fig. 2. *Distribution of Primary Energy Supply by Sectors in Turkey in 2020 [5]*

Forecasts of World Primary Energy Consumption according to different future scenarios of IEA (International Energy Agency) are presented in Table 1.

Table 1 IEA's World Primary Energy Consumption Forecasts [3]

CRITERION	SCENARIOS	REALIZATION	IN CASE OF CURRENT POLICIES' CONTINUE		IN CASE OF THE COMMITMENTS ARE FULFILLED		IN CASE OF IMPLEMENTING THE SUSTAINABLE DEVELOPMENT POLICIES		IN CASE OF ZERO EMISSIONS POLICIES ARE IMPLEMENTED	
		2020	2030	2050	2030	2050	2030	2050	2030	2050
PRIMARY ENERGY DEMAND	QUANTITY (EJ)	589,1	671,0	743,9	651,1	674,4	599,2	577,9	547,1	543,0
	Change from 2020 to 2050		**26,3%**		**14,5%**		**-1,9%**		**-7,7%**	
RENEWABLE ENERGY SUPPLY	QUANTITY (EJ)	68,5	109,0	192,5	120,6	248,4	142,7	316,4	166,6	362,1
	Change from 2020 to 2050		**181,0%**		**262,6%**		**361,9%**		**428,6%**	
OIL PRODUCTION	QUANTITY (Million Barrel /Day)	91,3	103,0	103,0	96,1	78,7	87,6	47,0		**No data**
	Change from 2020 to 2050		**12,8%**		**-13,8%**		**-48,5%**			
NATURAL GAS PRODUCTION	QUANTITY (Billion M^3)	4.014,0	4.554,0	5.113,0	4.249,0	3.852,0	4.038,0	2.452,0		**No data**
	Change from 2020 to 2050		**27,4%**		**-4,0%**		**-38,9%**			
COAL PRODUCTION	QUANTITY (Mtce)	5.462,0	5.132,0	4.020,0	4.878,0	2.672,0	3.786,0	1.189,0		**No data**
	Change from 2020 to 2050		**-26,4%**		**-51,1%**		**-78,2%**			
TOTAL CO2 RELEASE	QUANTITY (CO2)	34.156,0	36.267,0	33.903,0	33.640,0	20.726,0	28.487,0	8.170,0	21. 147	0,0
	Change from 2020 to 2050		**-0,7%**		**-39,2%**		**-76,1%**			**100%**

The industrial sector uses more energy than any other end-use sector, currently consuming around 37% of the world's total supplied energy.

Energy is consumed in the industrial sector by various industry groups, including manufacturing, agriculture, mining and construction, and for a wide variety of activities such as processing and assembly, space conditioning and lighting.

When the energy consumption trend is examined from the 1990s to 2019, it has been determined that the consumption of Asian countries increased by 69%, while the consumption of the Americas decreased to 23% and Europe was at the level of 47%. [3,]. Over the next 25 years, worldwide industrial energy consumption is expected to increase by an average of 1.4% per year from 51,275 ZeptoWatt (ZW) in 2006 to 71,961 ZW in 2030 [6].

In the studies carried out, great savings potentials appear in both industry and residences for Turkey, which has an energy-intensive economy. Energy efficiency studies are seen as new initiatives in our country and supply security is at risk compared to Turkey's growth rate. Increases in productivity are vital for Turkey's competitive and sustainable production. Approximately 43% of energy consumption in Turkey is realized in industry and it has the largest share. For this reason, the competent authorities have focused on energy saving studies especially for the industry [7].

In comparison, although Turkey has low energy consumption compared to developed countries, it also has a strong growth potential in terms of energy demand. Energy consumption per capita in Turkey in 2016 is 1.7 TOE, which is less than half of the OECD average (4.1 TOE per capita) and very close to the world average (1.9 TOE per capita). The energy consumption required to produce $1000 added value (constant 2010 PPP) decreased slightly from 0.086 toe to 0.074 toe between 1990 and 2016. Although this value is below the OECD average of 0.108 and the world average of 0.172, the low energy intensity of an economy may indicate either a less energy-intensive economic structure or/and more efficient energy use. For this reason, examining the sectoral structure and evaluating its effect on energy intensity changes is important in terms of calculating the real energy efficiency of Turkey [1].

Oil and natural gas occupy the first two places in primary energy supply in energy consumption in Turkey (Fig. 1.2), while industry and transportation take the first two places in energy consumption, excluding the Cycle and Energy sectors Fig. 3.) [5]

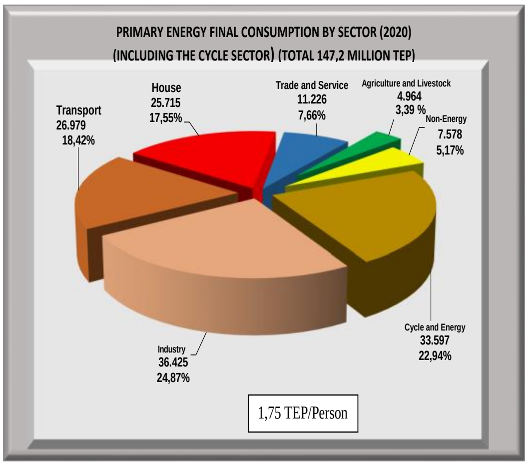

Fig. 3. Distribution of Primary Energy Consumption in 2020 by Sectors [5]

Turkey, which is in a rapid interaction process with the world economy, is in an effort to complete its infrastructure, realize its development goals, increase social welfare, and raise the industrial sector to a level that can compete in the international arena. This situation brings along a rapid increase in energy demand. However, the efficient use of energy has become increasingly important. The efficient use of energy ensures that less energy is consumed in the production process in order to obtain the same amount of product, thus reducing energy input costs, providing competitive advantages for industrial organizations both in the domestic and foreign markets and using environmentally friendly energy.

Ensuring sustainability in energy, reducing foreign dependency and efforts to combat climate change require efficient use of energy and energy resources in Turkey as well as in the rest of the world. The implementation of environmentally friendly policies and methods in energy production/consumption, the creation of resource alternatives, and the increase of efficiency by avoiding waste have been a policy that has been emphasized in Turkey. Energy efficient technologies in the sector are to use energy with high efficiency and savings without sacrificing production quality. The application of benchmarking methodologies to determine the efficiency of the industrial plant in terms of energy consumption and to compare it with similar enterprises in the same industry will provide a solid basis for the steps to be taken according to the current state of a particular industrial plant. Therefore, a set of criteria must be identified and applied for such a comparative analysis. For this purpose, there are two main types of criteria that can be used by grouping them as general and sectoral criteria.

In line with this information, in this study, considering both criteria, energy efficiency technologies and management practices that can be applied for different sectors in Turkey have been compiled. Studies in the literature within the scope of good practices on energy efficiency and management for the Textile, Iron-Steel, Cement and Glass sectors were examined and policy and strategy proposals for the dissemination of these studies to the locomotive sectors in Turkey were discussed.

2. Energy Efficiency, Savings, Intensity and Importance

Energy is the capacity of a system to do work. Energy can be both a resource, a product and a waste in a system. When it is added to or removed from any system, it causes at least one feature of the system to change (Fig. 4).

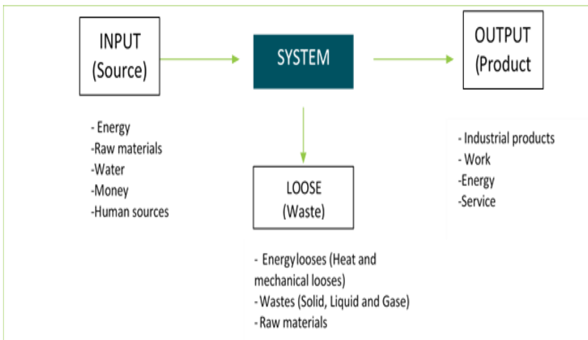

***Fig. 4**. Energy efficiency in an industrial system [İTÜ Enerji Enstitüsü ve Heinrich Böll Stiftung Derneği Türkiye Temsilciliği]*

Efficiency, on the other hand, is the capacity to achieve the most output with the least input, and it can be realized in 3 different ways in any system;

- More output with the same input
- Providing the same output with less input
- Providing more output with less input

Efficiency according to energy, which is one of the most important parameters for a system; It can be defined as the ratio of the energy we use to produce any product to the total energy given to the system [Eq.1].

Efficiency = [Utilized Energy / Input Energy] x 100 [Eq.1]

Therefore, Energy Efficiency covers a wide spectrum from the use of energy resources at the highest efficiency at all stages from production to consumption, minimization of energy losses and evaluation of all kinds of wastes, development of industrial processes and increasing efficiency in energy transmission.

Efficient use of energy is aimed with energy saving and energy efficiency. Energy saving is defined as using energy efficiently, not wasting it, and doing the same work using less energy without any reduction in production, living standards and workforce. Energy efficiency, on the other hand, is the reduction of energy consumption per unit service or product amount without a decrease in the standard of living and service quality in buildings, and production quality and quantity in industrial enterprises [8]

There is a small nuance difference between energy efficiency and energy saving, and the reduction in the amount of energy consumed at each stage to realize a certain amount of production and service with the measures taken by the users is called Energy Saving. A common measure of the Energy Efficiency of a country's economy is its Energy intensity. Energy intensity is a worldwide indicator ($/MTEP) representing the total amount of primary energy consumed per gross domestic product (GDP). Generally, the amount of TEP consumed for a revenue of $1000 is expressed in terms of energy intensity on an international scale. In other words, the lower the energy intensity of a country, the lower the energy spent to produce unit output in that country.

The energy density in the production of a good is calculated as follows;

Energy Intensity = E / V [Eq.2]

D = (1/ PPI) x (Σ Pi x Fi)

E: Annual energy consumption (TEP) of the enterprise

V: The economic value of the annual production of goods in thousand (1000) TL with the prices of the relevant year,

PPI: Producer Price Index of the relevant sector

Pi: Amount of goods produced during the year

Fi: Factory sales prices of goods produced during the year, in thousand (1000) TL

It is the most important resource for social and economic development, especially for developing countries. Obtaining energy safely, continuously, with high quality and based on environmental problems will increase people's living standards and well-being. In order for countries to achieve their economic growth, they need to make continuous production and ensure its continuity. Therefore, it is important that energy, which is an important part of production, is provided safely and cheaply [9].

Industrialization activities, efforts to reach new technologies, rising living standards and increasing population in Turkey cause us to consume more energy every year. Efforts to ensure sustainability in energy, reduce foreign dependency and combat climate change require efficient use of energy and energy resources in our country as well as in the rest of the world. Implementing environmentally friendly policies and methods in energy production/consumption and resource diversification, increasing efficiency by avoiding waste has been a policy that is emphasized in our country. Energy efficiency is to use energy with high efficiency and savings without compromising our quality of life, needs and production. Today, it is accepted all over the world that the energy saving, which will be achieved as a result of the efficient use of energy, is the fastest, cheapest and cleanest energy source. The energy that can be saved by increasing energy efficiency for Turkey, is a domestic and clean energy source that is cheaper than others and should be applied first. The increase in energy costs and demand for energy has made energy saving mandatory [10].

Worldwide industrial development will result in greater energy use and a greater concentration of greenhouse gases such as carbon dioxide (CO_2) and other emissions such as sulfur dioxide (SO_2), nitrous oxide (NO_x) and carbon monoxide (CO). All of them have negative consequences for the world's climate, such as increased heat, drought, floods, famine and economic turmoil. The Intergovernmental Panel on Climate Change (IPCC) has reported that continued emissions will lead to a temperature increase of 1.4 to 5.8 °C from 1990 to 2100.

The Department of Energy (United States) emphasized that global carbon emissions are more than 2% risky per year and may be more than 50% of 1997 levels by 2015, all due to increased energy demand and inefficient use of energy [6].

Energy efficiency in the industrial sector began to be seen as one of the basic functions in the 1970s. Since then, the world has reduced its energy budget by using higher efficiencies while continuing to grow economically and has realized the importance of protecting the environment [6].

It is important to adopt and maintain a systematic approach in energy efficiency in industrial enterprises. The proof of the existence of a systematic approach in terms of industrial enterprises in Turkey is that the energy policy of the enterprise has been determined, the appointed energy manager is carrying out activities in accordance with the existing legislation, especially the Energy Efficiency Law No. 5627 and the Energy Efficiency Strategy Document, the existence of the TS-EN ISO 50001 Energy Management System, It is the implementation of Energy Audits and studies to increase energy efficiency. Activities to increase energy efficiency are also carried out in organizations that do not implement energy management within the definition of a systematic approach.

However, these studies are generally based on investments based on technological development or on sudden savings decisions. The lack of necessary management planning, documentation, maintenance, measurement and monitoring in the works loses its effect as the savings decision falls off the agenda. It is seen that energy efficiency does not have continuity, and the increase in efficiency gained is lost again after a while [11].

Energy efficiency is a concept that covers a wide area such as protecting the environment, contributing to the world and national economy, a solution to unemployment, and contribution to the family budget. From another perspective, energy efficiency, power generation, transmission and distribution, heating, cooling, lighting, household appliances and office equipment in the home and service sector. While population growth and the development of technology increase the energy demand, new investments are made to meet this need in cases where the current production is not enough to meet this need. On the other hand, it is possible to close the energy gap primarily with energy efficiency investments and energy efficiency, which can be called free energy.Energy efficiency is defined in some sources as megawatts, megajoules, meaning negative energy.

As a result of the studies on energy efficiency in Turkey, it has been determined that there is an energy saving potential of approximately 2.5 billion USD, 30% in the construction sector, 20% in the industrial sector and 15% in the transportation sector. According to projections for 2020, primary 222-MTEP has the potential to reduce energy demand by at least 15% [4].

An important feature of energy efficiency programs is that they propose models that take environmental priorities into account. The environmental benefits of these programs are clear, as the least polluting energy is the energy that has never been produced. Reducing energy consumption for any need (by insulating houses, increasing engine efficiency, etc.) also automatically and proportionally reduces pollutant emissions.

3. Industrial Energy Efficient Technologies

Studies conducted in Turkey show that we have energy saving potentials of at least 20% in industry, at least 35% in buildings and at least 15% in transportation. When these potentials are evaluated, their energy value is higher than the energy we can produce from our renewable energy sources [10].

Efficiency and savings applications that can be made on a sectoral basis in the industry are directly dependent on the process of the relevant industrial establishment and the energy resources used in the process. In some processes, electrical energy comes to the fore, while in others, waste flue gases formed at very high temperatures or very high temperatures are encountered. For this reason, the measures to be taken to increase energy efficiency in existing and newly established industrial facilities are summarized in Table 2;

Table 2 Measures to be taken to increase energy efficiency in industrial facilities

PRECAUTIONS TO INCREASE ENERGY EFFICIENCY	**PRECAUTIONS TO INCREASE ENERGY EFFICIENCY IN THE PLANNED NEW FACILITIES**
Combustion of fuels in high efficiency combustion plants	Choosing new machines to be purchased from high energy efficient technologies in accordance with standardization attention to this situation in the selection of inputs that will provide uninterrupted energy supply
Increasing efficiency in heating, cooling, air conditioning and heat transfer processes	To design the facility in the most efficient way in terms of thermal insulation
To minimize heat loss by insulating all units that generate, distribute and use heat	To supply and install all measurement and monitoring devices that will ensure the sustainability of energy efficiency during the establishment of the facility
Implementing waste heat recovery	To use appropriate technology for minimizing air pollutant emissions and recycling/re use of waste emissions from consumed energy in a way that pollutes the environment the least and also to make the necessary arrangements
Increasing efficiency in the conversion of heat to work	Preferring the combined heat power generation first
To prevent losses in electricity consumption	
To increase efficiency in the generation and conversion of work and heat from electricity and prefer the combined heat power generation alternative if possible	
To prevent human induced inefficiency applications with automatic control factor applications	
To use appropriate technology for minimizing air pollutant emissions and recycling/re use of waste emissions from consumed energy in a way that pollutes the environment the least.	

3.1. Boilers

Boilers are generally defined as closed vessels that release the chemical energy in the fuel as heat energy and transmit it to the carrier fluid and operate under pressure. Steam boilers are defined as devices that produce steam at the desired pressure, temperature and flow rate.

Boilers, which are produced in many different types according to requirements, are very expensive energy generators in terms of initial investment and operating costs. For this reason, the boiler should be selected according to the purpose, and due care should be taken in its operation and maintenance.

A detailed analysis should be made in the selection of the boiler, taking into account the following factors:

- Purpose of use of the boiler
- The amount of steam to be produced

- Pressure and temperature
- Feed water inlet temperature to the boiler
- The hardness of the water
- Type of fuel to be used
- Fuel's lower calorific value and analysis
- Price of fuel

Boilers are at the forefront of processes with energy efficiency or savings potential, which are generally applied according to the sectors in the industry. Boilers are generally defined as closed vessels that release the chemical energy in the fuel as heat energy and transmit it to the carrier fluid and operate under pressure. Steam boilers are defined as devices that produce steam at the desired pressure, temperature and flow rate. [13].

Industrial boilers are the main thermal power equipment in many industrial fields such as metallurgy, chemical industry, textile and machinery, and although the number of gas-fired boilers has increased significantly, core-fired ones still account for about 80% of them [14].

Boilers, which are produced in many different types according to the needs used, are very expensive energy generators in terms of initial investment and operating costs. For this reason, the boiler should be selected in accordance with its intended use, and due care should be taken in its operation and maintenance.

In the selection of the boiler, a detailed analysis should be made considering the principles such as the purpose of use of the boiler, the amount of steam to be produced, its pressure and temperature, the inlet temperature of the feed water to the boiler, the hardness of the water, the type of fuel to be used, the lower calorific value and analysis of the fuel, and the price of the fuel [15].

The main factors affecting efficiency in boilers can be listed as follows [13];

- Incomplete combustion
- Excess air
- Heat loss in flue gas due to water vapor
- Flue gas temperature
- Fuel type • Burners
- Boiler load
- Heat losses from the boiler surface
- Heating surface contamination

The most important point to be considered in the efficient operation of the boilers is the flue gas temperature and, if possible, the provision of heat recovery. The waste gases from the chimney are generally discharged from the chimney at a temperature between 40°C and 80°C higher than the temperature of the steam produced. Recovering some of the waste heat will increase boiler efficiency and save fuel. Heat recovery can be accomplished using either an Economizer to preheat the boiler feed water or a combustion air preheater. Normally, it is preferred to have an economizer in the used boilers, but the air preheater is more economical in new boilers.

In many countries, it is preferred to install an economizer in small boilers with a steam production capacity of 2 tonnes/hour [13].

In order to increase efficiency in boilers, careful monitoring of flue gas temperature is of vital importance within the scope of managerial applications. The temperature should be measured immediately after the heat transfer surfaces are cleaned and the temperature rise should be monitored as the contamination gradually increases. The flue gas temperature also changes depending on the steam load of the boiler. For this reason, it should be checked whether the reading temperatures increase/increase in parallel with the steam production.

If the flue gas temperature is 30 °C above the required temperature when the surfaces are clean, the boiler needs to be cleaned. In this case, the extra losses for a well-tuned boiler are around 1-2 percent. [13].

The best method to maintain the cleanliness of a fuel oil-fired boiler is to make proper burner adjustments. Adjustment can be made using a smoke tester. If dark black smoke comes out of the chimney, this is an undesirable soot-forming situation. The brightness of the air and the natural state of the sky can affect the appearance of the smoke.

During operation of a well-maintained and well-operated burner, the measured sootiness of the flue gas is usually 4-5 on the Bacharach Scale.At values below 7, there is no case of serious soot formation. If around 5 readings are read, a soot cleaning is usually sufficient once a week. The ash, which is usually formed in boilers using heavy fuel oil, can cause deposits and corrosion in the hottest parts of the boiler, such as the serpentine pipes, even in very small amounts. Although fuel additives are used to prevent this situation, it should be kept in mind that some additives contain high levels of ash and as a result, high ash accumulation may occur instead of less ash [13].

On the other hand, in coal-fired boilers, soot and ash accumulated in the pipes should be cleaned at least once a day. Soot blowing equipment can be very useful even in small smoke tube boilers. Simple and stationary devices to be used for this purpose are inexpensive and suitable for small boilers. On the other hand, large boilers should be equipped with automatic systems operated by the operator or operating at fixed intervals according to the flue gas temperature. Although steam blowing cleaning is not expensive, compressed air system is mostly preferred. Because the water formed by the condensation of the steam can cause the accumulations to clump together, making further cleaning difficult. The amount of steam used for blowing must be measured. Intermittent blowing systems using high-pressure air are systems designed to keep air flow to a minimum, significantly increasing boiler efficiency.

In order to increase the efficiency of the boiler, the economizer to be used should be purchased very carefully. Since some deposits can easily occur between the blades in the large surface ones (with finned tube) and this will cause serious operational problems, this negative situation can be eliminated by performing periodic washing with a water spray device in cases where the system temperature is low.

3.2. Furnaces

The technical units that raise the materials placed inside or that are constantly charged to the process temperature by heating them economically and keep them at this temperature for the required period of time are called Furnaces or Oven. Furnaces, especially annealing furnaces operating at high temperatures, are systems that should be operated as efficiently as possible in terms of fuel consumption and pollution caused by waste gases given to the environment in industrial enterprises. Furnaces are at the forefront of the units that use energy most intensively in industrial facilities. Melting, heat treatment, baking, drying, tempering, etc. in industrial furnaces processes are carried out. Furnaces need to be fed with the necessary raw materials and energy to carry out the processes for which they are designed.

The main factors affecting the efficiency of furnaces can be listed as follows [13];

- Incomplete combustion
- Fuel type and air/fuel ratio
- Flue gas temperature
- Recuperators
- Wall losses
- Scale/material and cooling water losses
- Aperture loss
- Features of the combustion unit and material filling temperature

Excess air (O_2) in the furnace also causes an increase in scale/material loss. Therefore, the amount of excess air should be kept as low as possible. In order to achieve this, the level of O_2 in the flue gas must be controlled, the amount of oxygen must be brought to the lowest level possible by adjusting the air. For this purpose, the following steps should be taken:

- Air supply to the furnace must be sufficient and at constant pressure.
- Gas pressure entering the combustion unit must be constant.

One of the important factors affecting the furnace efficiency is the flue gas temperature. If the flue gas temperature is above the accepted values, excess energy will be discharged from the chimney to the atmosphere. This causes a decrease in furnace efficiency. One of the factors affecting the flue gas temperature in furnaces is the high energy discharged from the chimney due to the insufficient heat transfer rate in the recuperator (the heat exchanger that transfers the waste heat from the flue gas to the combustion air). This is followed by factors such as the fact that the combustion air in the furnace is more or less than usual, the flame length is too high in the furnace, and the combustion that may occur in the gas passageways.

In purchasing or projecting a new furnace, care should be taken to ensure that the furnace is of high quality in terms of energy efficiency, so that there is no temperature difference between the upper and lower surfaces of the parts entering the furnace at the entrance and exit, at the wall and core. In addition, suitable firing conditions must be provided in order to reduce the oxidation of the parts during the annealing of the parts at high temperature, which we call scaling, and the formation of the iron oxide layer. Moreover, it should not be affected by the size differences of the parts to be machined, and parts of different sizes can be heated and the speed of progression can be changed when desired. Especially when a change is made in the feed rate conditions, there should be no mechanical deterioration (bending, surface deterioration, sticking to each other, etc.) in the parts. On the other hand, it is very important in terms of energy efficiency that the flue gases formed at high temperatures are equipped with a system to return them to the furnace in order to save on the heating cost of the furnace. Furthermore, the cooling water used for the cooling of the furnace and exposed to thermal pollution (hot water, steam, boiling water, etc.) should also be returned to the system to be used in the boiler or other units within the facility.

3.3. Electric Motors

Electric Motors are devices that convert electricity into mechanical energy and result in motion.

There are two main types of motors: DC motors and AC motors. AC motors are supplied with an alternating current while DC motors are supplied with direct current. In DC motors, a coil carrying a DC current rotates between two magnets, producing motion. AC motors can use a variation of DC motors to spin a coil in the same way. More common are AC motors, known as induction motors, in which an alternating current is used to deflect the magnetic field of a stationary electromagnet called a stator.

Electric motors are frequently used in different types and capacities in many industrial devices and equipment, especially in pumps, fans and compressors. Considering the energy consumption distribution ratio in electric motors in the industry, it is stated by the practitioners that approximately 20% is in pumps, 17% is in air compressors, 11% is in cooling compressors, 4% is in conveyors, and the remaining 48% is in various other points. . The ratio of the mechanical power produced by the motor, which uses electrical energy to generate power, to the electrical energy drawn from the network or system is defined as the motor efficiency. 90% of the electric motors used today are asynchronous motors, therefore it is important to use high efficiency motors by reducing the losses of asynchronous motors in the industry[16].

Basic lost power in asynchronous motors [17] ;

- Friction and wind losses,
- Iron losses,
- Stator conductor (copper) losses,
- Rotor conductor (aluminum) losses,
- Additional losses

There are current studies on the estimation of losses and efficiency of these motors [18; 19]

Most of the industrial equipment used in the manufacturing sector generates power through electric motors. It is inversely proportional to the energy efficiency an electric motor draws for a given power output. Like all motors, electric motors cannot convert all the energy they use into mechanical energy.

The ratio of the mechanical power output of the motor to the electrical power drawn is called the motor efficiency and varies between 70% and 96% depending on the motor type and size [20].

In addition, the efficiency of motors operating at part load is also low. These efficiencies also vary from engine to engine. For example, while the efficiency of a motor is 90% at full load, 87% at half load, and 80% at ¼ load, another motor with the same specifications can operate with an efficiency of 91% at full load and 75% at ¼ load. The energy consumed by electric motors in enterprises constitutes approximately 65 percent of the total energy consumption. The purchase cost of a typical engine is less than 2% of the total cost of that engine. The energy cost can be 98 percent of the total cost. For this reason, it is important to choose "high efficiency" motors in business. The efficiency of electric motors varies depending on the motor type. However, various factors arising from engine design also affect engine efficiency. The efficiency of electric motors falls within wide limits, ranging from 30-35 percent for small universal motors to 95 percent for large three-phase motors [13].

The efficiency of the electric motor is the ratio of the received power to the delivered power. In other words, it is the mechanical power divided by the effective power. It indicates at what rate the electrical power drawn by the electric motor comes out as mechanical power from the motor shaft. Losses are one of the most important factors that reduce engine efficiency.

Energy losses occur in four categories in electric motors [13];

- Power losses
- Magnetic core losses
- Friction and oscillation losses
- Incorrect load losses

The main factors affecting the efficiency of electric motors [13] are:

- Applied voltage and frequency
- Required torque
- Applied load

Some operators rewind old engines over and over again because they are cheap. However, the already low efficiency of rewound old motors may decrease even more (up to 0.5% in each repair), and the cost savings provided by the repair can be lost in a short time with the increased energy consumption. Standard motors that do not stand out in terms of efficiency are in the EEF3 class, those with increased efficiency are in the EFF2 class, and the highest efficiency motors, which are first class in terms of efficiency, are in the EFF1 class. For example, the efficiency of a standard 20 hp engine is around 88%. However, the efficiency of a high efficiency motor with the same power goes up to 91%, and this value reaches 93% in the highest efficiency motors.

Although the cost of high efficiency motors developed in recent years is 15-25% more expensive than standard motors, this difference is recovered in a short time due to the low operating costs most of the time [9]. By increasing the cross section of the copper conductor used in the windings of these motors, the primary I2R losses can be reduced. Iron core losses can be limited by decreasing the flux density, usually by increasing the neck of the stator core. In addition, these losses can be reduced by reducing the plate thickness and using a quality alloy.Furthermore, due to the reduced losses in high-efficiency motors, the need for the heat to be released is reduced. In case of replacing a standard motor with a high efficiency motor, the energy to be saved can be calculated with the help of the following formula [21];

ES=TNPxWHxLRx1/ηstd−1/ηhe) [Eq.3]

ES: Energy Savings

TNP: Total Nominal Power

WT: working time

LR: load rate (ratio of actual load to full load)

ηstd: standard type motor efficiency

ηhe: high efficiency type motor efficiency

The money savings that can be achieved with the calculated amount of energy consumption are calculated with the below formula;

MS = ES x Unit price of energy [Eq.4]

MS: Money saving

Comparison of standard motor and high efficiency motors is given in Table 3 [21].

Table 3 Comparison of motor efficiencies* [21]

Nominal Motor Power (hp)	Nominal Motor Power (kW)	Standart type motor Average Efficiency	High efficiency motor Average Efficiency
1	0.746	0.825	0.865
1.5	1.119	0.840	0.894
2	1.492	0.840	0.888
2.5	1.865	0.812	0.870
3	2.238	0.875	0.895
4	2.984	0.827	0.889
5	3.73	0.875	0.902
7.5	5.595	0.895	0.917
10	7.46	0.895	0.917
15	11.19	0.910	0.930
18	13.428	0.878	0.924
20	14.92	0.910	0.936
25	18.65	0.924	0.941
30	22.38	0.924	0.941
40	29,84	0.930	0.945
50	37.3	0.930	0.950
60	44.76	0.936	0.954
75	55.95	0.941	0.954
100	74.6	0.945	0.958
125	93.25	0.945	0.954
150	111.9	0.950	0.958
200	149.2	0.950	0.958
250	186.5	0.954	0.962
300	223.8	0.954	0.962

** Values are the average value of eight companies and are valid for the engine running at full load.*

The application of motor wrapping is both easy and cheap, which is a very common situation in Turkey. However, although it may seem like a low cost of investment over the life of the motor (like 5-6%), the remaining 95% is reflected as energy loss during its operation. The main thing here is to find out why the motor burns out and to eliminate this cause without the need for winding, or to use a high efficiency IE3 electric motor instead. [21].

On the other hand, energy losses in fan systems of motors working with belt-pulley system are very common. Although using direct coupled motors here provides significant benefits, especially if there is a load change in the fans, for example, by using variable speed drives, a benefit of close to 50% can be achieved in power. In addition, applications such as selecting high-efficiency fans in fan systems, minimizing pressure drops by keeping the filters clean, cleaning the blades regularly, ensuring that it works only when necessary with a control system, and providing a transition from one fan to another to work with the appropriate fan when more than one fan is required, can be done at this point. energy efficient applications.

Among the efficiency applications that can be applied in pump systems may be summurazied in the following [10];

- Selection of high-efficiency pump and operating the pump at a point close to the power and load for which it is designed,
- If you always have to work at part load, use a smaller pump or make changes that will reduce the capacity of the existing pump,
- Considering that energy efficiency will decrease in systems to be operated with connected pumps when more than one pump has to be used, minimizing sharp corners to reduce losses in pipes,
- Choosing the new pipes to be installed from those with low friction coefficient and making applications to reduce the friction of the existing pipes, verifying that the pump inlet pressure is sufficient and not above the required value,
- Since the efficiency of a pump that is not maintained can decrease by 10%, regular maintenance of the pump, establishment of an observation system that shows the status of the pump for large capacity pumps.
- Calculation of the optimum time required for regeneration of the pump

Efficient use of energy in pumps can be considered in two stages, during pumping system design and during operation (Table 4).

The system should be chosen to meet the highest capacity, but from an economic point of view, it should be known at what capacity the system will operate for most of the time. Once these are known, the piping system can be designed.If the maximum capacity is required for a very short time, a large diameter pipe is not needed or if the system is operating at maximum capacity for most of the time, this should be taken into account when determining the pipe diameter.

While designing the piping system, the system curve must also be drawn strictly. It is very important to choose the pump with the highest efficiency and the most suitable operating range.

The lifetime costs of the pumps remain only between 3-5 percent of the initial purchase costs, making it mandatory for the operators to choose more carefully when purchasing a pump [10].

As a result, on the basis of all the above-mentioned issues, the following factors should be considered during the use of electric motors in order to save energy: (10)

- A list containing the usage of each electric motor, plate information (rated power, speed, efficiency, etc.) and annual working hours should be prepared in the enterprise.
- In order to achieve economic and energy efficiency-enhancing results, a motor repair/replacement policy should be prepared such as "replace it with a high efficiency motor immediately or when it fails, send it to the winding with the following features".
- Motors should be labeled for the most appropriate application.
- Motors should be selected in accordance with the load. Larger motor should not be selected. Thus, it should be prevented that the motors operate at low power and therefore with low efficiency compared to the rated powers written on their plates. The higher the load, the higher the efficiency.
- Motor efficiency usually reaches its maximum at 75 percent load.
- The electricity consumed at low loads is increasingly converted into heat instead of mechanical power. In this case, the risk of failure due to overheating of the engine increases and the life of the motor is shortened.
- Variable speed drive systems - also known as inverter or variable frequency drive systems. These systems prevent the motor from drawing excessive load by changing the frequency of the alternating current and thus the rotational speed of the motor. Thus, it is ensured that the same work is done using much less energy. Up to 50 percent energy savings can be achieved by adding an inverter system to the motors. In other words, the amount of electricity consumed by the motor for the same job can be reduced by half. The cost of motors equipped with an inverter is higher. However, in properly selected applications such as pumps and compressors, variable speed drive systems often pay for themselves in the energy they save in two years or less. According to some analyzes, only about 10 percent of the energy saving potential in motor systems can be achieved through efficiency gains. The remaining 90 percent can only be achieved by equipping the motors with inverter systems.
- In systems where the motor power is transmitted indirectly by flat belts or standard V-belts to the direct connection, losses occur between 2 percent and 8 percent due to belt slippage and friction. These losses and belt overheating can be avoided by replacing standard belts with serrated high-efficiency V-belts.

4.-Industrial Energy Efficient Technologies In Turkey

In the 1970s, studies on energy efficiency in the industrial sector began to be accepted as one of the main business processes. While the world's industries continue their economic growth without interrupting, they have aimed to consume energy resources, which they consider as an important input source, with high efficiency. In this period, energy efficiency awareness was expanded and the importance of protecting the environment was understood. Large industrial facilities with high energy consumption have considered reducing their energy consumption as an important problem. In the industrial sectors, investments with short payback periods such as heat recovery and reduction of losses gained importance. In industrial enterprises, energy efficiency can be improved with three different basic approaches:

- Energy saving through management systems [3].
- Energy saving through technological work and investment [3].
- Energy saving through energy policies and legal regulations [6].

Energy Management in Industries is the rational and effective use of energy in order to achieve maximum profit in order to reduce energy costs under competitive conditions. Energy management is the strategy of meeting the required energy demand at the desired time and place. To achieve this, it is necessary to reduce the energy requirement per unit output in energy consuming processes and procedures or to provide the same unit output with less energy cost [22]. As a result of the profile that emerged in the energy audit studies carried out in different sectors; It is seen that it is possible to save energy between 5-40% in 95% of industrial facilities and industrial enterprises. What is even more striking is that it is possible to save at least 10% of energy in industrial facilities and industrial enterprises by implementing measures with little or no investment. This ratio reveals the importance to be given to energy consumption and energy saving. Summary of some energy efficiency applications conducted for this purpose are given in Table 5 [23].

Table 4 Efficient use of energy in pumps [10]

IN PUMPIN SYSTEM DESIGN	**IN PUMP AND PUMPING SYSTEM OPERATION**
Combustion of fuels in high efficiency combustion plants	Choosing new machines to be purchased from high energy efficient technologies in accordance with standardization and quality security system requirements and also paying attention to this situation in the selection of inputs that will provide uninterrupted energy supply.
Increasing efficiency in heating, cooling, air conditioning and heat transfer processes	To design the facility in the most efficient way in terms of thermal insulation
To minimize heat loss by insulating all units that generate, distribute and use heat	To supply and install all measurement and monitoring devices that will ensure the sustainability of energy efficiency during the establishment of the facility
Implementing waste heat recovery	To use appropriate technology for minimizing air pollutant emissions and recycling/re-use of waste emissions from consumed energy in a way that pollutes the environment the least.and also to make the necessary arrangements.
Increasing efficiency in the conversion of heat to work	Preferring the combined heat-power generation first
To prevent losses in electricity consumption	
To increase efficiency in the generation and conversion of work and heat from electricity, and to prefer the combined heat-power generation alternative if possible.	
To prevent human-induced inefficiency applications with automatic control factor applications	
To use appropriate technology for minimizing air pollutant emissions and recycling/re-use of waste emissions from consumed energy in a way that pollutes the environment the least.	

Sub-sectors such as cement, glass and iron and steel, which we can call energy-intensive industrial sectors, have a significant share in the Turkish industry. Energy costs have a serious place among the production costs of these sectors.

In these sectors, energy costs constitute approximately 20% to 50% of total costs [11].

Tablo 5 Some energy efficiency applications in the industry

Sector	**Energy saving Point**	**Energy efficiency method**	**Application**	**Application results**
Chemical [23]	2 steam boilers with the same thermal capacity, one of which is a spare and the other is active.	Heating the feed water supplied to the boiler by making use of the sensible heat of the waste gases discharged from the existing steam boiler chimneys	Common flue gas economizer application for two boilers	Energy Saved: 240.909 Kcal/h Saved Energy Rate: 4% Feed Water Output Temperature: 10 Cost of Saved Energy: 123.480 TL/Y (For 7.200 h/year operation) Payback period: 7 months
Textile [23]	2 steam boilers with the same thermal capacity, one of which is a spare and the other is active.	Energy Saving with Steam Boiler Automation	The automatic surface blowdown system automatically measures the conductivity of the boiler water with its conductivity sensor (TDS < 3000 mg/l) and automatically enables the boiler to blow down as needed.	Energy Saved: 82.992 Kcal/h Fuel Economy: 11,83 Nm3/h Water Saving: 1.276.8 kg/h Chemical Saving: 128 gr/h Cost of Saved Energy: 48.312 TL/Ye (For 7,200 h/year operation) Payback period: 5 months
Tourism [23]	Condensate line that returned to the boiler room	Energy saving application with Flas Steam Recovery System	Reducing the flash vapor pressure from 4 bar (152 oC) to 0.2 bar	Energy Saved: 91.528,8 Kcal/h Fuel Economy: 13,05 Nm3/h Water Saving: 170,54 kg/h Chemical Saving: 15 gr/h Cost of Saved Energy: 48.620 TL/Ye (for 5.000 h/year operation) Payback period:4 Months
Food [23]	7 Chimneys of cooking furnaces	Discharged from the Chimneys of Process Furnaces Energy Saving Application from Gases	Flue gas economizer application to each chimney separately	Amount of Energy Saved: 927.770 K Saved Energy Rate: 4% Monetary Value of Total Savings: 39 TL/Yıl (6.400 h/yıl çalısma için) Payback Period: 9 Months
Textile [23]	Dyeing wastewater	Heat recovery from high flow and temperature wastewater	Heat exchanger application: by making use of the heat energy of the dyed wastewater to pre-heat of the clean water taken into the dyeing operation unit	Clean (Cold) Water Flow: 55.000 kg Clean (Cold) Water Inlet Temperatu °C Clean (Hot) Water Outlet Tempera 58 °C Energy Saved: 2.090.000 Kcal/h Cost of Saved Energy: 1.011.600 TL (for 7,200 h/year work) Payback Period: 8 Months
Furniture [24]	2 drying fans	Replacing Drying Fans and Electric Motors with Efficiency	Replacing fans and electric motors with more efficient ones	Total Energy Saved: 82.212 kWh/ye Total Cost of Saved Er 32.669,72TL/Year Electric motor replacement and cost:119.190,02 TL Payback period: 3,65 years
Pulp and paper [24]	Fans used in dust collection lines	Replacement of Dust Extraction Fans and Line Revision	Preventing unnecessary energy consumption in unused units by placing a separate fan in each unit instead of the currently used single one .	Total Energy Saved: 317.8 kWh/year Total Cost of Saved Er 66.741,49TL/Year Fan investment cost: 28.838,91 TL Revision Cost of Dust Suction I 78.323,56 TL Total investment cost: 107.162,47 Tl Payback period: 1,61 years
Industry not specified [24]	2 Fans used for heating	Fan Driver Application	Since these fans are selected with a power above the required capacity, the use of a damper on the suction side of the fans and a frequency converter are applied to both fans in order to adjust the required air amount.	Total Energy Saved: 240240 kWh/y Total Cost of Saved Energy: 475 TL/Year Total purchase price: 103286 TL Payback period: 2,17 years

4.1. Energy Efficient Technologies in Sub-Sectors

4.1.1. Iron and Steel Industry

The raw materials used in the iron and steel industry differ according to the production method. In basic oxygen furnace (BOF) based plants, iron ore, scrap metal and hard coal are used together. On the other hand, in the Electric Arc Furnace (EAO) facilities, production is carried out from scrap metal.

74.4% of global crude steel production is carried out in BOF-based integrated facilities, 25.1% in EAF facilities and 0.5% in other facilities [25]. Iron - Steel sector is a sector in which iron ore is produced by casting, forging, rolling, drawing and similar methods, starting from the concentration of iron ore from the underground. The products produced in the iron and steel sector are examined in three parts as intermediate products, main products and by-products. Intermediate products are products that are produced to be used as inputs in the production of another good. The main product is the products that do not require another process and are produced for final use, and by-products are the products that emerge with the main product at the end of the production process for technical reasons. Considering the diversity of the products produced, it is seen that the importance of the Iron - Steel sector is increasing more and more in technological fields as well as in traditional industries. As a result of the rapid developments in iron and steel production, the industrial revolution has taken place and there have been great developments in the field of technology.

Considering the existing technologies applied in the Iron and Steel Industry, these technologies can be listed as follows;

- Use of closed charging system in coke ovens
- Use of wet quenching process in coke ovens
- Use of dry quenching technology with heat recovery in coke furnace
- Waste gas circulation in sintering
- Blast furnace gas recovery
- Energy recovery at blast furnace peak pressure
- Preheating of scrap in Electric Arc Furnaces
- Heat recovery in the annealing line
- Use of Rotary Kiln, Rotary Stove Furnace, Multi-Stage Furnace (Coal fired)

Among these technologies, applications with potential in terms of energy efficiency especially focus on improving the hot furnace process control and improving the blast furnace process control in iron production, while providing scrap preheating and Oxy fuel burner assembly in steel production comes to the fore. In Rolling and Finishing processes, the use of regenerative burners for reheating furnaces, improvement of insulation and installation of Automation M&T system (cold rolling) becomes more important.

In this context, among the productivity improvement projects (VAP) carried out in Turkey for this sector, revision of the scrap transfer system with a return period of 1.4 years, motor and variable speed drive application in the fans of the power plant, and air purification fans with a return period of 6 months. It is seen that variable speed drive applications attract attention. In addition to this, despite the one-time expenditure of $762,000 for the improvement of coke dry extinguishing facilities, improvement of ignition furnaces in sinter machines, increasing the efficiency of steam jet water cooling machines, modernization of cooling towers, improvements made in blast furnace stoves and insulation of blast furnace combustion air line, every year Applications with savings of $4.6 million were also reported, and it was revealed that the expenditures were recovered in less than 2 months with the savings provided. Moreover, in the coal injection facility, insulation of the blast furnace flue gas pipe, changing the combustion periods of the blast furnace stove, completing the missing insulations and repairing the old insulations, making transparent lighting in the workshops, preventing idle running in the belts carrying coke from the coke plant to the blast furnaces, determining the blast furnace combustion air fan pressure values. It has been calculated that 4.9 million dollars can be saved every year, despite the one-time expense of 476,000 dollars by adjusting the water cooling tower, renewing the tower efficiency, using steel mill gas instead of coke gas in blast furnace stoves, and the expenditure can be recovered in about 1 month with the savings provided. Apart from these, with the improvement of the pure water plant, 18.8 million $ savings can be achieved every year, despite the one-time expenditure of 8 million dollars, and the expenditure is recovered in less than 6 months with the savings provided, once the front bearing design of the motor blower plant is changed. Despite the special spending of $ 500, it is possible to save $ 878,000 every year and the spent can be recovered in almost 1 day with the savings, the power plant old coke gas branch in the gas distribution system is converted to blast furnace gas, blast furnace charging facilities electrofilter and aspiration system improvement and sintering. It has been revealed that with the improvement of the crusher feeders, a one-time expenditure of 730,000 TL will save 37 million TL every year, and the expenditure can be recovered in approximately 1 week with the savings achieved [25].

4.1.2. Cement Industry

The cement sector is a sector that includes hydraulic binders produced by grinding the semi-finished clinker, which is obtained by cooking the raw materials containing silicon, calcium, aluminum, iron oxides, to the degree of sintering with technological methods, with a single or more type of additives.

In the cement production process, first of all, limestonnee, clay and marl are loaded onto conveyor vehicles in the quarry area as raw materials. Then the raw materials are ground in the mill and turned into raw meal. After then, the raw meal taken by weighing in the raw meal silo is fed to a preheater tower consisting of cyclones, heated from 30ºC to 1000ºC and calcined at a rate of 90%. The raw meal coming from the preheater is cooked in a rotary kiln at 1500ºC and granulated so that it can be calcined, and the resulting product is called clinker. The clinker that comes out of the cooler is considered an intermediate product in cement production and is obtained as a result of grinding the cement clinker with some calcium sulfate.

Considering the existing technologies applied in the Cement Industry, these technologies can be listed as follows;

- Using a rotary kiln with multi-stage preheater and precalcination,
- Ensuring good sealing of rotary kilns,
- Integration of an efficient and modern clinker cooler into the system,
- Reducing the clinker content of cement and cement products,
- Using vertical roller mills with high energy efficiency,
- Establishment of waste heat electricity generation (WHR) systems,
- Use of waste-derived fuels.

About 80% of the energy consumption takes place in clinker kilns.

Although there has been an increase of 28.8% in electrical energy production from waste heat with heat recovery projects in the last five years in the sector, an upward trend has been observed in the specific energy consumption of integrated and grinding plants.

The specific energy consumption of Turkey in 2020 was 0.098 TEP/tonne-cement for integrated facilities and 0.004 TEP/tonne-cement for grinding/packaging plants [26].

Among these technologies, applications with high potential in terms of energy efficiency, replacing ball mills with high efficiency roller mills as raw materials, optimizing combustion efficiency in kilns, reducing kiln body heat losses and cold air leaks, using efficient coolers in clinker production, process control and can be listed as applications to improve optimization conditions. Among the productivity improvement projects (VAP) carried out for this sector in Turkey, the installation of an elevator system instead of the pneumatic system in the Rotary kiln feeding system with a return period of 3.1 years, the application of variable speed drive to the coal mill hot gas fan with a return period of 9.6 months. is to be done. In addition, it is seen that the replacement of the Farin fan with an efficient fan with a return period of 3.9 years and the replacement of the Flue gas fan with an efficient fan and electric motor with a return period of 4.4 years are also included.

4.1.3. Glass Industry

Today, glass is a modern and versatile material. Glass, which is mostly used in transparent or translucent form, which is usually hard, brittle and allows the preservation of liquids, is preferred for packaging many products such as food, beverage, cosmetics and pharmaceuticals due to its transparency, shape, odor and taste and resistance to most chemicals. It has a very common usage area, from the simplest equipment to communication and space technologies. The most important inputs used in glass production are sand, soda, dolomite and quartz. Since Turkey is rich in these resources, the Turkish glass industry uses 98% of domestic raw materials. Glass material production consists of four consecutive cycles. These; preparation of the main materials, melting, forming and annealing.

In summary, glass production is carried out by mixing various raw materials in certain sizes according to the glass to be produced, melting them in glass furnaces, cooling them slowly, and shaping them into the desired shape with various techniques in this process. Flat glass, glass packaging, glassware and glass fiber constitute important sub-sectors of the glass industry. The glass sector provides input to many sectors such as construction and automotive, white goods, food, medicine, cosmetics, tourism, furniture, pipes, electrical-electronics and household goods.

The Distribution of Energy Consumption by Glass Industry Fields of Activity in Turkey as of 2020 has been reported as 42.3% for flat glass manufacturing, 38% for glass packaging manufacturing, 13.9% for glassware manufacturing and 5.8% for glass fiber manufacturing [27].

The glass production process generally consists of blend preparation, melting and affinity, conditioning and shaping, secondary processing, packaging and storage and shipping processes. When the distribution of energy consumption of the Glass Industry on the basis of process is examined, the processes in which energy consumption is used most are melting and affinity.

The ratio of energy use in the smelting and affinity process to the total energy consumption of the enterprises; It is 86% in flat glass factories, 53% in glassware factories, 76% in glass packaging factories and 47% in glass fiber factories [27].

Glass material forming methods can be listed as follows;

- Blowing method,
- Pouring rolling method,
- Pulling method,
- Flotation method,
- Pressing method,
- Fibrous method,
- Foaming method
- Other formatting methods.

Considering the current technologies applied in the Glass Industry, these technologies can be listed as follows;

- Use of side-fired regenerative furnaces,
- Use of rear-fired regenerative furnaces,
- Use of recuperative furnaces, use of oxy fuel melting furnaces,
- Combining fossil fuel and electrical melting, providing furnace insulation to prevent heat loss,
- Using waste glass/broken glass,
- Waste heat recovery in furnace and other systems

Among these technologies, applications that have a high potential in terms of energy efficiency, especially in heat production processes, to improve the combustion performance for furnaces, to minimize the use of excess air and to adjust the burners in the furnace come to the fore. On the other hand, the applications of preheating bulk and scrap glass and using regenerative furnaces in the melting process are also important. In addition, the use of more efficient glass feeding troughs in the process control processes draws attention, while the improvement of the processes in the annealing process draws attention as energy efficient applications.

Since 2009, applications for 24 VAP projects have been made by 11 factories in the glass industry. 7 of these projects have been canceled for various reasons, and the status of the other 15 projects as of today is given below. A total of 1.67 million TL support was paid for 14 projects with a total investment amount of 3.84 million TL, the implementation of which was completed successfully. If these projects are completed, it is estimated that an annual energy saving of 689.64 TEP and an annual financial savings of 1.67 million TL can be achieved. On the other hand, a support payment of 1.02 million TL is foreseen for one project whose implementation is ongoing and the projected investment amount is 3.41 million TL, and it is expected that with the completion of the implementation of the project, annual 77.45 TEP energy savings and 694,664 TL financial savings will be achieved [27].

4.1.4. Textile Industry

Textile covers processes such as yarn, weaving, knitting, dyeing and printing, starting from fiber, while ready-made clothing covers the processes that will turn this process into useable goods. The part from fiber to yarn and finished fabric is evaluated within the textile sector, and the process from fabric to clothing is evaluated within the ready-made clothing sector.

Considering the sub-sectors of the Manufacturing of Textile Products, it is seen that it covers the following sub-sectors.;

- Preparation and twisting of textile fiber,
- Weaving,
- Finishing of textile products,
- It is seen that the manufacture of other textile products takes place.
- Manufacturing of Clothing,
- Manufacture of clothing, excluding fur,
- Production of fur goods,

- Manufacture of knitted (knitted) and crocheted (crochet) products

Considering the existing technologies applied in the Textile Industry, below technologies can be listed as follows;

- Using enzymes for bleaching and washing
- Use of plasma technology (plasma technology)
- Ink-jet printing v Infrared drying (IR-drying)
- Use of hot melt technology
- Use of waterless dyeing technology (SC-CO_2 technology)
- Using UV technology in coating and finishing processes

Among these technologies, when the remarkable applications with potential in terms of energy efficiency are examined, it is seen that the following applications come to the fore, respectively;

- Use of energy efficient blower fans and mobile air cleaners (OHTCs) in the Spinning Process
- In Weaving Process; Taking measures for energy efficiency in weaving plans
- In Age Processing processes; using counterflow currents for washing and making improvements that can save energy in continuous washing machines
- Dyeing and Printing processes; Ensuring heat insulation in high temperature/high pressure (HT/HP) dyeing machines and heat recovery from hot rinsing water

Among the energy efficiency improvement projects (VAP) carried out for this sector in Turkey, it is seen that there are applications such as with a return period of 4.8 years, ensuring energy efficiency with efficient twisting machines, variable speed drive application in air conditioner humidification pumps with a return time of 7.2 months, and ram chimney waste heat recovery, prevention of trap leaks, 3.1 year return period, and switching of Hot oil stenter machines to the burner system.

5. Sectoral Comparisons for Energy Efficiency in Turkey

The application of benchmarking methodologies to determine the efficiency of the industrial plant in terms of energy consumption and to compare it with similar enterprises in the same industry will provide a solid basis for the steps to be taken according to the current situation of a particular industrial plant. In addition, benchmarking studies provide the following gains:

1. As a result of the research of best practices, it allows the determination of reasonable goals and targets by comparing the situation of the relevant enterprises in the sector with other enterprises.

2. It helps to create an action scheme in line with the targets set by the industries.

3. It provides comparison of the current situation of the industry with the data of the past years. In this way, it helps industries to improve themselves by pointing out the points that need revision.

4. In addition to enabling the reduction of energy investment costs per unit of production, it also supports industries to increase their motivation and performance.

Therefore, some criteria should be determined and applied for such a comparative analysis. In terms of energy efficiency/consumption, there are two main types of criteria that can be considered useful for benchmarking comparative analysis. The first of these can be called general criteria and can be applied in all sectors. The second set of criteria is sector specific. More than one criterion may need to be used when making a comparative analysis of industries in similar industries. However, while some general criteria may apply to all sectors, some criteria are sector specific.

1) Establishment year or renewal year is one of the basic criteria used for classification. It will help to identify the current status/conditions of the existing plants and will also be a good indicator of the technologies used in the processes at each plant.

2) Production capacity is one of the basic criteria used for benchmarking purposes. The type of production (stock or make-to-order) indicates the continuity of the facilities.

3) Product groups in production are the most complex criteria used to achieve meaningful outputs. When there are several types of end products in the industry, they need to be grouped before making a comparative analysis. One of the best ways to do this type of grouping is to use the economic activity code of businesses. For this grouping, the EuroStat economic activity codes document can be used. In sector-specific criteria, besides the specific energy consumption (SET), it is important to determine the SET values specific to each of the basic processes in the sector in question. In this approach, the SET value of the underlying processes is summed. The interaction of all processes determines the SET value of the entire industry. By improving the SET value of individual processes and/or the interrelationships between processes, the SET value of the industry also improves. This process, shown in Fig. 5, is done for all types of energy carrier processes.

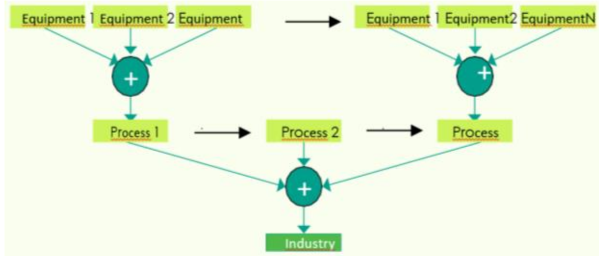

Fig. 5. *Bottom-up specific energy consumption process [26]*

The sum of the specific energy consumption used in the process gives the SET value of the basic processes. Separate SET values can be created for each of the basic equipment. The advantage of this approach is that inefficiencies can be traced down to the equipment level and necessary measures can be implemented. It is important to clearly define the boundaries of each process in benchmarking. This limit determines the specific energy consumption of the process in question. The process limit should be the same as the process limit used for the benchmark value (Fig. 6) [26].

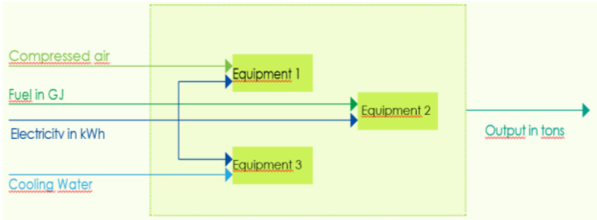

Fig. 6. *Inputs and outputs with boundaries of a sample process [26]*

Since multiple products are manufactured in a typical industry, the classic approach to benchmark calculations is to add the quantities of all products and calculate them collectively into a single product. This would be a reasonable approach where the specific energy consumption values of different products are not significantly different from each other. In this way, it is possible to compare different industries operating in a particular sector by comparing the energy they consume per unit of product. However, in cases where there are large differences between the specific energy consumption values of different products, a more precise procedure is required for the overall specific energy consumption calculation. Otherwise, comparing industries in different quantities and over different products would be risky to get accurate results.

In this case, the analysis requires reference to the relative energy consumption amounts for each product type based on the measurement, calculation and observation activities in the process lines by the plant personnel, as well as the relevant studies based on comprehensive energy studies. In any case, some uncertainty in the relative specific energy values is inevitable.

In this case, the proposed calculation procedure can be summarized as follows [26]:

- The plant's determination of the product with the highest production amount as the main or main product, the ratio of the specific energy of a product to the specific energy of the main product is called the "correction factor" or "normalization factor". Naturally, the correction factor of the main product is 1. It should be noted that the product with the highest (or lowest) specific energy consumption should be taken as the main or main product.
- Ensuring that the best correction factor estimates for all product types are entered at the ındustry if reliable correction factor data based on extensive energy studies are not available. For example, the correction factor of a product is 0.85; means that for the production of 1 unit of this product, 85% of the energy consumed for the production of process 1 of the main product is required. Estimates of correction factors should be continually improved based on the results of the energy studies performed.
- Collecting lists of best correction factor estimates from industry personnel and averaging each product to represent the industry average. This method of averaging is consistent with the law of large numbers used in statistics and usually gives results with reasonable precision. If available, it is necessary to compare this value with the relevant correction factor values in the literature and complete the list of correction factors by taking into account all available data and making realistic decisions as much as possible.

Since it is not possible to precisely calculate the energy consumption of each product type based on energy measurements, this approach can be considered the most practical approach. As an alternative approach, an all-sector-specific list of relative energy consumptions for each manufactured product can be prepared based on available benchmark data, and this list can be automatically loaded according to the user's sector selection.

This approach was also used in a benchmarking study conducted by Norway and supported by Intelligent Energy-Europe [28]

Specific energy consumption for an industry should be calculated taking into account the following steps [29];

- For each product, multiply the production amount by the product's correction factor and add the results.
- To obtain the specific energy consumption of the main product in kJ, MJ, GJ or kWh per unit quantity (kg, tonne, m, cubic meter, etc.), the total energy consumption of the facility is divided by this sum. When this value is multiplied by the correction factor of another product, the result will give the specific energy consumption of that product. By repeating this process for each product, a specific energy consumption list will be obtained for all products produced by that facility.
- The weighted average of the specific energy consumption of the products produced gives the specific energy consumption of the facility. There are only two parameters here. In these; The product quantities (mi for product i) and the specific energy consumption of each product (ei for product i). The weighted average (general specific energy consumption of the facility) is calculated by multiplying each product amount by its specific energy consumption, summing the results and dividing the result by the total product amount (m1xe1+m2xe2+…..)/(m1+m2+….).

5.1. Cement Industry Comparisons

Although the current benchmarking studies in the cement sector are mostly at the enterprise level, there are also studies at the process level. For example, some sources in the literature provide benchmark values for some processes, such as preparation of raw materials, preparation of fuels, preparation of additives (for special cements), clinker making and final grinding [30].

Since approximately 80% of the energy consumption in cement production takes place in clinker kilns, it is more meaningful to focus on improvements especially in electricity and fuel consumption. For this reason, it is recommended to make a comparison of the process given in Fig. 7 and Fig. 8 as a minimum in the cement sector.

The cement industry in Turkey must agree on the boundry of each process.It is recommended that process limits be chosen in such a way that at least 90% of the total energy consumption can be accurately calculated. Process limits are shown in Fig. 9.

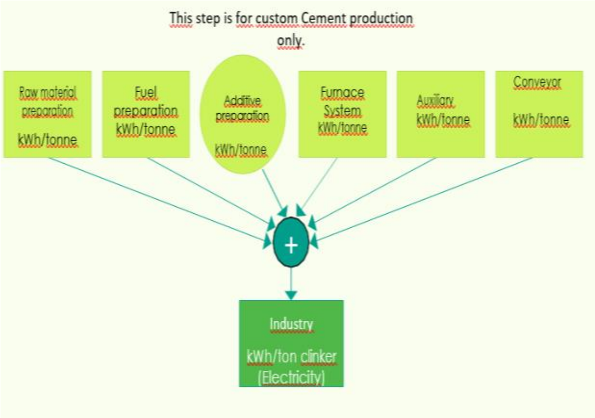

Fig. 7. *Comparison of electricity consumption in clinker production [26]*

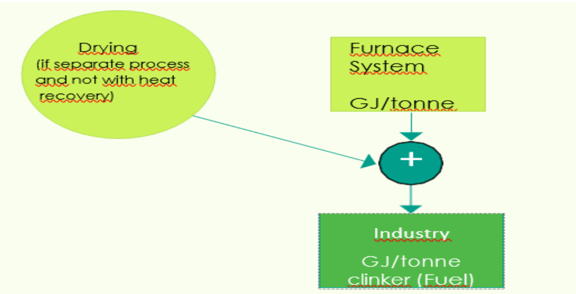

Fig. 8. *Comparison of fuel consumption in clinker production [26]*

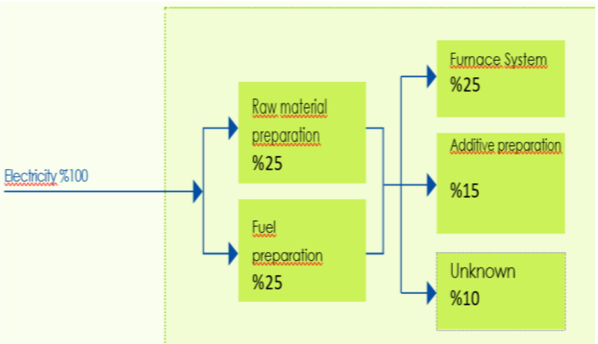

Fig. 9. *Process boundries in the cement industry [26]*

Cooling water and compressed air used in the processes are other important forms of energy used in the cement industry. Cooling towers consume electricity to produce the cooling water used in the process. Similarly, compressors consume electricity and produce compressed air for use in the process.

The SET values for the air compressor and cooling tower can be kWh/m³ of air and kWh/m³ of cooling water. These SET values can be added to the specific electricity consumption of the process using the process's specific compressed air and cooling water consumption in m³/tonnene.

Specific cooling water consumption of the process = X m³ cooling water/tonnene

• Specific electricity consumption of cooling water production = Y kWh/m³ cooling water

• Specific electricity consumption due to process cooling water consumption = X * Y kWh/tonne.

The same process can be applied for hot water, steam and other similar forms of energy. If steam and hot water production takes place in the process, the enthalpy difference should be taken into account when calculating the energy consumed for them. Within the scope of the 2020 Cement Industry Comparison Report in Turkey, a total of 55 facilities representing all integrated facilities in our country and 12 cement grinding facilities were evaluated. Limestone, marl and clay come to the fore in the raw material consumption of the facilities included in the cement sector benchmarking study. The most consumed auxiliary materials are gypsum, limestone and fly ash, and alternative raw materials are iron (Fe), silicon (Si) and Si-Ca-Fe-Al. The capacity utilization rates of the cement plants participating in the benchmarking study are in the integrated plants and while the clinker capacity utilization rate is 79.3%, the cement capacity utilization rate is 55.3%. The capacity utilization rate in cement grinding/packaging facilities is 46.7% . The total final energy consumption of all facilities included in the benchmarking study is 7.24 million TEP, and approximately 99.8% of this consumption belongs to integrated facilities [26].

5.2. Iron and Steel Industry Comparisons

The current benchmark results in the iron and steel industry; concentrated largely at the plant level and to some extent at the process level. For example, currently the most commonly used benchmarks are the SET for electricity and fuel use in iron and steel making, namely GJel/tonne, GJfuel/tonne or GJtotal/tonne. In some sources in the literature, there are benchmark values for processes such as coke plant, sintering plant, blast furnace plant, steel plant and rolling machine.

Electricity and fuel consumption in iron and steel production are given in Fig. 10 and Fig. 11, and process limits are given in Fig. 12. It is recommended that the process boundaries of the iron and steel industry in Turkey be chosen in such a way that at least 90% of the total energy consumption can be calculated clearly. Process boundries are shown in Fig. 12. Cooling water and compressed air used in the processes are other important forms of energy used in the iron and steel industry. For this reason, similar to the Cement sector, the SET values of the Iron and Steel sector are used in cooling towers, air compressors, hot water, steam, etc. It can also be applied to other forms of energy such as if steam and hot water production takes place in the process, the enthalpy difference should be taken into account when calculating the energy consumed for them.

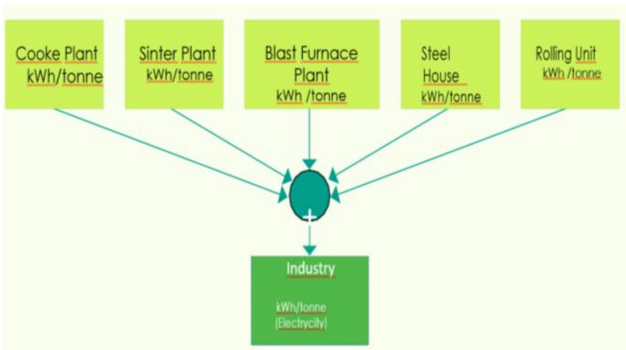

Fig. 10. *Comparison of electricity consumption in iron and steel production [26]*

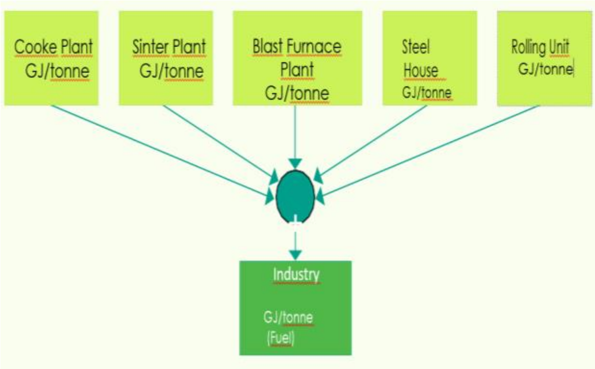

Fig. 11. *Comparison of fuel consumption in iron and steel production [26]*

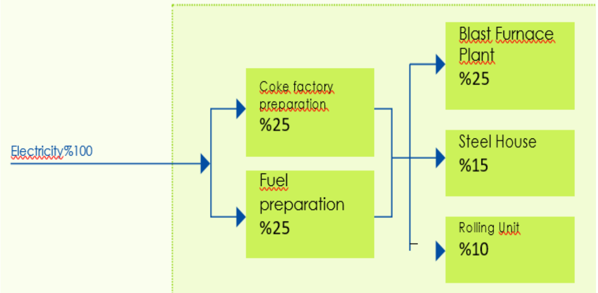

Fig. 12. *Process boundries in the Iron and Steel industry[26]*

5.3. Textile Industry Comparisons

Some of the textile processes require special indoor climatic conditions, especially air conditioning. In order to obtain a reliable database of benchmarking, it is necessary to “normalize” the portion of energy consumption that is dependent on external climatic conditions. This part of the energy can usually reach 25 to 27% of the annual consumption.

One convenient approach is to use “heating days”. The cooling load is highly dependent on internal heat sources and solar radiation; therefore, it is too complex an issue to be associated with the ambient climate. It would be recommended to normalize energy consumption for the period of heating days only. If the difference in heating days for the two periods in the comparison analysis is less than 10%, this normalization can be ignored. Simple algorithm for calculating the “climate indicator”: climate correction of energy consumption can be applied for the heating period of the year using heating days.

Heating days can be calculated with the following equation [29];

$HDDi = ni*(t_t - t_{orti})$ [Eq.5]

i - Number of months in the heating period

ni – number of heating days in month i,

t_t - The working ambient temperature required by the design of a particular technology. If there is more than one operating environment with different requirements, the tt value can be calculated as a weighted average,

$t_{ort,i}$- The monthly average of the ambient temperature observed at the relevant location in month i.

The climate correction/normalization indicator (IDG) to be multiplied by the climate-related energy consumption can be calculated as follows [29]:

$İDG = HDDry \sum_{i=1}^{n} \text{HDDi}$ [Eq.6]

i : The number of months in the heating period of the analysis year,
HDDry: Relative heating day degree of the reference year selected for comparison
HDD : Heating day degrees

5.4. Glass Industry Comparisons

Different final (salable) products or intermediates in the glass industry, each with different quality requirements, cause energy use to be variable.

In this sector, 3 types of correction factors must be taken into account [27];

1) Product mix
2) Basic production process = Temperature
3) The residence time of the melt in the furnaces

In the glass industry 1. Correction factor in the product mix category, in the production of flat glass with different product thicknesses, the thickness, machinability, thermal relaxation, etc. It has been defined for several reasons due to its effect on energy consumption. Here is the path to be followed in the energy consumption calculation [29];

- Measuring/recording energy consumption for a given quantity of product with thickness (x) in the reference (base) year.
- Keeping a record of the measured values before and after the production process.
- Calculation of the specific energy consumption of the product with thickness (x') in the reference (base) year.
- Measuring/recording energy consumption for a given quantity of products with thickness (y) in the reference (base) year.
- Calculation of the specific energy consumption of the product with thickness (y) in the reference (base) year.
- Calculating the specific energy consumption of x and y exponents in the following years and associating them with the values in the reference (base) year.

In the basic production processes, which is defined as the 2nd correction factor in the glass industry, temperature is defined to characterize the energy consumption that may occur from temperature differences in the coarse and fine melt. Here is the path to be followed in the calculation of energy consumption [29];

- Determination of the mean temperature in the reference (base) year (annual) in the smelter/furnaces.
- Measuring/recording the average temperature (annual) in the smelter/furnaces in the following years (analysis year).
- Obtaining the correction factor for each analysis year by proportioning the value in the analysis year with the value in the reference year.

The only point to note here is; if the glass processing plant does not produce its own glass melt, it is also necessary to consider the main processes and other factors that have the greatest impact on the plants.

The residence time of the melt, which is defined as the 3rd correction factor in the glass industry, is taken into account since the prolongation of the retention time causes an increase in energy requirements. Because the higher the desired glass quality, the longer the glass melt must remain in the fine melting range. Here is the path to be followed in the energy consumption calculation [29];

- Determination of the average retention time in the reference (base) year (annual) in the smelter/furnaces.
- Measuring/recording the average retention time (annual) in the smelter/furnaces in the following years (analysis year).
- Obtaining the correction factor for each analysis year by proportioning the value in the analysis year with the value in the reference year.

The point to be considered here is that if the glass shards belonging to the facility or recycled are used in certain proportions/amounts, the correction factor should be calculated considering that this will accelerate the melting and save energy.

6. Conclusion

The gradual decrease in fossil fuels, which constitute a significant part of the energy need, insecurity against nuclear energy facilities, the inability of alternative energy sources to meet the demand at the desired level, pollution of the environment and climate changes increase the importance of energy efficiency day by day. Energy efficiency is the most important component of sustainable development and competitiveness. The implementation of environmentally friendly policies and methods in energy production/consumption, the creation of resource alternatives, and the increase of efficiency by avoiding waste have been a policy that has been emphasized in Turkey. Energy efficient technologies in the sector are encouraged to use energy with high efficiency and savings without sacrificing production quality. The application of benchmarking methodologies to determine the efficiency of the industrial plant in terms of energy consumption and to compare it with similar enterprises in the same industry will provide a solid basis for the steps to be taken according to the current state of a particular industrial plant. For this purpose, it is important to determine the criteria that can be used by grouping them as general and sectoral criteria on a sectoral basis. In industrial enterprises where energy is used intensively, planned and systematic studies should be carried out to increase energy efficiency and its sustainability should be ensured.

While carrying out activities to increase energy efficiency in industrial enterprises, it should not only be based on investments based on technological development or random savings decisions, but also integrated with the Energy Management System (management planning, documentation, maintenance, measurement and monitoring). Otherwise, the continuity of energy efficiency is not ensured and it is seen that the gain in efficiency is lost again after a while. Research has shown that annual energy costs can be reduced between 5% and 20% with the Energy Management System and its tools. The ISO 50001 Energy Management System Standard application for systematic and permanent reduction of energy density for industrial enterprises should be expanded, and if possible, it should be applied in the industry as a legal obligation.

Legal regulations and processes related to energy efficiency should be closely followed, and efforts to increase energy efficiency should be kept on the agenda with the support of energy studies, voluntary agreements, efficiency-enhancing projects, incentives and energy efficiency consultancy companies

Author Contribution

Conceive-G.Y.T.; Design- G.Y.T.; Supervision-G.Y.T.; Literature Review- G.Y.T., G.E; Writer- G.Y.T., G.E.; Critical Reviews -G.Y.T.

Declaration of Competing Interest

The authors declared no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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