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Industrial Tea Waste and Energy Potential

Endüstriyel Çay Atığı ve Enerji Potansiyeli

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ABSTRACT

Türkiye is ranked seventh in the world in tea cultivation and tea cultivation is carried out only in the cities of Rize, Trabzon, Artvin, Giresun and Ordu. The annual production amount of tea is 1.357 million tons and the highest cultivation rate is 67% in Rize City and the lowest is 2% in the Giresun-Ordu region. The tea plant harvested from the field is processed in state or private tea factories. The product obtained as a result of this process is defined as tea, and the remaining parts consisting of fiber, garbage and dust are defined as industrial tea waste (ITW). It is a big problem for both growers and tea operators due to the same harvest time of the tea plant in all cities, the high potential of tea cultivation in the region and the lack of suitable land structure for the disposal of ITW. Removing ITW from the factory environment during the production period and adding to the country's economy as an energy source is important in terms of sustainable energy.

In the study prepared with 2023 statistical data, the energy potential that can be obtained by directly burning ITW formed after tea production in factories was examined. As a result, it was found that 1.06e9 MJ of electrical energy and 1.06e9 MJ of thermal energy would be obtained annually if ITW in Türkiye were burned directly in the cogeneration system.

Keywords: Biomass energy, direct burning, energy potential, industrial tea waste.

ÖZ

Türkiye Çay yetiştiriciliği sıralamasında Dünyada yedinci sıradadır ve çay yetiştiriciliği sadece Rize, Trabzon, Artvin, Giresun ve Ordu şehirlerinde yapılmaktadır. Yıllık üretim miktarı 1.357 milyon ton olan çayın en yüksek yetiştiricilik %67 oranla Rize ilinde, en az da %2 ile Giresun-Ordu bölgesinde yapılmaktadır. Tarladan hasat edilen çay bitkisi devlet veya özel çay fabrikalarında işlenir. Bu proses sonucunda elde edilen ürün çay, geride kalan lif, çöp ve tozdan oluşan kısımlar da endüstriyel çay atığı (EÇA) olarak tanımlanmaktadır. Çay bitkisinin tüm illerde aynı hasat zamanına sahip olması, bölgede çay tarımı potansiyelinin yüksek olması ve EÇA'nın imha edilmesi için uygun arazi yapısının olmaması hem üreticiler hem de çay işletmecileri için büyük bir sorundur. Üretim döneminde EÇA'nin fabrika ortamından uzaklaştırılması ve enerji kaynağı olarak ülke ekonomisine kazandırılması sürdürülebilir enerji açısından önemlidir.

2023 istatistik verileri ile hazırlanan çalışmada, fabrikalarda çay üretimi sonrası oluşan EÇA'nın doğrudan yakılmasıyla elde edilebilecek enerji potansiyeli incelendi. Sonuç olarak, Türkiye'deki EÇA'nın doğrudan kojenerasyon sisteminde yakılması durumunda yılda 1,06e9 MJ elektrik enerjisi ve 1,06e9 MJ termal enerji elde edildiği bulundu.

Anahtar kelimeler: Biyokütle enerjisi, direk yakma, enerji potansiyeli, endüstriyel çay atığı.

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Introduction

The most important effect of developing technology is undoubtedly the increasing living standards. The most obvious result of the growing population and rising living standards is the increasing energy consumption. The increase in energy consumption threatens the existence of societies due to environmental effects such as greenhouse gases and the decreasing amount of reserves. As a result, the condition of society's continuity is possible with the use of energy sources that do not harm the environment and do not have a reserve problem.

Today, instead of fossil-based non-renewable energy sources that have been actively used from the past to the present due to their high energy potential, the use of environmentally friendly and highly renewable energy sources is rapidly becoming widespread. The use of renewable energy sources varies according to the accessibility of countries to resources. While hydraulic, and solar energy are at the forefront among its renewable resources due to Türkiye's geographical structure, geothermal energy and biomass use are also available regionally.

The term biomass is most commonly defined as a substance obtained or produced from living beings and their waste. All plant and animal substances in nature are biomass. Domestic organic waste, agricultural waste, animal waste, city sewage waste, and industrial organic waste (beet pulp, tea waste, sunflower waste, etc.) are examples of biomass. It is possible to convert biomass resources into energy with three different main processes (Eryaşar, 2007)

1. Thermochemical processes: direct burning, gasification, pyrolysis and liquefaction,
2. Biochemical processes: anaerobic fermentation, alcohol fermentation,
3. Physicochemical: transesterification

It is possible to obtain energy from biomass resources by burning them directly or by converting them into a different form such as biofuel (biogas, biodiesel, bio-alcohols, etc.). Its waste resulting from agricultural and animal activities must be disposed of. Otherwise, it creates both visual and environmental problems. Biomass energy contributes to the environmental appearance and prevents harmful formations such as harmful insects, odors, and flies, as it allows waste to be used without waiting (Eryaşar, 2007).

Biomass energy, which has significant potential among renewable energy sources, is a continuous energy source, unlike the sun and wind. The advantages of biomass energy are that it is renewable, its energy and raw materials can be stored, waste harmful to the environment is converted into energy for the economy, it prevents external dependency on energy, and it creates employment in the regions where it is established. While organic wastes are converted into energy via biochemical and phytochemical processes that require high technology and professional system installations, biomass with weak or no microorganisms, such as tea waste, is converted into energy via thermochemical processes.

First cultivated in China and India, tea is a traditional beverage consumed by people of all ages, hot and cold, around the world. The fact that tea is dried allows it to be consumed in any season and at any time, making it a widespread beverage. Most of the production is carried out on the Asian continent, and 64% of the total area and 49% of the total production are in China (Erkal, 2023).

The harvested tea plant is exposed to the production phase. The product obtained as a result of the production process is tea, and the remaining is tea waste (Tiftik, 2016). Waste consists of discarded leaves, buds, and pruned stems (Debnath & Purkait, 2023). According to 2023 data, approximately 1,357 million tons of fresh tea are processed in Türkiye, and approximately 200 tons of this are released into the environment as industrial tea waste (ITW) (Ministry of Agriculture and Forestry, 2020). Due to the high potential of ITW, many studies have been conducted in the literature to prevent environmental pollution caused by ITW and to bring it into the economy.

Aşik and Kütük (2012) studied the effect of tea waste compost on germination and compared the results with farmyard manure and peat. They found that tea waste is more effective.

Boyraz et al. (2023) investigated whether tea wastes could be used in the production of activated carbon. The study showed that it could be produced by the hydrothermal method from tea facility wastes provided by Rize-ÇAYKUR facilities.

Müftüoğlu et al. (2009) searched the effect of tea waste on compost production time. The study found that using tea waste in composting shortened the compost production time.

Turumtay (2020) mixed tea waste with lignite coal in different proportions to use the energy of tea waste and examined the thermal capacities of the obtained mixtures.

This study aims to convert ITW generated after the production of tea grown in Türkiye into energy while disposing of it. The energy potential to be obtained from ITW was examined using 2023 tea statistics.

Tea Plant

The tea plant, known by its Latin name Camellia sinensis or Thea sinensis, belongs to the Theaceae family. This plant, which is a short shrub, grows in humid climates. China, India, Indonesia, Japan, and Taiwan have the highest production, and it is produced in 40 countries worldwide (Üstün & Demirci, 2013; Mammadow, 2024). It can be produced in regions where rainfall is more than 2000 mm and regular. While tea cultivation is carried out for 12 months in tropical and equatorial regions, it is only carried out for 6 months of the year in high-latitude countries such as Türkiye and Iran (Ministry of Agriculture and Forestry, 2020). According to the fermentation status of the tea plant, it is classified as green tea (unfermented), black tea (fermented) and oolong tea (semi-fermented) (Elmas & Gezer, 2019).

Tea leaves are harvested by using specific machinery or by hand. Black tea's quality highly relies on the physicochemical processes involved in its production, the timing of the harvest and the skills of the picker in selecting the most suitable leaves. Soon after tea leaves are plucked, they undergo various processing steps, including withering, rolling, fermentation, drying, classification, packaging and storage. Figure 1 shows steps in the manufacturing of tea leaves (Tiftik, 2016; Aaqil et al., 2023).

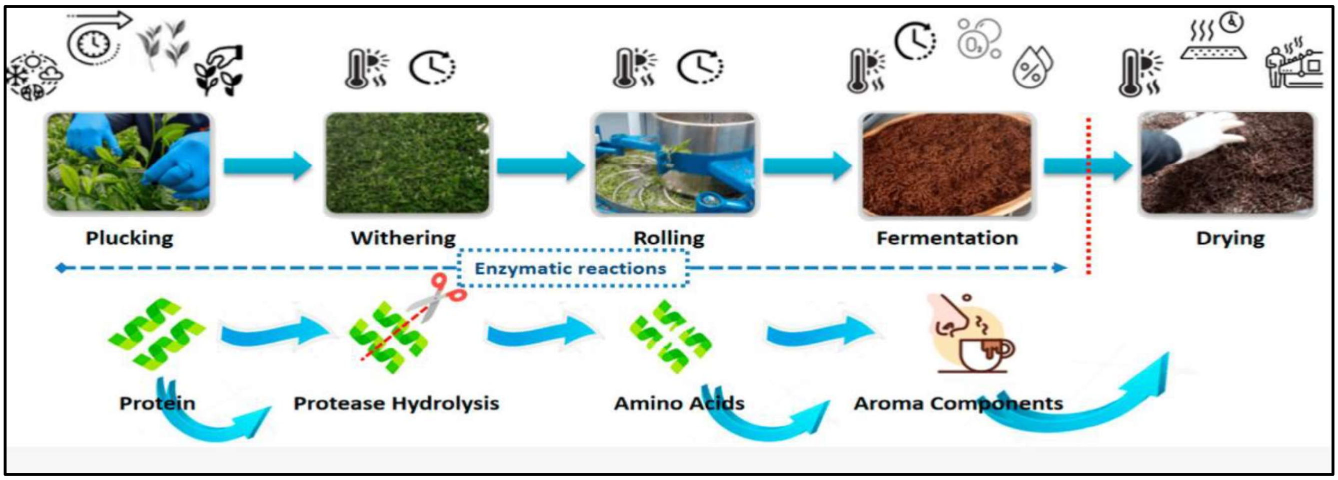

Figure 1.
Steps in the manufacturing of tea leaves.

Tea and Türkiye Potential

The first studies on tea cultivation in Türkiye were initiated in 1888 with the planting of seeds brought from China in the Bursa area. However, the Bursa studies did not yield positive results. In 1924, tea production studies were started in Rize and its surroundings, and when successful results were obtained, 20 tons of tea seeds were purchased and distributed to producers in 1937. In 1940, fresh tea leaves were processed to obtain dry tea, and in 1942, the import and domestic sale of tea were monopolized by the state. Due to the increasing tea production, the first tea factory with a capacity of 60 tons/day was opened in the Fener neighborhood of Rize in 1947. Tea enterprises, which were affiliated with the General Directorate of Tekel until 1971, were transferred to the General Directorate of Tea Institution and the title of the enterprise was changed to General Directorate of Tea Enterprises (ÇAYKUR) in 1984. In the same year, tea cultivation, production, processing and sale were freed in the markets. Today, tea production is carried out in more than 300 private enterprises other than ÇAYKUR (Üstün & Demirci, 2013).

Tea production in Türkiye is carried out in the Eastern Black Sea Region in the cities of Rize, Trabzon, Artvin, Giresun and Ordu. The teas grown are processed by ÇAYKUR Enterprises or private enterprises located in the same regions and added to the economy. According to 2023 data, approximately 1.357 million tons of fresh tea have been processed and this value is increasing day by day. The amount of fresh tea produced in Türkiye between 2000 and 2023 is presented in Table 1 and Figure 2 (TUİK, 2023).

In 2023, tea production was carried out on 791 decares, 67% of which was in Rize, 19% in Trabzon, 12% in Artvin and 2% in the Giresun-Ordu Region. Tea plantation areas and the number of tea producers are in Table 2. Distribution by province of the area reserved for tea plantations and of the number of tea producers is presented in Figure 3 and Figure 4, respectively (ÇAYKUR, 2023). Table 3 shows the amounts of fresh tea leaves between 2019 and 2023, and Figure 5 shows graphically the distribution according to province (Erkal, 2024).

According to the 2024 Tea Product Report published by the Turkish Ministry of Agriculture and Forestry, Türkiye has the highest efficiency value for the amount of tea produced per unit area, with 1,563 $kgda^{-1}$. Zimbabwe is in second place with 1,448 $kgda^{-1}$, and Malawi is in third place with 1,222 $kgda^{-1}$. In 2022, the efficient distribution of tea produced by the province is presented in Table 4 and Figure 6 (Erkal, 2024).

Table 1.
Tea production, 2000-2023

Year	Number of tea growers	Area reserved for tea plantation (Decare)	Production of green tea leaves (Tonnes)
2000	204491	767500	758038
2001	204112	766530	824946
2002	203028	766450	791700
2003	203318	766400	869000
2004	202431	766320	1105000
2005	202699	766250	1192004
2006	203431	766136	1121206
2007	203901	765808	1145321
2008	199231	758257	1100257
2009	200798	758513	1103340
2010	202494	758641	1305566
2011	205312	758895	1231141
2012	-	758566	1250000
2013	-	764255	1180000
2014	-	760494	1266311
2015	-	762073	1327934
2016	-	763609	1350000
2017	-	821079	1300000
2018	-	781334	1480534
2019	-	785693	1407448
2020	-	786813	1450556
2021	-	789001	1453964
2022	-	791285	1269546
2023	-	791984	1356556

Table 2.
Tea cultivation areas and the number of tea producers for 2023.

City	Area reserved for tea plantation (Decare)	Number of tea growers
Rize	530803	130399
Trabzon	152540	49322
Artvin	91929	19903
Giresun-Ordu	16712	7522
Total	791984	207146

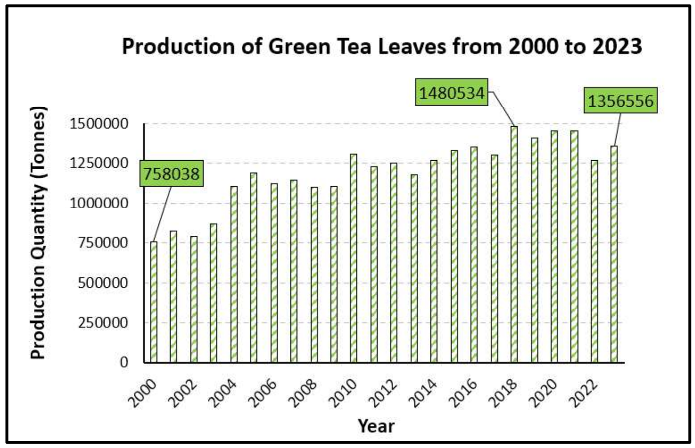

Figure 2.
Production of green tea leaves, 2000-2023

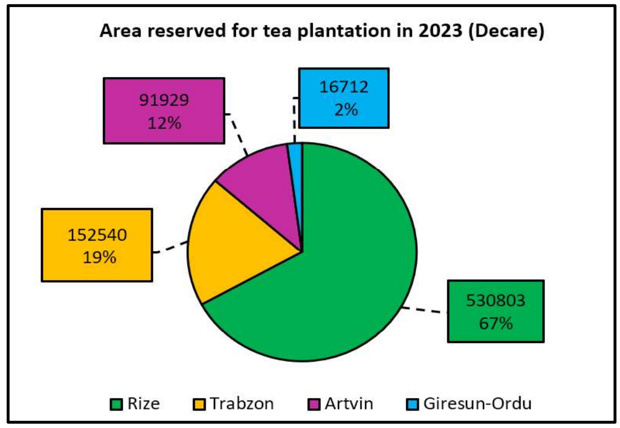

Figure 3.
Area reserved for tea plantation in 2023

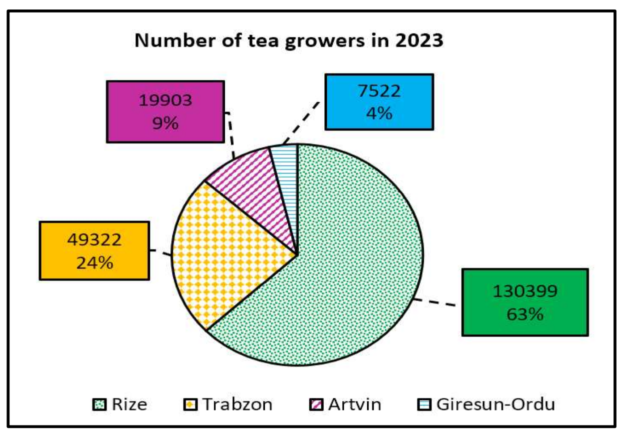

Figure 4.
Number of tea producers in 2023.

Table 3.
The amount of fresh tea leaves by province (Kilo Tonnes)

City	2019	2020	2021	2022	2023
Rize	906	934	935	821	872
Trabzon	325	333	328	287	306
Artvin	146	154	160	135	147
Giresun-Ordu	31	30	31	27	32
Total	**1408**	**1451**	**1454**	**1280**	**1357**

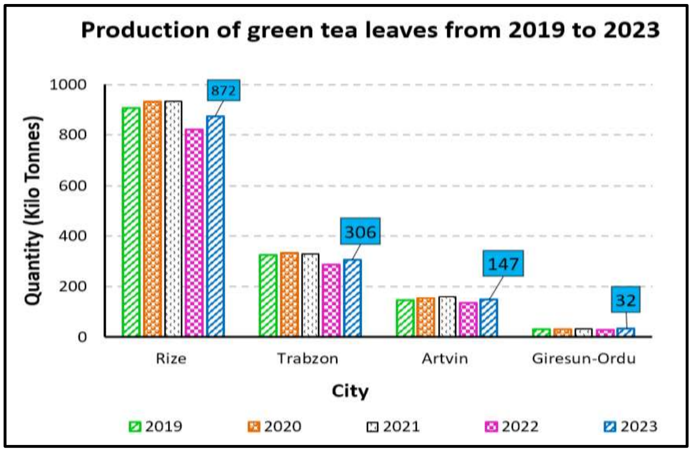

Figure 5.
The amount of fresh tea leaves by province from 2019 to 2023

Table 4.
Efficiency of tea produced from 2019 to 2023

City	2019	2020	2021	2022	2023
Trabzon	2.163	2.206	2.167	1.884	2.006
Giresun	1.880	1.825	1.861	1.634	1.899
Rize	1.716	1.769	1.767	1.547	1.643
Artvin	1.599	1.683	1.743	1.470	1.594
Ordu	0.621	0.552	0.567	0.478	0.478
Türkiye	1.791	1.844	1.843	1.604	1.713

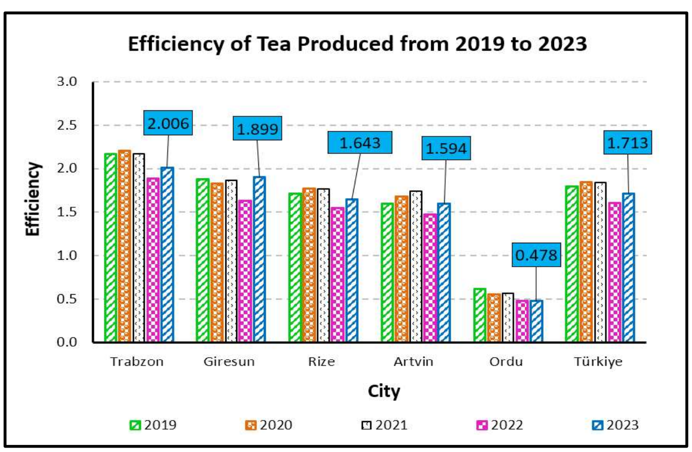

Figure 6.
Efficiency of tea produced from 2019 to 2023

Tea Losses

During the tea production phase, losses are caused during both production and consumption. Production losses in this study are named as ITW. Table 5 presents the losses of tea.

Table 5.
Tea losses

Year	Harvest (Tonnes)	Losses (Tonnes)			
		ITW	Cons.	Total	%
2019	1407448	211117	37577	248694	17.6699
2020	1450556	217583	39311	256894	17.7100
2021	1453964	218095	37880	255975	17.6053
2022	1269546	190432	33072	223504	17.6051
2023	1356556	203483*	35338*	238821*	17.6050*

** Approximately values accepted*

Loss values are determined annually from June to May of the following year. Since the loss data for 2023 had not yet been created when the study was prepared, the 2023 loss values were estimated based on the loss values for 2022 and 2021.

Energy Production from Industrial Tea Wastes

The energy released as a result of the burning of organic compounds is called by different names as thermal energy and calorific value. The amount of energy is calculated with Equ. 1.

$$Q = m.H \qquad (1)$$

here Q, m and H show thermal energy, the mass of ITWs and heat value of ITW, respectively. In the study, the heat value of ITW was accepted as 17.45 $MJkg^{-1}$ using Table 6.

Table 6.
The heat/calorific value of ITW in some studies in the literature

References	Heat Value
(Haque et al., 2024)	19.48 $MJkg^{-1}$
(Nagaraja et al., 2013)	16.19 $MJkg^{-1}$
(Pua et al., 2020)	17.393 $MJkg^{-1}$
(Turumtay, 2020)	4000 $kcalkg^{-1}$ (16.747 MJkg-1)
Mean (accepted)	17.45 $MJkg^{-1}$

Today, combined heat and power (CHP) systems, also known as cogeneration, are used for the production of electrical energy from thermal energy because they increase the unit efficiency by using the residual heat. The efficiency schema of the CHP system is in Figure 7 (Fuentes-Cortés et al., 2015).

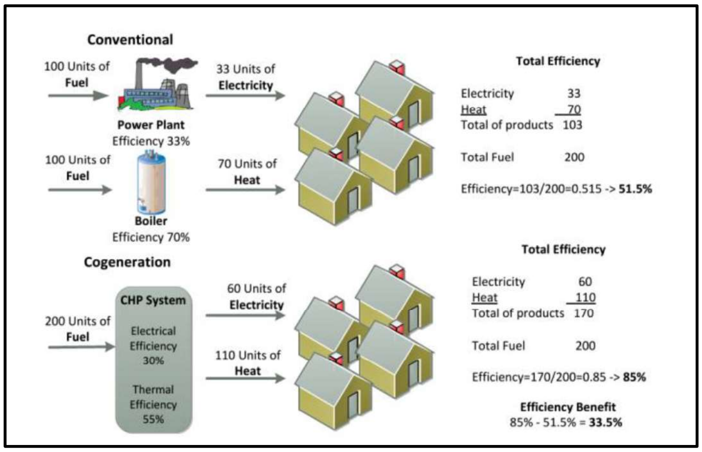

Figure 7.
Conventional systems and CHP systems

According to 2023 statistics, if 203483 tons of ITWs from the originated 1356556 tea plants are directly burned, 3550811664 MJ of thermal energy is produced. Suppose the thermal energy is converted via the CHP to electricity and thermal energy, 1065243499 MJ of electricity energy and 1952946415 MJ of thermal energy form. Production and transformation values of energy are shown in Table 7.

Table 7.
Production and transformation values of energy

Annually obtained from harvest	Tea (Tonnes)	1356556
	Waste (Tonnes)	203483
	Thermal energy (MJ)	3550811664
Annually required energy for residences	Electricity (kWh)	5500
	Heating system (MJ)	38058
	Hot water (MJ)	6280
CHF efficiency	Electricity (%)	30
	Thermal (%)	55
Produced energy from CHP	Electricity (MJ)	1065243499
	Thermal (MJ)	1952946415

Using the electricity and thermal energy produced in CHP is possible in residences. So, it is necessary to transport the ITW to a CHP system, where it must be converted into electricity and thermal energy and then distributed to residences. Considering the annual energy consumption of a 100 m^2 house and family of 4, it is possible to provide the electricity needs of approximately 40 thousand residences and the thermal needs of roughly 20 thousand residences.

Conclusion

Türkiye ranks seventh in the world's tea producers ranking, with more than 1 million tons of tea plants grown annually. After harvesting, the tea plant is processed in factories for tea production, and as a result of this process, a large amount of industrial tea waste is generated. The removal and disposal of İTW from the factory environment creates additional costs for factories.

The study prepared using 2023 Türkiye statistical data examined the disposal of ITW without harming the environment and the generation of energy by burning ITWs. When 203483 tons of ITW formed after tea production is directly burned, 3550811664 MJ of thermal energy is produced. It is possible to convert this energy into 1065243499 MJ of electrical energy and 1952946415 MJ of thermal energy via CHP.

Production electricity and thermal energy can be used in residences. if the energy is used in residences, it will reduce the unit efficiency of the obtained energy from ITW due to transportation costs and distribution losses. While losses in electrical energy are expected to be around 15%, thermal losses are expected to be around 50%. Therefore, processing the ITW by the factories where it is produced will increase the efficiency of the energy to be obtained from

There are two important results of doing the energy conversion process in the factories where the ITW is obtained.

1. It eliminates the negative environmental effects, as it will allow the ITW to be disposed of immediately.
2. It prevents additional losses, such as the transportation of the ITW to a different location and the transfer of the produced energy.

The advantages of converting ITW into energy in factories are listed below.

1. The electrical energy produced can be used for the electricity needs of the factory.
2. The thermal energy produced can be used in the drying process of the tea plant.
3. Since the ITW produced will be processed in the same factory, there is no need for a waste collection area.
4. Since the ITW will not be transferred to another location, the use of fossil fuels due to transportation is prevented.

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