ECONOMIC AND ENVIRONMENTAL ANALYSIS OF THE USAGE OF SOLAR, WIND AND HYDROELECTRIC ENERGY SYSTEMS IN WASTEWATER TREATMENT PLANTS IN TÜRKİYE

TÜRKİYE'DEKİ ATIKSU ARITMA TESİSLERİNDE GÜNEŞ, RÜZGAR VE HİDROELEKTRİK ENERJİ SİSTEMLERİNİN KULLANILMASININ EKONOMİK VE ÇEVRESEL AÇIDAN İNCELENMESİ

İREM BİLİR

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ABSTRACT

ECONOMIC AND ENVIRONMENTAL ANALYSIS OF THE USAGE OF SOLAR, WIND AND HYDROELECTRIC ENERGY SYSTEMS IN WASTEWATER TREATMENT PLANTS IN TÜRKİYE

İrem BİLİR

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The increasing global demand for water and energy, the limited availability of resources, and the problems caused by the climate crisis are putting significant pressure on water and energy supply systems. Therefore, sustainable energy and clean water supply are among the most critical issues worldwide. The fact that water is the primary material for energy production and energy is needed for water treatment demonstrates a mutual relationship between water and energy.

Wastewater treatment plants (WWTPs) are the primary energy consumers in many countries. Approximately 14% of WWTPs in Türkiye cannot be operated due to economic reasons resulting from high energy consumption. This issue is particularly observed in small city municipalities with higher unit energy requirements. Previous studies have shown that renewable energy integration is environmentally and economically feasible for large-scale wastewater treatment plants. However, the primary issue in Türkiye is that many small-capacity WWTPs are not operated due to high electricity demand.

Although there are many studies in the literature on integrating renewable energy sources into WWTPs with a certain capacity, there is no study for relatively small-capacity WWTPs in Türkiye that includes renewable energy source types. Therefore, the main aim of this study is to determine a threshold value for the capacity of wastewater treatment plants with feasible renewable energy integration using Particle Swarm Optimization in Python. The study evaluated 79 WWTPs in Türkiye that treat less than 1,000,000 m^3 of wastewater and identified nine as viable for renewable energy integration, with a payback period of seven years or less and the potential to meet at least 50% of the electricity demand. The study also indicated that renewable energy integration, including solar, wind, and hydro, is feasible for WWTPs with different capacities, with payback periods ranging from 5.5 to 8.6 years. WWTPs have significant potential for cost and emission reductions.

The optimization model developed includes two different scenarios. Scenario 1 is based on generating enough electricity from renewable energy sources to meet the WWTP's electricity consumption and optimize it with minimum cost. Due to the complexity of battery systems, electricity generated from renewable energy sources is assumed to be directly sold to the national grid. Therefore, in Scenario 1, the generation is limited to the amount consumed. In Scenario 2, conversely, more electricity can be generated than needed by using the maximum available photovoltaic area and selling it to the grid. In this case, there is no limitation on electricity generation in Scenario 2, and all the available potential in the area is used for electricity generation. The result of the study indicates that the threshold capacity for renewable energy integration in low-capacity WWTPs is 380,633 m^3/year in Scenario 1 and 100,611 m^3/year in Scenario 2. This study revealed that the average cost reduction is 22,300 \$/y in Scenario 1 and 29,300 \$/y in Scenario 2. WWTPs can contribute to a 56% emission reduction in Scenario 1 and 74% in Scenario 2, thanks to the electricity generated from renewable energy sources. Assuming a household's average annual electricity consumption is approximately 4,000 kWh, integrating renewable energy sources in the 79 WWTPs would result in emissions equivalent to the annual electricity consumption of approximately 2,000 households.

Keywords: Wastewater Treatment Plants, Renewable Energy, Particle Swarm Optimization, Python, Economic and Environmental Analysis, Emission Reduction

ÖZET

TÜRKİYE’DEKİ ATIKSU ARITMA TESİSLERİNDE GÜNEŞ, RÜZGAR VE HİDROELEKTRİK ENERJİ SİSTEMLERİNİN KULLANILMASININ EKONOMİK VE ÇEVRESEL AÇIDAN İNCELENMESİ

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Su ve enerji talebinin küresel çapta artması, kaynakların sınırlı oluşu ve iklim krizinin neden olduğu sorunlar su ve enerji tedarik sistemleri üzerinde büyük bir baskıya neden olmaktadır. Dolayısıyla sürdürülebilir enerji ve temiz su temini dünya çapında en kritik konular arasında yer almaktadır. Suyun enerji üretimi için birincil madde oluşu, su arıtımı için ise enerjiye ihtiyaç duyulması, su ve enerji arasında karşılıklı bir ilişki olduğunu göstermektedir.

Atık su arıtma tesisleri (AAT), birçok ülkede birincil enerji tüketicisidir. Türkiye'deki AAT’lerin yaklaşık %14'ü yüksek enerji tüketiminden kaynaklanan ekonomik nedenlerle işletilememektedir. Özellikle bu durum birim enerji ihtiyacının daha fazla olmasından kaynaklı küçük şehir belediyelerinde görülmektedir. Daha önceki çalışmalara bakıldığında, büyük ölçekli atıksu arıtma tesisleri için yenilenebilir enerji entegrasyonunun hem çevresel hem de ekonomik olarak uygulanabilir olduğu görülmektedir. Fakat Türkiye'deki birincil sorun, küçük kapasiteli AAT’lerin çoğunun yüksek elektrik talebi nedeniyle işletilmemesidir.

Literatürde, yenilenebilir enerji kaynaklarının belirli bir kapasiteye sahip AAT’lere entegre edilmesi konusunda birçok çalışma olmasına rağmen, Türkiye'de bulunan nispeten küçük kapasiteli AAT’ler için yenilenebilir kaynak türlerini içeren bir çalışma bulunmamaktadır. Bu nedenle, yenilenebilir kaynak entegrasyonuna sahip atıksu arıtma tesislerinin kapasitesi için bir eşik değer belirlemek, bu çalışmanın birincil amacıdır.

Python ile Parçacık Sürü Optimizasyonu kullanılarak bir matematiksel model oluşturulmuştur. Çalışma, Türkiye'de 1.000.000 m^3'ten daha az atık suyu arıtan 79 AAT'yi değerlendirmiş ve bunlardan dokuzunun yenilenebilir enerji entegrasyonu için uygun olduğunu, yedi yıl veya daha kısa bir geri ödeme süresine sahip olduğunu ve elektrik talebinin en az %50'sini karşılama potansiyeline sahip olduğunu belirlemiştir. Güneş enerjisine ek olarak rüzgar ve hidro da dahil olmak üzere yenilenebilir enerji entegrasyonunun, 5.5 ila 8.6 yıl arasında değişen geri ödeme süreleri ile farklı kapasitelerdeki AAT'ler için uygun olduğunu ve bu AAT'lerin maliyet ve emisyon azaltımları için önemli bir potansiyele sahip olduğunu işaret etmektedir.

Oluşturulan optimizasyon modelinde iki farklı senaryo yer almaktadır. Senaryo 1, AAT'nin elektrik tüketimini karşılayacak kadar elektrik üretmeye ve bunu minimum maliyetle optimize etmeye dayanmaktadır. Batarya sistemlerinin karmaşıklığı nedeniyle, yenilenebilir enerji kaynaklarından üretilen elektriğin doğrudan ulusal şebekeye satılacağı varsayılmaktadır. Bu nedenle, Senaryo 1'de üretim, tüketilen miktarla sınırlıdır. Senaryo 2'de ise, mevcut maksimum fotovoltaik alanı kullanılarak ve şebekeye satılarak ihtiyaç duyulandan daha fazla elektrik üretilebilir. Bu durumda, Senaryo 2'de elektrik üretimi için herhangi bir sınırlama yoktur ve bölgedeki mevcut tüm potansiyel, elektrik üretimi için kullanılmaktadır. Çalışma sonucu, düşük kapasiteli AAT'lere yenilenebilir enerji entegrasyonu için eşik kapasitenin Senaryo 1'de 380,633 m^3/yıl ve Senaryo 2'de 100,611 m^3/yıl olduğu belirlenmiştir. Bu çalışma, ortalama maliyet azaltımının Senaryo 1'de yıllık 22,300$ ve Senaryo 2'de yıllık 29,300$ olduğunu ortaya koymaktadır. AAT'ler, yenilenebilir enerji kaynaklarından üretilen elektrik ile, Senaryo 1'de %56 ve Senaryo 2'de %74 emisyon azaltımına katkıda bulunabilmektedir. Türkiye'de bir konutun yıllık ortalama elektrik tüketiminin yaklaşık 4.000 kWh olduğu varsayıldığında, yenilenebilir enerji kaynaklarının 79 AAT'ye entegre edilmesi, yaklaşık 2,000 konutun yıllık elektrik tüketimine bağlı emisyonuna denk gelmektedir.

Anahtar Kelimeler: Atıksu Arıtma Tesisleri, Yenilenebilir Enerji, Parçacık Sürü Optimizasyonu, Python, Ekonomik ve Çevresel Analiz, Emisyon Azaltımı

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SYMBOLS AND ABBREVIATIONS

Symbols

N	Nitrogen
P	Phosphorus

Abbreviations

AW	Artificial Wetland
AAO	Anaerobic-Anoxic-Oxic
AL	Aerated Lagoon
AO	Anaerobic-Oxic
AP	Aerated Pond
BF	BioFilm
BNR	Biological Nutrient Removal
CA	Canada
CAS	Conventional Activated Sludge
CN	China
COD	Chemical Oxygen Demand
DE	Germany
EAAS	Extended Aerated Activated Sludge
EI	Energy Intensity
ER	Emission Reduction
ES	Spain
FR	France
HEP	Hydroelectric Power
IAS	Improved Activated Sludge
IT	Italy
JP	Japan

KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Electricity
MBR	Membrane BioReactor
MDG	Mega Gallons per Day
MHP	Micro Hydropower
OD	Oxidation Ditch
O&M	Operation and Maintenance
PE	Population Equivalent
PP	Payback Period
PSO	Particle Swarm Optimization
PV	Photovoltaic
RES	Renewable Energy Source
SBR	Sequence Batch Reactor
SEF	Specific Emission Factor
SSR	Self Sufficiency Ratio
ST	Stabilization Tank
TF	Trickling Filter
UK	United Kingdom
US	United States of America
WW	Wastewater
WWTP	Wastewater Treatment Plant

1. INTRODUCTION

Water and energy consumption are increasing rapidly, parallel to population, industrialization, and urbanization. Growing the global demand for water and energy will cause massive pressure on supplying water and energy systems due to the limitation of resources and the problems caused by the climate crisis. It is foreseen that global freshwater and energy consumption will increase by half by 2050 compared to 2015. So, sustainable energy and clean water supply are two of the most critical issues worldwide [1].

There is a mutual relationship between water and energy. While water is the primary substance for energy production, water systems consume a significant amount of the world's energy sources [1]. Wastewater treatment plants (WWTPs) are the primary energy consumers in many countries, constituting about 1% of the national energy consumption [2].

WWTPs operated by metropolitan municipalities in Türkiye have performed reasonably well in recent years; however, others operated by small municipalities have not. Since energy consumption is high in wastewater treatment plants, many plants cannot be operated by small city municipalities due to increased energy expenditures. About 14% of WWTPs in Türkiye cannot be operated due to economic reasons caused by high energy consumption. Simultaneously, a higher share is expected for the unoperated wastewater treatment plants due to a lack of or missing information that could not be gathered from the municipalities [3].

In recent times, the high energy consumption of conventional activated sludge processes has drawn attention, leading to a growing trend towards lower energy-consuming processes and the development of innovative treatment schemes in Türkiye. In the workshop organized in this regard, criteria used to compare renewable energy alternatives include payback period, cost, ease of implementation, current technology level, environmental impact, domestic production potential, financing sources, positive impact on greenhouse gases, integration, implementation of current regulations, physical infrastructure, increased efficiency, human resource requirements, and existing policies. The criteria that stand out based on their weight are payback period, cost, environmental impact, and financing sources. The positive and negative aspects of renewable energy use in wastewater treatment plants are discussed through a SWOT analysis. Scoring and weighting of renewable energy alternatives against the criteria resulted in the highest scores for energy efficiency, sludge drying with solar and waste heat, electricity generation with biogas, and electricity generation with hydropower systems. The biggest barriers to electricity generation using solar and wind power were identified as payback period, cost, and domestic production potential. As a negative aspect of renewable energy use in AAT specifically, there is a lack of a master plan/feasibility study for which renewable energy source is viable for which treatment plant in each city or district [4].

The previous studies show that large-scale WWTPs had always been studied, and the renewable energy integration for these large-scale plants was both environmentally and economically viable. The primary problem in Türkiye is that most wastewater treatment plants with small capacities cannot be operated due to high electricity demand and there is a lack of a study for which renewable energy source is viable for which treatment plant.

1.1. Objective of the Study

The main objective of this study is to determine the threshold capacity for WWTPs with feasible renewable energy source integration in Türkiye. Although there are many studies in the literature on integrating renewable energy sources into WWTPs with a specific capacity, no researcher has worked on WWTP with relatively small capacities and compared the types of renewable sources located in Türkiye. So, determining a threshold value for the capacity of the WWTPs with feasible renewable resource integration is the primary purpose of this proposed study. The threshold value is determined according to whether renewable energy sources are viable for the plant or not.

There are many different models for the cost optimization of integrating renewable energy sources into WWTPs in the literature. In this study, the aim is to form a mathematical model by using Particle Swarm Optimization (PSO) in Python.

1.2. Scope of the Study

In this modelling system, WWTPs, where the treated wastewater is below 1,000,000 m^3/year, in Türkiye is selected as the system boundary. There are 94 WWTPs in the study area. These locations selected on Google Earth Pro are given in Figure 1.1.

Figure 1.1. WWTPs located in the system boundary

1.3. Structure of the Thesis

This thesis consists of a total of six sections. Section 1 is the introduction, which discusses the mutual relationship between water and energy, the problem statement, and the objective and scope of the study. Section 2 provides a brief overview of wastewater treatment technologies in Türkiye, along with the energy intensity of WWTPs. The energy intensity of WWTPs with different treatment technologies is classified globally, and the electricity consumption issue of WWTPs in Türkiye is indicated. In Section 3, previous studies investigating the integration of renewable energy sources into WWTPs are mentioned. These studies are classified by WWTP scale, process type, integrated renewable energy system types, and the countries where these systems were applied. The deliverables of these studies, such as emission reduction and cost reduction, are provided. Section 4 discusses the methodology and data sources in detail. The study results are presented in a step-by-step manner in Section 5, including a comparison with the results of previous studies. Finally, in Section 6, the conclusions and contributions to the literature are briefly summarized.

2. BACKGROUND INFORMATION

Increasing energy and water demand and concern about the climate crisis emphasized the need to evaluate renewable energy sources as an alternative to the energy supply. Water consumption for energy supply and energy consumption for clean water supply show a mutual relationship between energy and water. WWTPs use a significant percentage of the world's energy. The self-sufficiency of WWTPs with electricity generated from renewable sources is of great importance for the environment and the national economy when the global warming effects and energy dependence of Türkiye are considered.

In this chapter, a brief overview of wastewater treatment technologies in Türkiye and the energy intensity of WWTPs have been shortly mentioned. The energy intensity of WWTPs having different treatment technologies has been classified worldwide. Finally, the electricity consumption issue of WWTPs in Türkiye has been indicated.

2.1. Wastewater Treatment Technologies in Türkiye

Based on the Turkish Statistical Institute, there are four categories of WWTPs operated by the municipalities in Türkiye. These are physical treatment, biological treatment, advanced treatment, and artificial wetlands.

Physical treatment is a method used to treat wastewater by applying physical forces. Screening, grit removal, flow equalization, primary sedimentation, and flotation are examples of physical unit processes used for wastewater treatment [5].

Biological treatment is used to remove constituents in wastewater with biological activities. The biological treatment aims to convert colloidal or dissolved biodegradable organic substances to gases and biological flocs. So, gas forms can be emitted into the atmosphere, and biological flocs can be separated by settling or another solid removal method. Trickling filters, activated sludge, and oxidation ponds are the main processes used in biological treatment [5].

Advanced treatment is used to meet more stringent discharge criteria. This method primarily removes nutrients such as nitrogen and phosphorus to limit eutrophication, besides removing suspended solids and organic matter [5].

Artificial wetlands provide treatment in a natural and environmentally friendly way. Soil, plants, and gravels are the materials used for this treatment method. The artificial wetland is a lower-cost technology than the other methods, which is its advantage; however, slow rate performance is its disadvantage [6].

Based on the Turkish Statistical Institute, the number of WWTPs from 2010 to 2018 is shown in Figure 2.2. The graph shows the highest number of WWTPs where biological treatment is applied. Also, biological treatment has the highest rate of increase from 2010 to 2018 [7].

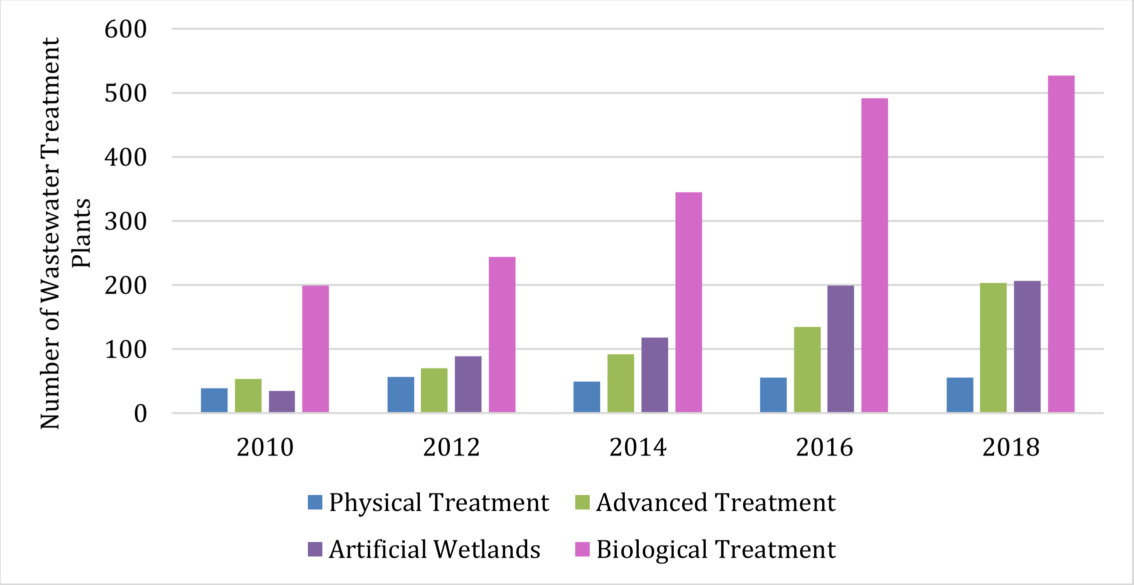

Figure 2.2. Number of WWTPs in Türkiye (adapted from [8])

Based on the Turkish Statistical Institute, the capacity of WWTPs from 2010 to 2018 is shown in Figure 2.3. As of 2018, advanced treatment has the highest capacity of the other methods. While there was no increase in the capacities of the physical treatment, biological treatment, and artificial wetlands from 2010 to 2018, the capacity of the advanced treatment plants increased gradually [9].

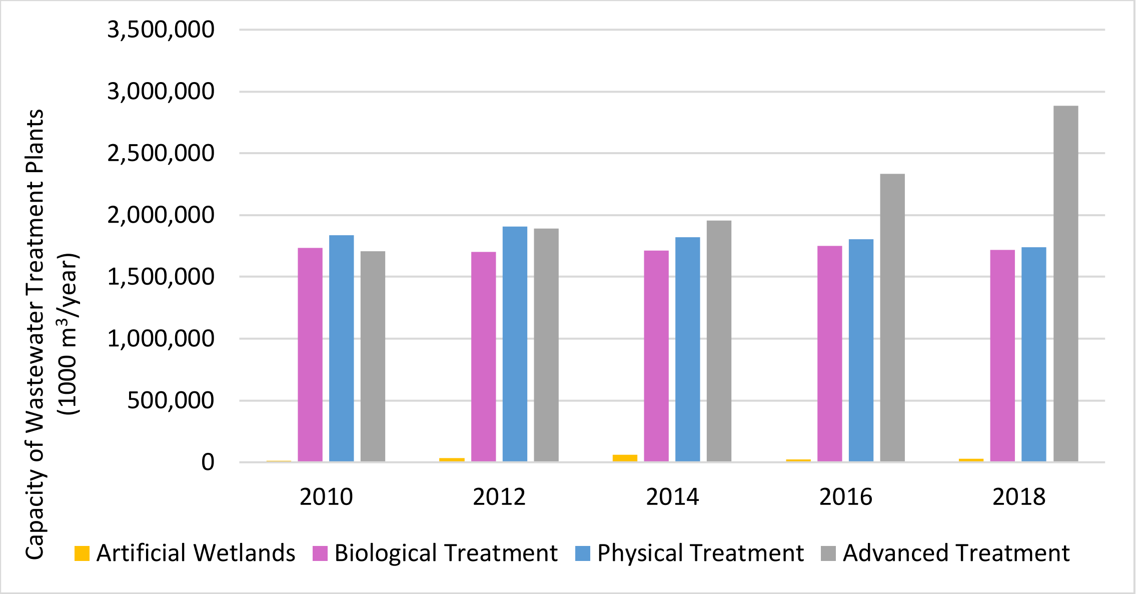

Figure 2.3. The capacity of WWTPs in Türkiye (adapted from [10])

As of 2018, there are 527 WWTPs where biological treatment is applied and 203 WWTPs where advanced treatment is applied. However, it is considered that the total capacity of the biological WWTPs is 1,718,037 thousand m^3/year, although the total capacity of the advanced WWTPs is 2,884,750 thousand m^3/year. While biological WWTPs are much more in number than advanced WWTPs, the total capacity of advanced WWTPs is approximately two times higher. It indicates that the capacity of each plant where advanced treatment is used is much more than biological treatment plants. In conclusion, advanced treatment is used in WWTPs with high capacity in Türkiye.

There were 201 WWTPs with biological treatment processes in 2010 based on the Ministry of Environment and Urbanization survey. The distribution of the processes is shown in Figure 2.4. Distribution based on the flow rate of treated wastewater for each process is given in Figure 2.5. In the evaluation, A/O, A^2/O, SBR, Bardenpho, MBR, and UCT processes are considered BNR. Pie charts illustrate that BNR and CAS processes are used for the high-capacity plants. Although EAAS is the most preferred process, it is preferred for the lower capacity treatment plants than the BNR and CAS processes. The same result was valid for the ST processes [11].

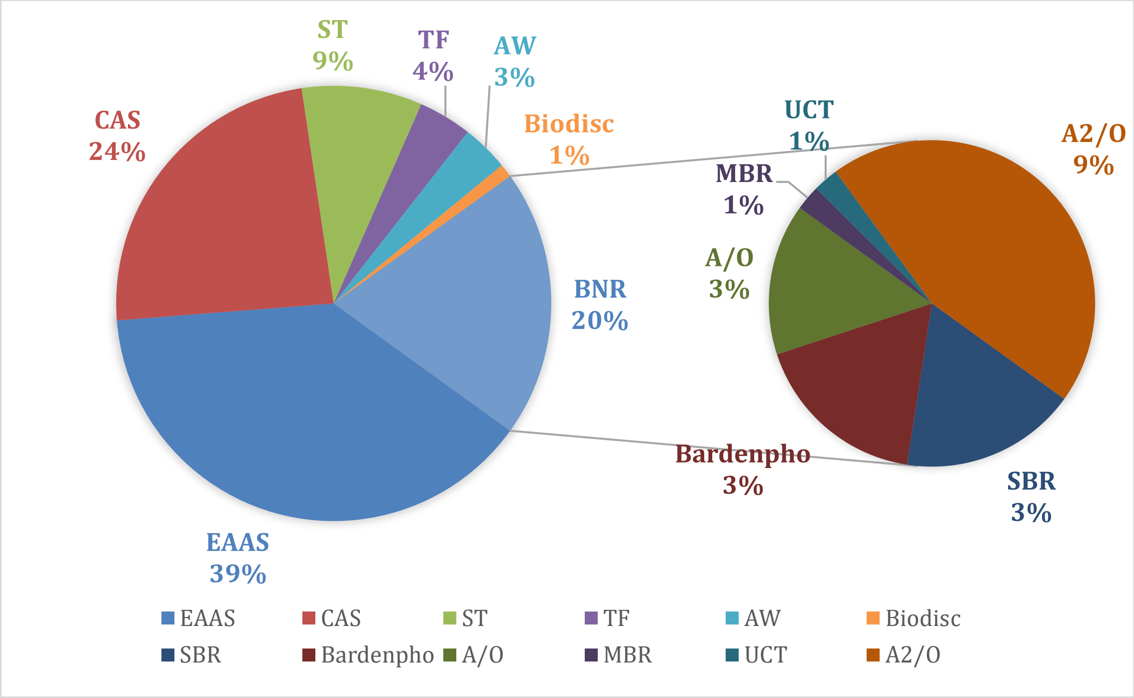

Figure 2.4. Biological WWTPs in Türkiye based on the number of WWTP (adapted from [12])

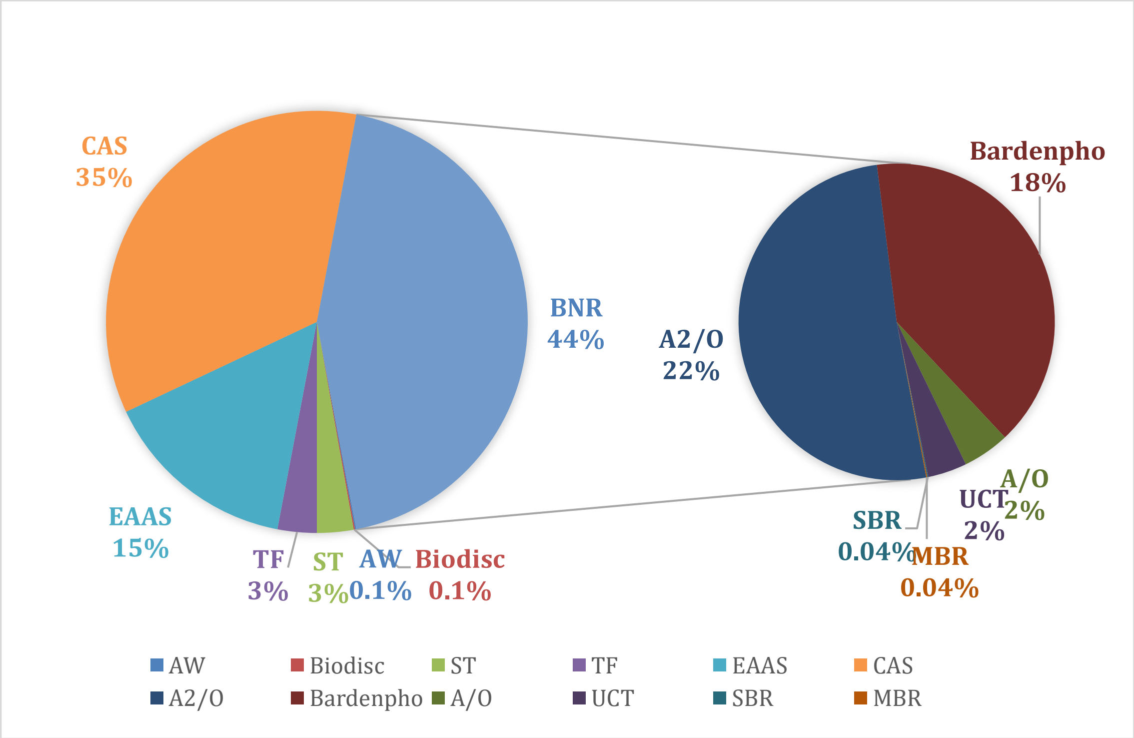

Figure 2.5. Biological WWTPs in Türkiye based on the treated wastewater (adapted from [12])

2.2. Energy Intensity of WWTPs

Li et al. (2020) evaluated the adverse impacts of WWTPs based on the life cycle assessment (LCA) approach using 54 studies covering 109 relevant case studies. Energy intensity was the primary factor contributing to the adverse impacts of WWTPs in terms of energy use and its indirect effect caused by fossil fuels. In this research, China has the highest energy intensity, followed by the rest of Asia, Europe, North America, and Africa, because of the old technology and unscientific management compared to other countries. Electricity intensity was estimated between 0.37 kWh/m^3 and 0.34 kWh/m^3 in other countries, while the operational phase is 0.29-0.33 kWh/m^3 for Chinese municipal WWTPs. Meta-analysis of the research shows that different technologies and discharge criteria also affect EI in the same country. A^{2}O process has a higher energy use than CAS and A/O processes at 0.39, 0.37, and 0.28 kWh/m^{3,} respectively [13].

The main factor that affects the EI is WWTP capacity based on the literature investigation. So, there are five categories of WWTPs which have 0-2, 2–5, 5–10, 10–20, and over 20 × 10^4 m^3 /d, respectively [13]. There is a reverse relationship between plant capacity and EI, as seen in Figure 2.6 [13].

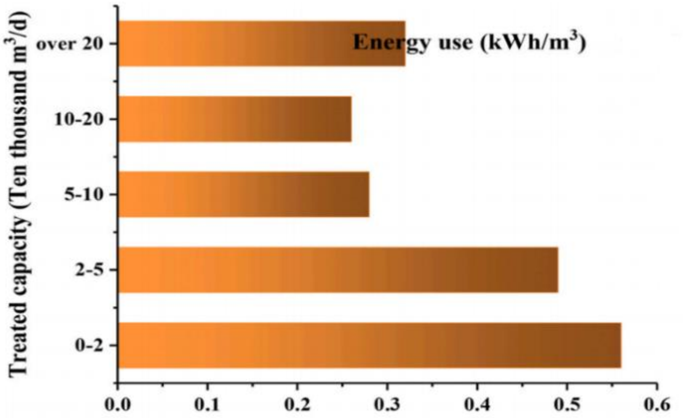

Figure 2.6. Relationship between WWTP capacity and EI [13]

Sabia et al. (2020) have proposed a methodology to evaluate the energy performance of WWTPs. Three key performance indicators have been identified: wastewater volume, population equivalent, and removed COD based on the data of 250 WWTPs in Italy. Energy intensity results are summarized in Figure 2.7. The result of the study is consistent with the other literature reviews showing that a larger capacity of WWTP decreases the key performance indicator value. Since small WWPPs generally have simplified configurations, fluctuating volumetric and organic load is not controlled in their operations. So, they are less economically sustainable than the WWPTs, which have larger design capacities [14].

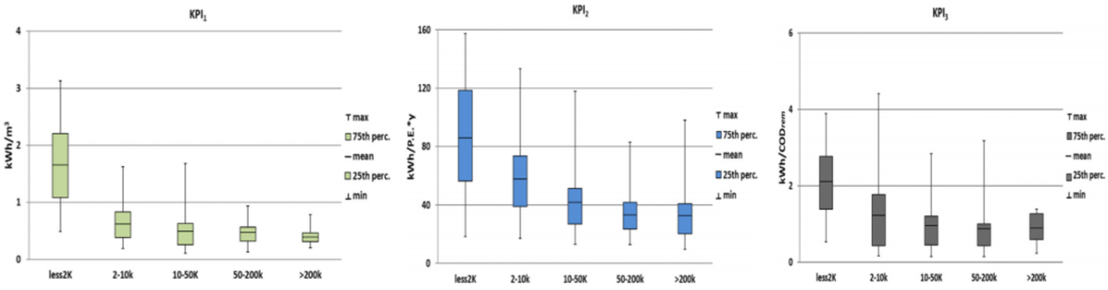

Figure 2.7. Energy intensity of different treatment technologies in different scales [14]

Niu et al. (2019) have found that China has the most energy-intensive WWTPs based on the extensive dataset they have compiled for their research. They have revealed that WWTPs should be evaluated according to their capacity and applied technology deeply in different countries. Figure 2.8 shows EI in terms of COD removal and treatment scale in PE in different countries with different technologies. As seen in the figure, there is more deviation in EI for WWTPs when PE is less than 2000 people. For instance, the median values of EI are larger in Italy than in China, followed by 3.2 kWh/kg COD, and 2.37 kWh/kg COD, respectively, when PE is less than 2000 people. However, EI is smaller in Italy than in China when PE is larger than 100.000 people. It is 0.80 and 0.88, respectively. So, it has been concluded that the median EI values in COD removal for those PE are more comparable for different countries. When looking at other countries, it is 0.65 kWh/kg COD in Austria and 0.69 kWh/kg COD in other countries [15].

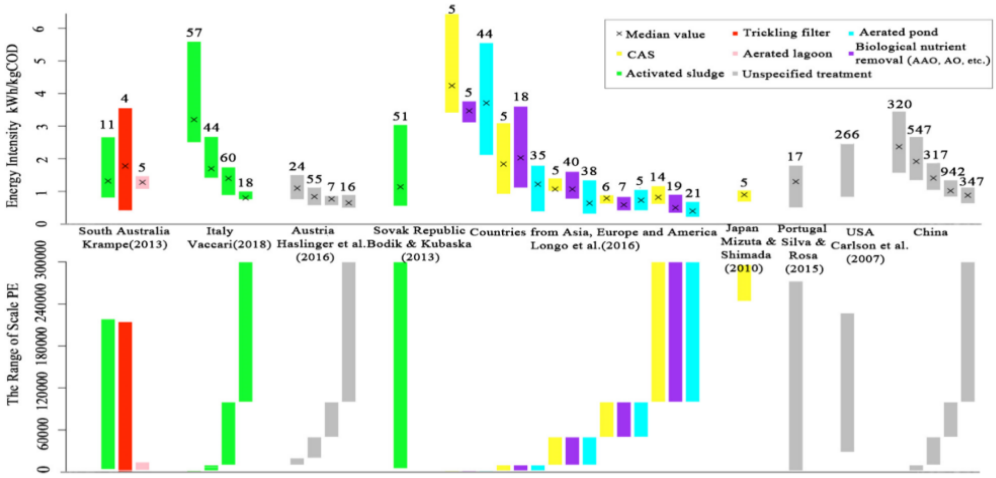

Figure 2.8. Energy consumption of WWTPs in different countries [15]

Niu et al. (2019) have evaluated the secondary treatment processes, the primary treatment process in China covering AAO, AO, OD, IAS, BF, and SBR. In the study, there are five categories in terms of PE. Figure 2.9 shows the energy intensity of WWTPs with different treatment technology in different treatment scales. It has been concluded that a more significant variance exists for PE smaller than 2000 people. When comparing treatment technologies, the energy intensity of OD and AAO is higher than BF and SBR [15].

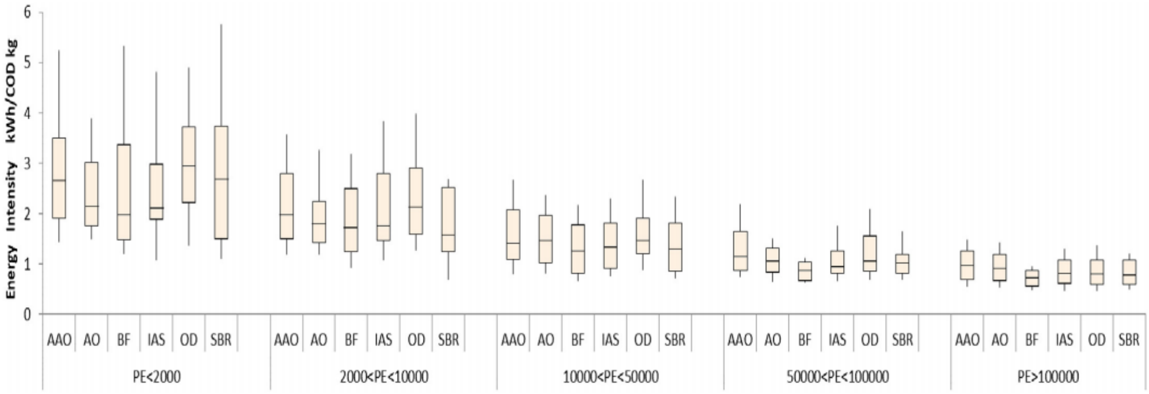

Figure 2.9. Energy intensity of different treatment technologies in different scales [15]

He et al. (2019) have done comprehensive research, including an analysis of 1,184 urban WWTPs to evaluate design parameters in terms of energy consumption over 30 years. Assessment of energy consumption of these WWTPs in terms of location, the scale of the plant, effluent discharge standards, and treatment process type has been considered in this paper. The first parameter was the location which is classified into seven regions of China. The energy intensities of the plants located in seven different regions of China were determined specifically. The second parameter was the scale of the plant. WWTPs are categorized into five groups based on their capacities. There were 714 plants with capacities of less than 50,000 m^3/day. The energy intensity range of these plants was between 0.330±0.216 kWh/ m^3. It was 0.256±0.091 kWh/ m^3 for 255 plants having a capacity between 50,000-100,000 m^3/day, 0.254±0.101 kWh/ m^3 for 147 plants having a capacity between 100,000-200,000 m^3/day, 0.249±0.072 kWh/ m^3 for 56 plants having a capacity between 200,000-500,000 m^3/day, and 0.308±0.092 kWh/ m^3 for 12 plants having a capacity more than 500,000 m^3/day. The third one is discharge criteria. Discharge criteria are divided into four groups. It was concluded that there was a certain increase in energy intensity when the discharge criteria were stricter. The last parameter is the treatment process type which includes A^2/O + A/O, oxidation ditch (OD), sequencing batch reactor (SBR), and membrane bioreactor (MBR) [16]. The energy intensity of four groups of treatment processes is given in Figure 2.10.

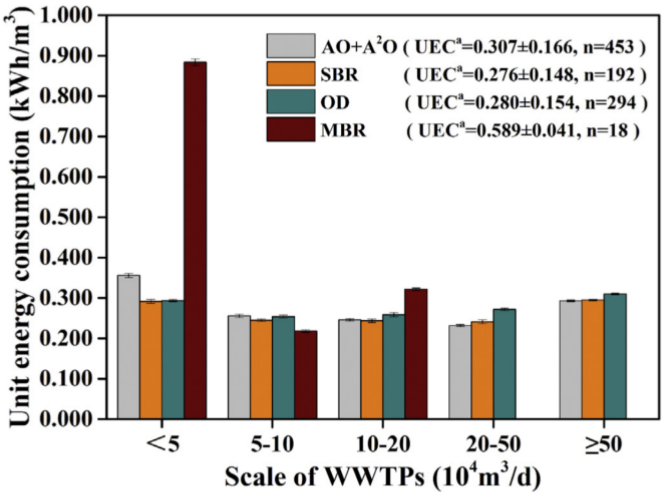

Figure 2.10. Energy intensity of different treatment technologies in different scales [16]

The amount of energy used and cost per cubic meter of the plants were determined using the Ministry of Environment and Urbanization survey data. The distribution of the energy used for the unit treated wastewater amount declared by the plants in the surveys according to the applied treatment processes is given in Figure 2.11 [11].

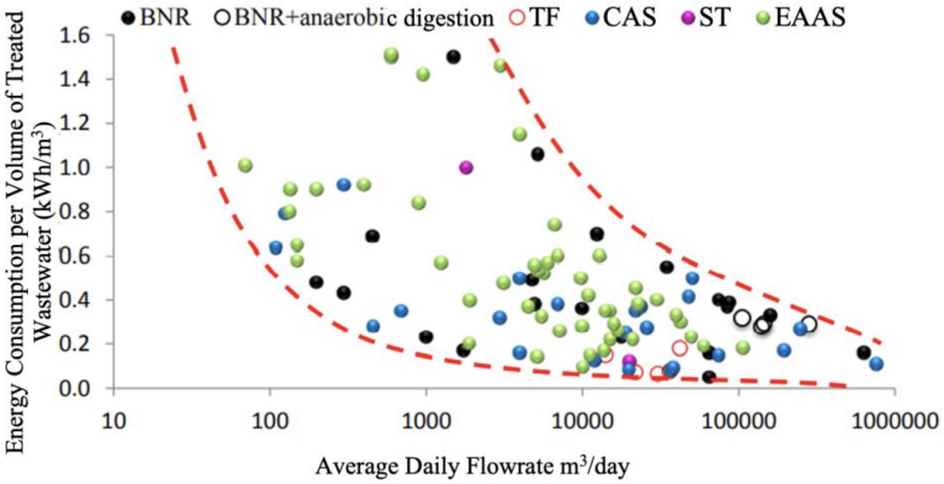

Figure 2.11. Energy consumed per unit treated wastewater in Türkiye [11]

Unit flow costs declared by the plants are given in Figure 2.12. When the graphs are compared, it is seen that as the plant capacity decreases, there are more energy consumption and cost deviations. Parallel to the increase in flow rate, energy consumption decreases, and therefore plant operating costs decrease [11].

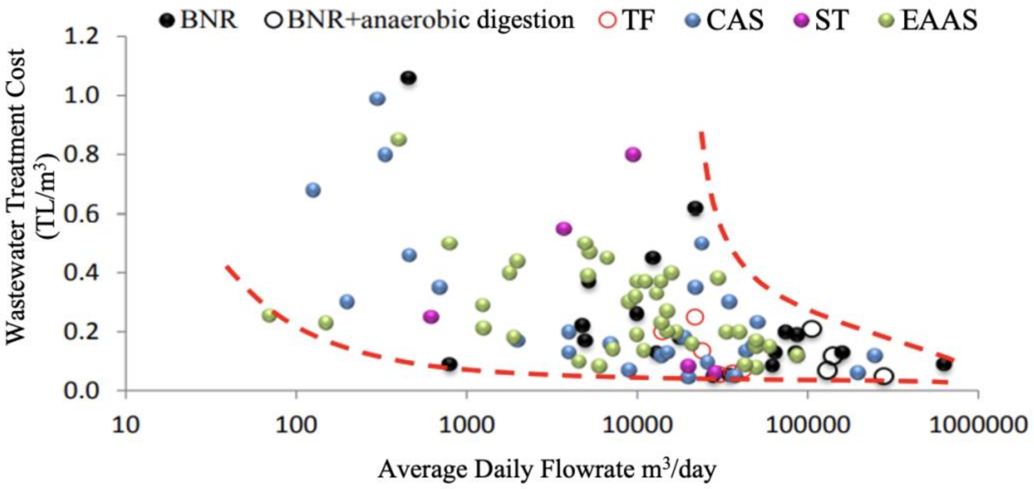

Figure 2.12. Unit treated wastewater costs of the plants in Türkiye [11]

Viciano *et al*. (2018) mentioned that the treated wastewater volume and contaminant load are considered for the cost functions in the literature. However, one more variable should be caused by the mismatching between WWTPs' capacity and treated wastewater volume design. So, three main parameters should be considered for the energy cost estimation.

These are the treated wastewater volume, contaminant load, and mismatches between design capacity and treated wastewater, called z value. Energy cost projection is given in Figure 2.13 [17] for different scenarios.

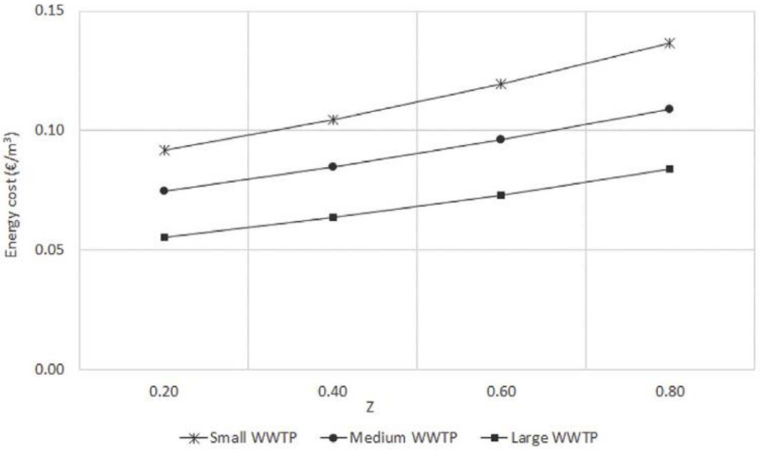

Figure 2.13. Energy cost projection for different scenarios [17]

Table 2.1. Summary table of studies on energy intensities

Parameter	**Energy Intensity**	**Unit**	**Location**	**References**
A/O	0.28	kWh/m^3	China	[13]
	0.90-2.18	kW/ kg COD_{rem}	-	[15]
A^2/O	0.39	kWh/m^3	China	[13]
	0.99-2.69	kW/ kg COD_{rem}	-	[15]
BNR	0.49-3.45	kWh/ kg COD_{rem}	Countries from Asia, Europe and America	[15]
	0.23-0.36	kWh/m^3	China	[16]
	0.10-1.50	kWh/m^3	Türkiye	[11]
BNR+Anaerobic Digestion	0.30	kWh/m^3	Türkiye	[11]
CAS	0.37	kWh/m^3	China	[13]
	1.31	kW/ kg COD_{rem}	South Australia	[15]
	0.80-3.20	kW/ kg COD_{rem}	Italy	[15]
	1.14	kW/ kg COD_{rem}	Sovak Republic	[15]
	0.80-4.24	kW/ kg COD_{rem}	Countries from Asia, Europe and America	[15]
	0.9	kW/ kg COD_{rem}	Japan	[15]
	0.10-0.90	kWh/m^3	Türkiye	[11]
EAAS	0.80-2.11	kW/ kg COD_{rem}	-	[15]
	0.10-1.50	kWh/m^3	Türkiye	[11]
MBR	0.22-0.88	kWh/m^3	China	[16]
SBR	0.79-2.70	kW/ kg COD_{rem}	-	[15]
	0.24-0.30	kWh/m^3	China	[16]

2.3. Closing Remarks

The energy intensity of WWTPs has been the most significant contributing factor in energy use and indirect effects caused by fossil fuels. Therefore, the factors affecting the energy intensity in the WWTPs should be overviewed before evaluating the integration of alternative energy sources into the plants. In Türkiye, biological treatment plants have the highest rate of increase, while advanced treatment has the highest capacity of the other methods. While biological WWTPs are much more in number than advanced WWTPs, the total capacity of advanced WWTPs is approximately two times higher. It indicates that the capacity of each plant where advanced treatment is used is much more than biological treatment plants. In conclusion, advanced treatment is used in WWTPs with high capacity in Türkiye. Although EAAS is the most preferred process, it is preferred for the lower capacity treatment plants than the BNR and CAS processes.

The energy intensity of WWTPs has been examined worldwide in many studies and evaluated based on the location, treatment scale, discharge criteria, and treatment process types. Different technologies and discharge criteria also affect EI in the same country as it varies on a country basis. Previous studies have shown that energy intensity could be analyzed mainly in kW per unit m^3 or per unit kg COD removal.

It was concluded that there was a reverse relationship between plant capacity and EI. Since they generally have simplified configurations, fluctuating volumetric and organic load is not controlled in small WWTPs. So, they are less economically sustainable than the WWTPs, which have a larger design capacity. When comparing treatment technologies, the energy intensity of A_2O, EAAS, and CAS processes was higher than that of other technologies. Furthermore, there was a certain increase in energy intensity when the discharge criteria were strict.

3. PREVIOUS STUDIES

Integrating renewable energy sources into WWTPs has taken off to supply the required energy demand for wastewater treatment reliably and sustainably. Providing the energy requirement for wastewater treatment from renewable sources and turning a wastewater treatment plant into an energy-independent and self-sufficient state is economically and environmentally beneficial.

There are many studies in the open literature on integrating renewable energy sources into WWTPs. In this chapter, these studies investigating the integration of renewable energy sources into WWTPs have been mentioned. They have been classified by WWTP scale, process type, integrated renewable energy systems types, and country where these systems were applied. Finally, deliverables of the studies, such as the amount of emission and cost reduction, have been provided.

3.1. PV-Only Systems

Han et al. conducted an experimental work about integrating PV without a battery into an oxidation ditch in China. The oxidation ditch influent flow rate was 30–45 L/hr. Since the system operates without a storage battery, which can reduce the cost of the PV system, the solar radiation intensity affects the amount of power output from the PV system. The oxidation ditch driven by the PV system without the battery worked during the day and stopped at night. Therefore, anaerobic, anoxic and aerobic conditions may periodically occur in the oxidation channel, which is favourable for nitrogen and phosphate removal from wastewater. Experimental results showed that the system was efficient based on average removal efficiencies [18].

Taha and Al-Sa'ed examined the energy consumption and removal efficiency of three WWTPs in Palestine and the potential application of renewable energy. As case studies, three urban WWTPs with different technologies were selected. These technologies were conventional activated sludge with anaerobic sludge digestion, extended aeration and membrane bioreactor (MBR). For two MBR plants, calculations were made using the earlier assumptions and showed that solar PV would cover about 9% and 15% of the energy demand for pump stations, respectively. However, less than 5% of pump stations were operated in the WWTP with the CAS system [19].

Yang et al. investigated whether WWTPs could save energy or even become a net energy producer by integrating sludge incineration, photovoltaic (PV) generation and thermal energy recovery. The model was developed using data from 347 WWTPs in China. All WWTPs under investigation had the anaerobic anoxic-aerobic (AAO) process. For WWTPs with influent flow rates of 1,296–100,000 m^3/d, the energy self-sufficiency rate in sludge incineration was −12.9 to −2.37% because of the high-water content. It was attractive to integrate PV in WWTPs because it could operate all year round and provide electricity directly to the WWTPs with minimal adverse environmental impact, which could meet 12.2–19.3% of total energy consumption. Compared to PV energy generation, thermal energy recovery showed a more significant energy recovery potential, which was 35.2–253.5% [20].

Chen and Zhou examined the PV potentials of large-scale WWTPs in China. For the PV potentials of the plants, 31 WWTPs were evaluated using financial and carbon emission models. These plants had different treatment technologies, such as SBR, AAO, AO and OD, in the order of power consumption. Among the 31 WWTP-PV projects in China, 26 were economically feasible, judging by the economic analysis. Further, WWTP-PV projects could reduce carbon emissions by 10%-40%. Among the study results, the PV potential of a WWTP is positively correlated with the planned wastewater treatment capacity [21].

3.2. Hydro-Only Systems

Micro hydropower (MHP) has been evaluated as a potential power source for WWTPs by a group of researchers. Power et al. examined the possibility of improving sustainability by using hydropower turbines at the outlets of WWTPs. The operational data of over 100 plants in Ireland and the UK was collected. The study results present that hydropower energy recovery is only feasible for large plants with high flow rates in Ireland and the UK, with annual savings totalling 168,664 Euro/yr in Ireland and a total of 777,643 Euro/yr in the UK. Moreover, it has been determined that in 14 plants where hydropower was feasible, carbon dioxide emissions of over 900 tons CO_2 and 50% of energy could be saved annually for them [22].

Bousquet et al. evaluated WWTPs in Switzerland. An economic analysis was made by determining these plants' hydroelectric potential, and GIS data were used to make this analysis. In the article, two evaluations were made for the wastewater coming to the plants and the plants' treated water. Micro-scale hydroelectric systems established upstream of the plants were found more suitable for urban areas in the economic analysis. These urban areas were located on an elevation with a head less than 10 meters, and WWTPs had a flow rate greater than 40,000 m^3/day in urban areas. However, systems established downstream of the plants were more profitable for the mountainous regions. Mountainous regions had a head higher than 400 meters, and WWTPs had a flow rate greater than 5,000 m^3/day in these regions. As a result of the study, the methodology applied to Switzerland resulted in the identified 110 sites with 18.7 GWh/year undiscovered and 3.5 GWh/year produced from current projects. However, under the assumptions of the proposed methodology, only 19 sites with a total of 9.3 GWh/year were considered profitable [23].

Chae et al. tested a micro-hydropower (MHP) system with a flow-variable turbine for over a year to determine its viability for small-scale municipal WWTPs with severe flow fluctuations. Compared with similar WWTP-based hydropower systems in South Korea, the semi-Kaplan MHP achieved 1.78–2.80 times higher normalized electricity in both flow rate and net head, indicating more efficient use. The applied MHP produces 69 MWh of green hydro-energy annually, reducing 39 tons of CO_2 emissions. Even though this MHP application is not self-sufficient in terms of energy, it can be used to reduce electricity expenses by decreasing or shifting electricity consumption to off-peak hours during critical peak periods when energy demand is high. These results should draw new interest in the WWTP-based MHP, which is considered unfeasible in Korea due to its low efficiency [24].

Ak et al. aimed to determine the most sustainable Low-Head (LH) hydropower technology option to generate hydropower at the outlet of WWTPs. In this study, economic, technical, and environmental criteria are evaluated. The fuzzy logic approach evaluates criteria such as investment cost, payback period, energy production performance, construction time, fish friendliness, and aeration capacity. This method has been applied to the Tatlar WWTP with a 750,000 m^3/day capacity in Türkiye. The study results show that the most viable hydroelectric technology for the outlet of Tatlar WWTP is the Archimedean screw due to its superior environmental and economic performance. The payback period for Archimedean screw installation is only 2.6 years. The electricity produced by a hydroelectric power plant installed at the outlet of the wastewater treatment plant can contribute to supplying approximately 34% of the plant's electricity consumption [25].

Bekker et al. analyzed previous studies on hydropower potential to address the gap in research to identify energy recovery potential with available data, specifically focusing on the feasibility of hydropower at WWTPs and the most appropriate technologies for them. With limited access to data, it was proposed to develop an evaluation framework for WWTW hydropower to help quantify hydropower potential in South African municipal WWTWs. The total hydropower potential of all WWTWs in Gauteng was determined using this framework. With the development of the existing hydroelectric potential, between 1,123 and 7,638 MWh/year of hydroelectricity can be produced in Gauteng's ten largest WWTWs with a capacity of 65-450 ML/day. According to the analyses, these sites could offer viable solutions [26].

3.3. Hybrid Systems or Combined Systems

Nguyen et al. described a holistic management approach for integrating renewable energy sources into a WWTP. Many factors, such as reliability and environmental and economic factors, were considered to determine the size of the hybrid renewable energy sources in the specified WWTP. Renewable energy sources, which were integrated into the plant, covered a hybrid photovoltaic-wind turbine system with hydrogen and battery storage. A fuzzy decision-making method was applied for sizing components and evaluating the feasibility of these energy sources in the plant. The optimization model results show that 165 PV and five wind turbines gave the best outcome for this WWTP with acceptable environmental emissions of 932.78 tons/year of CO_2 emission and an economical budget. In the scenario with the best configuration, the energy cost was found to be 0.0488 $/kWh/yr [27].

Campana et al. investigated the potential of self-sufficiency of WWTPs through an optimization model. The study mainly aimed to integrate photovoltaic systems with wind turbines, technologies of multi-energy storage, and reverse osmosis tertiary treatment to utilize the power production surpluses. As the first part of the study, the model was developed and applied to medium-scale Italian municipal WWTPs. Then the model was applied to different locations and plant scales across the globe, generalization was successively accomplished. The process was composed of pre-treatment, primary sedimentation, secondary biological treatment, and disinfection in the medium-scale Italian municipal wastewater treatment line. As a result of the optimization model, WWTP, with the highest share of renewable energy, has achieved a self-sufficiency ratio of 70%. Levelized costs of treated water at high-capacity WWTPs (i.e., more than 1,000 m^3/day) have not substantially increased when renewable energy penetration is high (i.e., greater than 90%), compared to the reference case (electricity demand covered by the electric grid) [28].

Xu et al. proposed a grid-connected PV system, wind turbines and battery storage devices for existing WWTPs and evaluated its regional potential. In this study, fuzzy numbers are used to estimate electricity consumption and available layout areas for 1,662 WWTPs which were classified into seven categories based on their scales. In the seven WWTP categories, the levelized cost of electricity (LCOE) and self-sufficiency ratio (SSR) had a V-shaped shape presenting WWTPs with flowrates between 20,000 and 50,000 m^3/day having the lowest LCOE and highest SSR. The decarbonization potential of these WWTPS was 2.572 Mt/year, and the annual electricity saved was 1.957 billion CNY [29].

Ali et al. evaluated many types of renewable energy sources to shift WWTPs' electricity production and demand to reduce the size of 100% renewable electricity grids and achieve perfect supply-demand matching. These renewable energy sources included hydro, biomass, wind, PV, CST, sewage methane and rooftop PV. An 11% reduction in LCOE was obtained as a result of the study [30].

Woo et al. proposed three self-sufficient designs to assess six WWTPs on Jeju Island, South Korea. Bi-level nonlinear optimization models were used to determine the environmental, social, and economic conditions of these WWTPs. Biogas-fed combined heat and power plants, solar-powered plants and hybrid CHPP plants retrofitted with PV systems were considered in this study. The results showed that WWTP with an SBR system and smaller capacity than others, was the most environmentally and economically profitable of the six WWTPs on Jeju Island, with the greatest environmental impacts and 6,809 USD per year [31].

Chae and Kang evaluated a WWTP with a modified activated sludge process in Korea. An economic analysis was made by considering the study's PV, hydroelectric, and heat recovery technologies. It has been concluded that many of these resources have a payback period of seven years. As a result of the analyses, it is aimed to guide those who organize and plan policies on this topic. The plants with a capacity above 30,000 m^3/day were analyzed. It was estimated that 261 tons of CO_2/yr would be reduced, and energy independence would reach 6.5% for the plant [32].

Brandoni and Bošnjaković investigated the benefits of renewable energy technologies when integrated into WWTPs in Africa's arid regions. The electrical loads of a WWTP based on a conventional activated sludge system and a WWTP based on a membrane bioreactor were analyzed using HOMER. Wind energy, solar energy and biogas were considered in this analysis. It was estimated that integrating renewable technologies would provide good coverage of the electrical load required by a WWTP and reach a renewable fraction of 33% - 74% for different scenarios [33].

Strazzabosco et al. assessed the current solar photovoltaic (PV) integration for WWTPs across various sizes and identified opportunities for solar PV. Data from 105 Californian WWTPs were compiled and analyzed in the study. A solar PV system was installed at 41 of the 105 plants studied. A solar PV system was installed at 40 of the 41 plants with a flow rate below 59 mega gallons day^{-1} (MDG), but not at any plant above 59 MGD unless specific circumstances occurred. Solar PV in hybrid energy configurations was positively influenced by anaerobic digestion in WWTPs with flow rates above 5 MGD. Biogas met 25% to 65% of the energy demand in plants in this flow range, while solar energy provided 8% to 30%. As a result of combining biogas with solar PV, the energy management strategies for the plants could be more flexible, decreasing their energy demand. The inability to generate energy from biogas in WWTPs with a flow rate below 5 MGD could have led to increased use of solar PV systems. Solar PV, the only renewable energy source, meets 30% and 100% of these plants' energy demands. These results showed a correlation between wastewater treatment plant size and solar PV adoption [34].

Helal et al. evaluated a wastewater treatment plant with an 8,000 m^3/day capacity in Egypt. Both environmental and economic studies focused on biogas, thermal energy, solar, and wind energies. AC-DC combinations for wind and solar were also evaluated in this article. HOMER simulation software was used for these analyses. The purpose of the simulation was to obtain the best system configuration and optimum size of the components for the lowest emissions with the minimum cost. Results proved the best connection of PV and wind turbines to the DC bus. However, battery storage was an expensive part of the system. The study demonstrated that biogas and combined heat power are more economical than PV and wind turbine systems because wind power may decrease, and PV systems are shut down at night [35].

3.4. Closing Remarks

Various studies evaluating the integration of various renewable energy sources into WWTPs are reviewed. Some of these studies included PV-only systems, some hydro-only systems, and some hybrid or combined systems in which many renewable sources such as solar, wind, hydro, and biogas were evaluated. The integration of renewable energy sources calculated how much emission and cost reduction could be achieved by which technology type and scales of the WWTPs. The results of these studies are summarized in Table 3.2.

When looking at these reviewed studies, it is seen that large-scale WWTPs are primarily analyzed, and the renewable energy integration for these large-scale plants was found to be both environmentally and economically viable. While the results highlighted a significant emission and cost reduction in plants, studies even concluded the feasibility of 100% self-sufficiency.

Table 3.2. Summary table of the overview of previous studies

Study	**WWTP Scale**	**Process Type of WWTP**	**Type of Integrated RES**	**Emission and Cost Reduction (%)**	**Country**
Nguyen et al. [27]	N/A	N/A	hybrid photovoltaic-wind turbine system with hydrogen and battery storage	Emission reduction is limited to an acceptable emission reduction of 932.78 tons CO_2/year, and the energy cost is found to be 0.0488 $/kWh/yr.	Vietnam
Campana et al. [28]	86, 400 PE (medium scale)	The treatment line is composed of pretreatment, primary sedimentation, secondary biological treatment, and disinfection	photovoltaic systems with wind turbines, technologies of multi-energy storage, and reverse osmosis tertiary treatment	Self-sufficiency ratio of 70%	Italy
Xu et al. [29]	seven categories between 1,000 and 500,000 m^3/day best scenario btw 20,000-50,000 m^3/day	N/A	PV systems, wind turbines and battery storage devices	2.572 Mt/year decarbonization 1.957 billion CNY saved	China
Ali et al. [30]	N/A	N/A	hydro, biomass, wind, PV, CST, sewage methane and rooftop PV	100% renewable electricity and 11% reduction in LCOE	Australia
Woo et al. [31]	N/A	N/A	biogas-fed combined heat and power, solar-powered and hybrid CHPP plants retrofitted with PV systems	The solar-powered plant is the most environmentally and economic scenario with 2 points/day and 6,809 USD/year	South Korea
Chae and Kang [32]	30,000 m^3/day	modified activated sludge process	PV, hydro and heat recovery	261 tons CO_2/yr and 6,5% Self-sufficiency	Korea
Brandoni and Bošnjaković [33]	N/A	Activated sludge process and Membrane bioreactor	Wind, PV, Biogas	33%-74% energy save	Africa
Strazzabosco et al. [34]	QWWTP<5 MGD	N/A	PV and Biogas	8% and 100% energy save	California

Study	WWTP Scale	Process Type of WWTP	Type of Integrated RES	Emission and Cost Reduction (%)	Country
	5 MGD<QWWTP<50 MGD 50 MGD<QWWTP				
Helal et al. [35]	8,000 m^3/day	Conventional activated sludge	biogas, thermal energy, solar, and wind energies	N/A	Egypt
Power et al. [22]	Suitable for large plants with high flow rates	N/A, however mainly based on Activated	Micro Hydropower	annual savings total 168,664 Euro/yr in Ireland total 777,643 Euro/yr in UK 900 tons of CO_2 and 50% energy could be saved annually for 14 WWTPs	Ireland and the UK
Bousquet et al. [23]	Large scale above 5,000 m^3/day	N/A	Micro Hydropower	feasible for 19 sites with a total of 9.3 GWh/year	Switzerland
Chae et al. [24]	0.35 m^3/s with a flexible range of flows from 57% to 123%	N/A	Micro Hydropower	39 tons CO_2/yr	South Korea
Ak et al. [25]	765,000 m^3/day	Active sludge	Micro Hydropower	supply 34% of the electricity consumption	Türkiye
Bekker et al. [26]	10 WWTWs 65-450 ML/day	N/A	Hydro	10 WWTWs could generate between 1,123 and 7,638 MWh/annum	South Africa
Han et al. [18]	36-45 L/hr	oxidation ditch	PV without battery	N/A	China
Taha and Al-Sa'ed [19]	N/A	conventional activated sludge, extended aeration and MBR	PV	5%-15% energy save	Palestine
Yang et al. [20]	1,296–100,000 m^3/d	AAO	sludge incineration, PV and thermal energy	12.2%-253.5% energy self-sufficiency rate	China
Chen and Zhou [21]	Large scale	Power Consumption SBR>AAO>AO>OD	PV	Among 31 WWTPs, 26 are economically viable	China

4. METHODOLOGY AND DATA SOURCES

In this chapter, methodology and data sources are discussed in detail. A flowchart diagram of the methodology is given in Figure 4.14.

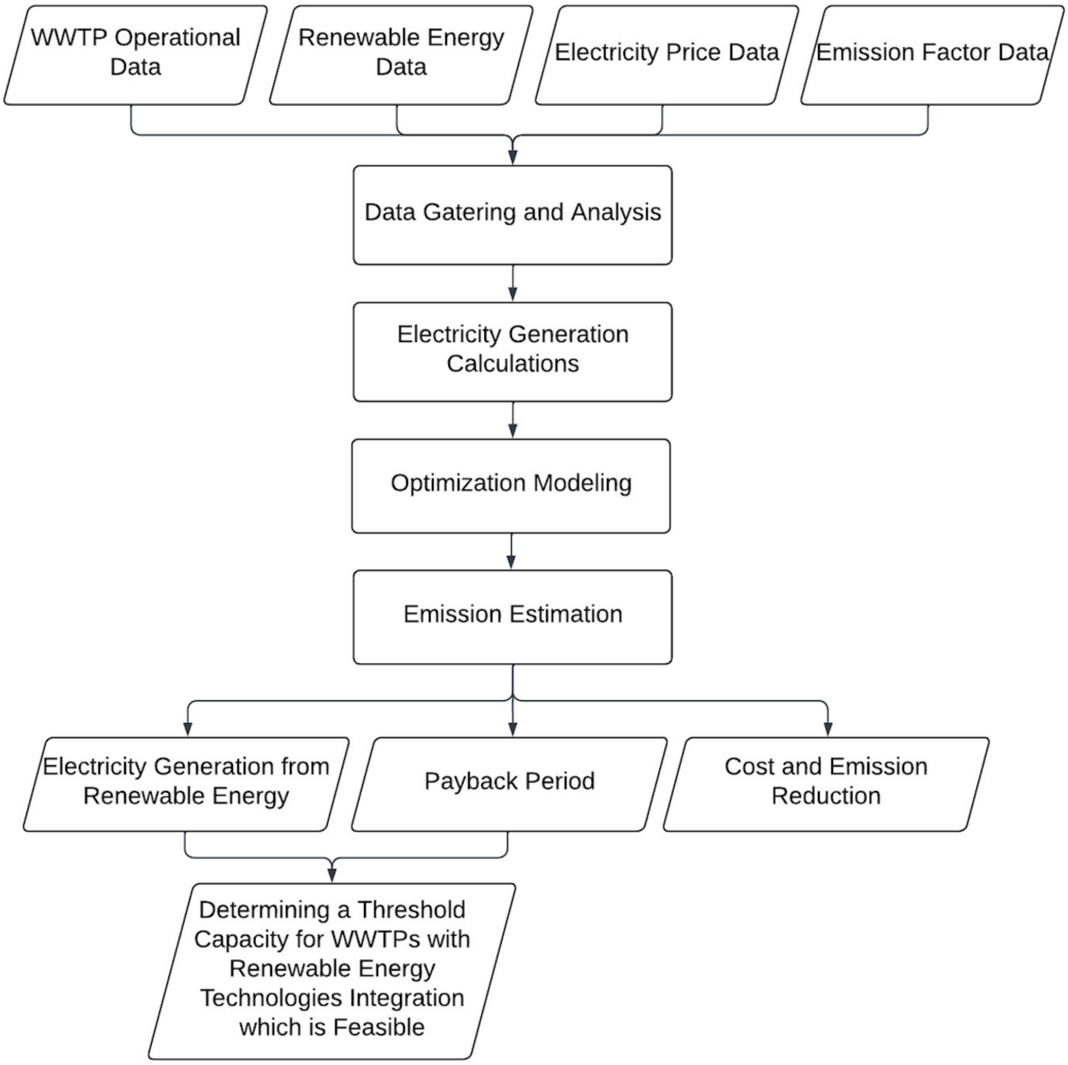

Figure 4.14. Flowchart diagram of the methodology

4.1. Data Gathering and Analysis

This section outlines the data gathering and analysis used in this thesis to achieve the study's objectives. It is divided into five main sections: WWTPs’ data, solar system data, wind system data, hydro system data, and electricity sale price. Once the raw data from the WWTPs have been gathered, a selection of plants is made for evaluation, and an analysis is conducted on the solar, wind, and hydro systems. Finally, data for the renewable energy potential of Türkiye, and investment and O&M costs of renewable energy technologies are obtained for each system. Electricity sale prices are determined as explained in Section 4.1.3.

4.1.1. Wastewater Treatment Plants Operational Data

WWTPs' operational data, such as their capacity (m^3/d), treated wastewater (m^3/y), and amount of annual electricity consumption (kWh/y), is obtained by Odabaşı's study [36] [37]. 86 WWTPs with treated wastewater flowrate below 1,000,000 m^3/year are selected in this study. The raw data includes WWTPs information such as treated WW flow rate, electricity consumption, location, aeration tank number, and dimensions, which is given in Appendix 1. The energy intensity of these plants (kWh/m^3) is determined by dividing the annual electricity consumption of the plant by the total annual treated wastewater volume, as presented in Section 5.1.

4.1.2. Renewable Energy Data

This part describes data gathered on the initial cost, O&M cost, technical specifications for PV panels, wind turbines, and micro-HEP turbines, and renewable energy potential by province.

4.1.2.1. Solar System Data

The number of aeration tanks and their area are determined by using Google Earth Pro. The total aeration tank area will be a limitation for the PV system implementation. RETScreen database selects the type of PV that will convert solar energy into electricity. Suntech is selected as a PV manufacturer, and mono-Si-HyPro STP285S-20/Wfb is selected for the model of the PV system. The area of each selected panel is 1.637 $m^{2,}$ and its capacity is 285 W. The initial cost of the PV system is 2,700 \$/kW, and the O&M cost is 33 \$/kW-y up to 100 kW capacity, and they are 2,100 \$/kW and 25 \$/kW-y, respectively, over 100 kW capacity. Global radiation values (kWh/m^2-d) by province are taken from the official website of the Directorate General of Energy Affairs. The annual electricity generation potential of solar energy is calculated by the province in Section 5.2.

4.1.2.2.Wind System Data

The initial cost of the wind turbine system is 5,675 $/kW, and the O&M cost is 35 $/kW-y for the residential wind turbines based on the 2020 NREL Report. Two different turbines with a capacity of 200 W and 300 W, which are micro turbines available in the market, are considered for the initial cost. Wind velocity (m/s @100 m) by province are taken from the official website of the Directorate General of Energy Affairs. The annual electricity generation potential of wind energy (@10 m) is calculated by the province in Section 5.2.

4.1.2.3.Hydro System Data

A microturbine that is currently available in the market and that provides the flow range of the WWTPs has been chosen. The investment cost of the microturbine is 1,800 USD, according to the manufacturer's specifications. The O&M cost ranges between 1% and 4% of the investment cost [38]. The investment cost is 1,800 USD, and the O&M is 4% of the investment cost to be conservative.

4.1.3. Electricity Sale Price Data

Electricity consumption cost is 405.9469 kr/kWh according to tariffs approved by EMRA as of the 1st of October 2022. In WWTPs where renewable energy systems are implemented, electricity consumption cost and sale price to the grid are very close to each other, with a maximum margin of 10%. This margin depends on the contracts made for the electricity sale price. Thus, the electricity sale price is considered conservative at 365.352 kr/kWh.

4.1.4. Emission Factor Data

The fuel-specific emission factors used to estimate the Turkish electricity sector emission intensity factor are presented in Table 4.3.

Table 4.3. Fuel specific emission factors (kg CO_2/MWh) [39]

Sources	**SEF, kg CO_2/MWh**
Hard coal	1,018
Lignite	1,080
Natural gas	374
Fuel oil	755
Hydro	0
Wind	0
Renewable + Waste heat	373
Geothermal	1,300
Solar	0

TEIAS data showing the distribution of Türkiye’s electricity generation by fuel type in year 2021, which is the most current data, are provided in Table 4.4.

Table 4.4. Distribution of Türkiye’s electricity generation by sources

Sources	**Generation (GWh)**	**Share (%)**
Imported coal	54,948.4	16.42
Hard coal + Asphaltite	5,450.3	1.63
Lignite	42,983.3	12.84
Natural gas	111,180.8	33.22
Fuel oil	281.5	0.08
Hydro	55,926.8	16.71
Wind	31,436.7	9.39
Renewable + Waste heat	7,779.1	2.32
Geothermal	10,793.2	3.22
Solar	13,942.9	4.17
Total	334,723.1	100.00

4.2. Electricity Generation Calculations

After the data gathering and analysis stage is completed, the amount of electricity generation by renewable energy technologies is calculated. This part describes the calculations used to determine the amount of electricity generated by renewable energy systems.

4.2.1. Solar System Electricity Generation

Global radiation values (kWh/m^2-d) by province are taken from the official website of the Directorate General of Energy Affairs. These values are given daily for each month and are first calculated annually for each city in the project boundary. The global radiation value of 13 different provinces is calculated annually. Then the obtained values are multiplied by the efficiency of the solar panels, which is assumed to be 21%.

4.2.2. Wind System Electricity Generation

Wind velocity (m/s @100 m) by province is taken from the official website of the Directorate General of Energy Affairs. However, wind velocity at 100 m needs to be converted to the value at 10 m since the microturbines elevation is taken at 10 m in this study. It is calculated by using Hellmann exponential law [40]. The potential of electricity generation is calculated by considering the efficiency of the systems for wind turbines.

$$V = V_0 \, (H/H_0)^{\alpha} \qquad \text{(Eq. 1)}$$

where;

H = Height at the speed V, m

H_0 = Height at the speed V_0, m

V = speed at the height H, m/s

V_0 = speed at the height H_0, m/s

α = friction coefficient or Hellman exponent, it is assumed to be 0.25, which is available for heavily forested land [40]

The power generated by a turbine is calculated as follows;

$$P = \frac{1}{2} \rho \, A \, V^3 \qquad \text{(Eq. 2)}$$

where;

P = the real power, W

ρ = air density in kg/m^3 (taken as 1.23 kg/m^3)

A = rotor area, m^2 (taken as 10.17 m^2, assuming rotor d = 3.6 m)

V = wind speed, m/s

$$\text{Electricity generation (kWh/y)} = P\ (\text{kW}) * C_p * 24\ \text{hrs} * 365\ \text{days} \qquad \text{(Eq. 3)}$$

where;

C_p = capacity factor (assumed to be 15% for micro wind turbines)

4.2.3. Hydro System Electricity Generation

Power generated by a micro-HEP turbine is calculated as follows;

$$\begin{aligned} P_e &= P_h * \eta \\ &= Q * g * H * \rho * \eta \qquad \text{(Eq. 4)} \end{aligned}$$

where;

P_e = electrical power, MW

P_h = hydraulic power, MW

η = efficiency of microturbine (assumed to be 80%

Q = flow of wastewater, m^3/s

ρ = density of the treated wastewater m^3/s (taken as 1000 m^3/s)

g = gravity of earth, m/s^2 (taken as 9.81 m/s^2)

$$\text{Electricity generation (kWh/y)} = P_e\ (\text{kW}) * C_p * 24\ \text{hrs} * 365\ \text{days} \qquad \text{(Eq. 5)}$$

where;

C_p = capacity factor (assumed to be 95% for micro-HEP turbines)

4.3. Optimization Modeling

The Particle Swarm Optimization (PSO) technique, which is a population-based heuristic optimization, was used in this mathematical model. Many PSO application areas have been discussed in the literature, especially health, environment, industrial, commercial, smart city, and general direction applications. Like many other meta-heuristic algorithms, PSO has its advantages and disadvantages. The main advantage of PSO is that it can have fewer parameters to tune. Simple implementation, robustness, high efficiency, low computation time, and the ability to create accurate mathematical models to solve complex problems are other essential advantages of PSO. On the other hand, difficulty in initializing control parameters and solving high-dimensional problems are disadvantages of PSO [41].

PSO is used as an effective technique in this study especially considering the advantages of PSO, such as the ability to reach a more reasonable solution with relatively fewer data and more quick convergence.

4.3.1. Particle Swarm Optimization

PSO is an optimization algorithm that is used in machine learning. Kennedy and Eberhart originally proposed PSO, a population-based heuristic algorithm. It was inspired by the observation that the movements of some animals, such as birds and bees that move in a herd while providing their basic needs, affect other individuals in the herd. The individual, who moves in a herd, achieves its goal more easily while meeting its basic needs. Using a group of candidate solutions, called "particles," it moves across the solution space, guided by the position and velocity of its peers and their own personal best experiences [42].

The image illustrating the energy cost projection for different scenarios simulation and PSO of bird flocks is given in Figure 4.15. Each particle adjusts its position judging by its current position, its current velocity, the distance between its current position and the best position of a particle (pbest), and the distance between its current position and the best position within the swarm (gbest).

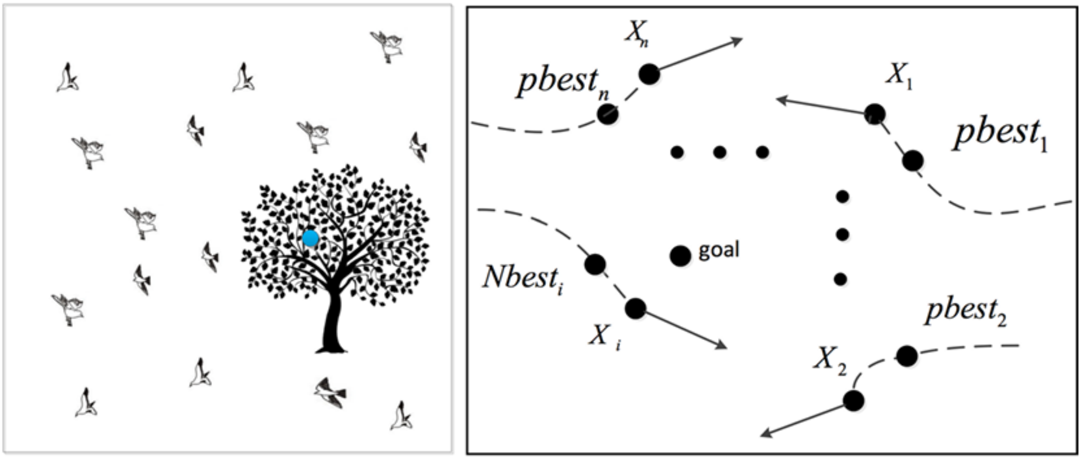

Figure 4.15. Energy cost projection for different scenarios simulation and PSO of bird flocks [43]

The flowchart of PSO describing its methodology is given in Figure 4.16.

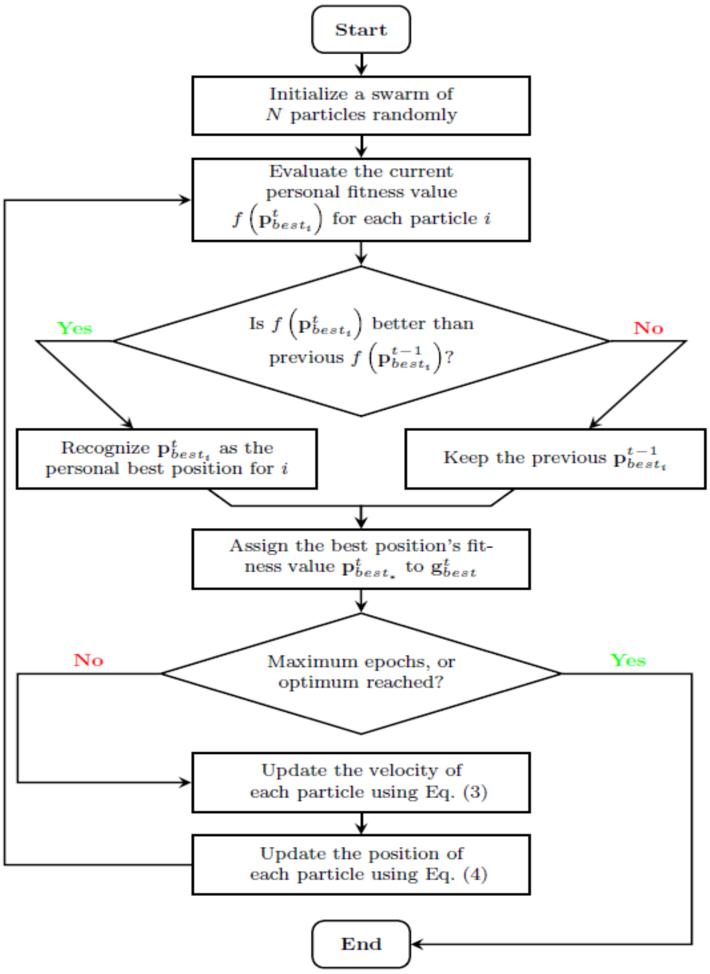

Figure 4.16. Flowchart of PSO [44]

4.3.2. Mathematical Modeling by Using PSO

The system is simulated by using Python in this study. Python has several libraries that can be used to implement PSO, and the scikit-opt (sko) module is used to apply the PSO algorithm. Inputs and variables of the model are given in Table 4.5.

Table 4.5. Optimization modeling inputs

Inputs	Description	Value
windCap	Capacity of wind systems in W	Table 5.7
hydroCap	Capacity of hydro systems in kW	Eq. 4
solarGen	Electricity generation of solar system (kWh/y)	Table 5.6
windGen	Electricity generation of wind system (kWh/y)	Table 5.7
salesPrice	Electricity sale price	365.352 kr/kWh
windInvCost	Investment cost of wind turbines	Section 4.1.2.2
windOMCost	O&M cost of wind turbines	Section 4.1.2.2
solarInvCost	Investment cost of solar panels	Section 4.1.2
solarOMCost	O&M cost of solar panels	Section 4.1.2
hydroInvCost	Investment cost of hydro turbines	Section 4.1.2.3
hydroOMCost	O&M cost of hydro turbines	Section 4.1.2.3
x1	Number of PV panel	Selected by PSO based on the the area
x2	Number of wind turbine	Selected by PSO
x3	Number of hydro unit	Selected by PSO

An optimization code has been developed and can be found in Appendix 2. The optimization modelling flowchart is given in Figure 4.17.

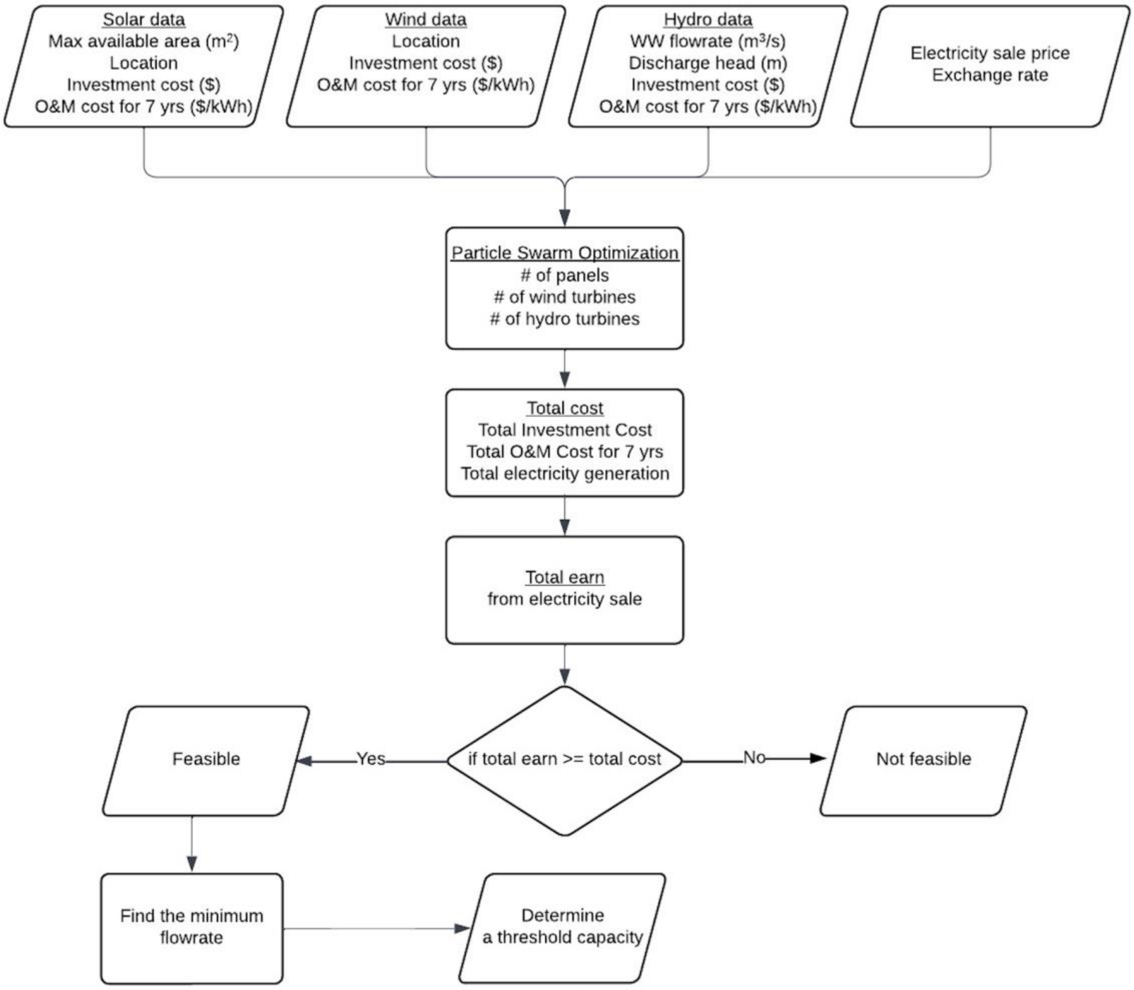

Figure 4.17. Flowchart of the optimization modelling

4.3.3. Assumptions and Constraints

Some assumptions should be made for the optimization to simplify the system. The simplifications and assumptions are important since wastewater treatment plants and renewable energy systems operations are very complicated. Therefore, we have some assumptions and simplifications in our modeling system. These are as follows.

- The wastewater discharge head is assumed as 4 meters.
- One micro-HEP turbine has been considered for each WWTP since only one micro-HEP turbine installation is reasonable at the plant outlet.
- The exchange rate of the dollar is assumed as 18 TL.
- The efficiency of PVs and micro-HEP turbines is 21% and 80%, respectively.

- Capacity factors of wind turbines and micro hydro turbines are 15% and 95%, respectively.
- Due to the complexity of the battery systems, it is assumed that the electricity generated from renewable energy sources will be sold directly to the national grid. In this case, this value is assumed as 365.352 kr/kWh.
- The flow rate will not change throughout the lifetime of the WWTP.
- The electricity sale price to the grid will remain constant throughout the lifetime of the WWTP.
- For a renewable energy integration to be feasible in a WWTP, it is expected to meet more than 50% of the electricity consumption and have a payback period of less than or equal to 7 years.

Some constraints in the modeling must be satisfied in the optimization problem. In this system simulation, constraints limit the range of possible values for the optimized variables or ensure that certain conditions are met.

The constraints used in this system simulation are as follows.

- The total solar panel area cannot be higher than the total area of aeration tanks in the WWTP.
- The maximum number of wind turbines is one because of the area limitations in the WWTP.

4.3.4. Scenarios Evaluated

Two scenarios have been established in the optimization model. Scenario 1 is based on generating enough electricity to meet the WWTP's electricity consumption and on optimizing it for the minimum cost. Due to the complexity of the battery systems, it is assumed that the electricity generated from renewable energy sources will be sold directly to the national grid. Therefore, in Scenario 1, the generation is limited to the amount consumed. At the same time, in Scenario 2, more electricity can be generated than needed by using the maximum available PV area and selling it to the grid. In this case, there is no limit to the electricity generation in Scenario 2, and all the available potential in the area is utilized for electricity generation.

4.3.5. Economical Analysis

The payback periods (PP) are calculated for all plants within the project boundary to show how long it takes to recover the total capital cost of renewable energy investments. In the baseline, WWTPs consume the electricity they need from the grid and make a payment for it. In this study, since it is assumed that the electricity generated will be sold to the grid, WWTP will continue to pay for the electricity it needs as in the baseline. Therefore, the payback period is calculated using the following formula.

$$\text{PP} = \frac{Initial\ Investment\ Cost\ (\$)}{\left(ElectricitySalePrice\ \left(\frac{\$}{kWh}\right) x\ ElectricityGenerated\ (kWh/year)\right) - O\&MCost\ (\$/year)} \qquad \text{(Eq. 6)}$$

4.3.6. System Outputs

The output parameters are the number of PV panels, micro-HEP turbines and micro wind turbines, initial investment cost, O&M cost, total generated electricity, total cost, and payback period. The feasibility of the plant and the share of renewable energy sources in cases that minimize the cost are other essential deliverables.

The feasibility of integrating renewable energy sources into WWTPs is determined by whether the payback period of renewable energy technologies is below seven years.

4.4. Emission Estimation

Emissions resulting from Türkiye's electricity generation are calculated using the shares of fuels in electricity generation (Table 4.4) and fuel-specific emission factors (Table 4.3) as in Eq. 7 [39].

$$E_T = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} (SEF_i\ x\ \propto_i\ x\ \varepsilon_i) \qquad \text{(Eq. 7)}$$

Where;

E_T = Total CO_2 emission (kg)

i = Fuel type

n = The number of fuel types

SEF_i = Specific emission factor (kg CO_2/MWh)

$\propto_i$ = Share of electricity generation by sources (%)

ε_i = Electricity consumption (MWh/yıl)

As per Eq.6, the current emission in Türkiye has been estimated as 0.498 kg/kWh, showing that 0.498 kg of CO_2 is released for 1 kWh of electricity generation in Türkiye.

4.5. Closing Remarks

The methodology and data sources have been thoroughly explained. This chapter consists of four main stages. The first stage is data collection and analysis. WWTP operation data, renewable energy data, electricity price data and emission factor data were collected and analyzed in this study. The second stage is electricity generation calculations. The amount of electricity that the PV panel and wind turbines can generate on a provincial basis and the amount of electricity generated from micro-hydroelectric turbines based on the plant's flow rate are calculated. Then, the methodology of the optimization model by using PSO in Python was presented. The optimization model estimated the optimum number of panel, hydro, and wind turbines to minimize the cost. The model gives electricity generation from renewable energy, payback period, and cost of renewables for 79 WWTP. Finally, emissions are estimated for 1 kWh of electricity generation. The current emission in Türkiye has been estimated as 0.498 kg/kWh.

5. RESULTS AND DISCUSSIONS

In this part of the thesis, the results of the study are presented in a step-by-step manner. The first step is analyzing the data gathered and determining the WWTPs to consider in the optimization model. The second step is to determine the electricity generation potential for WWTPs by province. The maximum amount of electricity that can be generated from PV panels and micro wind turbines is calculated according to the location of the WWTP, and the amount of electricity that can be generated from one micro-HEP turbine is based on the flow rate of the plant. After determining the data set to use as input, an optimization model is developed using the PSO model to determine the electricity generation from renewable energy, the payback period, and the cost of renewables for 79 WWTP. Finally, the annual cost and emission reduction amounts of these sources are calculated. The results are evaluated, and only feasible plants for integrating renewable energy technologies are determined to select a threshold capacity.

5.1.Analysis of the WWTPs Data

The energy intensity of WWTPs is calculated by dividing their electricity consumption by the amount of treated wastewater. The energy intensity of all WWTPs gathered is provided in Figure 5.18. According to Table 2.1, the energy intensity for different types of WWTPs varies between 0.1-1.5 kW/m^3. For this reason, WWTPs with energy intensities exceeding 1.5 kW/m^3 are categorized as out of the ordinary and excluded from the analysis. Therefore, to focus on the scope of the analysis, seven plants were excluded, bringing down the total number of plants being examined from 86 to 79. Analyzed data, including WWTPs information and energy intensities, are given in Appendix 3.

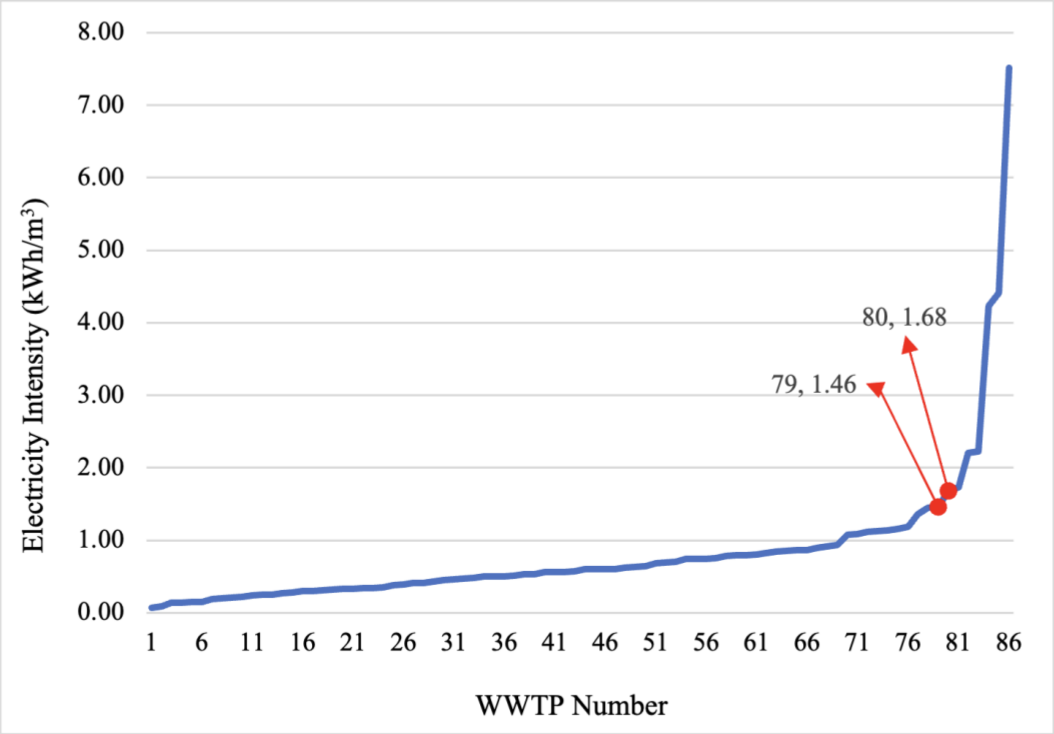

Figure 5.18. Energy intensity of WWTPs

Google Earth Pro is used to locate the remaining 79 WWTPs whose operational data are obtained and filtered based on their treatment capacity. These locations of the WWTPs on Google Earth Pro are given in Figure 5.19.

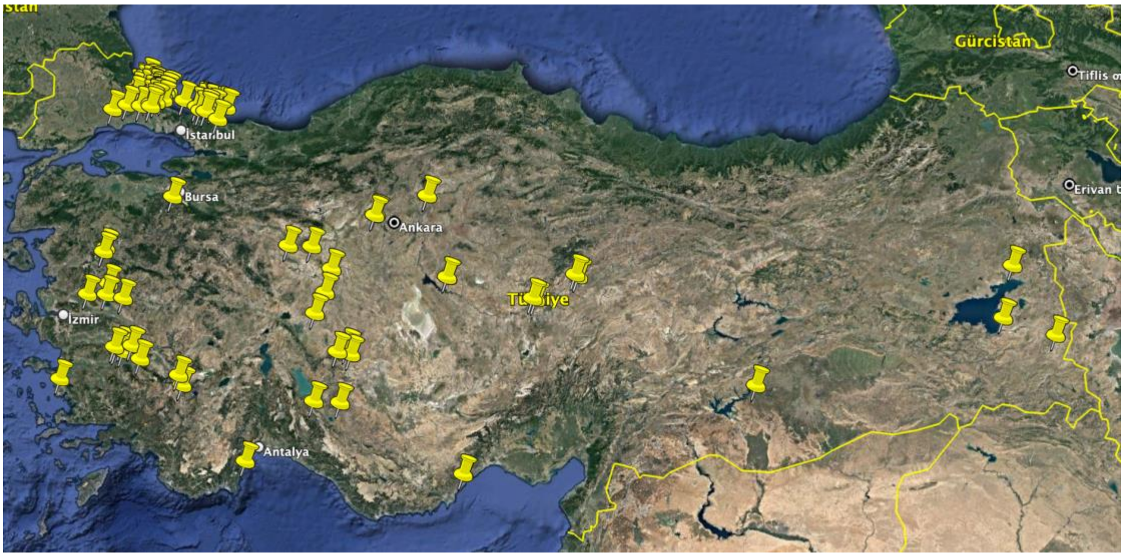

Figure 5.19. WWTPs located in the system boundary

WWTPs under consideration are located in different parts of Türkiye, mainly in the provinces of Ankara, Antalya, Aydın, Bursa, Denizli, Eskişehir, Istanbul, Kayseri, Konya, Manisa, Mersin, Şanlıurfa, and Van. The graph showing the number of plants according to the location is given in Figure 5.20.

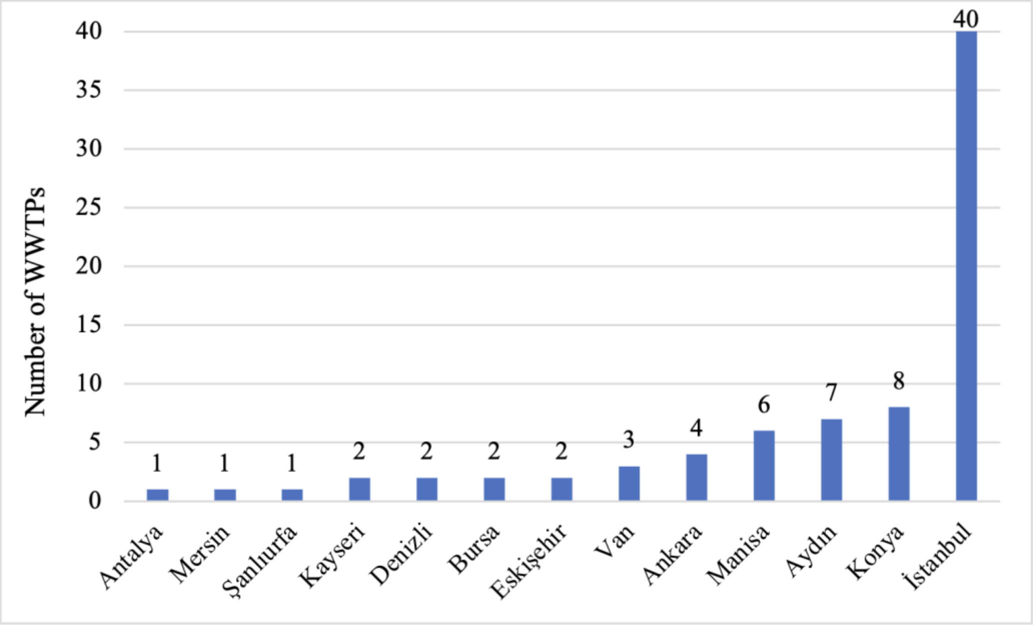

Figure 5.20. Number of WWTPs according to the location

The treated wastewater flow rate for the 79 WWTPs under consideration is below 1,000,000 m^3/year. The graph showing the number of plants according to the treated wastewater flow rate is given in Figure 5.21.

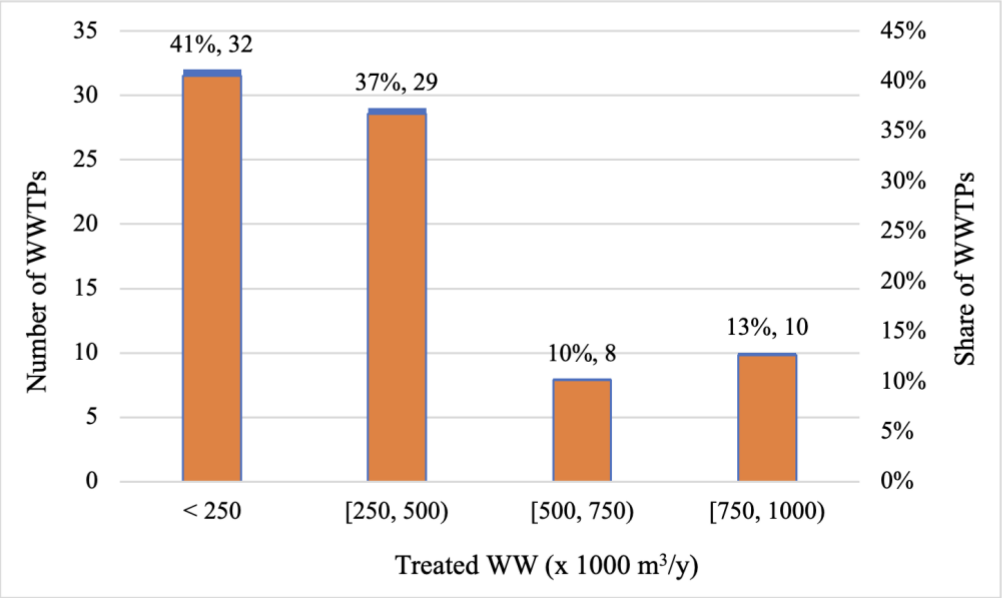

Figure 5.21. Number of WWTPs according to the treated wastewater flow rate

CAS, EAAS, EAAS+N&P, CAS+N&P, SBR+N&P, and Bardenpho processes are used in these plants. As there are very few WWTPs using CAS+N&P, SBR+N&P, and Bardenpho processes, these processes have been considered as others. The number of WWTPs based on applied treatment technologies is given in Figure 5.22. As can be seen in the graph, it is clear that the CAS process takes up the majority of all different technologies in these WWTPs.

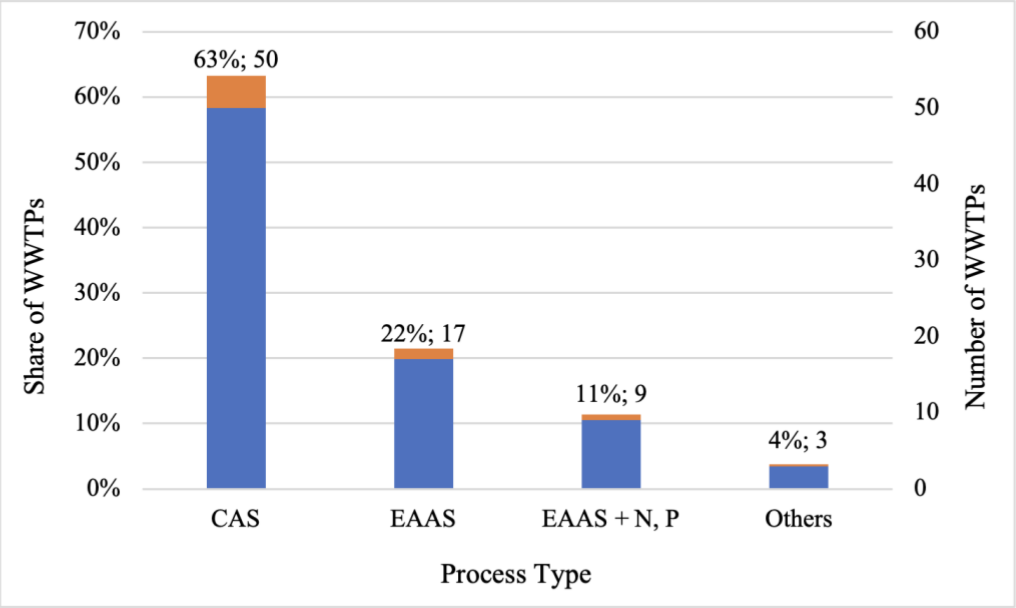

Figure 5.22. Number of WWTPs according to the process type

5.2.Renewable Energy Based Electricity Generation

As explained in Section 4.2, the annual electricity generation potential of three types of renewable energy technologies, solar, wind, and hydro, is calculated.

The global radiation value of 13 provinces is calculated annually. Then the obtained values are multiplied by the efficiency of the solar panels, which is assumed to be 21%. The electricity generation amount calculated for each city is given in Table 5.6.

Table 5.6. The electricity generation amount of solar systems by the province

	Global Radiation (kWh/m^2-y)	**PV Electricity Generation (kWh/m^2-y)**
Ankara	1,481.41	311.10
Antalya	1,655.39	347.63
Aydın	1,565.25	328.70
Bursa	1,400.79	294.17
Denizli	1,600.10	336.02
Eskişehir	1,480.52	310.91
İstanbul	1,638.57	344.10
Kayseri	1,597.45	335.46
Konya	1,617.57	339.69
Manisa	1,494.92	313.93
Mersin	1,633.45	343.02
Şanlıurfa	1,594.82	334.91
Van	1,644.66	345.38

The potential of electricity generation by wind turbines is calculated by using Eq.1, Eq.2, and Eq.3. The electricity generation from wind turbines calculated for each city is given in Table 5.7.

Table 5.7. The electricity generation amount of wind systems by the province

	V (m/s) @100m	**V (m/s) @10m**	**Power (W)**	**Generation kWh/y**	**Corresponding Capacity (W)**
Ankara	5.5	3.09	185.11	243.24	200
Antalya	3.5	1.97	47.70	62.68	200
Aydın	4.5	2.53	101.39	133.22	200
Bursa	4.0	2.25	71.21	93.57	200
Denizli	4.0	2.25	71.21	93.57	200
Eskişehir	3.5	1.97	47.70	62.68	200
İstanbul	6.0	3.37	240.33	315.79	300
Kayseri	5.0	2.81	139.08	182.75	200
Konya	4.0	2.25	71.21	93.57	200

	V (m/s) @100m	**V (m/s) @10m**	**Power (W)**	**Generation kWh/y**	**Corresponding Capacity (W)**
Manisa	4.5	2.53	101.39	133.22	200
Mersin	4.0	2.25	71.21	93.57	200
Şanlıurfa	5.0	2.81	139.08	182.75	200
Van	4.5	2.53	101.39	133.22	200

Power generated by a micro-HEP turbine is calculated using Eq.4, and the amount of electricity that can be produced from one micro-HEP turbine is based on the flow rate of the plant according to Eq.5 by using coding.

Based on all this information, the electricity generated from renewable energy sources such as solar, wind, and hydro is provided for 79 WWTPs in Appendix 4. It is observed that 20 plants out of 79 WWTPs have the potential to generate their own electricity.

5.3.Optimization Results

In this section of the study, two different scenarios were developed, and two different optimization models were run to find the electricity generation from renewable energy, the payback period, and the cost of renewables. Scenario 1 is when the WWTP generates only the necessary electricity from renewable sources. Scenario 2 is when the WWTP generates more than its needs if there is enough space for PV panels because the electricity generated is sold to the grid.

The optimization model for Scenario 1 calculates the optimum number of renewable energy technologies such as PV panels, micro wind turbines, and micro-HEP turbines to meet the electricity needs of the WWTP. Electricity generation from renewable energy, the cost of renewable systems, and the payback period are given in Appendix 5. WWTPs with a payback period of seven years or less and that can meet more than 50% of their electricity needs are considered feasible. The results show that only nine WWTPs meet these conditions.

The same optimization model is run for Scenario 2 as well. However, optimum numbers to meet the electricity consumption are not initially selected in this case. Instead, PV panels are used in all available areas, and then optimization is done if it is not enough to meet the demand. If the area is wide enough, it can generate more electricity than it needs. Electricity generation from renewable energy, the cost of renewables, and the payback period are given in Appendix 6.

5.3.1. Comparison of Scenario 1 and Scenario 2

Scenario 1 involves generating just enough electricity from renewables, whereas Scenario 2 involves generating excessive electricity as long as there is adequate space for PV panels. Therefore, there is a difference in some WWTPs between the number of PV panels selected in the two scenarios, which causes a change in the payback periods. The comparison of Scenario 1 and Scenario 2 based on their PV panels, whether there will be a turbine, and payback periods are presented in Appendix 7.

WWTPs that cannot meet all of their electricity consumption with renewable energy utilize the full available potential of renewable energy. This means using PV panels in all available areas, one wind turbine, and one hydro turbine. Some WWTPs meet their electricity consumption with solar energy by utilizing all available areas. There are 62 WWTPs which have no difference between the number of PV panels, turbines, and payback periods used in both scenarios. There are three WWTPs where the payback period remains the same despite an increase in the number of PV panels when all available areas are utilized when Scenario 2 is applied. The reason for this is that expenses increase in proportion to income.

In Scenario 1, it is found suitable to generate some of the required electricity with PV panels and some with wind turbine and/or micro-hydro turbine at the minimum cost. Still, when the entire area is used in Scenario 2, there are some increases or decreases in the payback periods without using these turbines. There are 14 WWTPs where there is a change in the payback periods. Out of these, ten have an increase in the payback period, while four have a decrease. This situation depends on many parameters, such as global radiation, wind speed, and plant flow rate, which are related to the location and capacity of the WWTP. The changes in the payback period in Scenario 2 are given in Figure 5.23.

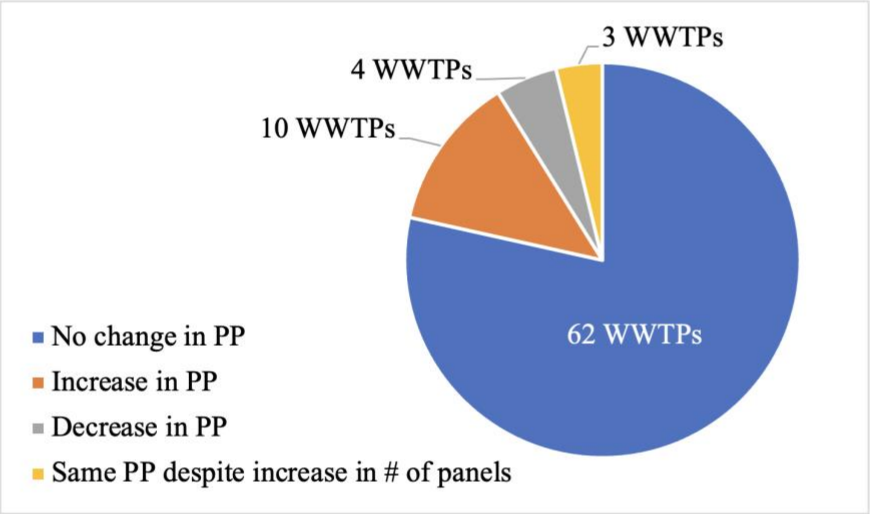

Figure 5.23. Changes in payback periods between Scenario 1 and Scenario 2

Figure 5.24 shows that there are more WWTPs in Scenario 2 with a payback period below 6 and between 7.0 and 7.5. WWTPs with a payback period between 6.5 and 7.0 and between 7.5 and 8.0 are more common in Scenario 1. This actually shows that it is viable to use renewable sources such as wind and hydro, not just focusing on solar energy, for the WWTPs within the scope of the study. Furthermore, these payback periods indicate that there are substantial periods to consider renewable energy integration into WWTPs as an alternative.

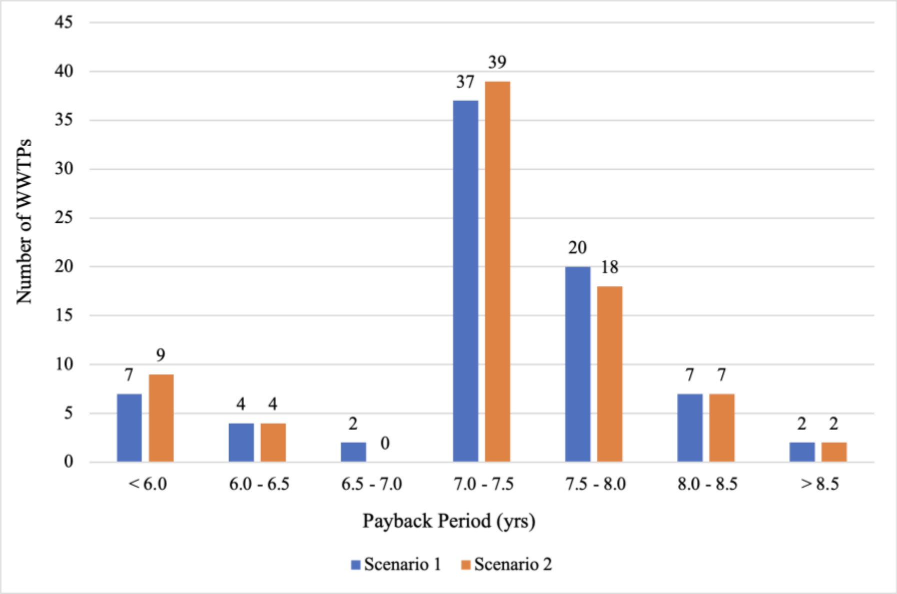

Figure 5.24. Payback periods in Scenario 1 and Scenario 2

The treated wastewater flow rate for the 79 WWTPs under consideration is below 1,000,000 m^3/year, as mentioned in Section 5.1. The flow range has been evaluated by dividing it into four categories. As seen in Figure 5.25, the average payback period increases as the flow rate decreases.

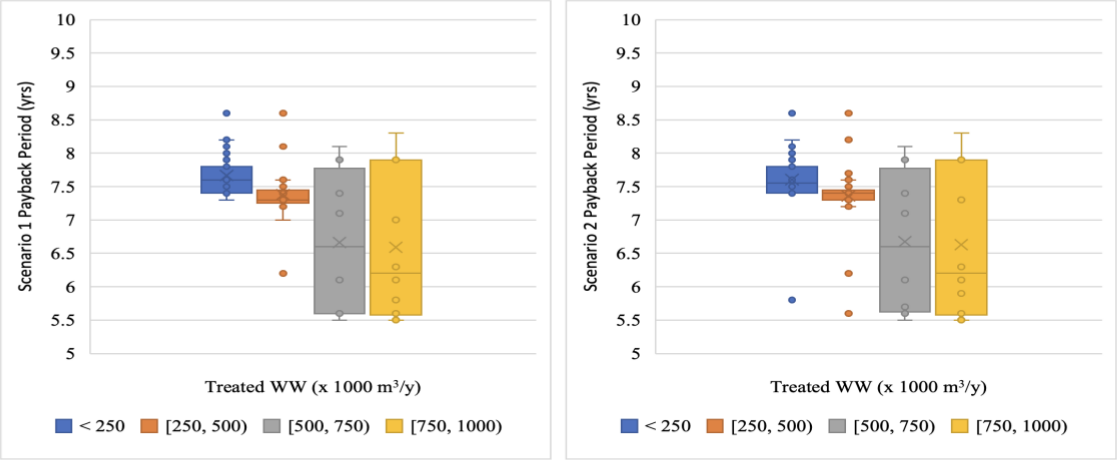

Figure 5.25. Payback periods of WWTPs according to treated wastewater amount

There are four different process types in the WWTPs considered. When the average payback periods are compared according to process type in Figure 5.26, the payback periods for others, which include CAS+N&P, SBR+N&P, and Bardenpho processes, are relatively lower than others. These process types are applied to plants with relatively higher treatment capacity and pollution load. Looking at EAAS + N, P, the average payback period for this process type is also less than seven years. This process type is also applied to plants with relatively higher treatment capacity and pollution load, which confirms the previous comment. The highest payback period is seen for the WWTPs with CAS systems.

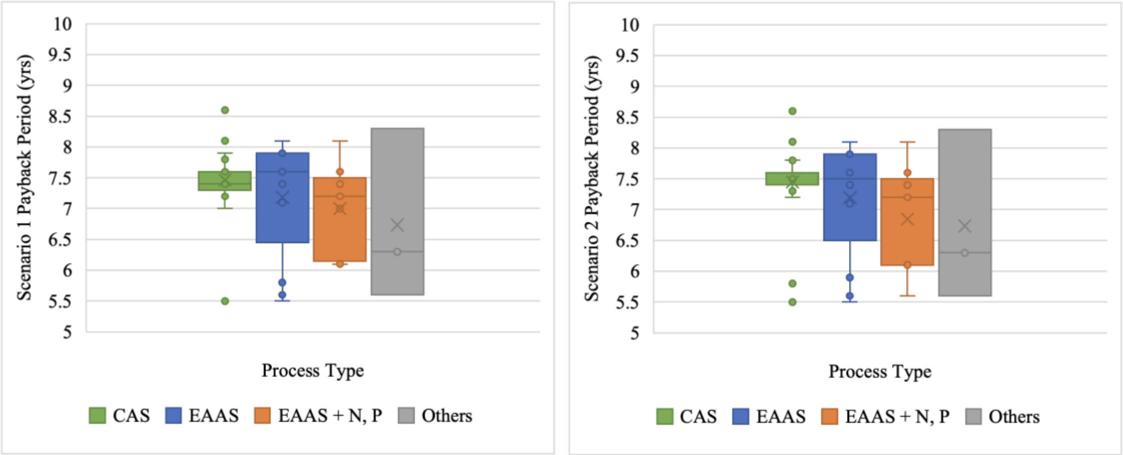

Figure 5.26. Payback periods of WWTPs according to the process type

There are 13 WWTPs, in which renewable energy is integrated, with a payback period of 7 years or fewer. However, at this point, it is also essential to determine how much of the electricity demand it meets. The pie chart in Figure 5.27 shows that 49 out of 79 plants meet more than 50% of their electricity demand. Therefore, those that can meet more than 50% of the electricity demand have been taken into account for feasibility assessment. To determine the threshold capacity, plants with the lowest capacity are among those that meet two specific criteria. Firstly, they should satisfy over 50% of their electricity demand, and secondly, they should have a payback period of seven years or fewer. By choosing the plants that meet both these conditions and have the lowest capacity, the threshold capacity is established. The number of plants that meet these two conditions decreased from 13 to 9. As a result, the threshold capacity for this integration is 380,633 m^3/year in Scenario 1 and 100,611 m^3/year in Scenario 2.

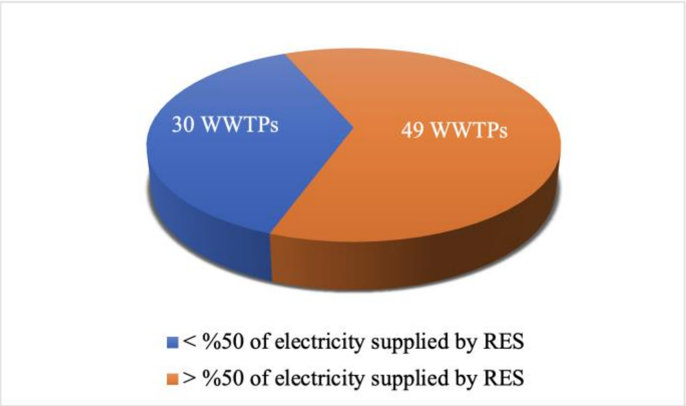

Figure 5.27. Percentage of electricity consumption met

Among 13 WWTPs with a payback period of seven or less, five of them can meet 100% of their electricity needs, while four can meet over 60% of their electricity needs, as shown in Appendix 5. Table 5.8 includes the list of the remaining nine plants for Scenario 1, whereas Table 5.9 shows the remaining nine plants for Scenario 2. When we examine previous studies, as seen in Table 3.2, Ak et al. [25] evaluated micro-hydro provided 34% self-sufficiency, while Taha and Al-Sa'ed [19] evaluated PV provided self-sufficiency between 5-15%. Ali et al. [30] evaluated all renewable sources and achieved 100% self-sufficiency, but their study included extra biomass, CST, and sewage methane, unlike this study.

Table 5.8. Summary table of nine feasible plants for Scenario 1

No	**Location**	**Process**	**Treated WW (m^3/y)**	**Electricity Consumption (kWh/y)**	**% of Electricity Generated from Renewables**	**PP (y)**
1	İstanbul	CAS	462,132	43,885	100%	7
2	Denizli	EAAS	744,972	249,876	100%	5.6
3	Antalya	EAAS	934,035	1,061,785	61%	5.5
4	Konya	EAAS	657,000	255,685	79%	5.6
5	İstanbul	CAS	599,379	297,616	90%	5.5
6	Ankara	EAAS+N,P	380,633	226,583	91%	6.2
7	Aydın	EAAS	912,500	388,045	100%	5.8
8	Van	EAAS+N,P	876,000	124,100	100%	7
9	İstanbul	Bardenpho	762,133	631,115	100%	5.6

Table 5.9. Summary table of nine feasible plants for Scenario 2

No	**Location**	**Process**	**Treated WW (m^3/y)**	**Electricity Consumption (kWh/y)**	**% of Electricity Generated from Renewables**	**PP (y)**
1	Denizli	EAAS	744,972	249,876	145%	5.7
2	Antalya	EAAS	934,035	1,061,785	61%	5.5
3	Konya	EAAS	657,000	255,685	79%	5.6
4	İstanbul	CAS	599,379	297,616	90%	5.5
5	Ankara	EAAS+N,P	380,633	226,583	91%	6.2
6	Aydın	EAAS	912,500	388,045	152%	5.9
7	Şanlıurfa	CAS	100,611	136,882	383%	5.8
8	Van	EAAS+N,P	365,000	109,500	999%	5.6
9	İstanbul	Bardenpho	762,133	631,115	238%	5.6

5.3.2. Sensitivity Analysis

As the efficiency of PV panels can be affected by various factors, the accepted value of 21% is varied with +/-5% and +/-10%. The average payback periods for Scenario 1 and Scenario 2 results for each variation are given below, in Table 5.10. Appendix 8 shows the table that indicates the payback periods for 79 plants in detail, taking into account the variation in the efficiency of +/-5% and +/-10%.

Table 5.10. Average payback periods according to different efficiency

Variance	**Efficiency**	**Average PP for Scenario 1 (y)**	**Average PP for Scenario 2 (y)**
-10%	19%	8.127	8.108
-5%	20%	7.671	7.691
0%	21%	7.323	7.299
+5%	22%	6.708	6.943
+10%	23%	6.656	6.634

5.3.3. Feasibility Parameter

The feasibility parameter, FIB is determined based on the potential to generate the electricity consumption of WWTPs and the payback period of integrated renewable energy systems. This parameter can be calculated by using the formula below;

$$F_{IB} = \frac{1}{2} \text{ x } \%RES \text{ x } \frac{1}{PP^2} \qquad \text{(Eq. 8)}$$

where;

F_{IB} = feasibility parameter

%RES = % of electricity generated from renewables

PP = payback period, year

Based on these two inputs, if a scale is determined, out of 79 plants, there are 32 plants where the F_{IB} is equal to 0.5 or less, 38 plants where the F_{IB} is between 0.5 and 1, and nine plants where the F_{IB} is equal to 1 or greater. When looking at this scale, WWTPs can be considered feasible if F_{IB} is equal to 1 or greater. It can be stated that plants with F_{IB} values between 0.5 and 1 are almost feasible, while those with F_{IB} values equal to 0.5 or less are not feasible as shown in Table 5.11.

Table 5.11. Feasibility scale of WWTPs

F_{IB}	Number of WWTPs	Output
<= 0.5	32	Not Feasible
0.5-1.0	38	Almost Feasible
>= 1.0	9	Feasible

5.4.Cost and Emission Reduction

The annual cost and emission reductions that could be achieved by meeting the electricity consumption of WWTPs with renewable energy sources are calculated and presented in Appendix 9. In the baseline scenario, WWTPs pay 405.947 kr/kWh for electricity consumption. The generated electricity is sold to the grid for 365.352 kr/kWh. Therefore, integrating renewable energy sources results in annual cost savings after its payback period. WWTPs can generate 56% of the total electricity demand in Scenario 1 and 74% in Scenario 2 via renewable energy sources.

When we examine previous studies, as seen in Table 3.2, Nguyen et al. [27] evaluated a hybrid photovoltaic-wind turbine system with hydrogen and battery storage. The energy cost is found to be 0.0488 $/kWh/yr. Woo et al. [31] evaluated that a solar-powered plant is the most economical scenario, with 6,809 USD/year. Power et al. [22] found total annual savings of 168,664 euro/yr in Ireland and 777,643 Euro/yr in the UK from micro hydropower. In this study, the energy cost is found to be approximately 0.2 $/kWh/y focusing solely on the O&M cost of the systems after their payback periods, and the cost reduction of the most economical plant is 131,349 $/yr in Scenario 1, and 338,910 $/yr in Scenario 2. The average cost reduction is 22,300 $/y in Scenario 1 and 29,300 $/y in

Scenario 2. The comparison of Scenario 1, Scenario 2, and previous studies can be seen in Figure 5.28.

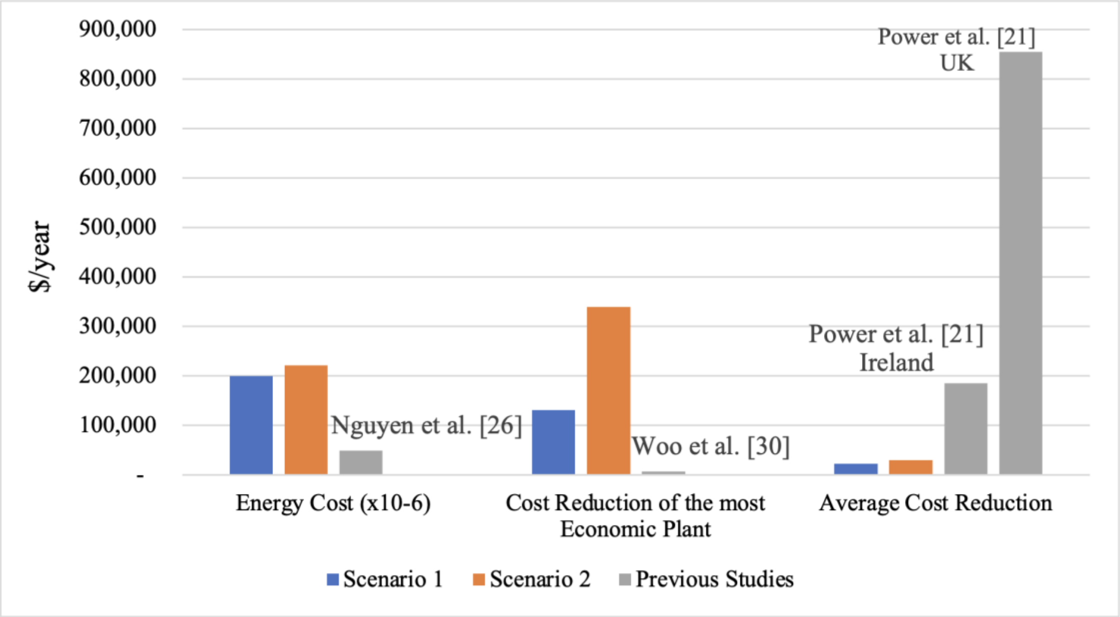

Figure 5.28. Cost reduction comparison of Scenario 1, Scenario 2, and previous studies

As per Eq.6 in Section 4.4, the current emission in Türkiye has been estimated as 0.498 kg/kWh. Multiplying the estimated emission factor of 0.498 kg/kWh for electricity generated from renewable sources gives the annual emission reduction as in Appendix 9. In this study, the total emission reduction for 79 WWTPs is 4,353 tCO_2/y in Scenario 1 and 5,724 tCO_2/y in Scenario 2. WWTPs can contribute 56% emission reduction in Scenario 1 and 74% in Scenario 2, thanks to the electricity generated from renewable energy sources. Assuming that the annual electricity consumption of a household is approximately 4,000 kWh/year, integrating only renewable energy sources into the 79 WWTPs would be equivalent to the emissions associated with the annual electricity consumption of around 2,000 households.

When we examine previous studies, as seen in Table 3.2, emission reduction is found in 932.78 tons/year by Nguyen et al. [27], 2.572 Mt/year by Xu et al. [29], 261 tons/year by Chae and Kang [32], 900 tons/year by Power et al. [22] and 39 tons/year by Chae et al. [24]. The comparison of Scenario 1, Scenario 2, and previous studies can be seen in Figure 5.29.

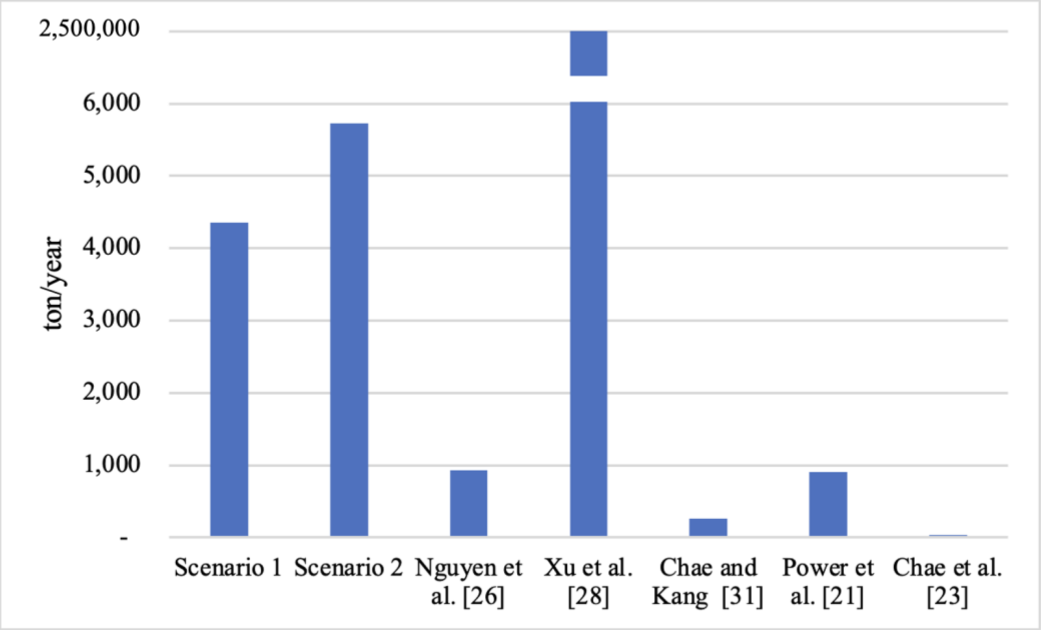

Figure 5.29. ER comparison of Scenario 1, Scenario 2, and previous studies

5.5.Closing Remarks

The study evaluated 79 different WWTPs that treat less than 1,000,000 m^3 of wastewater and found that 9 of them were feasible for integrating renewable energy. These 9 WWTPs have a payback period of equal to or fewer than seven years and can meet at least 50% of electricity demand. It is found that it is viable to use renewable sources such as wind and hydro, not just focusing on solar energy, for the WWTPs within the scope of the study. Furthermore, payback periods between 5.5-8.6 indicate that there are considerable periods to evaluate renewable energy integration into WWTPs as an alternative. Therefore, the study recommends considering renewable energy integration as an alternative to low-capacity WWTPs due to the high annual cost and emission reductions. The study found that previous research mainly focused on large-scale WWTPs, and renewable energy integration is economically and environmentally viable for them. However, this study determined that renewable energy integration is also viable for low-capacity wastewater treatment plants. The threshold capacity for this integration is 380,633 m^3/year in Scenario 1 and 100,611 m^3/year in Scenario 2. In this study, the energy cost is found to be approximately 0.2 $/kWh/y, and the cost reduction of the most economical plant is 131,349 $/yr in Scenario 1 and 338,910 $/yr. The average cost reduction is 22,300 $/y in Scenario 1 and 29,300 $/y in Scenario 2. The total emission reduction for 79 WWTPs is 4,353 tCO_2/y in Scenario 1 and 5,724 tCO_2/y in Scenario 2. WWTPs can contribute 56% emission reduction in Scenario 1 and 74% in Scenario 2, thanks to the electricity generated from renewable energy sources. If we consider that the annual electricity consumption of a household is approximately 4,000 kWh, integrating renewable energy sources in the 79 WWTPs would result in emissions equivalent to the annual electricity consumption of approximately 2,000 households.

6. CONCLUSION

The energy intensity of WWTPs has been the main factor contributing to energy use and indirect effects from fossil fuels. Therefore, it is important to examine the factors affecting energy intensity in WWTPs before considering integrating alternative energy sources. In Türkiye, biological treatment plants have shown the highest rate of increase, while advanced treatment methods have the highest capacity. Although there are more biological WWTPs in number, the total capacity of advanced WWTPs is approximately twice as high, indicating that advanced treatment is used in WWTPs with higher capacity in Türkiye. However, the most preferred process, EAAS, is used in lower-capacity treatment plants compared to BNR and CAS processes.

Energy intensity in WWTPs has been studied worldwide, considering factors such as location, treatment scale, discharge criteria, and treatment process types. Different technologies and discharge criteria also affect energy intensity at the country level. Previous studies have shown that energy intensity is analyzed in kW per unit m^3 or unit kg COD removal.

It has been concluded that there is an inverse relationship between plant capacity and energy intensity. The smaller WWTPs are less economically sustainable due to their simplified configurations and lack of control over fluctuating volumetric and organic load compared to larger WWTPs with larger design capacity. A_2O, EAAS, and CAS processes had higher energy intensity than other technologies, and stricter discharge criteria increased energy intensity.

Various studies have evaluated integrating renewable energy sources into WWTPs, including PV-only, hydro-only, and hybrid systems that utilize solar, wind, hydro, and biogas. These studies have calculated the potential emission and cost reduction achievable through renewable energy integration in different types and scales of WWTPs. Large-scale plants are found to be environmentally and economically viable for renewable energy integration. Some studies even concluded the feasibility of achieving 100% self-sufficiency in electricity generation.

This study's methodology and data sources consist of four main stages: data collection and analysis, electricity generation calculations, optimization model using PSO in Python, and estimation of emissions for electricity generation. The study evaluated 79 WWTPs in Türkiye that treat less than 1,000,000 m^3 of wastewater and identified nine as feasible for integrating renewable energy, with a payback period of seven years or less and the potential to meet at least 50% of electricity demand. The study found that renewable energy integration, including wind and hydro in addition to solar, is viable for WWTPs of different capacities, with payback periods ranging from 5.5 to 8.6 years, indicating significant potential for cost and emission reductions. Therefore, the study recommends considering renewable energy integration as an alternative for low-capacity WWTPs, with a threshold capacity of 380,633 m^3/year in Scenario 1 and 100,611 m^3/year in Scenario 2.

This study found that the energy cost is approximately $0.2 per kWh per year. The cost reduction for the most economically viable plant is $131,349 per year in Scenario 1 and $338,910 per year in Scenario 2. The average cost reduction is 22,300 $/y in Scenario 1 and 29,300 $/y in Scenario 2. The total emission reduction for the 79 WWTPs is 4,353 tCO_2 per year in Scenario 1 and 5,724 tCO_2 per year in Scenario 2. WWTPs can contribute to a 56% emission reduction in Scenario 1 and 74% in Scenario 2, thanks to the electricity generated from renewable energy sources. Assuming a household's average annual electricity consumption is approximately 4,000 kWh, integrating renewable energy sources in the 79 WWTPs would result in emissions equivalent to the annual electricity consumption of approximately 2,000 households.

7. RECOMMENDATIONS AND FUTURE STUDIES

Renewable energy systems can be integrated into WWTPs that have the threshold values mentioned as seen in this study. It is determined that there are nine WWTPs in Türkiye with a payback period of seven years or less and the potential to meet at least 50% of electricity demand. And by integrating these systems into WWTPs, where the treated wastewater is below 1,000,000 m^3/year, electricity generation can be easily achieved. Expected outputs will be beneficial for the environment and Türkiye's economy when considering the issues caused by the climate crisis and energy dependency in Türkiye. These expected outputs can be used by WWTPs that cannot be operated by small city municipalities due to increased energy expenditures, and by plants aiming to reduce electricity costs or to provide sustainable and safe energy.

In future studies, there is a need to further investigate this topic as my study does not evaluate battery systems due to their complex nature, and instead evaluated the sale of electricity generated to the grid. For future studies, it may be worth considering whether these plants can meet their own electricity consumption by directly using the generated electricity. Moreover, it is worth noting that the discharge head of the treated water for micro-hydro systems is assumed to be 4 meters in this study, which may not reflect a realistic evaluation. Therefore, determining more accurate discharge heads can result in a more precise evaluation.

Overall, integrating renewable energy systems into WWTPs that meet the identified threshold values has the potential to significantly reduce greenhouse gas emissions, decrease energy dependency, and promote sustainable development in Türkiye. Therefore, further studies in this field are necessary to fully explore and realize the benefits of these systems.

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APPENDICES

APPENDIX 1 – Raw Data

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	# of Aeration Tank	W (m)	L (m)
1	İstanbul	CAS	78,163	32,398	1	3	28
2	İstanbul	CAS	41,864	93,156	1	4	31
3	İstanbul	CAS	122,899	110,548	1	4	30
4	İstanbul	CAS	224,128	112,716	1	5	36
5	İstanbul	CAS	141,865	112,789	1	4	30
6	İstanbul	CAS	47,334	104,629	1	5.5	31
7	İstanbul	CAS	240,400	51,337	1	3.5	36
8	İstanbul	CAS	193,546	59,642	1	4	34
9	İstanbul	CAS	185,753	46,249	1	4	34
10	İstanbul	CAS	326,352	47,485	1	4	35
11	İstanbul	CAS	112,329	63,953	1	4	34.5
12	İstanbul	CAS	305,527	47,341	1	4	34
13	İstanbul	CAS	462,132	43,885	1	4	34
14	İstanbul	CAS	303,615	57,409	2	4	34
15	İstanbul	CAS	166,153	77,829	1	3.5	28
16	İstanbul	CAS	220,622	44,465	1	4	34
17	Konya	EAAS	103,295	87,807	1	8	10
18	Kayseri	CAS	117,682	131,617	8	23	114
19	Manisa	CAS	109,500	82,484	1	6	12
20	İstanbul	CAS	285,454	178,333	1	5	37
21	İstanbul	CAS	253,372	141,781	1	5	36.5
22	İstanbul	CAS	243,783	123,024	1	8	34
23	İstanbul	CAS	126,573	184,671	2	4	33
24	İstanbul	CAS	280,708	222,832	2	4	33
25	İstanbul	CAS	261,822	302,919	2	4	33
26	İstanbul	CAS	178,203	153,630	2	4	33
27	İstanbul	CAS	3,513	26,367	2	4	33
28	İstanbul	CAS	72,059	104,639	2	4	33
29	İstanbul	CAS	348,357	208,268	1	5	40
30	İstanbul	CAS	214,486	150,021	1	5	42
31	İstanbul	CAS	157,662	34,447	2	4	32
32	İstanbul	CAS	308,778	102,036	1	5	37
33	İstanbul	CAS	91,767	100,423	1	5	37
34	İstanbul	CAS	82,435	363,720	2	4	35
35	İstanbul	CAS	169,280	283,989	2	4	34
36	İstanbul	CAS	254,423	187,004	2	4	34
37	İstanbul	CAS	115,804	138,320	2	4	33
38	İstanbul	CAS	120,880	130,751	2	4	33
39	İstanbul	CAS	70,342	121,484	2	4	32
40	İstanbul	CAS	25,042	105,939	2	4	34
41	Kayseri	CAS	115,000	129,408	1	71	91
42	Manisa	CAS	182,471	83,464	1	8	20
43	Denizli	EAAS	744,972	249,876	3	8	45
44	İstanbul	CAS	328,351	174,207	2	5	35
45	İstanbul	CAS	313,602	252,899	2	5	37

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	# of Aeration Tank	W (m)	L (m)
46	İstanbul	CAS	317,951	276,593	2	5	37
47	İstanbul	CAS	469,690	113,852	2	5	37
48	Antalya	EAAS	934,035	1,061,785	4	11.5	40
49	İstanbul	CAS	317,748	299,895	2	5	38
50	Bursa	CAS	439,077	264,111	1	15	20
51	Ankara	CAS	302,730	83,700	1	15	20
52	Konya	EAAS	69,350	55,796	1	8	8
53	Konya	EAAS	80,300	54,699	1	8	8
54	Mersin	CAS	441,527	179,571	1	15	24
55	Konya	EAAS	657,000	255,685	2	12	24
56	Konya	EAAS	127,750	42,281	2	6	13
57	Konya	EAAS	337,625	179,701	1	14	21
58	Konya	EAAS + N, P	160,000	102,464	1	8	23
59	Konya	EAAS + N, P	401,500	141,814	1	11	29
60	Aydın	CAS	438,000	262,503	1	14	20
61	Denizli	EAAS	543,936	411,564	2	7	23
62	İstanbul	SBR + N, P	832,426	468,242	2	5	8
63	Manisa	EAAS	727,080	370,792	2	12	19
64	Aydın	EAAS	273,750	38,818	1	7	16
65	Aydın	EAAS	429,678	137,985	2	6	22
66	Aydın	EAAS	366,168	111,035	2	4	12
67	Aydın	EAAS	730,000	54,634	4	3	12
68	İstanbul	CAS	599,379	297,616	4	5	38
69	İstanbul	CAS	789,655	689,094	4	5	38
70	Aydın	EAAS	365,000	92,764	2	6	24
71	Manisa	EAAS	762,120	340,429	2	12	21
72	Ankara	EAAS + N, P	380,633	226,583	2	8	41
73	Eskişehir	EAAS + N, P	570,495	320,000	2	9	31
74	Eskişehir	CAS	804,460	388,000	2	9	22
75	Aydın	EAAS	912,500	388,045	2	30	30
76	Bursa	CAS + N, P	762,465	529,415	1	7	26
77	Manisa	CAS	237,221	89,274	1	8	23
78	Manisa	CAS	182,471	48,555	1	9	21
79	İstanbul	CAS	207,833	131,022	4	4	15
80	Ankara	EAAS + N, P	731,904	674,609	2	14	28
81	Ankara	EAAS + N, P	813,272	601,203	2	14	28
82	Şanlıurfa	CAS	100,611	136,882	3	18	29
83	Van	EAAS + N, P	365,000	109,500	6	10	66
84	Van	EAAS + N, P	876,000	124,100	2	8	32
85	İstanbul	Bardenpho	762,133	631,115	8	7	78
86	Van	EAAS + N, P	365,000	122,883	2	8	22

APPENDIX 2 – Optimization Modeling Code

Scenario 1

```
import sys
import math
import numpy as np
from sko.PSO import PSO
from openpyxl import load_workbook

print("\nCalculating Feasibility Scenario 1\n")

wb = load_workbook("Data.xlsx")
ws = wb["S1"]

threshold = 1000000
EXCHANGE_RATE = 18
SALES_PRICE = 3.65 / EXCHANGE_RATE
CONSUMPTION_COST = 4.06 / EXCHANGE_RATE

# City definitions
city_data = {
    "Ankara": {"solarGen": 311.10, "windCap": 200, "windGen": 243.44},
    "Antalya": {"solarGen": 347.63, "windCap": 200, "windGen": 62.68},
    "Aydın": {"solarGen": 328.70, "windCap": 200, "windGen": 133.22},
    "Bursa": {"solarGen": 294.17, "windCap": 200, "windGen": 93.57},
    "Denizli": {"solarGen": 336.02, "windCap": 200, "windGen": 93.57},
    "Eskişehir": {"solarGen": 310.91, "windCap": 200, "windGen": 62.68},
    "İstanbul": {"solarGen": 344.10, "windCap": 300, "windGen": 315.79},
    "Kayseri": {"solarGen": 335.46, "windCap": 200, "windGen": 182.75},
    "Konya": {"solarGen": 339.69, "windCap": 200, "windGen": 93.57},
    "Manisa": {"solarGen": 313.93, "windCap": 200, "windGen": 133.22},
    "Mersin": {"solarGen": 343.02, "windCap": 200, "windGen": 93.57},
    "Şanlıurfa": {"solarGen": 334.91, "windCap": 200, "windGen": 182.75},
    "Van": {"solarGen": 345.38, "windCap": 200, "windGen": 133.22}
}

def obj_func1(x):

    x1, x2, x3 = x # x1 = Number of PV Panel , x2 = Number of Wind Turbine,
x3 = Number of Hydro Unit

    global solarTotalCost, windTotalCost, hydroTotalCost
        global solarInvCost, solarOMCost, windInvCost, windOMCost,
hydroInvCost, hydroOMCost

     windInvCost = math.ceil(x2) * (city_data[city]["windCap"] / 1000) *
5675
    windOMCost = math.ceil(x2) * (city_data[city]["windCap"] / 1000) * 35
```

```
    windTotalCost = windInvCost + windOMCost

    hydroInvCost = math.ceil(x3) * 1800
    hydroOMCost = hydroInvCost * 0.04
    hydroTotalCost = hydroInvCost + hydroOMCost

    if((math.ceil(x1) * PV_PANEL_CAP / 1000) <= 100):
        solarInvCost = math.ceil(x1) * (PV_PANEL_CAP / 1000) * 2700
        solarOMCost = math.ceil(x1) * (PV_PANEL_CAP / 1000) * 33
        solarTotalCost = solarInvCost + solarOMCost

    elif((math.ceil(x1) * PV_PANEL_CAP / 1000) > 100):
        solarInvCost = math.ceil(x1) * (PV_PANEL_CAP / 1000) * 2100
        solarOMCost = math.ceil(x1) * (PV_PANEL_CAP / 1000) * 25
        solarTotalCost = solarInvCost + solarOMCost

    return solarTotalCost + windTotalCost + hydroTotalCost

for i in range(2, 81):

    # Inputs from data
    totalPower = int(ws.cell(i, 6).value)
    maxPVArea = float(ws.cell(i, 7).value)
    city = ws.cell(i, 3).value
    Q = float(ws.cell(i, 5).value / (365 * 24 * 3600))
    H = 4

    MAX_PV_NUMBER = maxPVArea / 1.637
    MAX_WIND_NUMBER = 1
    MAX_HYDRO_NUMBER = 1
    HYDRO_CAP = (Q * H * 9.81 * 0.8)
    PV_PANEL_CAP = 285 # Watt

        if((MAX_PV_NUMBER * 1.637 * city_data[city]["solarGen"]) +
(MAX_WIND_NUMBER * city_data[city]["windGen"]) + (MAX_HYDRO_NUMBER *
(HYDRO_CAP * 0.95 * 8760)) >= totalPower):

        #PSO Algorithm Parameters
        lowerBound = [0, 0, 0] # Minimum values for x1, x2, x3
        upperBound = [MAX_PV_NUMBER, MAX_WIND_NUMBER, MAX_HYDRO_NUMBER] #
Maximum values for x1, x2, x3
        constraintUeq = [lambda x: totalPower - (x[0] * 1.637 *
city_data[city]["solarGen"]) - (x[1] * city_data[city]["windGen"]) - (x[2]
* (HYDRO_CAP * 0.95 * 8760))]
        iteration = 150

        #PSO Algorithm
        pso = PSO(func=obj_func1, n_dim=3, pop=250,
                max_iter=iteration, lb=lowerBound, ub=upperBound,
```

```
                    constraint_ueq=constraintUeq, w=0.8, c1=0.5, c2=0.5)
        pso.run()

        # Investment and O&M Cost
        costInv = (solarInvCost) + (windInvCost) + (hydroInvCost) # Initial investment cost
        costOM = (solarOMCost) + (windOMCost) + (hydroOMCost) # Total O&M cost for a year

        # Total Earn from Electricity Generation
        totalGeneration = (((float(pso.gbest_x[0]) * 1.637 * city_data[city]["solarGen"]) + (float(pso.gbest_x[1]) * city_data[city]["windGen"]) + (math.ceil(float(pso.gbest_x[2])) * (HYDRO_CAP * 0.95 * 8760))))
        totalEarn = (totalGeneration) * (SALES_PRICE)

        for n in np.arange(0, 100, 0.01, dtype=float):
            cost = costInv + (costOM * n)
            earn = (totalGeneration) * SALES_PRICE * n
            if(earn >= cost):
                n = '{0:.2g}'.format(n)
                if(float(n) <= 7):
                    ws.cell(i, 22).value = n
                    if((ws.cell(i, 5).value) < threshold):
                        threshold = ws.cell(i, 5).value
                else:
                    ws.cell(i, 22).value = n
                break

        perHRES = round((totalGeneration / totalPower) * 100, 1)

        if(perHRES >= 50 and float(n) <= 7):
            ws.cell(i, 20).value = perHRES
            ws.cell(i, 21).value = "Feasible"
        else:
            ws.cell(i, 20).value = perHRES
            ws.cell(i, 21).value = "Not Feasible"


        # Total Electricity Generation and Cost
        ws.cell(i, 16).value = round(float(pso.best_x[0]) * 1.637 * city_data[city]["solarGen"], 2) # Yearly PV Electricity Generation
        ws.cell(i, 17).value = round(math.ceil(pso.gbest_x[1]) * city_data[city]["windGen"], 2) # Yearly Wind Electricity Generation
        ws.cell(i, 18).value = round(math.ceil(float(pso.gbest_x[2])) * (HYDRO_CAP * 0.95 * 8760), 2) # Yearly Hydro Electricity Generation
        ws.cell(i, 25).value = round(costInv + (float(n) * costOM), 2) # Total Cost
        ws.cell(i, 30).value = round(math.ceil(pso.best_x[0]), 0)
```

```
        ws.cell(i, 39).value = round(math.ceil(pso.best_x[1]), 0)
        ws.cell(i, 44).value = round(math.ceil(pso.best_x[2]), 0)


    else:

        #Total Earn from Electricity Generation
        totalGeneration = (MAX_PV_NUMBER * 1.637 * city_data[city]["solarGen"]) + (MAX_WIND_NUMBER * city_data[city]["windGen"]) + (MAX_HYDRO_NUMBER * (HYDRO_CAP * 0.95 * 8760))
        totalEarn = (totalGeneration) * (SALES_PRICE)

        #Investment and O&M Cost
        if((MAX_PV_NUMBER * PV_PANEL_CAP / 1000) <= 100):
            solarInvCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 2700
            solarOMCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 33

        elif((MAX_PV_NUMBER * PV_PANEL_CAP / 1000) > 100):
            solarInvCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 2100
            solarOMCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 25

        windInvCost = MAX_WIND_NUMBER * (city_data[city]["windCap"] / 1000) * 5675
        windOMCost = MAX_WIND_NUMBER * (city_data[city]["windCap"] / 1000) * 35

        hydroInvCost = MAX_WIND_NUMBER * 1800
        hydroOMCost = hydroInvCost * 0.04

        #Investment, O&M and Consumption Cost
        costInv = (solarInvCost) + (windInvCost) + (hydroInvCost) # Initial investment cost
        costOM = (solarOMCost) + (windOMCost) + (hydroOMCost) # Total O&M cost for a year
        costElectricityConsumption = (totalPower - totalGeneration) * CONSUMPTION_COST

        for n in np.arange(0, 100, 0.01, dtype=float):
            cost = costInv + (costOM * n)
            earn = (totalGeneration) * SALES_PRICE * n
            if(earn >= cost):
                n = '{0:.2g}'.format(n)
                if(float(n) <= 7):
                    ws.cell(i, 22).value = n
                    if((ws.cell(i, 5).value) < threshold):
                        threshold = ws.cell(i, 5).value
                else:
                    ws.cell(i, 22).value = n
```

```
                break

        perHRES = round((totalGeneration / totalPower) * 100, 1)

        if(perHRES >= 50 and float(n) <= 7):
            ws.cell(i, 20).value = perHRES
            ws.cell(i, 21).value = "Feasible"
        else:
            ws.cell(i, 20).value = perHRES
            ws.cell(i, 21).value = "Not Feasible"


        # Total Electricity Generation and Cost
        ws.cell(i, 16).value = round(MAX_PV_NUMBER * 1.637 * city_data[city]["solarGen"], 2) # Yearly PV Electricity Generation
        ws.cell(i, 17).value = round(MAX_WIND_NUMBER * city_data[city]["windGen"], 2) # Yearly Wind Electricity Generation
        ws.cell(i, 18).value = round(MAX_HYDRO_NUMBER * (HYDRO_CAP * 0.95 * 8760), 2) # Yearly Hydro Electricity Generation
        ws.cell(i, 19).value = round(totalPower - totalGeneration, 2)
        ws.cell(i, 25).value = round(costInv + (float(n) * costOM), 2) # Total Cost
        ws.cell(i, 30).value = round(MAX_PV_NUMBER, 0)
        ws.cell(i, 39).value = round(MAX_WIND_NUMBER, 0)
        ws.cell(i, 44).value = round(MAX_HYDRO_NUMBER, 0)

ws.cell(2, 23).value = threshold

wb.save("Data.xlsx")
wb.close()

print("Results was written to excel file.\n")
input("\nPress Enter to quit")

sys.exit()
```

Scenario 2

```
import sys
import math
import numpy as np
from sko.PSO import PSO
from openpyxl import load_workbook

print("\nCalculating Feasibility Scenario 2\n")

wb = load_workbook("Data.xlsx")
ws = wb["S2"]

threshold = 1000000
EXCHANGE_RATE = 18
SALES_PRICE = 3.65 / EXCHANGE_RATE
CONSUMPTION_COST = 4.06 / EXCHANGE_RATE

# City definitions
city_data = {
    "Ankara": {"solarGen": 311.10, "windCap": 200, "windGen": 243.44},
    "Antalya": {"solarGen": 347.63, "windCap": 200, "windGen": 62.68},
    "Aydın": {"solarGen": 328.70, "windCap": 200, "windGen": 133.22},
    "Bursa": {"solarGen": 294.17, "windCap": 200, "windGen": 93.57},
    "Denizli": {"solarGen": 336.02, "windCap": 200, "windGen": 93.57},
    "Eskişehir": {"solarGen": 310.91, "windCap": 200, "windGen": 62.68},
    "İstanbul": {"solarGen": 344.10, "windCap": 300, "windGen": 315.79},
    "Kayseri": {"solarGen": 335.46, "windCap": 200, "windGen": 182.75},
    "Konya": {"solarGen": 339.69, "windCap": 200, "windGen": 93.57},
    "Manisa": {"solarGen": 313.93, "windCap": 200, "windGen": 133.22},
    "Mersin": {"solarGen": 343.02, "windCap": 200, "windGen": 93.57},
    "Şanlıurfa": {"solarGen": 334.91, "windCap": 200, "windGen": 182.75},
    "Van": {"solarGen": 345.38, "windCap": 200, "windGen": 133.22}
}

def obj_func1(x):

    x2, x3 = x # x1 = Number of PV Panel , x2 = Number of Wind Turbine, x3
= Number of Hydro Unit

    global solarTotalCost, windTotalCost, hydroTotalCost
        global    solarInvCost,    solarOMCost,    windInvCost,    windOMCost,
hydroInvCost, hydroOMCost

     windInvCost  =  math.ceil(x2)  *  (city_data[city]["windCap"]  /  1000)  *
5675
    windOMCost = math.ceil(x2) * (city_data[city]["windCap"] / 1000) * 35
    windTotalCost = windInvCost + windOMCost
```

```
    hydroInvCost = math.ceil(x3) * 1800
    hydroOMCost = hydroInvCost * 0.04
    hydroTotalCost = hydroInvCost + hydroOMCost

    if((MAX_PV_NUMBER * PV_PANEL_CAP / 1000) <= 100):
        solarInvCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 2700
        solarOMCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 33
        solarTotalCost = solarInvCost + solarOMCost

    elif((MAX_PV_NUMBER * PV_PANEL_CAP / 1000) > 100):
        solarInvCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 2100
        solarOMCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 25
        solarTotalCost = solarInvCost + solarOMCost

    return solarTotalCost + windTotalCost + hydroTotalCost

for i in range(2, 81):

    # Inputs from data
    totalPower = int(ws.cell(i, 6).value)
    maxPVArea = float(ws.cell(i, 7).value)
    city = ws.cell(i, 3).value
    Q = float(ws.cell(i, 5).value / (365 * 24 * 3600))
    H = 4

    MAX_PV_NUMBER = maxPVArea / 1.637
    MAX_WIND_NUMBER = 1
    MAX_HYDRO_NUMBER = 1
    HYDRO_CAP = (Q * H * 9.81 * 0.8)
    PV_PANEL_CAP = 285 # Watt

       if((MAX_PV_NUMBER * 1.637 * city_data[city]["solarGen"]) +
(MAX_WIND_NUMBER * city_data[city]["windGen"]) + (MAX_HYDRO_NUMBER *
(HYDRO_CAP * 0.95 * 8760)) >= totalPower):

        #PSO Algorithm Parameters
        lowerBound = [0, 0] # Minimum values for x1, x2, x3
        upperBound = [MAX_WIND_NUMBER, MAX_HYDRO_NUMBER] # Maximum values
for x1, x2, x3
        constraintUeq = [lambda x: totalPower - (MAX_PV_NUMBER * 1.637 *
city_data[city]["solarGen"]) - (x[0] * city_data[city]["windGen"]) - (x[1]
* (HYDRO_CAP * 0.95 * 8760))]
        iteration = 150

        #PSO Algorithm
        pso = PSO(func=obj_func1, n_dim=2, pop=250,
                max_iter=iteration, lb=lowerBound, ub=upperBound,
                    constraint_ueq=constraintUeq, w=0.8, c1=0.5, c2=0.5)
        pso.run()
```

```
        # Investment and O&M Cost
        costInv = (solarInvCost) + (windInvCost) + (hydroInvCost) # Initial
investment cost
        costOM = (solarOMCost) + (windOMCost) + (hydroOMCost) # Total O&M
cost for a year
        totalCost = costInv + costOM

        # Total Earn from Electricity Generation
        totalGeneration = ((MAX_PV_NUMBER * 1.637 *
city_data[city]["solarGen"]) + (float(pso.gbest_x[0]) *
city_data[city]["windGen"]) + (math.ceil(pso.gbest_x[1])) * (HYDRO_CAP *
0.95 * 8760))
        totalEarn = (totalGeneration) * (SALES_PRICE)

        for n in np.arange(0, 100, 0.01, dtype=float):
            cost = costInv + (costOM * n)
            earn = (totalGeneration) * SALES_PRICE * n
            if(earn >= cost):
                n = '{0:.2g}'.format(n)
                if(float(n) <= 7):
                    ws.cell(i, 22).value = n
                    if((ws.cell(i, 5).value) < threshold):
                        threshold = ws.cell(i, 5).value
                else:
                    ws.cell(i, 22).value = n
                break

        perHRES = round((totalGeneration / totalPower) * 100, 1)
        if(perHRES >= 50 and float(n) <= 7):
            ws.cell(i, 20).value = perHRES
            ws.cell(i, 21).value = "Feasible"
        else:
            ws.cell(i, 20).value = perHRES
            ws.cell(i, 21).value = "Not Feasible"


        # Total Electricity Generation and Cost
        ws.cell(i, 16).value = round(MAX_PV_NUMBER * 1.637 *
city_data[city]["solarGen"], 2) # Yearly PV Electricity Generation
        ws.cell(i, 17).value = round(math.ceil(pso.gbest_x[0]) *
city_data[city]["windGen"], 2) # Yearly Wind Electricity Generation
        ws.cell(i, 18).value = round(math.ceil(float(pso.gbest_x[1])) *
(HYDRO_CAP * 0.95 * 8760), 2) # Yearly Hydro Electricity Generation
        ws.cell(i, 25).value = round(costInv + (float(n) * costOM), 2) #
Total Cost
        ws.cell(i, 30).value = round(MAX_PV_NUMBER, 0)
        ws.cell(i, 39).value = round(math.ceil(pso.best_x[0]), 0)
        ws.cell(i, 44).value = round(math.ceil(pso.best_x[1]), 0)
```

```
    else:

        #Total Earn from Electricity Generation
        totalGeneration = (MAX_PV_NUMBER * 1.637 *
city_data[city]["solarGen"]) + (MAX_WIND_NUMBER *
city_data[city]["windGen"]) + (MAX_HYDRO_NUMBER * (HYDRO_CAP * 0.95 *
8760))
        totalEarn = (totalGeneration) * (SALES_PRICE)

        #Investment and O&M Cost
        if((MAX_PV_NUMBER * PV_PANEL_CAP / 1000) <= 100):
            solarInvCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 2700
            solarOMCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 33

        elif((MAX_PV_NUMBER * PV_PANEL_CAP / 1000) > 100):
            solarInvCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 2100
            solarOMCost = MAX_PV_NUMBER * (PV_PANEL_CAP / 1000) * 25

        windInvCost = MAX_WIND_NUMBER * (city_data[city]["windCap"] / 1000)
* 5675
        windOMCost = MAX_WIND_NUMBER * (city_data[city]["windCap"] / 1000)
* 35

        hydroInvCost = MAX_WIND_NUMBER * 1800
        hydroOMCost = hydroInvCost * 0.04

        #Investment, O&M and Consumption Cost
        costInv = (solarInvCost) + (windInvCost) + (hydroInvCost) # Initial
investment cost
        costOM = (solarOMCost) + (windOMCost) + (hydroOMCost) # Total O&M
cost for a year
        costElectricityConsumption = (totalPower - totalGeneration) *
CONSUMPTION_COST
        totalCost = costInv + costOM

        for n in np.arange(0, 100, 0.01, dtype=float):
            cost = costInv + (costOM * n)
            earn = (totalGeneration) * SALES_PRICE * n
            if(earn >= cost):
                n = '{0:.2g}'.format(n)
                if(float(n) <= 7):
                    ws.cell(i, 22).value = n
                    if((ws.cell(i, 5).value) < threshold):
                        threshold = ws.cell(i, 5).value
                else:
                    ws.cell(i, 22).value = n
                break
```

```
        perHRES = round((totalGeneration / totalPower) * 100, 1)
        if(perHRES >= 50 and float(n) <= 7):
            ws.cell(i, 20).value = perHRES
            ws.cell(i, 21).value = "Feasible"
        else:
            ws.cell(i, 20).value = perHRES
            ws.cell(i, 21).value = "Not Feasible"

        # Total Electricity Generation and Cost
             ws.cell(i, 16).value = round(MAX_PV_NUMBER * 1.637 *
city_data[city]["solarGen"], 2) # Yearly PV Electricity Generation
                  ws.cell(i, 17).value = round(MAX_WIND_NUMBER *
city_data[city]["windGen"], 2) # Yearly Wind Electricity Generation
        ws.cell(i, 18).value = round(MAX_HYDRO_NUMBER * (HYDRO_CAP * 0.95
* 8760), 2) # Yearly Hydro Electricity Generation
        ws.cell(i, 19).value = round(totalPower - totalGeneration, 2)
        ws.cell(i, 25).value = round(costInv + (float(n) * costOM), 2) #
Total Cost
        ws.cell(i, 30).value = round(MAX_PV_NUMBER, 0)
        ws.cell(i, 39).value = round(MAX_WIND_NUMBER, 0)
        ws.cell(i, 44).value = round(MAX_HYDRO_NUMBER, 0)

ws.cell(2, 23).value = threshold

wb.save("Data.xlsx")
wb.close()

print("Results was written to excel file.\n")
input("\nPress Enter to quit")

sys.exit()
```

APPENDIX 3 – Analyzed Data

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	# of Aeration Tank	W (m)	L (m)	kWh/m^3
1	İstanbul	CAS	78,163	32,398	1	3	28	0.41
2	İstanbul	CAS	41,864	93,156	1	4	31	2.23
3	İstanbul	CAS	122,899	110,548	1	4	30	0.90
4	İstanbul	CAS	224,128	112,716	1	5	36	0.50
5	İstanbul	CAS	141,865	112,789	1	4	30	0.80
6	İstanbul	CAS	47,334	104,629	1	5.5	31	2.21
7	İstanbul	CAS	240,400	51,337	1	3.5	36	0.21
8	İstanbul	CAS	193,546	59,642	1	4	34	0.31
9	İstanbul	CAS	185,753	46,249	1	4	34	0.25
10	İstanbul	CAS	326,352	47,485	1	4	35	0.15
11	İstanbul	CAS	112,329	63,953	1	4	34.5	0.57
12	İstanbul	CAS	305,527	47,341	1	4	34	0.15
13	İstanbul	CAS	462,132	43,885	1	4	34	0.09
14	İstanbul	CAS	303,615	57,409	2	4	34	0.19
15	İstanbul	CAS	166,153	77,829	1	3.5	28	0.47
16	İstanbul	CAS	220,622	44,465	1	4	34	0.20
17	Konya	EAAS	103,295	87,807	1	8	10	0.85
18	Kayseri	CAS	117,682	131,617	1	6	20	1.12
19	Manisa	CAS	109,500	82,484	1	6	12	0.75
20	İstanbul	CAS	285,454	178,333	1	5	37	0.62
21	İstanbul	CAS	253,372	141,781	1	5	36.5	0.56
22	İstanbul	CAS	243,783	123,024	1	8	34	0.50
23	İstanbul	CAS	126,573	184,671	2	4	33	1.46
24	İstanbul	CAS	280,708	222,832	2	4	33	0.79
25	İstanbul	CAS	261,822	302,919	2	4	33	1.16
26	İstanbul	CAS	178,203	153,630	2	4	33	0.86
27	İstanbul	CAS	3,513	26,367	2	4	33	7.51
28	İstanbul	CAS	72,059	104,639	2	4	33	1.45
29	İstanbul	CAS	348,357	208,268	1	5	40	0.60
30	İstanbul	CAS	214,486	150,021	1	5	42	0.70
31	İstanbul	CAS	157,662	34,447	2	4	32	0.22
32	İstanbul	CAS	308,778	102,036	1	5	37	0.33
33	İstanbul	CAS	91,767	100,423	1	5	37	1.09
34	İstanbul	CAS	82,435	363,720	2	4	35	4.41
35	İstanbul	CAS	169,280	283,989	2	4	34	1.68
36	İstanbul	CAS	254,423	187,004	2	4	34	0.74
37	İstanbul	CAS	115,804	138,320	2	4	33	1.19
38	İstanbul	CAS	120,880	130,751	2	4	33	1.08
39	İstanbul	CAS	70,342	121,484	2	4	32	1.73
40	İstanbul	CAS	25,042	105,939	2	4	34	4.23
41	Kayseri	CAS	115,000	129,408	1	6	20	1.13
42	Manisa	CAS	182,471	83,464	1	8	20	0.46
43	Denizli	EAAS	744,972	249,876	3	8	45	0.34
44	İstanbul	CAS	328,351	174,207	2	5	35	0.53
45	İstanbul	CAS	313,602	252,899	2	5	37	0.81
46	İstanbul	CAS	317,951	276,593	2	5	37	0.87
47	İstanbul	CAS	469,690	113,852	2	5	37	0.24
48	Antalya	EAAS	934,035	1,061,785	4	11.5	40	1.14

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	# of Aeration Tank	W (m)	L (m)	kWh/m^3
49	İstanbul	CAS	317,748	299,895	2	5	38	0.94
50	Bursa	CAS	439,077	264,111	1	15	20	0.60
51	Ankara	CAS	302,730	83,700	1	15	20	0.28
52	Konya	EAAS	69,350	55,796	1	8	8	0.80
53	Konya	EAAS	80,300	54,699	1	8	8	0.68
54	Mersin	CAS	441,527	179,571	1	15	24	0.41
55	Konya	EAAS	657,000	255,685	2	12	24	0.39
56	Konya	EAAS	127,750	42,281	2	6	13	0.33
57	Konya	EAAS	337,625	179,701	1	14	21	0.53
58	Konya	EAAS + N, P	160,000	102,464	1	8	23	0.64
59	Konya	EAAS + N, P	401,500	141,814	1	11	29	0.35
60	Aydın	CAS	438,000	262,503	1	14	20	0.60
61	Denizli	EAAS	543,936	411,564	2	7	23	0.76
62	İstanbul	SBR + N, P	832,426	468,242	2	5	8	0.56
63	Manisa	EAAS	727,080	370,792	2	12	19	0.51
64	Aydın	EAAS	273,750	38,818	1	7	16	0.14
65	Aydın	EAAS	429,678	137,985	2	6	22	0.32
66	Aydın	EAAS	366,168	111,035	2	4	12	0.30
67	Aydın	EAAS	730,000	54,634	4	3	12	0.07
68	İstanbul	CAS	599,379	297,616	4	5	38	0.50
69	İstanbul	CAS	789,655	689,094	4	5	38	0.87
70	Aydın	EAAS	365,000	92,764	2	6	24	0.25
71	Manisa	EAAS	762,120	340,429	2	12	21	0.45
72	Ankara	EAAS + N, P	380,633	226,583	2	8	41	0.60
73	Eskişehir	EAAS + N, P	570,495	320,000	2	9	31	0.56
74	Eskişehir	CAS	804,460	388,000	2	9	22	0.48
75	Aydın	EAAS	912,500	388,045	2	30	30	0.43
76	Bursa	CAS + N, P	762,465	529,415	1	7	26	0.69
77	Manisa	CAS	237,221	89,274	1	8	23	0.38
78	Manisa	CAS	182,471	48,555	1	9	21	0.27
79	İstanbul	CAS	207,833	131,022	4	4	15	0.63
80	Ankara	EAAS + N, P	731,904	674,609	2	14	28	0.92
81	Ankara	EAAS + N, P	813,272	601,203	2	14	28	0.74
82	Şanlıurfa	CAS	100,611	136,882	3	18	29	1.36
83	Van	EAAS + N, P	365,000	109,500	6	10	66	0.30
84	Van	EAAS + N, P	876,000	124,100	2	8	32	0.14
85	İstanbul	Bardenpho	762,133	631,115	8	7	78	0.83
86	Van	EAAS + N, P	365,000	122,883	2	8	22	0.34

APPENDIX 4 – Electricity Generated from Renewables

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	Electricity Generated from Renewables (kWh)	% of Electricity that can be Generated from Renewables
1	İstanbul	CAS	78,163	32,398	29,691	92%
2	İstanbul	CAS	122,899	110,548	42,454	38%
3	İstanbul	CAS	224,128	112,716	63,571	56%
4	İstanbul	CAS	141,865	112,789	42,611	38%
5	İstanbul	CAS	240,400	51,337	45,117	88%
6	İstanbul	CAS	193,546	59,642	48,672	82%
7	İstanbul	CAS	185,753	46,249	46,249	100%
8	İstanbul	CAS	326,352	47,485	47,485	100%
9	İstanbul	CAS	112,329	63,953	48,563	76%
10	İstanbul	CAS	305,527	47,341	47,341	100%
11	İstanbul	CAS	462,132	43,885	43,885	100%
12	İstanbul	CAS	303,615	57,409	57,409	100%
13	İstanbul	CAS	166,153	77,829	34,926	45%
14	İstanbul	CAS	220,622	44,465	44,465	100%
15	Konya	EAAS	103,295	87,807	27,641	31%
16	Kayseri	CAS	117,682	131,617	41,245	31%
17	Manisa	CAS	109,500	82,484	23,138	28%
18	İstanbul	CAS	285,454	178,333	66,332	37%
19	İstanbul	CAS	253,372	141,781	64,940	46%
20	İstanbul	CAS	243,783	123,024	95,842	78%
21	İstanbul	CAS	126,573	184,671	92,054	50%
22	İstanbul	CAS	280,708	222,832	93,331	42%
23	İstanbul	CAS	261,822	302,919	93,175	31%
24	İstanbul	CAS	178,203	153,630	92,482	60%
25	İstanbul	CAS	72,059	104,639	91,603	88%
26	İstanbul	CAS	348,357	208,268	71,923	35%
27	İstanbul	CAS	214,486	150,021	74,194	49%
28	İstanbul	CAS	157,662	34,447	34,447	100%
29	İstanbul	CAS	308,778	102,036	66,526	65%
30	İstanbul	CAS	91,767	100,423	64,728	64%
31	İstanbul	CAS	254,423	187,004	95,930	51%
32	İstanbul	CAS	115,804	138,320	91,965	66%
33	İstanbul	CAS	120,880	130,751	92,007	70%
34	Kayseri	CAS	115,000	129,408	41,223	32%
35	Manisa	CAS	182,471	83,464	51,493	62%
36	Denizli	EAAS	744,972	249,876	249,876	100%
37	İstanbul	CAS	328,351	174,207	123,017	71%
38	İstanbul	CAS	313,602	252,899	130,218	51%
39	İstanbul	CAS	317,951	276,593	130,254	47%
40	İstanbul	CAS	469,690	113,852	113,852	100%
41	Antalya	EAAS	934,035	1,061,785	647,435	61%
42	İstanbul	CAS	317,748	299,895	133,632	45%
43	Bursa	CAS	439,077	264,111	91,856	35%
44	Ankara	CAS	302,730	83,700	83,700	100%
45	Konya	EAAS	69,350	55,796	22,355	40%
46	Konya	EAAS	80,300	54,699	22,446	41%

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	Electricity Generated from Renewables (kWh)	% of Electricity that can be Generated from Renewables
47	Mersin	CAS	441,527	179,571	126,725	71%
48	Konya	EAAS	657,000	255,685	200,718	79%
49	Konya	EAAS	127,750	42,281	42,281	100%
50	Konya	EAAS	337,625	179,701	102,427	57%
51	Konya	EAAS + N, P	160,000	102,464	63,699	62%
52	Konya	EAAS + N, P	401,500	141,814	111,298	78%
53	Aydın	CAS	438,000	262,503	95,774	36%
54	Denizli	EAAS	543,936	411,564	112,412	27%
55	İstanbul	SBR + N, P	832,426	468,242	34,250	7%
56	Manisa	EAAS	727,080	370,792	149,022	40%
57	Aydın	EAAS	273,750	38,818	38,818	100%
58	Aydın	EAAS	429,678	137,985	90,324	65%
59	Aydın	EAAS	366,168	111,035	34,375	31%
60	Aydın	EAAS	730,000	54,634	52,994	97%
61	İstanbul	CAS	599,379	297,616	266,648	90%
62	İstanbul	CAS	789,655	689,094	268,225	39%
63	Aydın	EAAS	365,000	92,764	92,764	100%
64	Manisa	EAAS	762,120	340,429	164,215	48%
65	Ankara	EAAS + N, P	380,633	226,583	207,105	91%
66	Eskişehir	EAAS + N, P	570,495	320,000	177,835	56%
67	Eskişehir	CAS	804,460	388,000	129,386	33%
68	Aydın	EAAS	912,500	388,045	388,077	100%
69	Bursa	CAS + N, P	762,465	529,415	113,315	21%
70	Manisa	CAS	237,221	89,274	59,656	67%
71	Manisa	CAS	182,471	48,555	48,555	100%
72	İstanbul	CAS	207,833	131,022	84,278	64%
73	Ankara	EAAS + N, P	731,904	674,609	249,738	37%
74	Ankara	EAAS + N, P	813,272	601,203	250,412	42%
75	Şanlıurfa	CAS	100,611	136,882	136,882	100%
76	Van	EAAS + N, P	365,000	109,500	109,500	100%
77	Van	EAAS + N, P	876,000	124,100	124,100	100%
78	İstanbul	Bardenpho	762,133	631,115	631,115	100%
79	Van	EAAS + N, P	365,000	122,883	122,883	100%

APPENDIX 5 – Scenario 1 Outputs Printed from Coding

No	City	Electricity Consumption (kWh/y)	PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PV Electricity Generation (kWh/y)	Wind Electricity Generation (kWh/y)	Hydro Electricity Generation (kWh/y)	% of Electricity Generated from Renewables	Cost of Renewables ($/y)	PP (y)	Feasibility
1	İstanbul	32,398	51	1	1	28,727.88	315.79	647.50	92%	47,131.81	7.8	Not Feasible
2	İstanbul	110,548	73	1	1	41,120.29	315.79	1,018.10	38%	65,520.89	7.6	Not Feasible
3	İstanbul	112,716	109	1	1	61,398.80	315.79	1,856.68	56%	95,574.57	7.4	Not Feasible
4	İstanbul	112,789	73	1	1	41,120.29	315.79	1,175.21	38%	65,520.89	7.6	Not Feasible
5	İstanbul	51,337	76	1	1	42,810.17	315.79	1,991.47	88%	67,884.37	7.4	Not Feasible
6	İstanbul	59,642	83	1	1	46,753.21	315.79	1,603.34	82%	73,844.36	7.5	Not Feasible
7	İstanbul	46,249	83	0	0	46,753.21	0	0	100%	69,645.05	7.4	Not Feasible
8	İstanbul	47,485	80	0	1	45,061.65	0	2,703.50	100%	69,295.68	7.2	Not Feasible
9	İstanbul	63,953	84	1	1	47,316.50	315.79	930.53	76%	74,771.65	7.6	Not Feasible
10	İstanbul	47,341	80	0	1	44,875.32	0	2,530.99	100%	69,295.68	7.2	Not Feasible
11	İstanbul	43,885	72	0	1	40,351.77	0	3,828.30	100%	62,448.12	7	Feasible
12	İstanbul	57,409	98	0	1	55,099.27	0	2,515.15	100%	84,365.57	7.2	Not Feasible
13	İstanbul	77,829	59	1	1	33,234.21	315.79	1,376.41	45%	53,747.20	7.6	Not Feasible
14	İstanbul	44,465	76	0	1	42,768.08	0	1,827.63	100%	66,025.49	7.3	Not Feasible
15	Konya	87,807	48	1	1	26,691.48	93.57	855.70	31%	44,061.48	7.9	Not Feasible
16	Kayseri	131,617	73	1	1	40,087.81	182.75	974.88	31%	65,079.91	7.8	Not Feasible
17	Manisa	82,484	43	1	1	22,097.85	133.22	907.10	28%	40,180.87	8.6	Not Feasible
18	İstanbul	178,333	113	1	1	63,651.96	315.79	2,364.70	37%	98,930.96	7.4	Not Feasible
19	İstanbul	141,781	111	1	1	62,525.38	315.79	2,098.93	46%	97,252.77	7.4	Not Feasible
20	İstanbul	123,024	166	1	1	93,506.42	315.79	2,019.50	78%	143,403.10	7.4	Not Feasible
21	İstanbul	184,671	161	1	1	90,689.96	315.79	1,048.53	50%	139,367.29	7.5	Not Feasible
22	İstanbul	222,832	161	1	1	90,689.96	315.79	2,325.39	42%	139,207.62	7.4	Not Feasible
23	İstanbul	302,919	161	1	1	90,689.96	315.79	2,168.93	31%	139,207.62	7.4	Not Feasible
24	İstanbul	153,630	161	1	1	90,689.96	315.79	1,476.23	60%	139,207.62	7.4	Not Feasible
25	İstanbul	104,639	161	1	1	90,689.96	315.79	596.94	88%	139,367.29	7.5	Not Feasible

No	City	Electricity Consumption (kWh/y)	PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PV Electricity Generation (kWh/y)	Wind Electricity Generation (kWh/y)	Hydro Electricity Generation (kWh/y)	% of Electricity Generated from Renewables	Cost of Renewables ($/y)	PP (y)	Feasibility
26	İstanbul	208,268	122	1	1	68,721.59	315.79	2,885.79	35%	106,359.84	7.3	Not Feasible
27	İstanbul	150,021	128	1	1	72,101.34	315.79	1,776.80	49%	111,517.42	7.4	Not Feasible
28	İstanbul	34,447	62	0	0	34,557.88	0	0	100%	52,024.01	7.4	Not Feasible
29	İstanbul	102,036	113	1	1	63,651.96	315.79	2,557.92	65%	98,816.43	7.3	Not Feasible
30	İstanbul	100,423	113	1	1	63,651.96	315.79	760.20	64%	99,160.01	7.6	Not Feasible
31	İstanbul	187,004	166	1	1	93,506.42	315.79	2,107.64	51%	143,403.10	7.4	Not Feasible
32	İstanbul	138,320	161	1	1	90,689.96	315.79	959.32	66%	139,367.29	7.5	Not Feasible
33	İstanbul	130,751	161	1	1	90,689.96	315.79	1,001.37	70%	139,367.29	7.5	Not Feasible
34	Kayseri	129,408	73	1	1	40,087.81	182.75	952.66	32%	65,079.91	7.8	Not Feasible
35	Manisa	83,464	97	1	1	49,848.63	133.22	1,511.59	62%	85,705.04	8.2	Not Feasible
36	Denizli	249,876	444	0	1	243,770.60	0	6,171.35	100%	285,652.80	5.6	Feasible
37	İstanbul	174,207	213	1	1	119,981.13	315.79	2,720.06	71%	182,632.08	7.3	Not Feasible
38	İstanbul	252,899	226	1	1	127,303.92	315.79	2,597.88	51%	193,528.12	7.3	Not Feasible
39	İstanbul	276,593	226	1	1	127,303.92	315.79	2,633.91	47%	193,528.12	7.3	Not Feasible
40	İstanbul	113,852	195	1	1	109,785.54	315.79	3,890.91	100%	167,353.62	7.2	Not Feasible
41	Antalya	1,061,785	1,124	1	1	639,635.03	62.68	7,737.55	61%	720,130.25	5.5	Feasible
42	İstanbul	299,895	232	1	1	130,683.67	315.79	2,632.22	45%	198,557.06	7.3	Not Feasible
43	Bursa	264,111	183	1	1	88,124.80	93.57	3,637.31	35%	159,234.49	8.6	Not Feasible
44	Ankara	83,700	160	0	1	81,458.06	0	2,507.82	100%	137,692.08	8.1	Not Feasible
45	Konya	55,796	39	1	1	21,686.83	93.57	574.50	40%	36,556.44	8.1	Not Feasible
46	Konya	54,699	39	1	1	21,686.83	93.57	665.21	41%	36,511.86	8	Not Feasible
47	Mersin	179,571	219	1	1	122,973.70	93.57	3,657.61	71%	187,067.97	7.3	Not Feasible
48	Konya	255,685	351	1	1	195,181.46	93.57	5,442.59	79%	227,455.80	5.6	Feasible
49	Konya	42,281	76	1	0	42,217.55	93.57	0	100%	65,102.53	7.6	Not Feasible
50	Konya	179,701	179	1	1	99,536.98	93.57	2,796.89	57%	153,717.96	7.4	Not Feasible
51	Konya	102,464	112	1	1	62,280.12	93.57	1,325.44	62%	97,724.94	7.6	Not Feasible
52	Konya	141,814	194	1	1	107,878.07	93.57	3,326.03	78%	166,304.42	7.4	Not Feasible

No	City	Electricity Consumption (kWh/y)	PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PV Electricity Generation (kWh/y)	Wind Electricity Generation (kWh/y)	Hydro Electricity Generation (kWh/y)	% of Electricity Generated from Renewables	Cost of Renewables ($/y)	PP (y)	Feasibility
53	Aydın	262,503	171	1	1	92,012.00	133.22	3,628.39	36%	147,342.64	7.6	Not Feasible
54	Denizli	411,564	196	1	1	107,812.69	93.57	4,505.97	27%	167,982.61	7.4	Not Feasible
55	İstanbul	468,242	48	1	1	27,038.00	315.79	6,895.82	7%	43,802.32	6.3	Not Feasible
56	Manisa	370,792	278	1	1	142,865.15	133.22	6,023.13	40%	238,135.36	7.9	Not Feasible
57	Aydın	38,818	68	0	1	36,589.57	0	2,267.75	100%	59,533.70	7.6	Not Feasible
58	Aydın	137,985	161	1	1	86,631.19	133.22	3,559.45	65%	138,932.86	7.6	Not Feasible
59	Aydın	111,035	58	1	1	31,208.75	133.22	3,033.34	31%	52,249.67	7.5	Not Feasible
60	Aydın	54,634	87	1	1	46,813.13	133.22	6,047.32	97%	76,251.87	7.1	Not Feasible
61	İstanbul	297,616	464	1	1	261,367.35	315.79	4,965.26	90%	299,843.25	5.5	Feasible
62	İstanbul	689,094	464	1	1	261,367.35	315.79	6,541.50	39%	299,843.25	5.5	Not Feasible
63	Aydın	92,764	167	0	1	89,851.61	0	3,023.66	100%	142,790.53	7.6	Not Feasible
64	Manisa	340,429	307	1	1	157,768.35	133.22	6,313.40	48%	262,605.55	7.9	Not Feasible
65	Ankara	226,583	400	1	1	203,708.28	243.44	3,153.16	91%	260,494.80	6.2	Feasible
66	Eskişehir	320,000	340	1	1	173,046.29	62.68	4,725.98	56%	291,106.27	8.1	Not Feasible
67	Eskişehir	388,000	241	1	1	122,659.28	62.68	6,664.15	33%	206,914.78	7.9	Not Feasible
68	Aydın	388,045	707	1	1	380,391.47	133.22	7,559.15	100%	455,749.47	5.8	Feasible
69	Bursa	529,415	222	1	1	106,905.50	93.57	6,316.26	21%	191,749.35	8.3	Not Feasible
70	Manisa	89,274	112	1	1	57,557.18	133.22	1,965.14	67%	98,291.12	8.1	Not Feasible
71	Manisa	48,555	95	0	0	48,685.22	0	0	100%	81,275.62	8.2	Not Feasible
72	İstanbul	131,022	146	1	1	82,240.59	315.79	1,721.69	64%	126,621.16	7.4	Not Feasible
73	Ankara	674,609	478	1	1	243,431.39	243.44	6,063.09	37%	310,274.97	6.1	Not Feasible
74	Ankara	601,203	478	1	1	243,431.39	243.44	6,737.15	42%	310,274.97	6.1	Not Feasible
75	Şanlıurfa	136,882	250	1	0	136,876.37	182.75	0	100%	211,432.70	7.6	Not Feasible
76	Van	109,500	189	0	1	106,489.77	0	3,023.66	100%	161,923.28	7.3	Not Feasible
77	Van	124,100	207	1	1	116,932.76	133.22	7,256.78	100%	176,402.35	7	Feasible
78	İstanbul	631,115	1,109	1	1	624,677.33	315.79	6,313.51	100%	712,588.50	5.6	Feasible
79	Van	122,883	213	0	1	120,079.80	0	3,023.66	100%	180,645.41	7.2	Not Feasible

APPENDIX 6 – Scenario 2 Outputs Printed from Coding

No	City	Electricity Consumption (kWh/y)	PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PV Electricity Generation (kWh/y)	Wind Electricity Generation (kWh/y)	Hydro Electricity Generation (kWh/y)	% of Electricity Generated from Renewables	Cost of Renewables ($/y)	PP (y)	Feasibility
1	İstanbul	32,398	51	1	1	28,727.88	315.79	647.50	92%	47,131.81	7.8	Not Feasible
2	İstanbul	110,548	73	1	1	41,120.29	315.79	1,018.10	38%	65,520.89	7.6	Not Feasible
3	İstanbul	112,716	109	1	1	61,398.80	315.79	1,856.68	56%	95,574.57	7.4	Not Feasible
4	İstanbul	112,789	73	1	1	41,120.29	315.79	1,175.21	38%	65,520.89	7.6	Not Feasible
5	İstanbul	51,337	76	1	1	42,810.17	315.79	1,991.47	88%	67,884.37	7.4	Not Feasible
6	İstanbul	59,642	83	1	1	46,753.21	315.79	1,603.34	82%	73,844.36	7.5	Not Feasible
7	İstanbul	46,249	83	0	0	46,753.21	0	0	101%	69,645.05	7.4	Not Feasible
8	İstanbul	47,485	85	0	0	47,879.79	0	0	101%	71,323.24	7.4	Not Feasible
9	İstanbul	63,953	84	1	1	47,316.50	315.79	930.53	76%	74,771.65	7.6	Not Feasible
10	İstanbul	47,341	83	0	1	46,753.21	0	2530.99	104%	71,807.33	7.2	Not Feasible
11	İstanbul	43,885	83	0	0	46,753.21	0	0	107%	69,645.05	7.4	Not Feasible
12	İstanbul	57,409	166	0	0	93,506.42	0	0	163%	139,290.10	7.4	Not Feasible
13	İstanbul	77,829	59	1	1	33,234.21	315.79	1,376.41	45%	53,747.20	7.6	Not Feasible
14	İstanbul	44,465	83	0	0	46,753.21	0	0	105%	69,645.05	7.4	Not Feasible
15	Konya	87,807	48	1	1	26,691.48	93.57	855.70	31%	44,061.48	7.9	Not Feasible
16	Kayseri	131,617	73	1	1	40,087.81	182.75	974.88	31%	65,079.91	7.8	Not Feasible
17	Manisa	82,484	43	1	1	22,097.85	133.22	907.10	28%	40,180.87	8.6	Not Feasible
18	İstanbul	178,333	113	1	1	63,651.96	315.79	2,364.70	37%	98,930.96	7.4	Not Feasible
19	İstanbul	141,781	111	1	1	62,525.38	315.79	2,098.93	46%	97,252.77	7.4	Not Feasible
20	İstanbul	123,024	166	1	1	93,506.42	315.79	2,019.50	78%	143,403.10	7.4	Not Feasible
21	İstanbul	184,671	161	1	1	90,689.96	315.79	1,048.53	50%	139,367.29	7.5	Not Feasible
22	İstanbul	222,832	161	1	1	90,689.96	315.79	2,325.39	42%	139,207.62	7.4	Not Feasible
23	İstanbul	302,919	161	1	1	90,689.96	315.79	2,168.93	31%	139,207.62	7.4	Not Feasible
24	İstanbul	153,630	161	1	1	90,689.96	315.79	1,476.23	60%	139,207.62	7.4	Not Feasible
25	İstanbul	104,639	161	1	1	90,689.96	315.79	596.94	88%	139,367.29	7.5	Not Feasible

No	City	Electricity Consumption (kWh/y)	PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PV Electricity Generation (kWh/y)	Wind Electricity Generation (kWh/y)	Hydro Electricity Generation (kWh/y)	% of Electricity Generated from Renewables	Cost of Renewables ($/y)	PP (y)	Feasibility
26	İstanbul	208,268	122	1	1	68,721.59	315.79	2,885.79	35%	106,359.84	7.3	Not Feasible
27	İstanbul	150,021	128	1	1	72,101.34	315.79	1,776.80	49%	111,517.42	7.4	Not Feasible
28	İstanbul	34,447	156	0	0	87,873.51	0	0	255%	130,899.13	7.4	Not Feasible
29	İstanbul	102,036	113	1	1	63,651.96	315.79	2,557.92	65%	98,816.43	7.3	Not Feasible
30	İstanbul	100,423	113	1	1	63,651.96	315.79	760.20	64%	99,160.01	7.6	Not Feasible
31	İstanbul	187,004	166	1	1	93,506.42	315.79	2,107.64	51%	143,403.10	7.4	Not Feasible
32	İstanbul	138,320	161	1	1	90,689.96	315.79	959.32	66%	139,367.29	7.5	Not Feasible
33	İstanbul	130,751	161	1	1	90,689.96	315.79	1,001.37	70%	139,367.29	7.5	Not Feasible
34	Kayseri	129,408	73	1	1	40,087.81	182.75	952.66	32%	65,079.91	7.8	Not Feasible
35	Manisa	83,464	97	1	1	49,848.63	133.22	1,511.59	62%	85,705.04	8.2	Not Feasible
36	Denizli	249,876	659	0	0	362,492.66	0	0	145%	421,175.14	5.7	Feasible
37	İstanbul	174,207	213	1	1	119,981.13	315.79	2,720.06	71%	182,632.08	7.3	Not Feasible
38	İstanbul	252,899	226	1	1	127,303.92	315.79	2,597.88	51%	193,528.12	7.3	Not Feasible
39	İstanbul	276,593	226	1	1	127,303.92	315.79	2,633.91	47%	193,528.12	7.3	Not Feasible
40	İstanbul	113,852	226	0	0	127,303.92	0	0	112%	189,635.92	7.4	Not Feasible
41	Antalya	1,061,785	1,124	1	1	639,635.03	62.68	7,737.55	61%	720,130.25	5.5	Feasible
42	İstanbul	299,895	232	1	1	130,683.67	315.79	2,632.22	45%	198,557.06	7.3	Not Feasible
43	Bursa	264,111	183	1	1	88,124.80	93.57	3,637.31	35%	159,234.49	8.6	Not Feasible
44	Ankara	83,700	183	0	0	93,196.54	0	0	111%	154,931.64	8.2	Not Feasible
45	Konya	55,796	39	1	1	21,686.83	93.57	574.50	40%	36,556.44	8.1	Not Feasible
46	Konya	54,699	39	1	1	21,686.83	93.57	665.21	41%	36,511.86	8	Not Feasible
47	Mersin	179,571	219	1	1	122,973.70	93.57	3,657.61	71%	187,067.97	7.3	Not Feasible
48	Konya	255,685	351	1	1	195,181.46	93.57	5,442.59	79%	227,455.80	5.6	Feasible
49	Konya	42,281	95	0	0	52,826.89	0	0	125%	79,803.56	7.5	Not Feasible
50	Konya	179,701	179	1	1	99,536.98	93.57	2,796.89	57%	153,717.96	7.4	Not Feasible
51	Konya	102,464	112	1	1	62,280.12	93.57	1,325.44	62%	97,724.94	7.6	Not Feasible
52	Konya	141,814	194	1	1	107,878.07	93.57	3,326.03	78%	166,304.42	7.4	Not Feasible

No	**City**	**Electricity Consumption (kWh/y)**	**PV Panel #**	**Wind Turbine #**	**Micro-HEP Turbine #**	**PV Electricity Generation (kWh/y)**	**Wind Electricity Generation (kWh/y)**	**Hydro Electricity Generation (kWh/y)**	**% of Electricity Generated from Renewables**	**Cost of Renewables ($/y)**	**PP (y)**	**Feasibility**
53	Aydın	262,503	171	1	1	92,012.00	133.22	3,628.39	36%	147,342.64	7.6	Not Feasible
54	Denizli	411,564	196	1	1	107,812.69	93.57	4,505.97	27%	167,982.61	7.4	Not Feasible
55	İstanbul	468,242	48	1	1	27,038.00	315.79	6,895.82	7%	43,802.32	6.3	Not Feasible
56	Manisa	370,792	278	1	1	142,865.15	133.22	6,023.13	40%	238,135.36	7.9	Not Feasible
57	Aydın	38,818	68	0	1	36,589.57	0	2,267.75	100%	59,533.70	7.6	Not Feasible
58	Aydın	137,985	161	1	1	86,631.19	133.22	3,559.45	65%	138,932.86	7.6	Not Feasible
59	Aydın	111,035	58	1	1	31,208.75	133.22	3,033.34	31%	52,249.67	7.5	Not Feasible
60	Aydın	54,634	87	1	1	46,813.13	133.22	6,047.32	97%	76,251.87	7.1	Not Feasible
61	İstanbul	297,616	464	1	1	261,367.35	315.79	4,965.26	90%	299,843.25	5.5	Feasible
62	İstanbul	689,094	464	1	1	261,367.35	315.79	6,541.50	39%	299,843.25	5.5	Not Feasible
63	Aydın	92,764	175	0	0	94,164.33	0	0	102%	147,335.74	7.7	Not Feasible
64	Manisa	340,429	307	1	1	157,768.35	133.22	6,313.40	48%	262,605.55	7.9	Not Feasible
65	Ankara	226,583	400	1	1	203,708.28	243.44	3,153.16	91%	260,494.80	6.2	Feasible
66	Eskişehir	320,000	340	1	1	173,046.29	62.68	4,725.98	56%	291,106.27	8.1	Not Feasible
67	Eskişehir	388,000	241	1	1	122,659.28	62.68	6,664.15	33%	206,914.78	7.9	Not Feasible
68	Aydın	388,045	1,099	0	0	591,352.01	0	0	152%	703,950.71	5.9	Feasible
69	Bursa	529,415	222	1	1	106,905.50	93.57	6,316.26	21%	191,749.35	8.3	Not Feasible
70	Manisa	89,274	112	1	1	57,557.18	133.22	1,965.14	67%	98,291.12	8.1	Not Feasible
71	Manisa	48,555	115	0	0	59,098.89	0	0	122%	97,253.26	8.1	Not Feasible
72	İstanbul	131,022	146	1	1	82,240.59	315.79	1,721.69	64%	126,621.16	7.4	Not Feasible
73	Ankara	674,609	478	1	1	243,431.39	243.44	6,063.09	37%	310,274.97	6.1	Not Feasible
74	Ankara	601,203	478	1	1	243,431.39	243.44	6,737.15	42%	310,274.97	6.1	Not Feasible
75	Şanlıurfa	136,882	956	0	0	524,124.77	0	0	383%	611,672.70	5.8	Feasible
76	Van	109,500	1,935	0	0	1,094,023.96	0	0	999%	1,235,304.00	5.6	Feasible
77	Van	124,100	312	0	0	176,400.76	0	0	142%	261,504.83	7.3	Not Feasible
78	İstanbul	631,115	2,668	0	0	1,502,862.26	0	0	238%	1,703,251.20	5.6	Feasible
79	Van	122,883	215	0	1	121,558.22	0	3,023.66	101%	182,319.84	7.2	Not Feasible

APPENDIX 7 - Payback Periods for Scenario 1 and Scenario 2

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	Scenario 1				Scenario 2			
					PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PP (y)	PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PP (y)
1	İstanbul	CAS	78,163	32,398	51	1	1	7.8	51	1	1	7.8
2	İstanbul	CAS	122,899	110,548	73	1	1	7.6	73	1	1	7.6
3	İstanbul	CAS	224,128	112,716	109	1	1	7.4	109	1	1	7.4
4	İstanbul	CAS	141,865	112,789	73	1	1	7.6	73	1	1	7.6
5	İstanbul	CAS	240,400	51,337	76	1	1	7.4	76	1	1	7.4
6	İstanbul	CAS	193,546	59,642	83	1	1	7.5	83	1	1	7.5
7	İstanbul	CAS	185,753	46,249	83	0	0	7.4	83	0	0	7.4
8	İstanbul	CAS	326,352	47,485	80	0	1	7.2	85	0	0	7.4
9	İstanbul	CAS	112,329	63,953	84	1	1	7.6	84	1	1	7.6
10	İstanbul	CAS	305,527	47,341	80	0	1	7.2	83	0	1	7.2
11	İstanbul	CAS	462,132	43,885	72	0	1	7	83	0	0	7.4
12	İstanbul	CAS	303,615	57,409	98	0	1	7.2	166	0	0	7.4
13	İstanbul	CAS	166,153	77,829	59	1	1	7.6	59	1	1	7.6
14	İstanbul	CAS	220,622	44,465	76	0	1	7.4	83	0	0	7.4
15	Konya	EAAS	103,295	87,807	48	1	1	7.9	48	1	1	7.9
16	Kayseri	CAS	117,682	131,617	73	1	1	7.8	73	1	1	7.8
17	Manisa	CAS	109,500	82,484	43	1	1	8.6	43	1	1	8.6
18	İstanbul	CAS	285,454	178,333	113	1	1	7.4	113	1	1	7.4
19	İstanbul	CAS	253,372	141,781	111	1	1	7.4	111	1	1	7.4
20	İstanbul	CAS	243,783	123,024	166	1	1	7.4	166	1	1	7.4
21	İstanbul	CAS	126,573	184,671	161	1	1	7.5	161	1	1	7.5
22	İstanbul	CAS	280,708	222,832	161	1	1	7.4	161	1	1	7.4
23	İstanbul	CAS	261,822	302,919	161	1	1	7.4	161	1	1	7.4
24	İstanbul	CAS	178,203	153,630	161	1	1	7.4	161	1	1	7.4
25	İstanbul	CAS	72,059	104,639	161	1	1	7.5	161	1	1	7.5

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	Scenario 1				Scenario 2			
					PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PP (y)	PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PP (y)
26	İstanbul	CAS	348,357	208,268	122	1	1	7.3	122	1	1	7.3
27	İstanbul	CAS	214,486	150,021	128	1	1	7.4	128	1	1	7.4
28	İstanbul	CAS	157,662	34,447	62	0	0	7.6	156	0	0	7.4
29	İstanbul	CAS	308,778	102,036	113	1	1	7.3	113	1	1	7.3
30	İstanbul	CAS	91,767	100,423	113	1	1	7.6	113	1	1	7.6
31	İstanbul	CAS	254,423	187,004	166	1	1	7.4	166	1	1	7.4
32	İstanbul	CAS	115,804	138,320	161	1	1	7.5	161	1	1	7.5
33	İstanbul	CAS	120,880	130,751	161	1	1	7.5	161	1	1	7.5
34	Kayseri	CAS	115,000	129,408	73	1	1	7.8	73	1	1	7.8
35	Manisa	CAS	182,471	83,464	97	1	1	8.2	97	1	1	8.2
36	Denizli	EAAS	744,972	249,876	444	0	1	5.7	659	0	0	5.7
37	İstanbul	CAS	328,351	174,207	213	1	1	7.3	213	1	1	7.3
38	İstanbul	CAS	313,602	252,899	226	1	1	7.3	226	1	1	7.3
39	İstanbul	CAS	317,951	276,593	226	1	1	7.3	226	1	1	7.3
40	İstanbul	CAS	469,690	113,852	195	1	1	7.2	226	0	0	7.4
41	Antalya	EAAS	934,035	1,061,785	1124	1	1	5.5	1124	1	1	5.5
42	İstanbul	CAS	317,748	299,895	232	1	1	7.3	232	1	1	7.3
43	Bursa	CAS	439,077	264,111	183	1	1	8.6	183	1	1	8.6
44	Ankara	CAS	302,730	83,700	160	0	1	8.1	183	0	0	8.2
45	Konya	EAAS	69,350	55,796	39	1	1	8.1	39	1	1	8.1
46	Konya	EAAS	80,300	54,699	39	1	1	8	39	1	1	8
47	Mersin	CAS	441,527	179,571	219	1	1	7.3	219	1	1	7.3
48	Konya	EAAS	657,000	255,685	351	1	1	5.6	351	1	1	5.6
49	Konya	EAAS	127,750	42,281	76	1	0	7.5	95	0	0	7.5
50	Konya	EAAS	337,625	179,701	179	1	1	7.4	179	1	1	7.4
51	Konya	EAAS + N, P	160,000	102,464	112	1	1	7.6	112	1	1	7.6
52	Konya	EAAS + N, P	401,500	141,814	194	1	1	7.4	194	1	1	7.4
53	Aydın	CAS	438,000	262,503	171	1	1	7.6	171	1	1	7.6

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	Scenario 1				Scenario 2			
					PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PP (y)	PV Panel #	Wind Turbine #	Micro-HEP Turbine #	PP (y)
54	Denizli	EAAS	543,936	411,564	196	1	1	7.4	196	1	1	7.4
55	İstanbul	SBR + N, P	832,426	468,242	48	1	1	6.3	48	1	1	6.3
56	Manisa	EAAS	727,080	370,792	278	1	1	7.9	278	1	1	7.9
57	Aydın	EAAS	273,750	38,818	68	0	1	7.6	68	0	1	7.6
58	Aydın	EAAS	429,678	137,985	161	1	1	7.6	161	1	1	7.6
59	Aydın	EAAS	366,168	111,035	58	1	1	7.5	58	1	1	7.5
60	Aydın	EAAS	730,000	54,634	87	1	1	7.1	87	1	1	7.1
61	İstanbul	CAS	599,379	297,616	464	1	1	5.5	464	1	1	5.5
62	İstanbul	CAS	789,655	689,094	464	1	1	5.5	464	1	1	5.5
63	Aydın	EAAS	365,000	92,764	167	0	1	7.6	175	0	0	7.7
64	Manisa	EAAS	762,120	340,429	307	1	1	7.9	307	1	1	7.9
65	Ankara	EAAS + N, P	380,633	226,583	400	1	1	6.2	400	1	1	6.2
66	Eskişehir	EAAS + N, P	570,495	320,000	340	1	1	8.1	340	1	1	8.1
67	Eskişehir	CAS	804,460	388,000	241	1	1	7.9	241	1	1	7.9
68	Aydın	EAAS	912,500	388,045	707	1	1	5.8	1099	0	0	5.9
69	Bursa	CAS + N, P	762,465	529,415	222	1	1	8.3	222	1	1	8.3
70	Manisa	CAS	237,221	89,274	112	1	1	8.1	112	1	1	8.1
71	Manisa	CAS	182,471	48,555	95	0	0	8.1	115	0	0	8.1
72	İstanbul	CAS	207,833	131,022	146	1	1	7.4	146	1	1	7.4
73	Ankara	EAAS + N, P	731,904	674,609	478	1	1	6.1	478	1	1	6.1
74	Ankara	EAAS + N, P	813,272	601,203	478	1	1	6.1	478	1	1	6.1
75	Şanlıurfa	CAS	100,611	136,882	250	1	0	7.6	956	0	0	5.8
76	Van	EAAS + N, P	365,000	109,500	189	0	1	7.3	1935	0	0	5.6
77	Van	EAAS + N, P	876,000	124,100	207	1	1	7	312	0	0	7.3
78	İstanbul	Bardenpho	762,133	631,115	1109	1	1	5.5	2668	0	0	5.6
79	Van	EAAS + N, P	365,000	122,883	213	0	1	7.2	215	0	1	7.2

APPENDIX 8 – Payback Periods According to Different PV Panel Efficiency

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	PP in Scenario 1 for Different PV Panel Efficiency (y)					PP in Scenario 2 for Different PV Panel Efficiency (y)				
					19%	20%	21%	22%	23%	19%	20%	21%	22%	23%
1	İstanbul	CAS	78,163	32,398	8.7	8.3	7.8	7.5	7.1	8.7	8.3	7.8	7.5	7.1
2	İstanbul	CAS	122,899	110,548	8.5	8	7.6	7.2	6.9	8.5	8	7.6	7.2	6.9
3	İstanbul	CAS	224,128	112,716	8.2	7.8	7.4	7.1	6.7	8.2	7.8	7.4	7.1	6.7
4	İstanbul	CAS	141,865	112,789	8.4	8	7.6	7.2	6.9	8.4	8	7.6	7.2	6.9
5	İstanbul	CAS	240,400	51,337	8.2	7.8	7.4	7.1	6.8	8.2	7.8	7.4	7.1	6.8
6	İstanbul	CAS	193,546	59,642	8.3	7.9	7.5	7.1	6.8	8.3	7.9	7.5	7.1	6.8
7	İstanbul	CAS	185,753	46,249	8.3	7.9	7.4	7	6.7	8.3	7.9	7.4	7	6.7
8	İstanbul	CAS	326,352	47,485	8.1	7.5	7.2	6.8	6.5	8.1	7.5	7.4	7	6.7
9	İstanbul	CAS	112,329	63,953	8.5	8	7.6	7.2	6.9	8.5	8	7.6	7.2	6.9
10	İstanbul	CAS	305,527	47,341	8.1	5.8	7.2	6.9	6.5	8.1	7.7	7.2	7	6.7
11	İstanbul	CAS	462,132	43,885	7.7	7.3	7	6.6	6.5	7.7	7.8	7.4	7	6.7
12	İstanbul	CAS	303,615	57,409	8.2	7.7	7.2	7	6.6	8.2	7.8	7.4	7	6.7
13	İstanbul	CAS	166,153	77,829	8.4	8	7.6	7.2	6.9	8.4	8	7.6	7.2	6.9
14	İstanbul	CAS	220,622	44,465	8.3	7.8	7.4	7	6.7	8.3	7.8	7.4	7	6.7
15	Konya	EAAS	103,295	87,807	8.8	8.3	7.9	7.5	7.1	8.8	8.3	7.9	7.5	7.1
16	Kayseri	CAS	117,682	131,617	8.7	8.2	7.8	7.4	7.1	8.7	8.2	7.8	7.4	7.1
17	Manisa	CAS	109,500	82,484	9.5	9	8.6	8.2	7.8	9.5	9	8.6	8.2	7.8
18	İstanbul	CAS	285,454	178,333	8.2	7.7	7.4	7	6.7	8.2	7.7	7.4	7	6.7
19	İstanbul	CAS	253,372	141,781	8.2	7.8	7.4	7	6.7	8.2	7.8	7.4	7	6.7
20	İstanbul	CAS	243,783	123,024	8.2	7.8	7.4	7	6.7	8.2	7.8	7.4	7	6.7
21	İstanbul	CAS	126,573	184,671	8.3	7.9	7.5	7.1	6.8	8.3	7.9	7.5	7.1	6.8
22	İstanbul	CAS	280,708	222,832	8.2	7.8	7.4	7	6.7	8.2	7.8	7.4	7	6.7
23	İstanbul	CAS	261,822	302,919	8.2	7.8	7.4	7	6.7	8.2	7.8	7.4	7	6.7
24	İstanbul	CAS	178,203	153,630	8.3	7.8	7.4	7.1	6.7	8.3	7.8	7.4	7.1	6.7
25	İstanbul	CAS	72,059	104,639	8.4	7.9	7.5	7.1	6.8	8.4	7.9	7.5	7.1	6.8
26	İstanbul	CAS	348,357	208,268	8.1	7.7	7.3	7	6.6	8.1	7.7	7.3	7	6.6

No	**City**	**Process**	**Treated WW (m^3/y)**	**Electricity Consumption (kWh/y)**	**PP in Scenario 1 for Different PV Panel Efficiency (y)**					**PP in Scenario 2 for Different PV Panel Efficiency (y)**				
					19%	**20%**	**21%**	**22%**	**23%**	**19%**	**20%**	**21%**	**22%**	**23%**
27	İstanbul	CAS	214,486	150,021	8.2	7.8	7.4	7.1	6.7	8.2	7.8	7.4	7.1	6.7
28	İstanbul	CAS	157,662	34,447	8.2	7.8	7.6	7.3	6.8	8.2	7.8	7.4	7	6.7
29	İstanbul	CAS	308,778	102,036	8.1	7.7	7.3	7	6.7	8.1	7.7	7.3	7	6.7
30	İstanbul	CAS	91,767	100,423	8.4	8	7.6	7.2	6.9	8.4	8	7.6	7.2	6.9
31	İstanbul	CAS	254,423	187,004	8.2	7.8	7.4	7	6.7	8.2	7.8	7.4	7	6.7
32	İstanbul	CAS	115,804	138,320	8.3	7.9	7.5	7.1	6.8	8.3	7.9	7.5	7.1	6.8
33	İstanbul	CAS	120,880	130,751	8.3	7.9	7.5	7.1	6.8	8.3	7.9	7.5	7.1	6.8
34	Kayseri	CAS	115,000	129,408	8.7	8.2	7.8	7.4	7.1	8.7	8.2	7.8	7.4	7.1
35	Manisa	CAS	182,471	83,464	9.1	8.7	8.2	7.8	7.5	9.1	8.7	8.2	7.8	7.5
36	Denizli	EAAS	744,972	249,876	6.3	5.9	5.7	5.4	5.1	6.4	6	5.7	5.5	5.2
37	İstanbul	CAS	328,351	174,207	8.2	7.7	7.3	7	6.7	8.2	7.7	7.3	7	6.7
38	İstanbul	CAS	313,602	252,899	8.2	7.7	7.3	7	6.7	8.2	7.7	7.3	7	6.7
39	İstanbul	CAS	317,951	276,593	8.2	7.7	7.3	7	6.7	8.2	7.7	7.3	7	6.7
40	İstanbul	CAS	469,690	113,852	8.1	7.6	7.2	6.8	6.5	8.2	7.8	7.4	7	6.7
41	Antalya	EAAS	934,035	1,061,785	6.1	5.8	5.5	5.2	5	6.1	5.8	5.5	5.2	5
42	İstanbul	CAS	317,748	299,895	8.2	7.7	7.3	7	6.7	8.2	7.7	7.3	7	6.7
43	Bursa	CAS	439,077	264,111	9.5	9	8.6	8.1	7.8	9.5	9	8.6	8.1	7.8
44	Ankara	CAS	302,730	83,700	9	8.6	8.1	1.1	7.3	9.2	8.7	8.2	7.8	7.4
45	Konya	EAAS	69,350	55,796	9	8.5	8.1	7.7	7.3	9	8.5	8.1	7.7	7.3
46	Konya	EAAS	80,300	54,699	8.9	8.5	8	7.6	7.3	8.9	8.5	8	7.6	7.3
47	Mersin	CAS	441,527	179,571	8.1	7.7	7.3	6.9	6.6	8.1	7.7	7.3	6.9	6.6
48	Konya	EAAS	657,000	255,685	6.2	5.9	5.6	5.3	5.1	6.2	5.9	5.6	5.3	5.1
49	Konya	EAAS	127,750	42,281	8.4	7.9	7.5	7.2	6.9	8.3	7.9	7.5	7.1	6.8
50	Konya	EAAS	337,625	179,701	8.2	7.8	7.4	7	6.7	8.2	7.8	7.4	7	6.7
51	Konya	EAAS + N, P	160,000	102,464	8.4	8	7.6	7.2	6.9	8.4	8	7.6	7.2	6.9
52	Konya	EAAS + N, P	401,500	141,814	8.2	7.8	7.4	7	6.7	8.2	7.8	7.4	7	6.7
53	Aydın	CAS	438,000	262,503	8.4	8	7.6	7.2	6.9	8.4	8	7.6	7.2	6.9
54	Denizli	EAAS	543,936	411,564	8.2	7.8	7.4	7	6.7	8.2	7.8	7.4	7	6.7

No	City	Process	Treated WW (m^3/y)	Electricity Consumption (kWh/y)	PP in Scenario 1 for Different PV Panel Efficiency (y)					PP in Scenario 2 for Different PV Panel Efficiency (y)				
					19%	20%	21%	22%	23%	19%	20%	21%	22%	23%
55	İstanbul	SBR + N, P	832,426	468,242	6.9	6.6	6.3	6.1	5.8	6.9	6.6	6.3	6.1	5.8
56	Manisa	EAAS	727,080	370,792	8.8	8.3	7.9	7.5	7.2	8.8	8.3	7.9	7.5	7.2
57	Aydın	EAAS	273,750	38,818	8.5	8.1	7.6	7.2	6.9	8.5	8.1	7.6	7.2	7
58	Aydın	EAAS	429,678	137,985	8.4	8	7.6	7.2	6.9	8.4	8	7.6	7.2	6.9
59	Aydın	EAAS	366,168	111,035	8.3	7.9	7.5	7.2	6.9	8.3	7.9	7.5	7.2	6.9
60	Aydın	EAAS	730,000	54,634	7.8	7.4	7.1	6.7	6.4	7.8	7.4	7.1	6.7	6.4
61	İstanbul	CAS	599,379	297,616	6.2	5.8	5.5	5.3	5	6.2	5.8	5.5	5.3	5
62	İstanbul	CAS	789,655	689,094	6.1	5.8	5.5	5.3	5	6.1	5.8	5.5	5.3	5
63	Aydın	EAAS	365,000	92,764	8.5	6.1	7.6	7.3	6.9	8.5	8.1	7.7	7.3	7
64	Manisa	EAAS	762,120	340,429	8.8	8.3	7.9	7.5	7.2	8.8	8.3	7.9	7.5	7.2
65	Ankara	EAAS + N, P	380,633	226,583	6.9	6.5	6.2	1.1	5.6	6.9	6.5	6.2	5.9	5.6
66	Eskişehir	EAAS + N, P	570,495	320,000	9	8.5	8.1	7.7	7.3	9	8.5	8.1	7.7	7.3
67	Eskişehir	CAS	804,460	388,000	8.8	8.3	7.9	7.5	7.2	8.8	8.3	7.9	7.5	7.2
68	Aydın	EAAS	912,500	388,045	6.5	6.1	5.8	5.5	5.3	6.5	6.2	5.9	5.6	5.3
69	Bursa	CAS + N, P	762,465	529,415	9.3	8.8	8.3	8	7.6	9.3	8.8	8.3	8	7.6
70	Manisa	CAS	237,221	89,274	9.1	8.6	8.1	7.7	7.4	9.1	8.6	8.1	7.7	7.4
71	Manisa	CAS	182,471	48,555	9.2	8.7	8.1	7.9	7.4	9.1	8.6	8.1	7.7	7.4
72	İstanbul	CAS	207,833	131,022	8.2	7.8	7.4	7.1	6.7	8.2	7.8	7.4	7.1	6.7
73	Ankara	EAAS + N, P	731,904	674,609	6.8	6.5	6.1	1	5.6	6.8	6.5	6.1	5.8	5.6
74	Ankara	EAAS + N, P	813,272	601,203	6.8	6.4	6.1	1	5.6	6.8	6.4	6.1	5.8	5.6
75	Şanlıurfa	CAS	100,611	136,882	6.5	8	7.6	7.3	7	6.4	6.1	5.8	5.5	5.2
76	Van	EAAS + N, P	365,000	109,500	8.2	7.6	7.3	6.9	6.5	6.2	5.9	5.6	5.3	5.1
77	Van	EAAS + N, P	876,000	124,100	7.8	7.4	7	6.7	6.3	8.2	7.7	7.3	7	6.6
78	İstanbul	Bardenpho	762,133	631,115	6.2	5.9	5.5	5.3	5	6.2	5.9	5.6	5.3	5.1
79	Van	EAAS + N, P	365,000	122,883	8.1	7.7	7.2	6.9	6.6	8.1	7.7	7.2	7	6.6

APPENDIX 9 – Cost and Emission Reductions

No	City	Process	Treated WW (m^3/y)	Scenario 1			Scenario 2		
				Emission Reduction (ton/y)	Cost Reduction ($/y)	Energy Cost ($/kWh-y)	Emission Reduction (ton/y)	Cost Reduction ($/y)	Energy Cost ($/kWh-y)
1	İstanbul	CAS	78,163	15	5,840	0.006	15	5,840	0.006
2	İstanbul	CAS	122,899	21	8,504	0.200	21	9,462	0.223
3	İstanbul	CAS	224,128	32	12,792	0.201	32	14,226	0.224
4	İstanbul	CAS	141,865	21	8,535	0.200	21	9,496	0.223
5	İstanbul	CAS	240,400	22	9,047	0.201	22	10,064	0.223
6	İstanbul	CAS	193,546	24	9,767	0.201	24	10,865	0.223
7	İstanbul	CAS	185,753	23	9,457	0.202	23	10,511	0.225
8	İstanbul	CAS	326,352	24	9,662	0.202	24	10,765	0.225
9	İstanbul	CAS	112,329	24	9,744	0.201	24	10,839	0.223
10	İstanbul	CAS	305,527	24	9,589	0.202	25	11,082	0.225
11	İstanbul	CAS	462,132	22	8,934	0.202	23	10,511	0.225
12	İstanbul	CAS	303,615	29	11,661	0.202	47	21,055	0.225
13	İstanbul	CAS	166,153	17	6,976	0.200	17	7,764	0.222
14	İstanbul	CAS	220,622	22	9,019	0.202	23	10,511	0.225
15	Konya	EAAS	103,295	14	5,522	0.200	14	6,145	0.222
16	Kayseri	CAS	117,682	21	8,292	0.201	21	9,222	0.224
17	Manisa	CAS	109,500	12	4,603	0.199	12	5,125	0.221
18	İstanbul	CAS	285,454	33	13,353	0.201	33	14,849	0.224
19	İstanbul	CAS	253,372	32	13,070	0.201	32	14,535	0.224
20	İstanbul	CAS	243,783	48	19,343	0.202	48	21,504	0.224
21	İstanbul	CAS	126,573	46	18,573	0.202	46	20,649	0.224
22	İstanbul	CAS	280,708	46	18,833	0.202	46	20,938	0.224
23	İstanbul	CAS	261,822	46	18,801	0.202	46	20,903	0.224
24	İstanbul	CAS	178,203	46	18,661	0.202	46	20,746	0.224
25	İstanbul	CAS	72,059	46	18,481	0.202	46	20,547	0.224

No	City	Process	Treated WW (m^3/y)	Scenario 1			Scenario 2		
				Emission Reduction (ton/y)	Cost Reduction ($/y)	Energy Cost ($/kWh-y)	Emission Reduction (ton/y)	Cost Reduction ($/y)	Energy Cost ($/kWh-y)
26	İstanbul	CAS	348,357	36	14,489	0.201	36	16,111	0.224
27	İstanbul	CAS	214,486	37	14,949	0.201	37	16,622	0.224
28	İstanbul	CAS	157,662	17	6,981	0.202	44	19,785	0.225
29	İstanbul	CAS	308,778	33	13,393	0.201	33	14,894	0.224
30	İstanbul	CAS	91,767	32	13,025	0.201	32	14,485	0.224
31	İstanbul	CAS	254,423	48	19,361	0.202	48	21,524	0.224
32	İstanbul	CAS	115,804	46	18,555	0.202	46	20,629	0.224
33	İstanbul	CAS	120,880	46	18,563	0.202	46	20,638	0.224
34	Kayseri	CAS	115,000	21	8,288	0.201	21	9,217	0.224
35	Manisa	CAS	182,471	26	10,361	0.201	26	11,523	0.224
36	Denizli	EAAS	744,972	124	50,707	0.203	181	81,727	0.225
37	İstanbul	CAS	328,351	61	24,860	0.202	61	27,634	0.225
38	İstanbul	CAS	313,602	65	26,321	0.202	65	29,258	0.225
39	İstanbul	CAS	317,951	65	26,328	0.202	65	29,266	0.225
40	İstanbul	CAS	469,690	57	23,029	0.202	63	28,677	0.225
41	Antalya	EAAS	934,035	322	131,349	0.203	322	145,950	0.225
42	İstanbul	CAS	317,748	67	27,014	0.202	67	30,028	0.225
43	Bursa	CAS	439,077	46	18,551	0.202	46	20,623	0.225
44	Ankara	CAS	302,730	42	17,010	0.203	46	20,985	0.225
45	Konya	EAAS	69,350	11	4,448	0.199	11	4,952	0.222
46	Konya	EAAS	80,300	11	4,467	0.199	11	4,973	0.222
47	Mersin	CAS	441,527	63	25,638	0.202	63	28,496	0.225
48	Konya	EAAS	657,000	100	40,676	0.203	100	45,203	0.225
49	Konya	EAAS	127,750	21	8,502	0.201	26	11,881	0.225
50	Konya	EAAS	337,625	51	20,705	0.202	51	23,015	0.225
51	Konya	EAAS + N, P	160,000	32	12,843	0.202	32	14,280	0.224
52	Konya	EAAS + N, P	401,500	55	22,506	0.202	55	25,016	0.225
53	Aydın	CAS	438,000	48	19,353	0.202	48	21,513	0.225

No	**City**	**Process**	**Treated WW (m^3/y)**	**Scenario 1**			**Scenario 2**		
				Emission Reduction (ton/y)	**Cost Reduction ($/y)**	**Energy Cost ($/kWh-y)**	**Emission Reduction (ton/y)**	**Cost Reduction ($/y)**	**Energy Cost ($/kWh-y)**
54	Denizli	EAAS	543,936	56	22,732	0.202	56	25,267	0.225
55	İstanbul	SBR + N, P	832,426	17	6,853	0.200	17	7,625	0.223
56	Manisa	EAAS	727,080	74	30,159	0.202	74	33,520	0.225
57	Aydın	EAAS	273,750	19	7,854	0.202	19	8,730	0.225
58	Aydın	EAAS	429,678	45	18,247	0.202	45	20,284	0.225
59	Aydın	EAAS	366,168	17	6,892	0.200	17	7,667	0.223
60	Aydın	EAAS	730,000	26	10,674	0.201	26	11,869	0.224
61	İstanbul	CAS	599,379	133	54,040	0.203	133	60,053	0.225
62	İstanbul	CAS	789,655	134	54,360	0.203	134	60,409	0.225
63	Aydın	EAAS	365,000	46	18,818	0.203	47	21,204	0.225
64	Manisa	EAAS	762,120	82	33,243	0.202	82	36,946	0.225
65	Ankara	EAAS + N, P	380,633	103	41,968	0.203	103	46,639	0.225
66	Eskişehir	EAAS + N, P	570,495	89	36,006	0.202	89	40,017	0.225
67	Eskişehir	CAS	804,460	64	26,174	0.202	64	29,092	0.225
68	Aydın	EAAS	912,500	193	78,705	0.203	294	133,340	0.225
69	Bursa	CAS + N, P	762,465	56	22,909	0.202	56	25,464	0.225
70	Manisa	CAS	237,221	30	12,019	0.201	30	13,364	0.224
71	Manisa	CAS	182,471	24	9,849	0.202	29	13,295	0.225
72	İstanbul	CAS	207,833	42	16,996	0.202	42	18,896	0.224
73	Ankara	EAAS + N, P	731,904	124	50,622	0.203	124	56,255	0.225
74	Ankara	EAAS + N, P	813,272	125	50,759	0.203	125	56,407	0.225
75	Şanlıurfa	CAS	100,611	68	27,733	0.202	261	118,171	0.225
76	Van	EAAS + N, P	365,000	55	22,203	0.203	545	246,706	0.226
77	Van	EAAS + N, P	876,000	62	25,152	0.202	88	39,750	0.225
78	İstanbul	Bardenpho	762,133	314	128,055	0.203	748	338,910	0.226
79	Van	EAAS + N, P	365,000	61	24,954	0.203	62	28,063	0.225
Total				**4,353**	**1,767,305**		**5,724**	**2,585,002**	