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Application of energy efficiency obligation scheme for electricity distribution companies in Turkey

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ABSTRACT

To realize the existing energy-saving potential in a short time according to 2012/27/EU Energy Efficiency Directive, in 2017, Turkey published National Energy Efficiency Action Plan (NEEAP), containing Energy Efficiency Obligation Schemes EEOS establishment action. Since research studies are needed to guide the NEEAP, this study was conducted to establish an exemplary model for Turkish EEOS. Based on the literature, the main hypothesis of the study is "EEOS could contribute significantly to NEEAP targets". Electricity Distribution Companies (EDCs) are assumed as obligated parties, a guideline containing standard energy efficiency (EE) actions for residential, commercial, and industrial sectors was prepared. Concerning EDCs' market shares, mixed-integer linear programming models, minimizing EE actions' costs, were developed to examine four annual saving targets (0.8%, 1.5%, 2%, and least) under three scenarios (yearly-based obligation, yearly-based with using 5% of each action and no constraints). Saving target 2% for 7 years with no constraint gives the highest energy-saving (above 200 TWh) and the least is from the least annual target for 10 years with yearly based obligation (below 100 TWh). In conclusion, if EDCs fulfill their obligations under specified targets and scenarios, Turkish NEEAP's saving target can be fulfilled between 10% and 44%, supporting the hypothesis of the study.

1. Introduction

Energy efficiency is a prominent issue on the world agenda due to climate change, increasing energy costs, and rising energy demand. Therefore, energy efficiency is regarded as an important component of sustainable development, as it provides benefits such as reducing external dependency on energy, the burden of energy on the economy, and ensuring energy supply security (del Mar Solà et al., 2021; Bertoldi and Mosconi, 2020). Due to such benefits of energy efficiency, many developed and developing countries have designated strategies for the improvement of energy efficiency (Malinauskaite et al., 2019; Simsek et al., 2019). For instance, The European Union (EU) is ambitiously willing to make its energy system decarbonized, competitive, reliable, and sustainable, and for these reasons, the EU set 2020, 2030, and 2050 targets to reduce greenhouse gas emissions, increase energy efficiency and renewable energy utilization. The EU enacted the 2012/27/EU Energy Efficiency Directive to increase energy efficiency and reach the specified targets. Article 7 of the Directive, describes the obligation schemes for energy companies to achieve energy savings in annual sales to final consumers or to achieve energy savings equivalent annual reduction in national energy sales (Directive, 2012).

EEOS is a legally binding energy efficiency policy mechanism that obliges companies that selling energy (distributors, retailers, suppliers, etc.) to carry out energy efficiency studies on final consumers (Fawcett et al., 2019). EEOS is also a market-based policy mechanism that sets a policy framework specifying the outcome to be delivered by market actors without prescribing the delivery mechanisms and the measures, used in more than 50 countries and states on 6 continents (Rosenow et al., 2019). With these perspectives, EEOS can be specified as a flexible mechanism and each application is almost unique. EEOS has a structure that imposes obligations on obligated parties to meet quantitative energy saving targets in their customer portfolios. The obligated parties can independently choose the measures and methods that are most suitable for them while meeting their obligations, within some basic rules determined by the managing authority. EEOS is considered a highly efficient tool to ensure energy efficiency and a mechanism that enables exploration of the most cost-effective way to save energy (Malinauskaite et al., 2019; EBRD & EnCS, 2019). The verified energy savings are certified in some EEOS applications. Obligated parties can earn these certificates, called "white certificates" or "energy efficiency

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certificates", with their energy efficiency and saving actions, purchasing certificates from other parties, or selling their excess certificates to other parties to achieve their obligations. Besides, the EEOS requires a penalty system to determine whether the obligated parties fulfilled their obligations and to impose sanctions if unsuccessful. Usually, obligated parties who fail to achieve their goals have to pay a financial penalty (Cin et al., 2021). More than 40% of the energy-saving target within the scope of Article 7 of the EU EED was achieved by EEOS in 2016 (Zangheri et al., 2019).

After the enactment of the Energy Efficiency Law in 2007, Turkey prepared and published the Energy Efficiency Strategy Document (2010–2023) to create strategies related to energy efficiency. In the EU Directive, member states are also required to prepare their National Energy Efficiency Action Plans (NEEAP) to set out estimated energy consumption, planned energy efficiency measures, and the improvements expected to achieve. In line with the EU, the Turkish NEEAP was prepared by taking into account the current needs of the country, the best practices in the world, and the previous national energy efficiency strategies. In Turkish NEEAP, during the period 2017–2023, with USD 10.9 billion investment, a cumulative reduction of 23.9 Mtoe in Turkish primary energy consumption is targeted. Moreover, along with the continuity of energy efficiency practices, 86.37 Mtoe energy savings are envisaged within the scope of NEEAP until 2033. According to Turkish national energy policy, it is aimed to ensure the sustainable development of the country with the efficient and environmentally friendly use of energy resources at all stages from production to final consumption. On this policy basis, 55 actions in 6 different categories namely buildings and services, energy, transport, industry and technology, agriculture, and cross-cutting (horizontal) areas were defined within the scope of Turkish NEEAP. Actions "Y2 - Develop national financing mechanism for energy efficiency" and "Y11 - Establish an obligation programme for Energy Distribution or Retail Companies" defined under the category of the horizontal areas are directly related to the implementation of EEOS. The purpose of the action Y2 is to establish a national energy efficiency financing mechanism to provide additional financial support for energy efficiency studies. Within the scope of the action, it is planned that the parties taking energy efficiency obligations will pay in proportion to their obligations that they could not fulfill to the national energy efficiency fund. The action is planned to be implemented in 2021. The scope of the action Y11 is giving obligations to energy (electricity, natural gas, petroleum) companies in a proportion of their market shares and achieving their obligations by developing various projects on end-users or increasing energy efficiency in their activities. Energy companies are allowed to reflect the costs of the energy efficiency services they offer on their customers' bills under appropriate conditions. It is also planned that energy companies that cannot fulfill their obligations will pay their penalties to the national energy efficiency fund. Moreover, it was decided to prepare a catalog that standardizes energy efficiency measures for the different end-users with the energy-saving potential and the cost of the action. Hence, obligated companies will offer energy efficiency projects to their customers in line with this catalog to achieve their obligations. The action Y11 is planned to be implemented between 2020 and 2022 (ETKB, 2017). However, there is no preparation (legislative works, guide catalog, etc.) presented by the Turkish government so far. For this reason, there is a need for guiding and motivating research studies that take into account country specific conditions for EEOS implementation.

After summarizing the policy context for Turkey, when the literature is examined, it is seen that only a few studies were published for the EEOS practice in Turkey. Among them, Düzgün and Kömürgöz evaluated the applicability of the white certificate system in Turkey in terms of electricity and natural gas markets, their obligated parties, and potential barriers. According to study, a white certificate system can be implemented under ministerial institutions and the most possible alternatives for the obligated parties are electricity suppliers for the electricity market and distribution companies for the natural gas market (Duzgun and Komurgoz, 2014). Argun et al. proposed two mixed-integer linear programming models with maximum energy savings and minimum cost from the EEOS regulator and electricity distribution companies' perspective, respectively. These two models have similarities considering financial constraints and minimum 2% annual energy saving targets, but also have differences with regard to incentives and penalties proposed as well as the objective function. The first model (from the regulatory perspective) aims to maximize energy-saving with obligations and incentives, and the second (from the obligated parties' perspective) aims to minimize the total costs of energy efficiency projects and penalties to meet the obligations. In the end, it was suggested that incentives and penalties should be balanced for a successful EEOS (Argun et al., 2021). Cin et al. examined and explained the EEOS and its practices in EU countries and summarized the best practices and key issues in designing and implementing EEOS. After that, they conducted an energy expert survey study and the results of the survey were analyzed with different scenarios by using Bayesian Belief Networks to propose a possible EEOS structure for Turkey based on experts' opinions. According to the results of the analysis, the responsible authority should be the Ministry of Energy and Natural Resources, an energy agency should establish for managing authority, all energy distributors and suppliers exceeding a certain threshold value in all energy types should be obligated parties, voluntary parties should be included in the scheme, certificate trade should be allowed on the stock market, obligated parties who fail to reach a certain percentage of energy targets are penalized, and finally, it is recommended that obligated parties should be supported with incentives. Under these circumstances, they found that the success probability of the proposed EEOS structure is about 84% (Cin et al., 2021). In the limited literature on EEOS in Turkey, possible Turkish EEOS with its design requirements have been investigated. Unlike existing studies, this study aims to contribute to the literature in terms of presenting an implementation plan for Turkish EEOS and providing the necessary guidelines containing a standard energy efficiency action list with associated cost and electrical energy saving calculations through modeling scenarios with real market data.

Additionally, in various studies in the literature, it was stated that significant gains can be achieved in terms of protecting energy security and the environment and providing financial benefit with the applications for energy efficiency measures in the end-use sectors. Table 1 summarizes some of these studies and their findings.

Based on the end-use sector analysis, EEOS can be considered as an important mechanism for reaching Turkish NEEAP targets on a sectoral basis and being a flexible mechanism that can be implemented according to Turkish local conditions. Under this framework, this study aims to contribute to the possible Turkish EEOS by preparing a guideline for energy efficiency measures, calculating the cost of the energy efficiency actions, and developing application scenarios and recommendations. Contrary to the studies in the literature, which mostly focus on either only the residential and/or commercial sectors or only the industrial sector as can be seen in Table 1, this study aims to be a comprehensive study for residential, commercial, and industrial sectors. Therefore, in this study, it is suggested a standard energy efficiency actions list that has high energy efficiency potential for residential, commercial, and industrial end-use sectors. Because of having a more mature and liberalized market structure, the electricity was chosen as the fuel type to construct a viable and successful scheme. Taking into consideration the EU Directive and the energy-saving targets specified in the Turkish NEEAP, obligations were set for 21 EDCs operating in the energy market of Turkey. Then, mixed-integer linear programming models with four different targets were developed under three different scenarios with various time frames and it was aimed to determine the energy savings to be achieved by EEOS with minimum cost as well as to perform a comparative analysis in terms of quantity and cost of the energy efficiency actions. The models in the study are designed from the perspective of the company managers of EDCs. From this point of view, EDCs want to meet their obligations at a minimum cost. Different from the

Table 1
Literature on the results of energy efficiency applications to the end-use sectors.

Study	End-use sectors	Findings/Benefits
Üçtuğ and Yükseltan, 2012; Wada et al. (2012); Baldini and Trivella (2018)	Residential	By replacing inefficient appliances with efficient ones to increase energy efficiency, significant energy savings can be achieved and CO_2 emission can be prevented.
Yilmaz et al. (2020)	Residential	The peak energy demand will be reduced by using energy-efficient appliances.
Tan et al. (2016); Afshari and Friedrich (2016); Fan and Xia (2017); Fan and Xia (2018a); Fan and Xia (2018b)	Building	Conducting energy efficiency studies to increase the energy efficiency of buildings will provide financial and environmental benefits
Bataineh and Alrabee (2018)	All sectors	Energy efficiency studies could create job opportunities that could reduce unemployment.
Du Plessis et al. (2013); Nel et al. (2019)	Industrial	Energy savings and financial benefits can be increased and greenhouse gas emissions can be reduced by adding variable speed drives to inefficient electric motors.
Tallini and Cedola (2016)	Industrial and Commercial	High energy consumption in industrial and commercial sectors can be reduced by replacing inefficient electric motors with efficient ones.
Hasanbeigi and Price (2012); Andersson et al. (2018)	Industrial	Enterprises in industrial sub-sectors, which are mostly small and medium-sized, can reduce their energy consumptions and provide economic benefits with energy efficiency actions.
Yue et al. (2018); Bühler et al. (2018)	Industrial	The chemical industry has a great energy-saving potential to reduce energy consumption and greenhouse gas emissions.
Hasanbeigi et al. (2013); Zhang et al. (2016); Zhang et al. (2021)	Industrial	In the cement sector, where energy consumption is high, it has been determined that in addition to the energy savings achieved through energy efficiency, the emission of greenhouse gases and other gases harmful to human health can be reduced and air quality can be improved.
Ates (2015); Karali et al. (2017); Zhang et al. (2017); Wang et al. (2020)	Industrial	In the iron and steel industry, which is one of the energy-intensive sectors, through energy efficiency actions, together with the energy-saving, greenhouse gas emission reduction, and economic benefits can be also achieved.

most energy efficiency optimization studies in the literature, EDCs are not restricted by budget constraints. In studies restricted by the budget, energy efficiency actions that provide maximum savings per unit cost or reduce maximum CO_2 are preferred first, depending on the objective function. Researchers then solve their models with different budget values to learn about possible results. In this study, on the other hand, EDCs were given the chance to show their potential in the best way, by not adding any budget constraints. In the designed EEOS, the obligated parties were motivated by penalty and financial incentive practices to achieve their energy-saving targets.

According to the above-mentioned literature review, the novelty/originality of the study can be stated as follows:

- For the first time, possible Turkish EEOS is demonstrated assuming EDCs as obligated parties, using real electrical energy consumption data, since it is considered that in the current market structure EDCs are the most suitable actors to become obligated parties.
- A possible energy efficiency action list was prepared for residential, commercial, and industrial end-use sectors based on existing local energy efficiency projects' outputs and energy-saving potentials in Turkey to guide EDCs.
- In line with EU practices and NEEAP's targets, four different targets with three different scenarios were modelled with mixed-integer linear programming in order to observe the relation between energy saving achieved and the associated costs with the perspective of EDCs.
- It is intended to evaluate the contribution of the proposed EEOS with possible energy savings to meet the NEEAP target as a realistic example.

As mentioned before, there is no progress on the establishment of Turkish EEOS, yet. On the contrary to NEEAP's time plan, legislative works and guidelines should be prepared so far. It can be stated that in Turkey, there is still a need for a better understanding and know-how of implementing EEOS by the stakeholders. In other words, related governmental institutions, possible obligated parties, end-users, energy service market participants, and financial institutions either do not know the system at all or have little knowledge. Therefore, this study aims to help especially policymakers and EDCs to form a base for possible Turkish EEOS with alternative scenario analyses in line with EU practices and NEEAP's targets with possible energy efficiency action lists. In addition, defined energy efficiency actions, their costs, and saving calculations will be useful for end-users, energy service market participants, and financial institutions to see the relationships between the cost and achieved energy saving.

On this basis, the paper is organized as follows: the second section summarizes the current state of the electricity market of Turkey. In the third section, the methodology of the study is explained. The fourth section includes the results and evaluations of the models and scenarios. Lastly, final remarks and policy implications are given in the fifth section.

2. Turkish electricity market

Countries need to provide electricity to end-users in a timely, steady, and cheap manner. The supply of reliable and cheap energy, which contributes to the economic development of countries, brings great economic burdens, as well. For several decades, countries have not wanted to deal with these huge burdens alone and they started to allow investors to be involved in the process with a win-win approach to ease that burden. Especially, electricity markets are being transformed by liberalization to reduce public investments and involve private sector investments. The electricity market of Turkey has followed this trend. After 1993, the Electricity Authority of Turkey (TEK) which is responsible for electricity generation, transmission, trading, and distribution was divided into two companies that are Turkish Electricity Transmission Generation Co. (TEAS) for production, transmission, and trade and Turkey Electricity Distribution Co. (TEDAS) for distribution. In 2000, Turkey's electricity market generation, transmission, and distribution were mostly under state control (Asan and Tasaltin, 2017). After the 2001 economic crisis, Turkey has started the process of liberalization of the electricity market by the enactment of the Energy Market Law prepared by taking international experiences into account. With this law, it was aimed to increase the market transparency, competition, efficiency, and service quality as well as the participation of the private sector in the electricity market investments. This law is also important for harmonization with EU legislation. Considering the electricity supply chain, TEAS was also divided into three companies that are Turkey Electricity Transmission Company (TEIAS), Electricity Generation

Corporation (EUAS), and Turkey Electricity Trading and Contracting Co. (TETAS) (Fig. 1).

Again in 2001, Energy Market Regulatory Authority (EMRA) was established to regulate and supervise the activities in the market. In 2004, 21 distribution regions (Fig. 2) have been determined in Turkey, and electricity distribution privatizations have begun. Now, electricity distribution is carried out entirely by the private sector. In the beginning, EDCs carried out both distribution and retail sales activities in their regions. Later, they had to establish a separate retail company. There are currently 21 EDCs operating and each EDC has a separate supply company for electricity sales. Now, EMRA regulates the electricity tariffs and TEDAS controls the consumption invoiced by EDCs (Şirin, 2017).

3. Methodology

In this section, the methodology of the study is explained under four sub-section. First, it is described how energy efficiency potentials and the standard energy efficiency action lists are prepared. Secondly, it is explained how the obligations to be distributed to EDCs are determined. Thirdly, the construction of models and scenarios are clarified and lastly, the Mix-integer linear programming approach is explained.

3.1. *Energy efficiency potentials and standard energy efficiency action list*

When different consumer groups are examined for EDCs, it is observed that their electricity consumption, electricity loads, and energy efficiency potentials differ from each other depending on the regions of Turkey. Consequently, it is crucial to know the energy-saving potentials and costs of energy efficiency actions to be carried out to fulfill the obligations, set by the EEOS (Chowdhury et al., 2018; Cristino et al., 2021; Grillone et al., 2020; Hesselink and Chappin, 2019). In this respect, a guideline containing standardized energy efficiency actions is prepared and used in several EEOS such as Slovenia, Luxembourg, and Poland. In this study, based on engineering experience, studies in the literature, market research and the results of the related project carried out in the country, three sample action packages (residential, commercial, industrial) for EDCs have been developed for energy savings by evaluating the energy efficiency potential in different customer groups. In this context, ten energy efficiency actions in total are recommended as five energy efficiency actions for white appliances (refrigerator, air conditioner, washing machine, dishwasher) and energy-consuming systems (lighting system) in the residential customer group, two energy efficiency actions (lighting and heating-cooling-air conditioning systems) in the commercial customer group and three energy efficiency actions (lighting system, electric motors, and variable speed driver applications) in the industrial customer group. By using the 2018 electricity consumption data of these three sectors, the number and potential of energy efficiency actions that each EDC can realize in proportion to their customer consumption share in the same year have been determined. Safarzadeh and Barzoki stated that the maximum amount of energy can be saved when the rebound effect is not taken into account (Safarzadeh and Rasti-Barzoki, 2020). Moreover, most of the studies in the literature also ignored the rebound effect (Üçtuğ and Yükseltan, 2012; Wada et al., 2012; Yilmaz et al., 2020; Tan et al., 2016; Afshari and Friedrich, 2016; Fan and Xia, 2017, 2018b; Fan and Xia, 2018a; Bataineh and Alrabee, 2018; Du Plessis et al., 2013; Nel et al., 2019; Yue et al., 2018; Bühler et al., 2018; Zhang et al., 2017, 2021; Karali et al., 2017; Wang et al., 2020). In this study, the rebound effect was not taken into account to achieve the maximum amount of energy savings and the interest rate has been taken as 5% for the relevant cost analysis.

3.1.1. *Residential sector*

In Turkey, the residential consumers were responsible for 23.4% of the total electricity consumption billed in 2018, and 24.6% in 2019 (EMRA, 2019; EMRA, 2020). The energy-saving potential for this sector is declared as 29% (World Bank, 2011).

The consumption shares of white appliances are shown in Table 2 (MMO, 2012). As can be seen from the table, the ones that consume electricity more are refrigerators, air conditioners, lighting systems, heaters and washing machines, respectively. Replacing these white appliances and systems with those with high energy efficiency classes will reduce electricity consumption in residential buildings (Hesselink and Chappin, 2019).

In Turkey, refrigerators, washing machines, and dishwashers are available in almost every household. While air conditioners are generally used for cooling purposes, natural gas and other solid fuels are used instead of electrical heaters. For the replacement of inefficient refrigerators, air conditioners, washing machines, and dishwashers, the "Updated Buildings Sector Appliance and Equipment Costs and Efficiencies" report published by the United States Energy Information Administration (EIA) in 2018 was used (EIA, 2018). For the replacement, economic and low energy consumed products of the leading domestic appliances manufacturers in Turkey are preferred. In this context, Table 3 shows the savings to be achieved and the costs to be acquired by five energy efficiency actions determined for the residential sector. As can be seen from the table, the lighting action has the lowest cost and savings. While the costliest action is air conditioner replacement, the action that will cause the most savings is refrigerator replacement.

The number of energy efficiency studies that EDCs can take with these five replacement actions on their residential consumers was determined by taking into account the amount of energy savings that can be achieved from each action, and distributed to each company according to their market share in 2018 residential electricity consumption. The electricity consumption, energy-saving potential, and the maximum number of proposed energy efficiency actions are shown in Table 4.

According to Table 4, the most preferred action was lamp

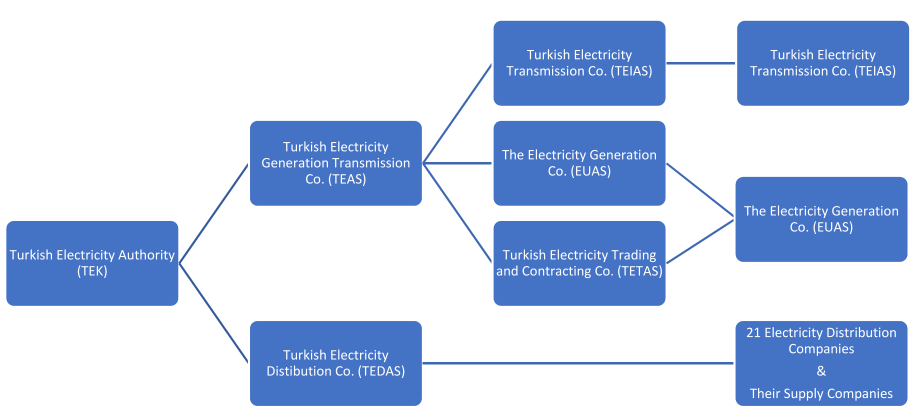

Fig. 1. Institutions in the Electricity Market of Turkey from past to present.

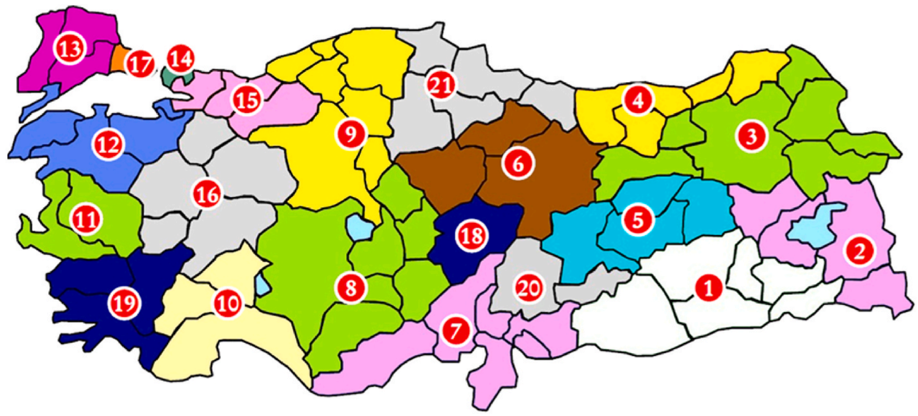

Fig. 2. Electricity distribution regions.

Table 2
The consumption shares of electrical home appliances (%) (MMO, 2012).

Refrigerator	31.2
Air Conditioner	15.0
Lighting	11.7
Heaters	9.3
Washing Machine	8.5
TV	6.7
Stand-By	5.0
Dishwashers	3.5
Dryers	3.2
Others	5.9

replacement in the lighting system, while the most savings were achieved by changing the refrigerator, as expected.

3.1.2. Commercial sector

Consumers using electricity for commercial purposes (shopping malls, food and beverage establishments, stores, hotels, etc.) are included in the commercial customer group of EDCs. In Turkey, the commercial consumers were responsible for 29.2% of the total electricity consumption billed in 2018, and 28.4% in 2019 (EMRA, 2019; EMRA, 2020). Commercial consumer groups vary more among themselves than the residential consumer group in terms of usage purposes, structural features, energy loads, and energy consumption figures. However, especially heating, ventilation, and air conditioning systems (HVAC), lighting systems, computer systems, and office equipment, respectively, can be listed as major energy-consuming systems in commercial consumer groups. For example, generally, approximately 55% of electrical energy consumption is consumed by HVAC and 20% by lighting systems in the commercial sectors (Kahn et al., 2013). Turkey aims to reduce at least 20% of the energy consumption in public buildings by 2023 compared to 2010. In line with this goal, energy efficiency studies were conducted in 166 public buildings in 2014. According to the analysis results of electricity consumption in public schools, student dormitories, universities, hospitals, administrative buildings, and airports, HVAC and lighting systems account for more than half of the electricity consumption. Besides, the electrical energy saving potential for commercial buildings is stated as 29% (World Bank, 2011). It has been announced that energy efficiency actions to be carried out in HVAC and lighting systems can save 230 million Turkish Liras (TL) annually in public buildings (YEGM, 2018). In this respect, adding motion sensors in lighting systems, replacement and modernization of auxiliary elements (ballast, driver, etc.), and modernization in HVAC systems are recommended for commercial customer groups of EDCs (Table 5).

The number of energy efficiency actions that EDCs can apply to their commercial consumers was determined by considering the amount of energy savings that can be achieved from each action, and distributed to each company according to their market share in 2018. Hence, the electricity consumption, energy-saving potential, and the maximum number of proposed energy efficiency actions are shown in Table 6.

As can be clearly understood from Table 6, the first choice was again the lighting system applications. Although there are few in practice, most of the saving potential can be achieved by the modernization of HVAC systems.

Table 4
The electricity consumption, energy-saving potential, and the maximum number of determining replacement actions for the residential sector.

Replacement EE Actions	Electricity Consumption in 2018 (TWh)	Electricity saving potential (TWh)	Maximum number of actions can be made (unit)
Refrigerator	17.08	4.95	12,232,085
Air Conditioner	8.21	2.38	8,821,215
Washing Machine	4.65	1.35	3,845,145
Dishwasher	1.92	0.55	4,445,893
Lighting	6.40	1.86	35,051,847
Total	38.26	11.09	–

Table 3
Features of residential energy efficiency actions.

Replacement actions	Inefficient appliances' consumption (kWh)	Efficient appliances' consumption (kWh)	Annual electricity savings (kWh)	Cost (USD)	One-year work assumption
1-Refrigerator	657	252	405	307.00	8760 h
2-Air Conditioner	395	125	270	500.00	350 h cooling
3-Washing Machine	513	162	351	300.00	150 times
4-Dishwasher	383	258	125	241.50	280 times
5- Lighting	60	7	53	4.00	1000 h in the evening peak period

Table 5
Features of Commercial energy efficiency actions.

Energy efficiency actions	Inefficient system consumption (kWh)	Efficient system consumption (kWh)	Annual electricity savings (kWh)	Cost (USD)	One-year work assumption
6-Lighting	77	36.50	141.75	70	3500 h
7-HVAC	44,858	15,604	29,254	37,630	3800 h

Electricity unit price has been taken as 0.25 TL/kWh and 1 USD equals 6 TL.

Table 6
The electricity consumption, energy-saving potential, and the maximum number of determining energy efficiency actions for the commercial sector.

Energy efficiency actions	Electricity consumption in 2018 (TWh)	Electricity saving potential (TWh)	Maximum number of actions can be made (unit)
HVAC	37.56	10.89	373,346
Lighting	13.66	3.96	27,943,220
Total	51.22	14.85	–

Electricity unit price has been taken as 0.25 TL/kWh and 1 USD equals 6 TL.

3.1.3. Industrial sector

In Turkey, industrial sectors were responsible for 41.5% of the total electricity consumption billed in 2018, and 41.1% in 2019 (EMRA, 2019; EMRA, 2020). Moreover, high energy intensity is an important cost item for industrial enterprises. It is identified that in general, the Turkish industry has 25% electrical energy saving potential (World Bank, 2011). In this respect, energy efficiency is a very important tool for ensuring energy security in the industry (Biresselioglu et al., 2017). According to the “Improving Energy Efficiency in Industry” program under the 10th Development Plan of Turkey, it is stated that the most important policy action for the sake of energy saving is the replacement of low efficient AC electric motors with more efficient ones since it was revealed that approximately 72% of industrial electricity consumption is due to the AC motors which have 7.5 kW power and over. In other words, it was determined that the replacement of approximately 3.8 million inefficient AC motors (7.5 kW and over) used in the industry will save 33.8 TWh of electrical energy, annually. When the unit price of the electricity is accepted as 0.25 TL/kWh (0.083 USD/kWh), the monetary equivalent of the annual savings to be obtained is 8.4 billion TL (2.78 billion USD) per year and the cost of replacing these motors is approximately 14.6 billion TL (4.83 billion USD). It was also stated that a variable speed driver (VSD) should be added to approximately 167 thousand of the motors that need to be changed. It was announced that with VSD, an annual electricity saving of 6.6 TWh can be achieved. The monetary equivalent is 1.6 billion TL (530 million USD), annually and the cost of the VSD action is 563 million TL (186.4 million USD). Table 7 shows the results of motor replacement and VSD action scenarios (T.C. Bilim, Sanayi ve Teknoloji Bakanlığı, 2016).

Furthermore, considering the lighting systems have a share of at least 0.4% and at most 13.3% in industrial electricity consumption, which varies according to the sectors, it is assumed that these systems have an undeniable potential for energy efficiency applications. The share of lighting systems in the total electricity consumption of the industry sectors is taken as 7% on average (Onaygil et al., 2009). In this respect, the proposed energy efficiency action for the commercial lighting system has also been proposed for the industry customer group. Table 8 contains a summary of energy efficiency actions for the industry sectors.

Related energy saving potentials and the number of energy efficiency actions covering electric motor replacement and VSD addition were determined based on the report which was published by the Republic of Turkey Science, Industry and Technology Ministry and these can be seen from Table 9 together with actions regarding lighting systems.

Table 7
Results of motor replacement and VSD addition scenarios.

Replacement with Efficient Motors	
Replacement Cost (Billion TL)	14.6
Payback Period (months)	21
Number of Replaced Motors	3,783,695
Annual Electricity Savings (TWh/year)	33.8
Annual Savings (Billion TL/year)	8.4
VSD action	
Replacement Cost (Billion TL)	563.4
Payback Period (months)	4
Number of Motors with VSD	166,789
Annual Electricity Savings (TWh/year)	6.6
Annual Savings (Billion TL/year)	1.6
Replacing Inefficient Motors with Efficient Motors and Adding VSD to Required Motors	
Replacement Cost (Billion TL)	14.5
Payback Period (months)	18
Annual Electricity Savings (TWh/year)	38.7
Annual Savings (Billion TL/year)	9.7

Electricity unit price has been taken as 0.25 TL/kWh and 1 USD equals 6 TL.

3.2. Energy efficiency obligations

According to Directive, 2012)/27/EU, member states take obligations based on the three-year average energy consumption before EEOS. Following the Directive, these average values for all EDCs in residential, commercial, and industrial consumer groups in 2016, 2017, and 2018 were obtained. This 3-year average (212,220,478.80 MWh) was used in the obligation calculations specified in the directive. The obligation ratio of each EDC was determined according to the share of the consumption invoiced by residential, industrial, and commercial consumer groups in the total consumption of all companies in 2018. The determined energy efficiency obligation ratios are used in the models to distribute them to EDCs. In Table 10, the obligation rates determined according to the electricity consumption invoiced by the EDCs based on consumer groups in 2018 are shown.

For Turkish EEOS the amount of energy savings (kWh) and costs of the energy efficiency actions that can be carried out by EDCs are important to achieve its main purpose as a policy measure for providing energy efficiency. Naturally, obligated parties will often want to take the most cost-effective energy efficiency actions. However, the most cost-effective energy efficiency actions may not always be sufficient to achieve the specified energy efficiency targets. For this reason, it is necessary to use penalty and/or incentive mechanisms to realize the targets. For the obliged parties the penalty per unit of energy saving that is not fulfilled is taken as 1 USD/kWh and the incentive value as 0.005 USD/kWh for each excessive unit energy saving.

3.3. Models and scenarios

This study developed the hypothesis that EEOS implementation may have a critical role in achieving a significant part of the energy-saving targets set out in Turkish NEEAP since it is important to achieve these targets to ensure energy supply security, which is a focus of Turkey’s energy policies. As detailed in the previous sections, the three-year (2016, 2017, and 2018) consumption data of residential, commercial, and industrial end-users invoiced by electricity distribution companies

Table 8
Features of industrial energy efficiency actions.

Energy efficiency actions	Inefficient product consumption (kWh)	Efficient product consumption (kWh)	Annual electricity savings (kWh)	Cost (USD)	One-year work assumption
8-Electric Motors	–	–	8925.27	814.90	5456 h
9-VSD	–	–	39,660.23	717.97	5456 h
10-Lighting	77	36.5	141.75	70.00	3500 h

Electricity unit price has been taken as 0.25 TL/kWh and 1 USD equals 6 TL.

Table 9
The energy-saving potential and the maximum number of determining energy efficiency actions for the industrial sector.

Energy efficiency actions	Electricity saving potential (TWh)	Maximum number of actions can be made (unit)
Electric Motors	33.77	3,783,695
VSD	6.61	166,789
Lighting	1.70	11,970,057
Total	42.08	–

Table 10
Energy efficiency obligation ratios of EDCs.

EDC	Energy Efficiency Obligation Ratio (%)	EDC	Energy Efficiency Obligation Ratio (%)	EDC	Energy Efficiency Obligation Ratio (%)
ADM	4.3	Çoruh	1.6	Osmangazi	4.3
Akdeniz	4.5	Dicle	3.5	Sakarya	7.2
Akedaş	2.2	Fırat	1.4	Toroslar	12.0
Aras	1.1	GDZ	9.1	Trakya	4.4
Başkent	8.1	İst. Anadolu	6.0	Uludağ	8.3
Boğaziçi	12.1	Kayseri ve C.	1.5	Vangölü	0.8
Çamlıbel	1.2	Meram	3.6	Yeşilırmak	2.7

were used to determine the obligations, energy-saving potentials, and possible energy efficiency studies following the 2012/27/EU Directive and NEEAP's targets.

As can be seen in Table 11, it is aimed to reach four different energy-saving targets, selected according to the 2012/27/EU Directive and NEEAP targets as well as the existing market conditions, with minimum cost in three different scenarios. While selecting the scenario alternatives, yearly basis energy efficiency targets of Turkish NEEAP are primarily considered. Due to having more mature market structure, electricity was chosen as a fuel type in order to design a viable and successful scheme. Electrical energy consumption profiles of consumer groups (residential, commercial and industrial) of EDCs in Turkey and existing local energy efficiency projects' outputs were taken into account while choosing the possible energy efficiency actions and related saving potentials under the scenarios and models with different saving targets under different scenarios are solved for each EDC, separately. By this way, it is aimed to cover and represent all possible situations based on EU practices and Turkish NEEAP. It is worth to mention that models were built with the perspective of EDCs within the framework of the rules of the energy efficiency obligation system. In the first scenario, electricity distribution companies meet their annual obligations for each year by performing energy efficiency studies at a level that will only fulfill their obligations in that year. In the second scenario, electricity distribution companies meet their obligations by performing energy efficiency studies at a level that will only fulfill their obligations in that year and by using at least 5% of each energy efficiency action potential. In the third scenario, there is no annual energy saving constraint as in the first and second scenarios, and electricity distribution companies can do any energy efficiency studies in any year. In the third scenario, electricity distribution companies can obtain incentives in return for the excess energy savings they will achieve. With these incentives, companies can finance their costs at varying rates.

Table 11
Models and scenarios.

Models	Scenarios
A-Seven-Year Model with 1.5% Annual Target	A1- Yearly based obligation A2- Yearly based and using 5% energy saving potential of each action A3- No constraints
B-Seven-Year Model with the Least Annual Target	B1- Yearly based obligation B2- Yearly based and using 5% energy saving potential of each action B3- No constraints
C-Seven-Year Model with 2% Annual Target	C1- Yearly based obligation C2- Yearly based and using 5% energy saving potential of each action C3- No constraints
D-Ten-Year Model with 0.8% Annual Target	D1- Yearly based obligation D2- Yearly based and using 5% energy saving potential of each action D3- No constraints

3.4. Mixed integer linear programming

Linear programming is a mathematical model that enables the most appropriate use of resources and the most appropriate selection among various alternatives to achieve a specific target (Lauinger et al., 2016). This mathematical programming method, which was developed for the solution of new and complex military problems at the beginning of World War II, is still widely used in solving problems in many different fields, and energy can be listed among these fields (Pfenninger et al., 2014).

Linear programming has three components:

1 Objective function: It is the maximum or minimum functions that provide the solution to the problem.
2 Constraints: Mathematical expression of limited or restricted resources in a linear programming problem.
3 Non-negativity: The variables used in the model cannot be negative.

Generally, the linear programming model can be defined as follows.
Objective Function

$$\text{Max veya Min } Z = c_1x_1 + c_2x_2 + \ldots. + c_nx_n$$

Constraints

$$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \ (\leq, =, \geq) \ b_1$$

Non-negativity

$$x_1 \geq 0, \ldots, x_n \geq \quad 0$$

In real-life problems, the decision variables may need to be integers. Models with integer decision variables are called integer linear programming models. Models that take variables as both integers and continuous variables are classified as mixed-integer linear programming models. Decision variables that take two values such as yes or no can also be in mixed-integer linear programming models. These decision variables are called a binary or 0–1 variables. In this study, even though the number of energy efficiency actions to be performed by the obliged parties is an integer, mixed-integer linear programming was used, since the amount of penalties they will pay if they fail to fulfill their obligations may not be integers. Finding the global optimum solution highlights the power of mixed-integer linear programming (Urbanucci, 2018). Various programs are used to solve complex integer linear programming problems in the computer environment. OpenSolver, which is an open-source coded solver, can be ideal for solving mixed-integer linear programming models and preferred to be used in this study because of these advantages (Mason, 2012).

3.5. Mathematical model

In this study, electricity distribution companies are planned to meet their energy efficiency obligations with minimum cost under three different scenarios. Four models have the same objective function and various constraints for these scenarios. The description of the mathematical models consisting of the objective function, decision variables, and constraints is explained below:

The objective function of the models is to meet energy efficiency obligations with the minimum cost.

$$Min\ Z = Mi\ \forall i \tag{1}$$

M_i represents the total cost of meeting energy efficiency obligations for i_{th} electricity distribution company and is calculated using Eq. (2).

$$Mi = \sum_j \sum_t (Xijt \times cjt) + \rho \times \sum_t Fit \forall i \tag{2}$$

X_{ijt}, integer decision variable, is the number of jth energy efficiency action implemented by ith electricity distribution company for year t. It is worth to mention that the total quantity of each energy efficiency action that can be implemented is different for each electricity distribution company. c_{jt} is the cost of jth energy efficiency action in year t and its unit is USD. F_{it}, continuous decision variable, is the not satisfied obligation of ith electricity distribution company in year t and its unit is kWh. Obligated companies have to pay penalties for their not satisfied obligations. ρ is penalty value per kWh and its value 1 USD/kWh. The indexes of electricity distribution companies and energy efficiency actions are $i \in I = \{1, 2 \ldots, 21\}$ and $j \in J = \{1, 2 \ldots, 10\}$ respectively. There are two sets of the index for yearly planning. For seven-year scheme and ten-year scheme, the indexes are $t \in T = \{1, 2 \ldots, 7\}$ and $t \in T = \{1, 2 \ldots, 10\}$ respectively.

Electricity distribution companies meet their obligations by implementing energy efficiency action and/or paying penalties. The constraint is shown in Eq. (3).

$$Eit + Fit \geq Oit\ \forall i, t \tag{3}$$

E_{it} is the total energy saving amount obtained by ith electricity distribution company in year t and its unit is kWh. E_{it} is calculated using Eq. (4).

$$Eit = \sum_j Xijt \times ejt\ \forall i, t \tag{4}$$

e_{jt} is the energy-saving amount delivered by jth energy efficiency action in year t and its unit is kWh. It is assumed that the energy-saving amount delivered by each energy efficiency action remains the same during planning horizons.

O_{it} is the amount of energy efficiency obligation for ith electricity distribution company for year t and is calculated using Eq. (5).

$$Oit = A \times \beta t \times \theta i \forall i, t \tag{5}$$

A is the three-year average of the summation of residential, commercial, and industrial electricity consumptions in 2016, 2017, and 2018 as 212.220.478,80 MWh. β_t is energy efficiency target in year t and its values can be 0,8%, 1%, 1,25%, 1,5% and 2%. θ_i is the energy efficiency obligation rate of ith electricity distribution company and is calculated using Eq. (6). K_i, H_i, and S_i are the electricity consumptions invoiced by ith electricity distribution company in 2018 in residential, commercial, and industrial sectors respectively.

$$\theta i = \frac{Ki + Hi + Si}{\sum_{i=1}^{21} Ki + Hi + Si}\ \forall i \tag{6}$$

Q_j is the total quantity of jth energy efficiency action. Qk_{ij}, Qh_{ij}, and Qs_{ij} are the total number of jth energy efficiency actions that can be implemented by ith electricity distribution company in residential, commercial, and industrial sectors respectively and are calculated using Eqs. (7)–(9) based on the market shares. k_i, h_i, and s_i, are the market shares of ith electricity distribution company in 2018 in residential, commercial, and industrial sectors respectively.

$$Qkij = Qj \times ki\ j \in \{1, 2, 3, 4, 5\}\ \forall i, j \tag{7}$$

$$Qhij = Qj \times hi\ j \in \{6, 7\}\ \forall i, j \tag{8}$$

$$Qsij = Qj \times si\ j \in \{8, 9, 10\}\ \forall i, j \tag{9}$$

Electricity distribution companies have a limited number of applications of each energy efficiency action based on their market shares. The constraints are shown in Eqs. (10)–(12).

$$\sum_t Xijt \leq Qk_{ij}\ j \in \{1, 2, 3, 4, 5\}\ \forall i, j \tag{10}$$

$$\sum_t Xijt \leq Qh_{ij}\ j \in \{6, 7\}\ \forall i, j \tag{11}$$

$$\sum_t Xijt \leq Qs_{ij}\ j \in \{8, 9, 10\}\ \forall i, j \tag{12}$$

Obligated parties deliver their annual obligations every year under the first and second scenarios. The costs of energy efficiency actions increase during planning horizons. Thus, obligated parties want to carry out energy efficiency actions in the first year of the scheme. In the first and second scenarios, the quantity of energy savings that can be obtained yearly by the companies is restricted to 101% of their annual obligations so that the companies can invest every year. The constraint is shown in Eq. (13).

$$Eit + Fit \leq \%101 \times Oit\ \forall i, t \tag{13}$$

In the second scenario, at least 5% of the potentials of energy efficiency actions are implemented in addition to the first scenario's particular constraint. The constraints are shown in Eqs. (14)–(16). The constraints (14), (15), and (16) are only for the second scenario.

$$\sum_t Xijt \geq \%5 \times Qk_{ij}\ j \in \{1, 2, 3, 4, 5\}\ \forall i, j \tag{14}$$

$$\sum_t Xijt \geq \%5 \times Qh_{ij}\ j \in \{6, 7\}\ \forall i, j \tag{15}$$

$$\sum_t Xijt \geq \%5 \times Qs_{ij}\ j \in \{8, 9, 10\}\ \forall i, j \tag{16}$$

In the third scenario, there is no particular constraint; and, therefore, companies can carry out energy efficiency actions when and how they want. The incentives that electricity distribution companies could obtain were calculated for the savings that the companies achieved in excess of their obligations according to the results in the third scenario, but the incentives were not included in the models. The companies achieve more energy savings than energy savings in other scenarios with the least cost as they can take all energy efficiency actions that meet their obligations in the first year. B_i is the total incentive of ith energy distribution company and is calculated using Eq. (17). τ is incentive value per kWh and its value 0.005 USD/kWh.

$$Bi = \tau \times \sum_t (Eit - Oit) \forall i \tag{17}$$

As an example, the mathematical model of the first scenario is as follows:

$$Min\ Z = Mi\ \forall i \tag{18}$$

Subject to:

$$Mi = \sum_j \sum_t (Xijt \times cjt) + \rho \times \sum_t Fit\ \forall i \tag{19}$$

$$Eit + Fit \geq Oit\ \forall i, t \tag{20}$$

$$Oit = A \times \beta t \times \theta i\ \forall i, t \tag{21}$$

$$\theta i = \frac{Ki + Hi + Si}{\sum_{i=1}^{21}(Ki + Hi + Si)}\ \forall i \tag{22}$$

$$Eit = \sum_j Xijt \times ejt\ \forall i, t \tag{23}$$

$$\sum_t Xijt \leq \begin{cases} Qkij\ j \in \{1,2,3,4,5\}\ \forall i,j \\ Qhij\ j \in \{6,7\}\ \forall i,j \\ Qsij\ j \in \{8,9,10\}\ \forall i,j \end{cases} \tag{24}$$

$$Qkij = Qj \times ki\ j \in \{1,2,3,4,5\}\ \forall i,j \tag{25}$$

$$Qhij = Qj \times hi\ j \in \{6,7\}\ \forall i,j \tag{26}$$

$$Qsij = Qj \times si\ j \in \{8,9,10\}\ \forall i,j \tag{27}$$

$$Eit + Fit \leq \%101 \times Oit\ \forall i, t \tag{28}$$

$$F_{it} \geq 0 \tag{29}$$

$$X_{ijt} \in N \tag{30}$$

4. Results and discussions

In this section, EEOS results and their evaluation under three different scenarios for four different energy-saving targets are explained.

4.1. Models with annual 1.5% fixed energy saving target

As can be seen from Table 11, the model with an annual target of 1.5% constant energy savings during the seven years is notated as A and A1, A2 and A3 represent the scenario analyses. In these analyses, each year it is aimed to achieve energy savings of at least 1.5% of the three-year average energy consumption of the selected end-users before the beginning of EEOS. During the seven-year period, EEOS must achieve a cumulative energy savings of 1.5%, 3%, 4.5%, 6%, 7.5%, 9% and 10.5%, respectively. Additionally, at the end of the seven years, it is mandatory to achieve energy savings of at least 42% of the three-year average energy consumption. The results of 21 electricity distribution companies obtained for three different scenarios in which EEOS has an annual energy efficiency obligation of 1.5% are summarized in Table 12.

Since there is no annual energy saving constraint in the third scenario, energy efficiency studies that will meet the seven-year obligations can be carried out within the first year when the action costs are the lowest. Hence, electricity distribution companies can achieve more energy savings at a lower cost. As requested, in scenarios with an annual fixed energy saving of 1.5%, 42% of the three-year electricity consumption average must be achieved as the saving amount, while in the third scenario, 73.5% of the three-year electricity consumption average is achieved.

Table 12
Results of three scenarios with 1.5% annual energy saving obligation.

	A1	A2	A3
Energy Saving (TWh)	89.80	89.80	155.98
Total Cost (billion USD)	1.86	3.43	1.58
Total Punishment (USD)	209.11	36.14	209.11
Unit Cost of Energy Saving (USD/kWh)	0.0196	0.0382	0.0101
NEEAP 2021–2027 target reached (%)	18.89	18.89	32.82
NEEAP 2021–2030 target reached (%)	12.95	12.95	22.50
NEEAP Investment share (%)	16.12	31.42	14.47

4.2. Models with the least energy saving target

Models with the least energy-saving target (B1, B2, B3 from Table 11) are required to achieve annual energy savings of 1% in the first two years, 1.25% in the second two years, and 1.5% in the last three years (each as a percentage of the average energy consumption of the previous three years before the beginning of EEOS, as mentioned before) within seven years. During this period, it can be expected that energy savings of 1%, 2%, 3.25%, 4.5%, 6%, 7.5%, and 9% must be achieved, respectively, through the implementation of EEOS. Moreover, at the end of these seven years, it is obligatory to have at least 33.25% of the average three-year energy consumption as the total energy saving. It is worth to mention that this kind of distribution has been used by some EU member states (Rosenow et al., 2016). The results obtained for 21 electricity distribution companies in three different scenarios with this model are summarized in Table 13.

As can be calculated from Table 13, 63% of the average three-year electricity consumption (which is expected to be 33.25%) is achieved in the third scenario. This value indicates that approximately 90% more saving was reached with this scenario.

4.3. Models with annual 2% fixed energy saving target

In this study, taking into account the urgency of reaching the energy efficiency targets because of import dependency of Turkish energy supply, it is intended to increase the target to 2% fixed annual energy savings, unlike from the 2012/27/EU Directive. Thus, during the seven years, EEOS must achieve a cumulative energy saving of 2%, 4%, 6%, 8%, 10%, 12%, and 14% respectively. At the end of the seven years, it is also obligatory to reach at least 56% of the average three-year energy consumption as the total energy saving. Consequently, the results obtained by three different scenarios (C1, C2, and C3 from Table 11) for 21 electricity distribution companies are presented in Table 14. Compared to other models, in each scenario, both more energy savings, as expected, were realized and also more costly solutions were revealed.

In this model, it is required to achieve 56% of the three-year average of electricity consumption as the total energy saving. In the third scenario, 98% of this consumption is realized as the saving. In other words, this value shows that 75% more of the obligation was reached in the third scenario.

Table 13
Results of three scenarios with the least annual energy saving obligation.

	B1	B2	B3
Energy Saving (TWh)	71.08	71.08	133.70
Total Cost (billion USD)	1.41	3.10	1.25
Total Punishment (USD)	51.97	24.26	47.29
Unit Cost of Energy Saving (USD/kWh)	0.0199	0.0436	0.0094
NEEAP 2021–2027 target reached (%)	14.95	14.95	28.13
NEEAP 2021–2030 target reached (%)	10.25	10.25	19.29
NEEAP Investment share (%)	12.94	28.38	11.44

Table 14
Results of three scenarios with 2% annual energy saving obligation.

	C1	C2	C3
Energy Saving (TWh)	119.73	119.73	207.98
Total Cost (billion USD)	3.12	4.57	2.83
Total Punishment (USD)	104.43	9426.78	104.43
Unit Cost of Energy Saving (USD/kWh)	0.0260	0.0381	0.0136
NEEAP 2021–2027 target reached (%)	25.19	25.19	43.76
NEEAP 2021–2030 target reached (%)	17.27	17.27	30.00
NEEAP Investment share (%)	28.53	41.80	25.87

4.4. Models with 0.8% fixed annual energy saving as a long-term target

EU has defined a longer-term EEOS program to increase the feasibility of applications by its new directive, dated September 25, 2019 and numbered as 1658. In this new approach, it is mandatory to achieve energy savings corresponding to 0.8% of the three-year average of energy consumption for each year over ten years. This means that 0.8%, 1.6%, 2.4%, 3.2%, 4%, 4.8%, 5.6%, 6.4%, 7.2%, and 8%, respectively. At the end of the ten years, energy savings of at least 44% of the three-year average of energy consumption should be realized. In this circumstance, the results obtained for 21 electricity distribution companies in three different scenarios (D1, D2, and D3 from Table 11) are shown in Table 15.

In the third scenario, since there is no annual energy saving constraint, electricity distribution companies can take energy efficiency actions to meet their ten-year obligations from the first year when the costs are the lowest. Therefore, in this scenario, energy savings equal to 80% of the three-year electricity consumption are achieved.

4.5. Evaluation of models and scenarios

As can be observed from the previous section, in the first and second scenarios, where the electricity distribution companies are constrained that they do not fulfill the excess (101%) of the obligations in each year, fewer energy savings were achieved as compared to the third scenario. Furthermore, since there was no constraint on the types of energy efficiency actions to meet the obligation, in the first scenario, the systems preferred the cheapest energy efficiency actions and the cost per kWh energy saving was lower than the second scenario. On the other hand, in the second scenario, where at least 5% of all actions' potentials must be used, the cost per kWh energy saving was higher. In Fig. 3, the rate of utilization of each energy efficiency action potential is indicated for the second scenario of the model with an annual energy saving target of 2% (C2). As can be seen from the figure, whole potentials of the DHS action (EE9) were used together with the residential lighting action (EE5). Also, the electric motor action (EE8) and the commercial lighting action (EE6) stand out, while the industrial lighting action (EE10) and the refrigerator action (EE1) were preferred more than the other remaining actions. Since there is no annual energy saving constraint in the third scenario, electricity distribution companies can carry out energy efficiency actions in an amount to meet their entire obligations from the first year when the costs are the lowest. Therefore, energy savings equal to 80% of the three-year average electricity consumption are realized in this scenario.

Table 15
Results obtained by three scenarios with 0.8% fixed annual energy saving obligation.

	D1	D2	D3
Energy Saving (TWh)	94.14	94.14	169.78
Total Cost (billion USD)	1.22	2.92	1.04
Total Punishment (USD)	24.85	0.00	24.85
Unit Cost of Energy Saving (USD/kWh)	0.0130	0.0311	0.0061
NEEAP 2021–2027 target reached (%)	19.81	19.81	35.72
NEEAP 2021–2030 target reached (%)	13.58	13.58	24.49
NEEAP Investment share (%)	11.18	26.75	9.52

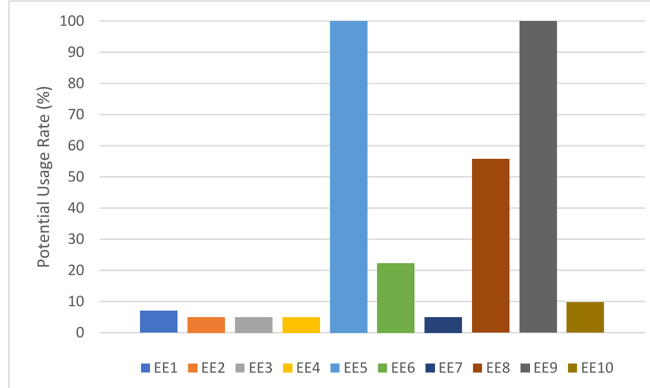

Fig. 3. The potential usage rate of the energy efficiency actions (%).

In all models, the highest amount of energy savings occurred in the third scenario, since there are no constraints about the actions and obligations as well as incentives are given for excessive savings. Table 16 presents cost recovery rates of electricity distribution companies in the model with a long-term annual 0.8% energy saving obligation by means of the incentives. Possible incentives can be minimum of 20.69% and a maximum of 52.46% of energy efficiency investment costs made in different models with a value of 0.005 USD/kWh.

When the models (A, B, C, and D) with the same assumptions are compared under three scenarios (1, 2, and 3), it is seen that the highest electrical energy savings are achieved with model (C), which has a fixed energy saving target of 2% per year, and the least saving is realized in the model with low energy saving target (B) as expected. When the total costs of the models are observed, the least-cost model is the ten-year model (D) with an annual fixed energy saving target of 0.8%, whereas the highest cost is the seven-year model (C) with a fixed energy saving target of 2% per year. Fig. 4 indicates the comparison of the four models considering the amount of energy savings (kWh) with respect to the total cost (USD) under three scenarios.

By comparing the European Union's seven-year program with an annual energy saving rate of 1.5% in 2012 and the ten-year program with an annual energy saving target of 0.8% in 2019, it can be specified that the amount of electrical energy savings to be achieved over the total duration of the programs has similar values, but the difference in the total cost amounts is to be more remarkable. For instance, a total of 89.8 TWh of energy savings can be achieved in seven years in A1 and 94.1 TWh in ten years in D1. On the other hand, the total cost in A1 is 1.86 billion USD, although it is 1.22 billion USD in D1.

4.6. Discussions

In this study, it was aimed to develop four mixed-integer linear programming models with different targets under three different scenarios for the possible Turkish energy efficiency obligation system and to compare their results with each other. In this respect, the study focused on the energy savings that electricity distribution companies can provide in residential, commercial, and industrial consumer groups with EEOS, and standardized energy efficiency actions are proposed for the realization of their energy efficiency potentials. When the approach and results of the study are compared to the literature, important similarities can be identified. As stated by (Duzgun and Komurgoz, 2014; Chowdhury et al., 2018; Cristino et al., 2021; Grillone et al., 2020; Hesselink and Chappin, 2019), one of the biggest obstacles for the energy efficiency is not knowing exactly the costs and the benefits of the action to be taken. With standardized energy efficiency actions, the uncertainties that are faced with by the obliged parties and energy efficiency investors can be removed (Afshari and Friedrich, 2016). states that with

Table 16
Cost recovery rates for electric distribution companies by incentives.

Distribution Company	Cost Recovery Rate (%)	Distribution Company	Cost Recovery Rate (%)	Distribution Company	Cost Recovery Rate (%)
ADM	33.74	**Çoruh**	31.30	**Osmangazi**	46.12
Akdeniz	29.75	**Dicle**	31.76	**Sakarya**	47.52
Akedaş	45.32	**Fırat**	34.40	**Toroslar**	42.66
Aras	28.07	**GDZ**	38.34	**Trakya**	52.46
Başkent	33.29	**İst. Anadolu**	30.71	**Uludağ**	43.30
Boğaziçi	31.11	**Kayseri ve C.**	40.86	**Vangölü**	20.69
Çamlıbel	34.29	**Meram**	35.93	**Yeşilırmak**	35.22

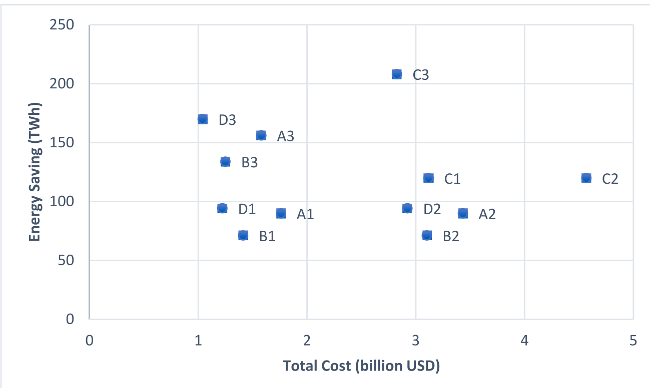

Fig. 4. Comparison of the scenarios based on the models.

standardized actions, EEOS can contribute a lot to Turkey, and electricity distribution companies will be the most appropriate obliged parties (Cin et al., 2021; Duzgun and Komurgoz, 2014). specify that the electricity distribution companies would be appropriate obliged parties in Turkey, as well (Argun et al., 2021). proposes two mixed-integer linear programming models with a target of maximum energy savings with minimum cost from the perspectives of EEOS regulator and electricity distribution companies. The models have similarities considering financial constraints, annual minimum energy savings of 2%, incentives, and penalty practices with the ones in this study. For instance, in this study, models desire to meet the obligations with a minimum cost as a requirement of the company managers' point of view. By means of not adding budget constraints, companies were given the chance to best demonstrate their potential and were motivated by penalties and financial incentives to achieve their energy-saving targets. As an example, according to the D3 scenario, a total savings of about annual 17 TWh can be achieved at less than one USD cent per kWh. Hence, the results of both studies show that energy-saving targets can be achieved cost-effectively (Tan et al., 2016). determined that if 96 million USD is invested in buildings in Turkey for energy efficiency, energy savings of more than 2 TWh can be achieved annually, stressing that the cost per kWh of energy efficiency studies is low, and energy efficiency actions, such as the ones in this study, can be carried out throughout the country. Moreover, reducing energy consumption through energy efficiency studies allows the reduction in the peak demand. For example (Afshari and Friedrich, 2016), determined that with the proposed 25% more efficient chiller action, the peak demand across the UAE could be reduced by 13.5%. Furthermore (Yilmaz et al., 2020), reported that power consumption and system-wide power demand can be reduced by 20% with LED action in residential buildings during the evening time. In the D3 scenario in this study, it was found that only residential LED action can reduce peak demand by 2% throughout the evening (17:00–22:00), and this value is valuable for demand-side management. As a side effect, more efficient use of energy can reduce energy consumption and economic burden, as well as the greenhouse gas emissions that cause climate change. For instance (Tan et al., 2016), indicates that with an energy efficiency investment of 100 thousand USD to be realized in buildings, 32 GWh energy savings can be achieved in 15 years and 8 tons of CO_2 emissions can be reduced. According to the D3 scenario, it was determined that approximately 17 TWh of energy savings per year together with more than 15 million tons of CO_2 emission reduction could be achieved (Tantisattayakul et al., 2016). proposes the establishment of an emission trading system for CO_2 emission reduction to be achieved through energy efficiency actions (Cin et al., 2021; Duzgun and Komurgoz, 2014; Argun et al., 2021). suggest launching an energy-saving certificate trading system with the emissions trading system in Turkey, so that energy efficiency actions can be encouraged and funded.

5. Conclusions and policy implications

Within the scope of the study, we focused on the energy savings that electricity distribution companies can provide in residential, commercial, and industrial consumer groups, and by making some suggestions and assumptions following the energy-saving targets specified in the Directive, 2012/27/EU and NEEAP, models have been established to achieve four different energy efficiency obligation targets with minimum cost in three different scenarios considering 21 electric distribution companies in Turkey.

In accordance with Directive, 2012/27/EU, two models with a fixed energy saving target of 1.5% per year and with the least energy-saving target have been established for seven years, respectively. Besides, to see the effect of higher obligation rates apart from the directive recommendations, a model with 2% constant energy saving per year has been designed for Turkish EEOS. The ten-year model with an annual fixed energy saving of 0.8% determined by the European Commission for the 2021–2030 period has also been established and the results have been obtained with the same assumptions. The highest total cost and the most energy savings are achieved with a 2% fixed energy saving targeted model; while the lowest total cost, the lowest cost per kWh saved, and the second-highest energy savings were achieved with the ten-year model with a fixed energy saving of 0.8% per year. For a successful EEOS program, selecting trivial and achievable targets at the beginning and increasing the targets over time would be the right approach. In the examples to date, it is realized that EEOS, which did not have attainable targets and were not well planned, became unsuccessful (Fawcett et al., 2019). EEOS model targeting 0.8% annual saving for a three-year trial, covering 2021–2030, may be appropriate for Turkey and also for the countries having a similar structure.

The feasibility and cost-effectiveness of energy efficiency actions that can be implemented in the successful EEOS can be identified as the most important factors. It can be obvious that in real applications, obliged parties will want to implement the most cost-effective actions. On the other hand, the most cost-effective actions may not always be sufficient to fulfill the obligations at the desired levels. For this reason, penalties and/or incentives are also used in EEOS to fulfill required energy efficiency obligations. Penalties and incentives should be at a level that allows obliged parties to meet their obligations by carrying out energy efficiency actions. In this study, the penalty was determined as 1 USD/kWh and the incentive as 0.005 USD/kWh, considering the costs per saved kWh of energy efficiency actions proposed for obliged parties to fulfill their obligations by carrying out the specified actions. In the designed models, electricity distribution companies generally found it more economical to carry out energy efficiency actions instead of paying penalties, and for this reason, the amount of penalties remained very low. It should be noted that a balance must be provided between the deterrence of the penalty and its economic impact. Charging penalties based on the level of obligations that cannot be met may also be appropriate for a successful EEOS. For example, if a participant who fails to fulfill 5% of its obligations receives a penalty of less than 50% per kWh from a participant who fails to fulfill more than 50%, then, it will be a driving force for obliged parties to do energy efficiency actions.

As stated in Turkish NEEAP, EEOS is planned for distributors and retailers serving all fuel type. In this study in order to demonstrate a viable and successful scheme, the electricity was chosen as the fuel type, since it has a more mature and liberalized market structure. There are 21 distribution and retail companies in Turkey. Although distributors and retailers may seem independent due to the market structure, they are actually members of the same group of companies, so their customer portfolios are also similar. In other words, choosing one of them as an obligated party will have resembling results. In this study, the actual consumption data invoiced in the distribution regions is used and the obligations are distributed proportionally according to the market share of the companies and in accordance with the EU Energy Efficiency Directive. Also, the standard energy efficiency action list was prepared considering existing local energy efficiency projects' outputs and energy-saving potentials in Turkey. For these reasons, this study can be accepted as realistic implementation example for Turkey. Certainly, there will be some inadequacies and limitations in the implementation phase of this mechanism, i.e., lack of energy efficiency financing mechanism and measurement & verification infrastructure in Turkey. Also, issues such as rebound effect or additionality were neglected while making the calculations in this study. Despite these limitations, this study is beneficial for Turkey in a way that it includes the first energy efficiency actions manual and will be the basis for future work carried out within the scope of NEEAP. Furthermore, if the electric distribution companies meet their obligations by implementing these actions, it is assumed that the NEEAP targets can be met at rates ranging from about 10% to 44%. While the stated energy savings are achieved in the electricity market, it may be possible to realize more savings by including other fuel types in the mechanism with a proper structure. In case of natural gas market, measures such as thermal insulation, boiler replacement, cogeneration, waste heat recovery etc. can also be included in the standard energy efficiency action list. It should be noted that natural gas market is not enough mature and liberalized (a governmental company is dominant in the natural gas market) like the electricity market to be added to EEOS. In addition, up to know there is no heat market constructed in Turkey. With the maturation and liberalization of natural gas and heat markets, it will be possible to improve the scheme.

EEOS is an important policy mechanism on Turkey's energy agenda and needs to be examined in detail and will have profitable results for Turkey with the right practices. The results of this study are important for public, academia, and electricity market players in terms of setting energy efficiency obligation targets for electricity distribution companies in achieving NEEAP targets, preparing manuals for energy efficiency actions, evaluating energy efficiency potentials in different end-use sectors, and calculating the savings amounts that can be achieved with different scenario analyses. In addition, defined energy efficiency actions, their costs, and saving calculations with the acceptance of applicable incentive and penalty values will be useful for end-users, energy service market participants, and financial institutions to see the relationships between the cost and achieved energy saving. For further studies, this work can be improved by establishing more complex models, including energy-saving certification and emission trading systems.

As a conclusion, with this kind of market-based policy mechanism, evaluating the energy efficiency studies carried out through different channels and/or supported by different funds with a holistic approach will ensure that the desired success and results will be achieved in terms of national or international targets.

CRediT authorship contribution statement

Berat Berkan Ünal: Conceptualization, Methodology, Software, Writing – original draft. **Sermin Onaygil:** Conceptualization, Supervision, Writing – original draft. **Ebru Acuner:** Conceptualization, Writing – review & editing. **Rabia Cin:** Conceptualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Glossary

Acronyms

AC: Alternative current
EDC: Electricity distribution company
EE: Energy efficiency
EEOS: Energy efficiency obligation scheme
EIA: United States Energy Information Administration
EMRA: Energy Market Regulatory Authority
EUAS: Electricity Generation Corporation
HVAC: Heating, ventilation, and air conditioning system
NEEAP: National energy efficiency action plan
TEAS: Turkish Electricity Transmission Generation Co.
TEDAS: Turkey Electricity Distribution Co.
TEIAS: Turkey Electricity Transmission Co.
TEK: Electricity Authority of Turkey
TETAS: Turkey Electricity Trading and Contracting Co.
TL: Turkish Lira
VSD: Variable speed driver

Symbols

M_i: Total cost of meeting energy efficiency obligations for ith electricity distribution company
X_{ijt}: Number of jth energy efficiency action implemented by ith electricity distribution company for year t
c_{jt}: Cost of jth energy efficiency action in year t
F_{it}: Not satisfied obligation of ith electricity distribution company in year t
ρ: Penalty value per kWh
i: Index of electricity distribution company
j: Index of energy efficiency action
t: Index of year
E_{it}: Total energy saving amount obtained by ith electricity distribution company in year t
e_{jt}: Energy-saving amount delivered by jth energy efficiency action in year t
O_{it}: amount of energy efficiency obligation for ith electricity distribution company for year t
A: three-year average of the summation of residential, commercial, and industrial

electricity consumptions in 2016, 2017, and 2018

β_t: energy efficiency target in year t

θ_i: energy efficiency obligation rate of ith electricity distribution company

K_i: electricity consumptions invoiced by ith electricity distribution company in 2018 in residential sector

H_i: electricity consumptions invoiced by ith electricity distribution company in 2018 in commercial sector

S_i: electricity consumptions invoiced by ith electricity distribution company in 2018 in industrial sector

Q_j: total quantity of jth energy efficiency action

Qk_{ij}: total number of jth energy efficiency actions that can be implemented by ith electricity distribution company in residential sector

Qh_{ij}: total number of jth energy efficiency actions that can be implemented by ith electricity distribution company in commercial sector

Qs_{ij}: total number of jth energy efficiency actions that can be implemented by ith electricity distribution company in industrial sector

k_i: market share of ith electricity distribution company in 2018 in residential sector

h_i: market share of ith electricity distribution company in 2018 in commercial sector

s_i: market share of ith electricity distribution company in 2018 in industrial sector

B_i: total incentive of ith energy distribution company

τ: incentive value per kWh