ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

EVIDENCE-BASED ANALYSIS OF TÜRKİYE'S ENERGY EFFICIENCY OBLIGATION SCHEME: SECTORAL APPLICATIONS, ENERGY POVERTY, FLEXIBILITY OPTIONS AND POLICY IMPLICATIONS

Ph.D. THESIS

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

TÜRKİYE ENERJİ VERİMLİLİĞİ YÜKÜMLÜLÜKLERİ SİSTEMİNİN KANITA DAYALI ANALİZİ: SEKTÖREL UYGULAMALAR, ENERJİ YOKSULLUĞU, ESNEKLİK SEÇENEKLERİ VE POLİTİKA ÇIKARIMLARI

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Rabia CİN a Ph.D. student of İTU Graduate School student ID 301182012, successfully defended the thesis/dissertation entitled “EVIDENCE-BASED ANALYSIS OF TÜRKİYE'S ENERGY EFFICIENCY OBLIGATION SCHEME: SECTORAL APPLICATIONS, ENERGY POVERTY, FLEXIBILITY OPTIONS AND POLICY IMPLICATIONS”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To the just energy transition of Türkiye,

FOREWORD

First of all, I would like to express my deepest gratitude to Prof. Dr. Sermin ONAYGİL, who introduced me to the concept of Energy Efficiency Obligation Schemes back in 2017, during the very beginning of my master's thesis journey. Since then, this topic has been at the core of our academic path together, through articles, projects, and ongoing discussions. Her continuous guidance, encouragement, and belief in the importance of this subject have played a vital role in shaping this work into a Ph.D. thesis. I am sincerely thankful for her support and mentorship throughout this long and transformative journey.

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I am deeply thankful to my dear friends and family, whose unwavering support and presence have been with me throughout this journey. Their encouragement, understanding, and belief in me made even the most challenging moments manageable and meaningful.

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April 2025 — Rabia CİN
(Research Assistant)

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ABBREVIATIONS

AB : Avrupa Birliği
ABD : Amerika Birleşik Devletleri
ADEME : Agence de la Transition Écologique
ANOVA : Analysis of Variance
ARERA : Autorità di Regolazione per Energia Reti e Ambiente
BEPC : Building Energy Performance Certificate
BOTAŞ : Petroleum Pipeline Transportation Joint Stock Company
CBAM : Carbon Border Adjustment Mechanism
CEE : Certificats d'Économies d'Énergie
CEPI : Compound Energy Poverty Index
CFL : Compact Fluorescent Lamp
CO_2 : Carbon Dioxide
DGEC : General Directorate for Energy and Climate
ECO : Energy Company Obligation
EED : Energy Efficiency Directive
EEOS : Energy Efficiency Obligation Scheme
EI : Eligibility Index
EKA : Energy and Carbon Reduction
EMRA : Energy Market Regulatory Authority
ENEA : Agenzia Nazionale per Le Nuove Tecnologie, L'energia e Lo Sviluppo Economico Sostenibile
ENVER : Energy Efficiency Portal
EPC : Energy Performance Contract
EPDK : Enerji Piyasası Düzenleme Kurumu
EPI : Energy Poverty Index
EPİAŞ : Enerji Piyasaları İşletme Anonim Şirketi
EPVI : Energy Poverty Vulnerability Index
ERO : Energy Regulatory Office
ESCO : Energy Service Company
ESPC : Energy Service Provider Company
ETKB : Enerji ve Tabii Kaynaklar Bakanlığı

ETS : Emissions Trading System
EU : European Union
EVÇED : Directorate of Energy Efficiency and Environment
EVD : Energy Efficiency Consultancy
EVYS : Enerji Verimliliği Yükümlülük Sistemi
EXIST : Energy Exchange Istanbul
GDP : Gross Domestic Product
GHG : Greenhouse Gas
GME : Gestore dei Mercati Energetici
GSE : Gestore dei Servizi Energetici
GWh : Giga Watt hour
HBS : Household Budget Survey
IPMVP : International Performance Measurement and Verification Protocol
ktoe : kilo tons of oil equivalent
LIHC : Low Income High Cost
LILEA : Low Income, Low Efficiency Area
LILEE : Low Income Low Energy Efficiency
MENR : Ministry of Energy and Natural Resources
MEPI : Multidimensional Energy Poverty Index
MCA : Multiple Correspondence Analysis
MCP : Market Clearance Price
MiSE : Ministero dello Sviluppo Economico
MJ : Mega Joule
MPP : Monitoring Plan Project
MTEP : Milyon Ton Eşdeğer Petrol
Mtoe : Million tons of oil equivalent
MWh : Mega Watt hour
M&V : Measurement and Verification
NECP : National Energy and Climate Plan
NEEAP : National Energy Efficiency Action Plan
NDC : Nationally Determined Contributions
NUTS : Nomenclature of Territorial Units for Statistics
OP : Obligated Parties
Ö&D : Ölçme ve Doğrulama
PNCEE : Pôle National des Certificats d'Économies d'Énergie

SDG : Sustainable Development Goal
SEAI : Sustainable Energy Authority of Ireland
SILC : Survey of Income and Living Conditions
SME : Small and Medium-Sized Enterprise
SO : Supplier Obligations
SP : Simplified Project
TEE : Titoli di Efficienza Energetica
TES : Total Energy Supply
TGE : Polish Power Exchange
TL : Turkish Lira
toe : ton of oil equivalent
TUİK : Türkiye İstatistik Kurumu
TurkStat : Turkish Statistical Institute
TÜBİTAK : Scientific and Technological Research Council of Türkiye
TWh : Tera Watt hour
T&D : Transmission & Distribution
UEVEP : Ulusal Enerji Verimliliği Eylem Planı
UK : United Kingdom
USA : United States of America
USD : United States Dollar
VAP : Efficiency Improvement Project
VAT : Value Added Tax
WSS : Within-Cluster Sum of Squares

SYMBOLS

$\boldsymbol{AC_t}$	: Administrative cost of the regulator in year t
$\boldsymbol{B_{EU}}$	: Total benefit of the end-users
$\boldsymbol{B_{OP}}$	: Total benefit of the suppliers
$\boldsymbol{BPS_{i,t}}$	: Benefit of power sold to the pool market of ith supplier in year t
$\boldsymbol{c_{ij}}$	: Contribution of indicator i to dimension j
$\boldsymbol{c_{ij}^{norm}}$	: Normalized contribution of indicator i to dimension j
$\boldsymbol{C_{jt}}$	: Unit energy efficiency investment cost of j^{th} sector in year t
$\boldsymbol{C_{EU}}$	: Total cost of the end-users
$\boldsymbol{C_{OP}}$	: Total costs of the suppliers.
$\boldsymbol{C_t^{OP}}$	: Total cost of the suppliers in year t
$\boldsymbol{CPB_{i,t}^{OP}}$	: Cost of power bought from the wholesale market of i^{th} supplier in year t
$\boldsymbol{CPB_{i,j,t}^{EU}}$	: Cost of power bought from the pool market of j^{th} sector of i^{th} supplier in year t
$\boldsymbol{D_j}$	: Set of indicators assigned to dimension j
$\boldsymbol{DC_{i,j,t}}$	: Direct energy efficiency cost of the i^{th} supplier on j^{th} sector in year t
$\boldsymbol{E_i}$	: Expected frequency
$\boldsymbol{EBR_{j,t}}$	: Electricity bill reduction of jth sector in year t
$\boldsymbol{ECR_{i,t}}$	: Time Energy cost reduction of i^{th} supplier in year t
$\boldsymbol{EF_{j,t}}$	: The total EEOS fee paid by j^{th} sector in year t
$\boldsymbol{EI}$	: Eligibility Index
$\boldsymbol{En}$	: Total energy expenditure of a household
$\boldsymbol{ES_{i,j,t}}$	: Energy saving amount obtained by i^{th} supplier in the j^{th} sector in year t
$\boldsymbol{ES_{i,j,t}^{EU}}$	: Energy saving amount on the supplier side
$\boldsymbol{ES_{i,j,t}^{OP}}$	: Energy saving amount on the end-user side
$\boldsymbol{EP_{j,t}}$	: Energy price of the j^{th} sector in year t
$\boldsymbol{F_t}$	: Total amount of money collected in the energy efficiency fund in year t

$\boldsymbol{FS_{i,t}}$	: Unfulfilled obligation/failed saving amount of i^th supplier in year t
$\boldsymbol{I_{i,t}}$	: Incentive gained by i^th supplier in year t
$\boldsymbol{IC_{i,t}}$	: Internal/indirect cost of i^th supplier in year t
Inc	: Total disposable income of a household
$\boldsymbol{MCP_t}$	: Market clearance price in year t
$\boldsymbol{MS_i}$	: The market share of i^th supplier in base year
$\boldsymbol{P_{i,t}}$	: Penalty amount paid by i^th supplier in year t
$\boldsymbol{PB_{i,j,t}^{EU}}$	: Power bought of j^th sector from i^th supplier in the pool market in year t
$\boldsymbol{PB_{i,t}^{OP}}$	: Total power bought from the wholesale market of i^th supplier in year t
$\boldsymbol{PMP_t}$	: The pool market price in year t
$\boldsymbol{PS_{i,j,t}^{OP}}$	: Power sold of i^th supplier to the j^th sector in the pool market in year t
$\boldsymbol{R}$	: Standardised residual
$\boldsymbol{RP_{j,t}}$	: Remaining energy saving potential of j^th sector in year t
$\boldsymbol{SB_i}$	: Base electricity sales of i^th supplier
$\boldsymbol{O_i}$	: Observed frequency
$\boldsymbol{O(i,t)}$	: Obligation amounts of suppliers
$\boldsymbol{\Theta_t}$	: Obligation rate in year t
$\boldsymbol{TB_j}$	: Base electricity consumption of j^th sector
$\boldsymbol{TP_j}$	: Total energy saving potential of j^th sector
$\boldsymbol{v_j}$	: Explained variance of dimension j
$\boldsymbol{w_i}$	: Weighted contribution of indicator i
$\boldsymbol{w_i^{norm}}$	: Weight assigned to indicator i
i, j, t	: Indexes
$\boldsymbol{\alpha}$	: Significance level
$\boldsymbol{\alpha_{adjusted}}$	: Bonferroni-adjusted significance level
$\boldsymbol{k}$	: The number of pairwise comparisons
$\boldsymbol{\chi^2}$	: Chi-square test statistic
$\boldsymbol{\mu}$	: EEOS fee rate
$\boldsymbol{\eta}$	: Internal cost of suppliers
$\boldsymbol{\rho_t}$	: Penalty amount in year t
$\boldsymbol{\pi}$	: Administrative cost rate

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EVIDENCE-BASED ANALYSIS OF TÜRKİYE'S ENERGY EFFICIENCY OBLIGATION SCHEME: SECTORAL APPLICATIONS, ENERGY POVERTY, FLEXIBILITY OPTIONS AND POLICY IMPLICATIONS

SUMMARY

Energy efficiency is a fundamental pillar of energy transition. It plays a crucial role in enhancing energy security, reducing greenhouse gas emissions, and driving the transition to a low-carbon economy. Among the various policy instruments developed to promote energy efficiency, market-based mechanisms, particularly Energy Efficiency Obligation Schemes (EEOS), stand out for their flexibility, cost-effectiveness, and potential to mobilize private sector participation. With the 2012/27/EU Energy Efficiency Directive (EED), EEOS has become a key policy tool across European Union (EU), where its importance has grown in parallel with rising climate ambition and increasing focus on energy poverty.

Following the adoption of the 2007 Energy Efficiency Law, Türkiye introduced a series of legislations and strategic documents aimed at enhancing energy efficiency across all sectors. In alignment with EU EED, Türkiye published its first National Energy Efficiency Action Plan (NEEAP) for the 2017–2023 period, which included the implementation of an EEOS action. However, despite this clear intent, the EEOS was not implemented during the plan period, primarily due to institutional, regulatory, and technical challenges. In 2024, Energy Efficiency 2030 strategy and the second NEEAP reaffirms Türkiye’s commitment and schedules the implementation of the scheme by 2027. This Ph.D. thesis aims to contribute to the successful realization of a EEOS in Türkiye through analytical groundwork, policy-oriented modeling, and applied research.

Beyond academic contribution, this Ph.D. thesis seeks to offer practical insights for policymakers, support better understanding among potential scheme participants, and serve as a reference for the institutionalization and internalization of the EEOS within Türkiye’s energy policy landscape. The primary purpose of this thesis is to provide a comprehensive, evidence-based foundation for the potential implementation of an EEOS in Türkiye. Based on existing international experience and lessons learned, this Ph.D. thesis aims to address the multidimensional requirements of such a scheme, including its sectoral applications, economic feasibility, social equity implications, internal flexibility mechanisms, institutional design, and policy integration. These objectives are pursued through applied, data-oriented and evidence-based research, policy-relevant modeling, and strategic recommendations. The ultimate goal is to support Türkiye in developing a cost-effective, socially inclusive, and institutionally viable EEOS tailored to its national circumstances.

The thesis is structured into ten chapters. Chapter 1 introduces the background, motivation, and structure of the thesis. It begins by establishing the critical role of energy efficiency, explains how EEOS emerged, traces its development within the EU

framework, and discusses Türkiye’s evolving policy landscape. The chapter also outlines the motivation, contribution, and purpose of the thesis.

Chapter 2 introduces the EEOS by examining its conceptual foundations, core components, and global evolution as a policy tool. The chapter provides a structured review of international implementation experiences, with particular focus on European countries, and evaluates the academic literature to identify key design considerations, operational challenges, and success factors. By synthesizing lessons learned from both practice and research, the chapter lays the groundwork for understanding how EEOS can be adapted to Türkiye’s context, offering early insights into the opportunities and constraints shaping its potential adoption.

Chapter 3 presents an ex-ante cost-benefit assessment of a possible EEOS structure for Türkiye, focusing on the industrial sub-sectors and commercial buildings. Within this framework, incumbent electricity suppliers are designated as obligated parties. A two-level distributed optimization model is employed, allowing obligated parties and end-users to independently pursue their economic objectives while preserving market realism. By evaluating various policy scenarios such as different obligation structures, EEOS fee rates, and penalty levels, the chapter offers insights into the financial feasibility, cost distribution, and policy effectiveness of a basic EEOS model. The findings support the conclusion that a self-financing, balanced scheme can be established in Türkiye, provided that design parameters are carefully calibrated.

Chapter 4 explores the intersection of energy poverty and EEOS. It begins by distinguishing between fuel poverty and energy poverty, making the case for adopting the energy poverty terminology in the Turkish context. The chapter then traces the historical development of the concept in academic and policy literature, examining key definitions and measurement methods. It continues with a review of international experiences where social concerns have been integrated into EEOS design, highlighting various targeting strategies and associated risks. The chapter also assesses Türkiye’s current policy framework and research efforts related to energy poverty, identifying existing gaps and opportunities. By providing a comprehensive understanding of the conceptual, policy, and practical dimensions of energy poverty, this chapter lays a critical foundation for the analyses presented in Chapters 5 and 6.

Chapter 5 conducts a comparative assessment of income- and energy expenditure-based definitions of energy poverty to determine their effectiveness in identifying vulnerable households in Türkiye. Drawing on microdata from the Turkish statistical Institute’s (TurkStat) 2022 Household Budget Survey, the chapter examines key energy poverty drivers to evaluate how each definition reflects actual deprivation. Furthermore, a simulation of an EEOS-related cost increase in households’ energy bills is performed to analyse its potential impact on energy poverty rates under these definitions, incorporating updated energy price dynamics and macroeconomic trends for 2024. The results provide evidence-based insights into the strengths and limitations of each definition and offer critical implications for the equitable integration of energy poverty concerns into a future EEOS framework.

Chapter 6 builds upon the previous chapter’s findings by proposing a more comprehensive and context-sensitive approach to identifying and targeting energy-poor households within the EEOS framework in Türkiye. Recognizing the limitations of conventional income- and expenditure-based definitions, this chapter develops a custom statistically robust eligibility index using detailed housing and socio-economic data from the TurkStat Survey on Income and Living Conditions. By combining indicators of physical inefficiency, financial difficulty, and regional differences the study categorizes households into three groups (priority energy-poor, at-risk, and regular) using clustering techniques. Finally, the spatial distribution of these groups and their corresponding energy efficiency needs are mapped across Türkiye, offering policymakers a data-driven and geographically informed strategy for equitable EEOS implementation.

Chapter 7 expands the discussion by focusing on design elements that can enhance the adaptability, cost-effectiveness, and policy coherence of a potential EEOS of Türkiye. Building on earlier findings, the chapter examines key flexibility mechanisms for compliance (buy-out, banking, borrowing, and saving trading) that allow obligated parties to meet their targets with greater efficiency. In addition to reviewing international practices, the chapter evaluates the applicability and implications of these flexibility options within the context of Türkiye. It then turns to the market-based feature of EEOS, the white certificate schemes, exploring their evolution, institutional typologies, and implementation experiences across Europe. Drawing from these international insights, the chapter proposes a reference framework for Türkiye, outlining how a well-structured white certificate scheme could be integrated into national energy efficiency policy. The framework is designed to reflect Türkiye's institutional capacity and policy context, supporting the launch of a pilot program that is both technically sound and socially equitable.

Chapter 8 focuses on the strategic positioning of a potential EEOS within Türkiye's broader energy efficiency policy mix. The interactions between EEOS and other existing policy instruments are discussed through a review of relevant literature, aiming to establish connections with the current policy frameworks in Türkiye. Based on the existing energy efficiency mechanisms and the targets set in Türkiye's Energy Efficiency 2030 Strategy and 2nd NEEAP, an attempt will be made to forecast the future role of the EEOS within the country's broader energy efficiency strategy.

Chapter 9 synthesizes the key findings of the thesis and presents forward-looking policy recommendations to inform the design and implementation of an EEOS in Türkiye, building on the analytical results and insights developed throughout the thesis study.

Chapter 10 presents the conclusion of the thesis by offering an overall evaluation of the findings, synthesizing insights from previous chapters. The chapter also revisits the main policy recommendations and reflects on their potential to shape Türkiye's energy efficiency agenda. Finally, it outlines possible directions for future research, emphasizing the need for continued empirical work, institutional learning, and policy innovation to ensure the long-term success of EEOS in the national context.

TÜRKİYE ENERJİ VERİMLİLİĞİ YÜKÜMLÜLÜKLERİ SİSTEMİNİN KANITA DAYALI ANALİZİ: SEKTÖREL UYGULAMALAR, ENERJİ YOKSULLUĞU, ESNEKLİK SEÇENEKLERİ VE POLİTİKA ÇIKARIMLARI

ÖZET

Enerji verimliliği, sürdürülebilir enerji politikalarının temel taşlarından biri olarak; enerji arz güvenliğini desteklemesi, sera gazı emisyonlarını azaltması ve enerji tüketimiyle ilişkili ekonomik yükleri hafifletmesi sayesinde, ulusal ve uluslararası enerji ve iklim stratejilerinin vazgeçilmez bir unsuru hâline gelmiştir. Günümüzde enerji verimliliği politikaları, arz güvenliği, erişilebilirlik, çevresel koruma ve düşük karbonlu ekonomiye geçiş gibi temel hedeflere eşzamanlı katkı sağlayarak stratejik bir kesişim alanı yaratmaktadır. Etkili enerji verimliliği politikaları yalnızca iddialı hedefler değil, aynı zamanda iyi tasarlanmış araçları da gerektirmektedir. Enerji verimliliği önlemleri genellikle ön yatırım, uzun vadeli planlama ve sistematik izleme gerektirdiğinden, ülkeler; düzenleyici mevzuatlar, mali teşvikler, bilgilendirme kampanyaları ve gönüllü anlaşmalar gibi çeşitli politika mekanizmaları geliştirmiştir. Bu mekanizmalar arasında piyasa temelli yaklaşımlar, maliyet etkinlikleri ve özel sektörün katılımını artırma potansiyelleri nedeniyle giderek daha fazla önem kazanmaktadır.

Bu piyasa temelli araçlardan biri olan Enerji Verimliliği Yükümlülük Sistemi (EVYS) enerji şirketlerine nihai kullanıcılar üzerinde enerji verimliliği önlemleri uygulayarak belirli miktarda enerji tasarrufu sağlama yükümlülüğü getirmektedir. EVYS, nihai kullanıcı düzeyinde ölçülebilir verimlilik artışlarını teşvik ederken, aynı zamanda yükümlü taraflara farklı ve maliyet-etkin uyum yolları sunarak esneklik de sağlamaktadır. Son yirmi yılda EVYS, birçok ülkede enerji verimliliği politikalarının merkezinde yer almıştır.

EVYS'nin kökeni, Amerika Birleşik Devletleri'nde (ABD) uygulanan kamu hizmeti talep tarafı yönetimi programlarına dayanmaktadır. Ancak bu yaklaşımı kurumsallaştıran yapı, 2012 yılında Avrupa Birliği (AB) tarafından kabul edilen 2012/27/EU sayılı Enerji Verimliliği Direktifi olmuştur. Direktifin 7. maddesi ile Üye Devletlere, yıllık nihai enerji satışlarının %1,5'i oranında enerji tasarrufu sağlayacak şekilde EVYS kurmaları veya alternatif politika önlemleri uygulamaları yükümlülüğü getirilmiştir. 2018 yılında yapılan değişiklikle hedefler yükseltilmiş, 2030 yılına kadar en az %32,5 enerji verimliliği artışı hedefi ve 2021–2030 döneminde yıllık %0,8 tasarruf yükümlülüğü getirilmiştir. 2023 yılında Avrupa Yeşil Mutabakatı ve REPowerEU girişimi kapsamında yapılan yeniden düzenleme ile bu hedefler daha da ileri taşınmış; 2024-2030 döneminde yıllık tasarruf zorunluluğu neredeyse iki katına çıkarılmış ve enerji yoksulluğu ile mücadele, kamu sektörünün örnek rolü ve kırılgan gruplara yönelik önlemler gibi sosyal boyutlar daha güçlü şekilde vurgulanmıştır.

AB aday ülkesi olan Türkiye, enerji verimliliği politikalarını AB mevzuatıyla uyumlu hâle getirmeye çalışmaktadır. 2007 yılında yürürlüğe giren 5627 sayılı Enerji Verimliliği Kanunu'nun ardından Türkiye, enerji verimliliğini artırmaya yönelik

çeşitli yasal düzenlemeler, mevzuat çalışmaları ve ulusal strateji belgeleri geliştirmiştir. Bunlar arasında 2010-2023 Ulusal İklim Değişikliği Stratejisi, 2012-2023 Enerji Verimliliği Strateji Belgesi ve 10. Kalkınma Planı'nda yer alan "Enerji Verimliliğini Artırma Programı" öne çıkmaktadır. 2015-2019 dönemi Enerji ve Tabii Kaynaklar Bakanlığı Stratejik Planı da enerji verimliliğini temel hedeflerden biri olarak benimsemiştir. Bu çerçevede, 2017 yılı sonunda yayımlanan ilk Ulusal Enerji Verimliliği Eylem Planı (UEVEP), AB Enerji Verimliliği Direktifi doğrultusunda hazırlanmış ve 2023 yılına kadar birincil enerji tüketiminde %14 yani 23,9 Milyon Ton Eşdeğer Petrol (MTEP) azalma hedefi koymuştur. Bu hedefe ulaşmak üzere bina ve hizmetler, enerji, ulaştırma, sanayi ve teknoloji, tarım ve bütün sektörleri ilgilendiren yatay konulara yönelik altı ana kategoride toplam 55 eylem belirlenmiş ve yaklaşık 10,9 milyar ABD doları yatırım öngörülmüştür.

UEVEP'te yatay konular başlığı altındaki Y-11 numaralı eylem, "Enerji Dağıtım veya Perakende Şirketlerine yönelik Enerji Verimliliği Yükümlülük Programı" başlığı altında bir EVYS kurulmasını hedeflemiştir. Elektrik, doğalgaz ve petrol sektörlerindeki şirketlere, pazar payları oranında yıllık enerji tasarrufu yükümlülüğü getirilmesi planlanmıştır. Yükümlülüklerin şirketlerin kendi faaliyetlerinde enerji verimliliğini artırmaları ya da son kullanıcılarına yönelik enerji verimliliği projeleri gerçekleştirmeleri yoluyla yerine getirilebileceği, uygulamanın etkinliğini sağlamak için tasarruf potansiyeli ve maliyet gibi unsurları içeren standart bir kataloğun hazırlanması öngörülmüştür. Yükümlü tarafların, hazırlanacak katalogda yer alan ya da eşdeğer nitelikteki projeleri seçerek hayata geçirmeleri hedeflenmiş ve bu projelere ilişkin maliyetlerin belirli düzenleyici koşullar altında son kullanıcılara yansıtılmasına da olanak tanınacağı açıklanmıştır. Eylemin sorumlu kurumu olarak Enerji ve Tabii Kaynaklar Bakanlığı (ETKB) belirlenmiş, Enerji Piyasası Düzenleme Kurumu (EPDK) ile Hazine ve Maliye Bakanlığı ise ilgili kurumlar olarak tanımlanmıştır. Uygulama takvimi doğrultusunda, 2018-2019 döneminde mevzuat ve operasyonel altyapının oluşturulması, 2020-2022 döneminde ise EVYS'nin tam ölçekli şekilde uygulanması planlanmıştır. Ancak tüm bu ayrıntılı planlamaya rağmen, söz konusu program birinci eylem planı döneminde hayata geçirilememiş ve Y-11, plan kapsamında tamamlanamayan az sayıdaki eylemden biri olarak kalmıştır.

2024 yılında Türkiye, "Enerji Verimliliği 2030 Stratejisi ve İkinci Ulusal Enerji Verimliliği Eylem Planı"nı yayımlayarak enerji verimliliğine yönelik kararlılığını yeniden göstermiştir. Bu yeni plan, 2030 yılına kadar birincil enerji tüketimini %16 oranında azaltmayı, toplamda 37,1 MTEP tasarruf sağlamayı ve yaklaşık 20,2 milyar ABD doları yatırım yapılmasını hedeflemektedir. Sektörel sınıflandırma bir önceki planla büyük ölçüde benzer olmakla birlikte "Start-up ve Dijitalleşme" başlığı altında yeni bir tematik alan eklenmiştir.

İkinci UEVEP'te EVYS, Y-8 numaralı eylem altında yeniden gündeme getirilmiş; ancak bu kez daha kısa ve araştırmaya açık bir çerçevede sunulmuştur. Elektrik, doğal gaz ve petrol sektörlerinde hizmet veren dağıtım ve/veya tedarik şirketleri için verimlilik yükümlülüklerinin belirlenmesi ve beyaz sertifika sisteminin pilot uygulaması eylemin ana başlıkları arasında yer almıştır. Kurumsal yapıda da değişiklik yapılmış, önceki planda ilgili kurum olarak yer alan Hazine ve Maliye Bakanlığı'nın yerini Enerji Piyasaları İşletme Anonim Şirketi (EPİAŞ) almıştır. Bu durum, piyasa bazlı yaklaşımlara geçiş yönünde bir iradenin göstergesi olarak değerlendirilebilmektedir. Eylem, yasal altyapı çalışmalarının 2024-2026 döneminde tamamlanmasını ve EVYS uygulamasının 2027 yılında başlatılmasını hedeflemektedir.

Her ne kadar EVYS, birinci UEVEP'te detaylı ve somut bir politika eylemi olarak yer almış olsa da, plan dönemi içerisinde hayata geçirilememiştir. Bu gecikme, birbirine bağlı bir dizi yapısal ve kurumsal zorlukla ilişkilendirilebilir. İlk olarak, düzenleyici kurumlar, yükümlü taraflar, piyasa işletmecileri ve son kullanıcılar arasında yakın koordinasyon gerektiren çok aktörlü EVYS tasarımı, entegre enerji verimliliği yönetişimi açısından henüz olgunlaşma sürecinde olan bir düzenleyici ortamda önemli ölçüde karmaşıklık yaratmıştır. İkinci olarak, politika iradesi net olmasına rağmen, standart enerji verimliliği önlemlerinin tanımlanması, etkili bir uyum izleme sisteminin oluşturulması ve uygun finansman mekanizmalarının tasarlanması kapsamında idari hazırlık ve teknik kapasite açısından daha fazla gelişime ihtiyaç duyulmuştur. Üçüncü olarak, enerji şirketlerinin yükümlülükleri gelir kaybı riski ya da operasyonel yük olarak görmesi nedeniyle direnç göstermesi, politika yapıcılar nezdinde tereddüt yaratmıştır. EVYS kapsamında uygulanacak maliyetlerin son kullanıcıya yansıtılması ihtimali de özellikle ekonomik belirsizliklerin ve enerji maliyetlerinin arttığı bir dönemde politik kabul edilebilirlik açısından zor olarak nitelendirilmiştir. Son olarak, merkezi ve sağlam bir Ölçme ve Doğrulama (Ö&D) mekanizmasının eksikliği, tasarruf iddialarının güvenilirliğini ve uygulanabilirliğini sınırlamıştır. Tüm bu örtüşen engeller, EVYS'nin hayata geçirilmesi için gereken yasal ve kurumsal altyapının kurulmasını yavaşlatmıştır.

Bundan sonraki süreçte, Türkiye'nin çabaları, sağlam ve adil bir EVYS'nin sahada uygulanmasını destekleyecek kurumsal hazırlık ve teknik kapasitenin güçlendirilmesine odaklanabilir. Politika yapıcılar gerekli mevzuat altyapısını ve uygulamaya yönelik kurumsal düzenlemeleri oluştururken, akademiye de bu sürece katkı sunma sorumluluğu düşmektedir. Araştırmacıların, mekanizmanın etkin ve adil biçimde işlemesini sağlamak amacıyla sağlam analizler, tasarım çalışmaları ve kanıta dayalı politika önerileri geliştirmesi beklenmektedir. Bu doktora tezi de bu ihtiyacın yarattığı motivasyonla ortaya çıkmıştır ve Türkiye'deki olası bir EVYS'nin başarılı şekilde hayata geçirilmesine katkı sunmayı amaçlamaktadır.

Türkiye'ye yönelik mevcut akademik çalışmalar, EVYS konusunda önemli başlangıç bilgileri sunmuş olsa da, genellikle sadece arz tarafındaki aktörlere veya düzenleyici bakış açılarına odaklanmış; son kullanıcı etkileri, maliyet-fayda dinamikleri ve enerji yoksulluğu gibi konulara bütüncül bir perspektiften yaklaşamamıştır. Bu tez çalışması, söz konusu boşluğu doldurmayı amaçlamakta; hem ekonomik hem de sosyal boyutları içeren çok boyutlu ve kanıta dayalı bir değerlendirme ile Türkiye bağlamında uygulanabilecek bir EVYS'yi kapsamlı bir şekilde ele almaktadır. Akademik literatüre katkının ötesinde, bu tez çalışması aynı zamanda politika yapıcılar için uygulanabilir içgörüler sunmayı, potansiyel sistem katılımcılarının mekanizmayı daha iyi anlamasına katkı sağlamayı ve Türkiye'nin enerji politikası bağlamında EVYS'nin kurumsallaştırılması ve içselleştirilmesine referans olmayı hedeflemektedir.

Bu bağlamda, bu tez çalışmasının temel amacı, Türkiye'de olası bir EVYS'nin hayata geçirilmesine yönelik kapsamlı ve kanıta dayalı bir temel oluşturmaktır. Uluslararası deneyimler ve edinilen dersler ışığında, söz konusu sistemin sektörel uygulamaları, ekonomik uygulanabilirliği, sosyal eşitlik etkileri, iç esneklik mekanizmaları, kurumsal tasarımı ve politika entegrasyonu gibi çok boyutlu gereksinimlerinin ele alınması hedeflenmektedir. Tez çalışmasında bu hedefler, uygulamalı, veri odaklı ve kanıta dayalı analizler, politika ile ilişkili modellemeler ve stratejik öneriler aracılığıyla gerçekleştirilmiştir. Nihai hedef, Türkiye'nin ulusal koşullarına uygun, maliyet etkin, sosyal açıdan kapsayıcı ve kurumsal olarak uygulanabilir bir EVYS geliştirmesine katkı sağlamaktır.

Bu tez çalışmasının her bir bölümü kendi içerisinde yoğun ve detaylı, aynı zamanda devam eden bölümlerle uyum içerisinde tasarlanmıştır. Bu bağlamda, birinci bölümdeki girişin ardından, ikinci bölüm EVYS'nin kavramsal temellerini, bileşenlerini ve küresel düzeydeki gelişimini inceleyerek mekanizmanın genel yapısını sunmaktadır. Özellikle Avrupa ülkelerindeki uygulamalara odaklanan bu bölüm, uluslararası deneyimleri ve akademik literatürü değerlendirerek tasarım kriterleri, operasyonel zorluklar ve başarı faktörleri gibi temel konuları ele almaktadır. Hem uygulama örneklerinden hem de literatürden elde edilen dersler aracılığıyla Türkiye bağlamına aktarılabilir içgörüler sunulmaktadır.

Üçüncü bölümde Türkiye için olası temel bir EVYS yapısının sanayi alt sektörleri ve ticari binalar özelinde ön maliyet-fayda analizi gerçekleştirilmektedir. Bu çerçevede, görevli elektrik tedarik şirketleri yükümlü taraflar olarak tanımlanmış ve yükümlü taraflarla son kullanıcıların kendi ekonomik hedeflerine göre bağımsız hareket etmelerine olanak tanıyan iki seviyeli dağıtık optimizasyon modeli uygulanmıştır. Farklı yükümlülük seviyeleri, son kullanıcı faturalarına eklenecek değişken EVYS ücreti oranları ve farklı ceza düzeyleri gibi politika senaryoları değerlendirilerek, sistemin fizibilitesi, maliyet dağılımı ve politika etkinliği analiz edilmiştir. Sonuç olarak, Türkiye EVYS'sinin adil EVYS ücret oranları altında kazan-kazan yaklaşımıyla kendini tamamen finanse edebileceği uygulama alternatiflerine ulaşılmıştır. Çalışma aynı zamanda, ceza mekanizmasının oynadığı kritik rolü de ortaya koymaktadır.

Dördüncü bölüm, enerji yoksulluğu ile EVYS arasındaki ilişkiyi ele almaktadır. Enerji yoksulluğu kavramı akademik ve politik literatürdeki tarihsel gelişimi, ölçüm yöntemleri ve tanımları üzerinden incelenmekte; sosyal hedeflerin EVYS tasarımına entegre edilebildiği uluslararası örnekler ve hedefleme stratejileri ele alınmaktadır. Türkiye'nin mevcut politika çerçevesi ve enerji yoksulluğuna dair araştırmalar incelenerek var olan boşluklar değerlendirilmektedir. Bu bölüm, beşinci ve altıncı bölümlerde gerçekleştirilen analizler için kavramsal bir temel oluşturmaktadır.

Beşinci bölüm, enerji yoksulluğunu tanımlamada sıklıkla kullanılan gelir ve enerji harcaması temelli yaklaşımları karşılaştırmalı olarak incelemekte, bu tanımların Türkiye bağlamında enerji yoksulluğunu ne ölçüde temsil edebildiğini analiz etmektedir. Türkiye İstatistik Kurumu'nun (TÜİK) 2022 yılı Hanehalkı Bütçe Anketi mikro verileri kullanılarak, temel göstergeler ışığında hangi tanımın enerji yoksulluğunu daha doğru ve kapsayıcı bir şekilde yakalayabildiği araştırılmıştır. Ayrıca, hem 2022 hem de 2024 yılı güncel enerji fiyatları ve ekonomik koşulları dikkate alınarak, son kullanıcılara yansıtılabilecek %5'lik olası bir EVYS ücretinin hane bütçelerine etkisi simüle edilmiştir. Bu çalışma, farklı enerji yoksulluğu tanımlarının politika sonuçlarını nasıl etkilediğine dair önemli çıkarımlar sunarken, aynı zamanda söz konusu tanımların enerji yoksulluğunu yeterli düzeyde temsil etmede çeşitli yetersizlikler barındırdığını da ortaya koymaktadır. Bu durumun, özellikle EVYS kapsamında sosyal açıdan hassas grupların doğru biçimde tespit edilmesi açısından dikkatle ele alınması gerektiğine işaret etmektedir.

Altıncı bölüm Türkiye'deki olası EVYS çerçevesi içerisinde enerji yoksulu hanelerin belirlenmesi ve hedeflenmesi konusunda kapsamlı bir yaklaşım önermektedir. Geleneksel gelir ve enerji harcaması temelli tanımların sınırlamalarını kabul eden bu bölümde, TÜİK 2023 Gelir ve Yaşam Koşulları Anketi mikro verilerini kullanarak istatistiksel temellere dayanan bir EVYS uygunluk endeksi geliştirilmiştir. Öncelikle enerji verimsiz haneler tespit edilmiş ve bu haneler üzerinden belirlenen finansal zorluk göstergelerine göre istatistiksel temellere dayanan uyumluluk endeksi oluşturulmuştur. Fiziksel verimsizlik, uyumluluk endeksi puanları ve bölgesel farklılık göstergeleri dikkate alınarak, kümeleme teknikleri kullanılarak verimsiz haneler üç gruba (öncelikli enerji yoksulu, risk altında ve düzenli) ayrılmıştır. Her bir hane grubunun EVYS uygulamasında farklı muamele görmesi öngörülmektedir. Son olarak, bu grupların bölgesel dağılımı ve bunlara karşılık gelen enerji verimliliği ihtiyaçları Türkiye genelinde haritalanarak politika yapıcılara adil bir EVYS uygulaması için veri odaklı ve coğrafik bir strateji sunulmaktadır.

Yedinci bölümde, Türkiye için potansiyel bir EVYS'nin uyarlanabilirliğini ve maliyet etkinliğini artırmaya yönelik tasarım unsurlarına odaklanılmaktadır. İlk olarak uyum esnekliği sağlayan çeşitli esneklik mekanizmaları olan ikame ödeme, biriktirme, borçlanma ve tasarruf ticareti seçenekleri incelenmektedir. Uluslararası uygulamalar gözden geçirilmekle birlikte, bu esneklik seçeneklerinin Türkiye bağlamında uygulanabilirliği ve olası etkileri de değerlendirilmektedir. Bölümün devamında ise, EVYS'nin piyasa temelli özelliği olan beyaz sertifika sistemlerine odaklanılmakta; bu sistemlerin tarihsel gelişimi, kurumsal yapıları ve Avrupa'daki uygulama deneyimleri detaylı bir şekilde ele alınmaktadır. Bu uluslararası bulgulardan yola çıkılarak, Türkiye'ye özgü koşulları yansıtan bir referans çerçeve önerilmektedir. Bu çerçeve, ulusal enerji verimliliği politikasına entegre edilebilecek sağlam bir beyaz sertifika sisteminin nasıl tasarlanabileceğini ortaya koymakta; teknik yeterlilik ve kurumsal kapasite açısından içgörüler sunarak pilot programın hayata geçirilmesini desteklemeyi amaçlamaktadır.

Sekizinci bölüm, Türkiye'nin genel enerji verimliliği politika bileşimi içerisindeki EVYS'nin stratejik konumlanmasına odaklanmaktadır. Bu kapsamda, EVYS'nin diğer mevcut politika araçlarıyla olan etkileşimleri ilgili literatür üzerinden ele alınarak, Türkiye'deki güncel politika çerçeveleriyle olan ilişkileri ortaya konulmaktadır. Mevcut enerji verimliliği mekanizmaları ve ikinci UEVEP'te belirlenen hedefler dikkate alınarak, EVYS'nin gelecekteki rolüne ilişkin bir öngörüde bulunulması amaçlanmaktadır.

Son olarak, dokuzuncu bölümde, tez boyunca elde edilen bulgular sentezlenmekte ve Türkiye'de uygulanabilir bir EVYSS'nin tasarımına yön verecek ileriye dönük politika önerileri sunulmaktadır.

Sonuç olarak, bu doktora tezi çalışması, Türkiye'de uygulanması planlanan ancak henüz gerçekleştirilemeyen EVYS'nin çok boyutlu yapısını kavramsal, ekonomik ve sosyal açılardan ele alan, veri temelli ve kanıta dayalı bir analiz sunmaktadır. Uluslararası deneyimlerden çıkarılan dersler, ampirik verilerle yapılan değerlendirmeler ve sektörel düzeyde geliştirilen politika önerileri aracılığıyla, EVYS'nin Türkiye bağlamında etkin, adil ve sürdürülebilir bir şekilde tasarlanmasına katkı sağlanması amaçlanmaktadır. Bu kapsamlı yaklaşımın, hem karar vericiler hem de uygulayıcılar için yol gösterici olması; ayrıca akademik literatüre de özgün bir katkı sunması hedeflenmektedir. Çalışmanın, Türkiye'nin enerji verimliliği hedeflerine ulaşmasında ve EVYS'nin başarılı bir şekilde kurumsallaşmasında somut bir zemin oluşturması arzu edilmektedir.

1. INTRODUCTION

Energy efficiency is a crucial pillar of sustainable energy policy, as it directly supports energy security, reduces greenhouse gas emissions, and alleviates economic burdens associated with energy consumption. It plays a cross-cutting role in national strategies by contributing simultaneously to the goals of supply security, affordability, environmental protection, and the transition to a low-carbon economy. In this context, improving energy efficiency has become an indispensable element of both national and international energy and climate strategies.

Effective energy efficiency policy requires not only ambition but also well-designed instruments. Energy efficiency measures often demand upfront investment, long-term planning, and systematic monitoring. In response, countries have developed various policy mechanisms to promote energy efficiency, including regulatory standards, financial incentives, information campaigns, and voluntary agreements. Among these, market-based mechanisms have received increasing attention for their cost-effectiveness and ability to mobilize private sector participation.

One of the most widely adopted market-based instruments is the Energy Efficiency Obligation Scheme (EEOS), which mandates energy companies to achieve a certain amount of energy savings on their end-users. EEOS not only drives measurable improvements in end-use efficiency but also provides flexibility in compliance, allowing obligated parties to choose cost-effective pathways for delivering savings. Over the past two decades, EEOS has become a central element of energy efficiency policy in many countries (Bertoldi et al., 2010; Fawcett et al., 2019; Rosenow et al., 2019).

The origins of EEOS can be traced back to the United States of America (USA), where utility demand-side management programs laid the foundation for modern obligation schemes. However, it was the European Union (EU) that institutionalized EEOS as a key policy tool through the adoption of the 2012/27/EU Energy Efficiency Directive (EED). Article 7 of the directive required Member States to implement EEOS or alternative policy measures to achieve annual energy savings equivalent to 1.5% of final energy sales (European Parliament, 2012). The EED aimed to help the EU achieve its target of a 20% improvement in energy efficiency by 2020. In 2018, the directive was amended to raise ambition, setting a new target of at least 32.5% energy efficiency improvement by 2030 and requiring Member States to achieve 0.8% annual savings during the 2021–2030 period (European Parliament, 2018). Most recently, the directive was recasted in 2023 as part of the European Green Deal and REPowerEU initiatives. The 2023 recast further increased the binding EU-level target, setting a goal of 11.7% reduction in primary and final energy consumption by 2030 compared to the 2020 reference scenario, and nearly doubled the annual energy savings obligation in the 2024–2030 period. It also introduced enhanced provisions on energy poverty alleviation, the exemplary role of the public sector, and promotion of energy efficiency in vulnerable households and hard-to-reach segments (European Parliament, 2023).

As a candidate country for EU membership, Türkiye has aligned its energy efficiency strategies with the EU framework. Following the enactment of the Energy Efficiency Law in 2007 (Law No. 5627), Türkiye developed successive legislations, strategic documents, and national plans to enhance energy efficiency and support long-term sustainability goals. Key policy documents include the 2010–2023 National Climate Change Strategy, which emphasized reducing greenhouse gas emissions through improved efficiency in buildings, industry, and transport; the 2012–2023 Energy Efficiency Strategy Paper, which provided a results-oriented roadmap supported by specific targets and policy instruments; and the Tenth Development Plan (2014–2018), which introduced the “Energy Efficiency Improvement Program” to guide sectoral actions. Additionally, the 2015–2019 Strategic Plan of the Ministry of Energy and Natural Resources highlighted energy efficiency under two strategic objectives: “Becoming a Country Using Energy Efficiently” and “Developing Capacity for Energy Efficiency and Conservation.” These efforts were further reinforced by Türkiye’s adoption of the 2012/27/EU EED as a guiding framework for establishing national obligations and designing structural mechanisms such as the National Energy Efficiency Action Plan. Building on these foundations, Türkiye published its first National Energy Efficiency Action Plan (NEEAP) at the end of 2017, covering the period from 2017 to 2023. Developed in line with the EU EED, the first NEEAP aimed to achieve a 14% reduction in primary energy consumption by 2023, with an estimated energy saving of 23.9 million tons of oil equivalent (Mtoe) through 55 specific actions. These actions were structured under six main categories: buildings and services, energy, transport, industry and technology, agriculture, and cross-cutting issues. The plan projected a total investment need of 10.9 billion United States Dollars (USD) and emphasized mobilizing both public and private resources to realize the savings potential (MENR, 2018).

One of the key actions outlined in the first NEEAP was the introduction of an EEOS. Among the cross-cutting issues, Action Y11 titled "Energy Efficiency Obligation Program for Energy Distribution or Retail Companies" directly proposed the design and implementation of an EEOS. The primary aim was to assign annual energy saving obligations to these companies in proportion to their market shares in electricity, natural gas, and petroleum. These obligations could be met either through improving the efficiency of their own operations or by implementing end-use energy efficiency projects for their customers. To facilitate implementation, a standardised catalog of eligible energy-saving measures (detailing potential savings and associated costs) was planned to be developed. Obligated parties would be required to select and carry out projects from this catalog or equivalent alternatives. The costs of these measures could be passed on to end-users under specific regulatory conditions, ensuring transparency and fairness. Companies failing to meet their obligations would be subject to financial penalties, which would be collected and directed to the National Energy Efficiency Financing Mechanism to support broader energy efficiency initiatives. The Ministry of Energy and Natural Resources (MENR) was designated as the lead responsible institution, with key supporting roles assigned to the Energy Market Regulatory Authority (EMRA), and the Ministry of Treasury and Finance. The action plan envisioned the development of regulatory and operational infrastructure, including the preparation of the measure catalog and implementation procedures, during 2018-2019, with full-scale implementation of the obligation program scheduled for the 2020–2022 period (MENR, 2018). However, despite these detailed plans, the program was could not be implemented during the first plan period, making EEOS one of the few actions in the NEEAP that remained incomplete.

In 2024, Türkiye reaffirmed its commitment to energy efficiency by publishing the Energy Efficiency 2030 Strategy and the Second National Energy Efficiency Action Plan. The second plan aims to reduce primary energy consumption by 16% by 2030, corresponding to a cumulative saving of 37.1 Mtoe, and foresees an investment of USD 20.2 billion to implement 61 actions across multiple sectors. The sector categories largely mirror those of the first NEEAP with an addition of a new theme: Start-ups and Digitalization. Like the first plan, the second NEEAP is grounded in the 2007 Energy Efficiency Law and supported by core regulations such as the Regulation on Increasing Efficiency in the Use of Energy Resources and Energy (2008), the Regulation on Energy Performance in Buildings (2008), and the Regulation on Energy Efficiency Audits (2018). In addition, it is aligned with and draws legitimacy from several overarching policy documents, including the 12th Development Plan (2024-2028), the Türkiye National Energy Plan (2023), the Medium-Term Program (2024-2026), the National Climate Change Strategy, and Türkiye's updated Nationally Determined Contributions (NDC) under the Paris Agreement. These references not only reinforce the strategic orientation of the Second NEEAP but also demonstrate its integration into the broader policy architecture guiding Türkiye's energy and climate actions (MENR, 2024).

The Second NEEAP continues to include the establishment of an EEOS, now under Action Y8 titled "Development of the Energy Efficiency Obligation Program." Compared to the previous NEEAP, which presented a detailed roadmap for EEOS implementation, including annual obligations, standardised project catalogs, penalty mechanisms, and end-user cost pass-throughs, the second plan adopts a more concise and exploratory approach. Y-8 primarily focuses on aligning the EEOS with national climate goals and introduces three main activities: defining energy efficiency obligations for electricity, gas, and petroleum distribution and/or supply companies; setting these obligations as a quality performance criterion for electricity companies; and initiating a pilot for the implementation of a white certificate market. This signals a shift from administratively heavy planning toward a more performance- and carbon-oriented framework. Another notable change lies in the institutional setup. While the MENR remains the lead authority, the Ministry of Treasury and Finance, previously listed among relevant institutions, has been replaced by the Energy Exchange Istanbul (EXIST). This suggests a stronger emphasis on market integration and trading infrastructure in the new phase of EEOS development. Furthermore, the action plan now highlights electricity more prominently than other fuels, which may reflect a strategic focus on decarbonizing the power sector as a near-term priority. The timeline also confirms this preparatory orientation: legislative and institutional groundwork is scheduled for 2024–2026, with the program set to launch in 2027 (MENR, 2024).

Although EEOS was included as a concrete policy action in the first NEEAP, it could not be launched within the plan period. This delay can be attributed to several interrelated structural and institutional challenges. First, the multi-actor design of EEOS, which requires close coordination among regulators, obligated parties, market operators, and end-users, posed significant complexity in a regulatory environment still maturing in terms of integrated energy efficiency governance. Second, while the policy intent was clear, further development in administrative readiness and technical capacity was needed to define standardised measures, build effective compliance tracking systems, and design appropriate financing mechanisms. Third, potential resistance from energy companies, who perceived obligations as a threat to revenue streams or feared operational burdens, created further hesitation. The scheme's potential impact on end-user prices (cost pass-through) also raised concerns about political acceptability, especially in a period marked by economic uncertainty and rising energy costs. Finally, the absence of a robust, centralized mechanism for Measurement and Verification (M&V) limited the credibility and enforceability of any savings claims. These overlapping barriers ultimately slow downed the legislative and institutional groundwork required for EEOS implementation.

1.1 Motivation and Contribution of the Thesis

Moving forward, Türkiye's efforts can focus on enhancing institutional readiness and technical capacity to support the practical rollout of a robust and equitable EEOS. As policymakers work to establish the necessary legislative and regulatory framework, along with the institutional arrangements required for implementation, the academia also has a crucial role to play. Researchers are expected to provide rigorous analyses, design studies, and solid recommendations to ensure that the mechanism operates efficiently and equitably. This Ph.D. thesis is motivated by this very need and aims to contribute to the successful realization of a Turkish EEOS through analytical groundwork, policy-oriented modelling, applied research and critical discussions.

So far, several academic studies have explored the feasibility, design, and implementation challenges of an EEOS tailored to Türkiye's context. One of the earliest contributions came from Düzgün and Kömürgöz (2014), who examined the applicability of a white certificates in Türkiye by analysing potential market mechanisms (Düzgün and Kömürgöz, 2014). Later, Cin et al. (2021) conducted an expert survey to propose an institutional and operational design for a national EEOS (Cin et al., 2021). Argun et al. (2021) developed optimization-based models from the perspectives of both regulators and obligated parties, focusing on incentive-penalty structures to balance economic efficiency and compliance, while Ünal et al. (2022) offered a guideline for standard energy efficiency measures across different sectors, based on a cost minimization framework centred on electricity distribution companies (Argun et al., 2021; Ünal et al., 2022).

While these studies provided foundational insights, they tended to focus on either supply-side actors or regulatory perspectives and largely lacked integrated assessments that also consider end-user impacts, cost-benefit dynamics, and energy poverty concerns. This Ph.D. thesis addresses this gap by placing an emphasis on end-user outcomes, which are considered for the first time in Türkiye within an integrated EEOS evaluation. It introduces a novel two-level distributed optimization model, applied for the first time in the Turkish context and within the international EEOS literature under a cost-benefit framework. This model captures the dual structure of the scheme by allowing the simultaneous optimization of objectives for both obligated parties and end-users. Unlike previous models focusing solely on regulatory or supply-side perspectives, this framework enables an inclusive, multi-perspective assessment of scheme design. It is applied using real-world data on energy sales, consumption and actual energy efficiency investment costs in Türkiye, enabling a robust and context-specific cost-benefit analysis.

Beyond modelling, the thesis applies a series of statistical methods using nationally representative household microdata. It presents the first empirical attempt in Türkiye to link energy poverty to a potential EEOS, drawing on large-scale national survey data, it conducts Chi-square and Post-hoc tests to compare alternative energy poverty definitions and evaluate their association with key household characteristics. Building on this analysis, the thesis simulates the impact of an EEOS-related increase in household energy bills to assess how different definitions respond to changes in energy expenditure, offering valuable insights into the policy's potential distributional consequences. Moreover, the thesis develops a novel approach for assessing and prioritizing energy-poor households within a potential EEOS in Türkiye. It focuses on identifying energy-inefficient households and introduces a statistically grounded eligibility index using Multiple Correspondence Analysis to determine which of these inefficient households are also financially vulnerable. To support a data-driven and evidence-based targeting strategy, the thesis applies the k-prototypes clustering algorithm to classify households by jointly considering inefficiency levels, eligibility index scores, and regional disparities. The resulting framework offers a solid basis for designing equitable, localized, and analytically robust interventions within the context of EEOS.

In addition to its applied analyses, the thesis offers an in-depth examination of advanced design features of a potential EEOS, including flexibility mechanisms and white certificates. Drawing from extensive international practice reviews, it critically assesses the operational feasibility, institutional requirements, and contextual applicability of these mechanisms for Türkiye, providing a practical reference for future policy implementation. The thesis also explores, for the first time, how a potential EEOS could be strategically positioned within Türkiye's broader energy efficiency policy landscape. Through a review of literature and practical experiences, it analyses the interactions between EEOS and existing and planned instruments, offering original insights into the scheme's alignment with Türkiye's current policy architecture and its envisioned role in the future.

In addition to academic contribution, the Ph.D. thesis also seeks to offer evidence-based and practically relevant insights for policymakers, support better understanding among potential scheme participants, and serve as a reference for the institutionalization and internalization of the EEOS within Türkiye's energy policy landscape.

1.2 Purpose of the Thesis

The primary purpose of this thesis is to provide a comprehensive, evidence-based foundation for the potential implementation of an EEOS in Türkiye. Based on existing international experience and lessons learned, this Ph.D. thesis aims to address the multidimensional requirements of such a scheme, including its sectoral applications, economic feasibility, social equity implications, internal flexibility mechanisms, institutional design, and policy integration. These objectives are pursued through applied and data-oriented research, policy-relevant modelling, and strategic recommendations. The ultimate goal is to support Türkiye in developing a cost-effective, socially inclusive, and institutionally viable EEOS tailored to its national circumstances.

The structure of the Ph.D. thesis reflects these objectives through a sequential and comprehensive framework. As shown in Figure 1.1, the study begins with a review of international EEOS practices and literature to extract transferable insights. It then moves on to sector-specific analyses in the context of Türkiye, focusing on industrial and commercial buildings as well as the household sector. Subsequent sections focus on compliance and market-based mechanisms, including flexibility options and the white certificate schemes. The thesis then examines policy interactions and the potential future role of EEOS within Türkiye's broader energy efficiency and climate policy landscape. The final part synthesizes the findings and offers overall insights and policy recommendations to support the design of a coherent and effective EEOS for Türkiye.

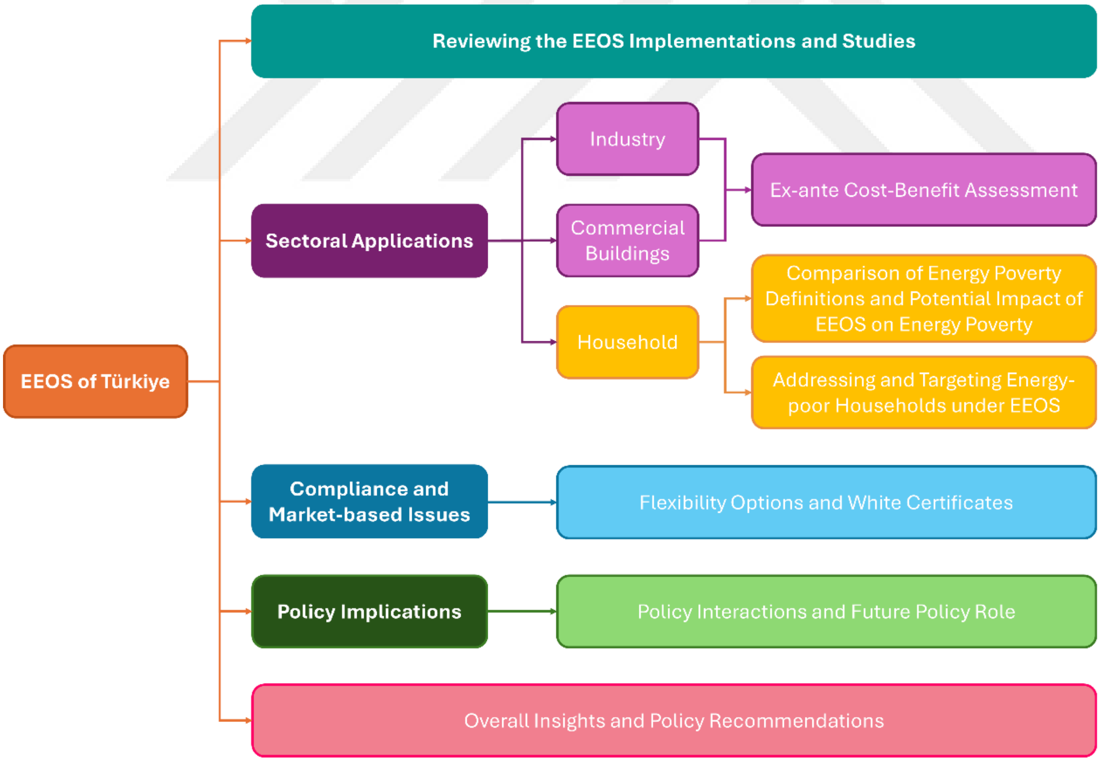

Figure 1.1 : The General Framework of the Ph.D. Thesis.

1.3 Chapters of The Thesis

Chapter 1 introduces the background, motivation, and structure of the thesis. It begins by establishing the critical role of energy efficiency, explains how EEOS emerged, traces its development within the EU framework, and discusses Türkiye's evolving policy landscape. The chapter also outlines the motivation, contribution, and purpose of the thesis.

Chapter 2 introduces the EEOS by examining its conceptual foundations, core components, and global evolution as a policy tool. The chapter provides a structured review of international implementation experiences, with particular focus on European countries, and evaluates the academic literature to identify key design considerations, operational challenges, and success factors. By synthesizing lessons learned from both practice and research, the chapter lays the groundwork for understanding how EEOS can be adapted to Türkiye's context, offering early insights into the opportunities and constraints shaping its potential adoption.

Chapter 3 presents an ex-ante cost-benefit assessment of a possible EEOS structure for Türkiye, focusing on the industrial sub-sectors and commercial buildings. Within this framework, incumbent electricity suppliers are designated as obligated parties. A two-level distributed optimization model is employed, allowing obligated parties and end-users to independently pursue their economic objectives while preserving market realism. By evaluating various policy scenarios such as different obligation structures, EEOS fee rates, and penalty levels, the chapter offers insights into the financial feasibility, cost distribution, and policy effectiveness of a basic EEOS model. The findings support the conclusion that a self-financing, balanced scheme can be established in Türkiye, provided that design parameters are carefully calibrated.

Chapter 4 explores the intersection of energy poverty and EEOS. It begins by distinguishing between fuel poverty and energy poverty, making the case for adopting the energy poverty terminology in the Turkish context. The chapter then traces the historical development of the concept in academic and policy literature, examining key definitions and measurement methods. It continues with a review of international experiences where social concerns have been integrated into EEOS design, highlighting various targeting strategies and associated risks. The chapter also assesses Türkiye's current policy framework and research efforts related to energy poverty, identifying existing gaps and opportunities. By providing a comprehensive understanding of the conceptual, policy, and practical dimensions of energy poverty, this chapter lays a critical foundation for the analyses presented in Chapters 5 and 6.

Chapter 5 conducts a comparative assessment of income- and energy expenditure-based definitions of energy poverty to determine their effectiveness in identifying vulnerable households in Türkiye. Drawing on microdata from the Turkish statistical Institute's (TurkStat) 2022 Household Budget Survey, the chapter examines key energy poverty drivers to evaluate how each definition reflects actual deprivation. Furthermore, a simulation of an EEOS-related cost increase in households' energy bills is performed to analyse its potential impact on energy poverty rates under these definitions, incorporating updated energy price dynamics and macroeconomic trends for 2024. The results provide evidence-based insights into the strengths and limitations of each definition and offer critical implications for the equitable integration of energy poverty concerns into a future EEOS framework.

Chapter 6 builds upon the previous chapter's findings by proposing a more comprehensive and context-sensitive approach to identifying and targeting energy-poor households within the EEOS framework in Türkiye. Recognizing the limitations of conventional income- and expenditure-based definitions, a custom targeting framework is proposed to more effectively identify energy-poor households under a potential EEOS in Türkiye. This framework builds on microdata from the TurkStat Survey on Income and Living Conditions, allowing for the identification of physically inefficient dwellings and the subsequent detection of financially vulnerable households within this group. A statistically grounded eligibility index is developed based on financial difficulty indicators. By combining inefficiency indicators, eligibility index scores, and regional disparities, the study categorizes households into three groups (priority energy-poor, at-risk, and regular) using clustering techniques. Finally, the spatial distribution of these groups and their corresponding energy efficiency needs are mapped across Türkiye, providing policymakers with a data-driven and geographically informed strategy for equitable EEOS implementation.

Chapter 7 expands the discussion by focusing on design elements that can enhance the adaptability, cost-effectiveness, and policy coherence of a potential EEOS of Türkiye. Building on earlier findings, the chapter examines key flexibility mechanisms for compliance (buy-out, banking, borrowing, and saving trading) that allow obligated parties to meet their targets with greater efficiency. In addition to reviewing international practices, the chapter evaluates the applicability and implications of these flexibility options within the context of Türkiye. It then turns to the market-based feature of EEOS, the white certificates, exploring their evolution, institutional typologies, and implementation experiences across Europe. Drawing from these international insights, the chapter proposes a reference framework for Türkiye, outlining how a well-structured white certificate scheme could be integrated into national energy efficiency policy. The framework is designed to reflect Türkiye’s institutional capacity and policy context, supporting the launch of a pilot program that is technically sound.

Chapter 8 focuses on the strategic positioning of a potential EEOS within Türkiye’s broader energy efficiency policy mix. The interactions between EEOS and other existing policy instruments are discussed through a review of relevant literature, aiming to establish connections with the current policy frameworks in Türkiye. Based on the existing energy efficiency mechanisms and the targets set in Türkiye’s Energy Efficiency 2030 Strategy and 2nd NEEAP, an attempt is made to forecast the future role of the EEOS within the country's broader energy efficiency strategy.

Chapter 9 synthesizes the key findings of the thesis and presents forward-looking policy recommendations to inform the design and implementation of an EEOS in Türkiye, building on the analytical results and insights developed throughout the Ph.D. thesis study.

Chapter 10 presents the conclusion of the thesis by offering an overall evaluation of the findings, synthesizing insights from previous chapters. The chapter also revisits the main policy recommendations and reflects on their potential to shape Türkiye’s energy efficiency agenda. Finally, it outlines possible directions for future research, emphasizing the need for continued empirical work, institutional learning, and policy innovation to ensure the long-term success of EEOS in the national context.

2. ENERGY EFFICIENCY OBLIGATION SCHEME[1]

The primary motivation of this chapter is to review existing EEOS implementations and studies to derive insights for establishing an EEOS in Türkiye. By conducting a systematic literature review and analysing practical evidence from international EEOS experiences, this chapter aims to:

- Examine the conceptual foundations of EEOS, including its design elements, policy mechanisms, and historical evolution.
- Analyse the practical experiences of EEOS implementations in European countries.
- Review the academic literature on EEOS, categorizing studies based on their focus areas.
- Discuss the key lessons learned for Türkiye, addressing potential barriers, policy recommendations, and design considerations for a feasible EEOS framework.

By synthesizing findings from literature and real-world applications, this chapter provides a comprehensive assessment of EEOS as a policy tool and explores its potential role in Türkiye's energy efficiency landscape. The insights derived from this review can contribute to shaping a well-structured EEOS that aligns with national energy efficiency objectives while ensuring economic feasibility and social equity.

2.1 The Concept

EEOS is a worldwide known energy efficiency policy mechanism. It first emerged as a utility end-use energy efficiency scheme in the USA after the 1973 oil crisis, and then its applications became widespread worldwide (Waide and Buchner, 2008).

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[1] This chapter is based on the following publication: **Cin, R.,** & Onaygil, S. (2024). Reviewing the implementations and studies of energy efficiency obligation schemes towards establishing a scheme in Turkey. *Energy Efficiency*, *17*(1), 2.

In 2012, the 2012/27/EU EED was enacted to assist the EU and Member States in achieving at least a 20% energy efficiency increase by 2020. The EED advised that Member States implement EEOS or alternative policy measures (energy/carbon taxes, financial incentives, voluntary agreements, etc.) under Article 7. EEOS mandated energy companies to attain annual energy savings equivalent to 1.5% of total sales to end-users (European Parliament, 2012).

In Europe, the United Kingdom (UK) is the first country that established EEOS as Supplier Obligations. Italy, Denmark, France, and Bulgaria implemented their EEOS after the UK. With the introduction of the EED, the adoption of EEOS across the EU significantly increased (Cin et al., 2021).

In 2018, the amendment to the EED increased the directive's ambition, aligning it with the EU's 2030 target of at least a 32.5% increase in energy efficiency. The amendment also led to Article 7 being renumbered as Article 8, while simultaneously increasing the annual energy savings obligation by an additional 0.8% (European Parliament, 2018). In July 2021, the European Commission initiated the legislative process of the EED recast as part of the 'Fit-for-55' package, which was later supplemented by an additional proposal under the REPowerEU plan in May 2022. The recasted directive, officially adopted on July 25, 2023, embraced the "energy efficiency first" principle across energy and non-energy policies. Furthermore, it set a new, more ambitious target: by 2030, the EU must achieve an 11.7% reduction in primary and final energy consumption compared to projections made in 2020 (European Parliament, 2023).

Beyond its legally binding nature, EEOS is a market-based energy efficiency policy mechanism, allowing energy companies to achieve their required energy saving obligations without a predefined delivery route. This means that energy companies can select and implement the most suitable measures for their operations, provided they follow the overall framework established by the scheme regulator (Rosenow et al., 2019). While EEOS imposes strict compliance, it simultaneously enables obligated parties to choose the most cost-effective and practical pathways to meet their obligations. This characteristic distinguishes EEOS from traditional command-and-control policies, making it an adaptable mechanism that can be tailored to different national contexts while maintaining its core objective of driving end-use energy efficiency improvements.

The structure of the EEOS can be examined under two main categories: Parties and Implementation Issues (Cin et al., 2021; Cin and Onaygil, 2024).

2.1.1 Parties

EEOS involves multiple parties, each playing a crucial role in the scheme's operation and enforcement. These include regulatory authorities, obligated parties, end-users, and other parties.

2.1.1.1 Regulatory authorities

The successful implementation of EEOS depends on a well-structured regulatory framework and a designated responsible and managing authority for the scheme. Each EEOS has a responsible authority that defines its objectives and general rules, typically linked to the relevant ministries in the country. In some cases, the responsible and managing authorities are the same, while in others, a separate managing authority oversees the scheme’s operation. Managing authorities are often national energy agencies or institutions affiliated with the ministries. Other organizations may provide technical support to ensure the scheme operates effectively. Both responsible and managing authorities can collaborate with multiple institutions, and the involvement of energy market regulators also plays a significant role in the scheme.

Additionally, responsible and managing authorities ensure compliance by imposing penalties for non-compliance and offering incentives for exceeding targets, while also coordinating EEOS with other energy efficiency policies. In some cases, they manage an energy efficiency fund to assist energy companies or end-users in implementing efficiency measures. They approve and regulate eligible energy efficiency measures and work with scheme participants to enhance policy design and execution. If a white certificate trading mechanism is in place, they oversee the trading rules and platform to ensure transparency and efficiency. Monitoring and verification are also key responsibilities, ensuring that energy companies meet their obligations effectively, sometimes with support from other technical institutions.

2.1.1.2 Obligated parties

Obligated energy companies are called Obligated Parties (OP) in EEOS, and they are the main actors of the scheme. They may include suppliers, distributors, or retailers of various types of energy, such as electricity, natural gas, petroleum products, LPG, and heat. In some cases, small energy companies may be exempt from the obligation, depending on the scheme’s design. To do this, schemes set specific thresholds, such as annual energy sales or the number of customers, to determine which companies are included.

2.1.1.3 End-users

The EEOS can cover all end-use sectors, including residential, commercial, industrial, and transport. While some schemes focus on specific sectors by setting targeted obligations, others adopt a broader approach, encompassing all sectors under a single framework. Additionally, sub-targets can be introduced to prioritize certain sectors based on policy priorities, energy-saving potential, or social objectives.

2.1.1.4 Other parties

OPs can collaborate with third parties, such as Energy Service Companies (ESCOs), contractors, local authorities, manufacturers, or other entities, to implement energy efficiency projects.

EEOS also includes eligible/voluntary parties which are not obligated under EEOS but can play a role in facilitating energy savings. If a white certificate system is in place, they can contribute to the scheme by certifying their energy savings projects and trading them.

2.1.2 Implementation issues

This sub-section describes the main components shaping the operational design of EEOS. It focuses on how energy saving obligations are defined, the eligibility and segmentation of efficiency measures, the control processes ensuring compliance, and the financing and flexibility mechanisms that support scheme implementation.

2.1.2.1 Obligations

Energy saving obligation targets in EEOS are typically defined as cumulative lifetime savings of any type of energy, though some schemes may establish periodic targets. The total obligation is allocated among OPs based on predetermined criteria, often considering their market share or energy sales. Compliance periods generally range from 1 to 3 years, depending on national regulations, ensuring that OPs achieve the required energy savings within a specified timeframe.

2.1.2.2 Energy efficiency measures

Following are the key aspects related to the eligibility, segmentation, and social targeting of energy efficiency measures within EEOS frameworks.

Eligibility: EEOS often includes a standardised catalog of eligible energy efficiency measures, specifying which actions can be promoted or restricted.

Segmentation: In some cases, certain measures receive greater incentives or bonuses through differentiated rewards or sector-specific sub-targets to maximize their impact.

Social goals: EEOS can be designed to support broader social objectives, such as alleviating energy poverty and mitigating climate change, by directing energy efficiency improvements toward vulnerable groups or high-impact areas.

2.1.2.3 Control

Following are the key aspects related to the measurement, monitoring and verification, and evaluation processes within EEOS frameworks.

Measurement: The effectiveness of EEOS is assessed through various energy efficiency measurement techniques and statistical calculations to ensure accurate tracking of energy savings.

Monitoring & Verification: Regular audits and verification mechanisms are implemented to confirm that OPs meet their targets, and that reported savings are valid.

Evaluation: Independent institutions or organizations periodically evaluate the scheme to assess its overall performance and recommend improvements, ensuring continuous optimization and alignment with policy goals.

2.1.2.4 Financing and compliance

Following are the key aspects related to the financing mechanisms, flexibility options, and compliance enforcement under EEOS frameworks.

Funds & subsidies: National energy efficiency funds or alternative financial resources can be allocated to support OPs in fulfilling their energy-saving targets. These funds can help reduce the financial burden on OPs and facilitate the implementation of energy efficiency measures, ensuring that a lack of financial resources does not hinder compliance.

Cost-sharing: Cost-sharing mechanisms may be introduced to distribute the financial responsibility of EEOS implementation among end-users. By sharing costs among different end-users, these mechanisms help ensure that the financial burden is not placed solely on OPs, promoting a more balanced approach to funding energy efficiency improvements.

Banking & borrowing: OPs may have the flexibility to bank surplus energy savings for use in future compliance periods or borrow savings from the next obligation cycle. Banking allows OPs to carry forward excess savings, while borrowing provides an option to compensate for shortfalls by using future savings, helping them manage their compliance strategies more effectively.

Buy-out: OPs may partially or fully fulfil their obligations by paying a predefined price per unit of energy savings instead of directly implementing energy efficiency measures. The buy-out option offers flexibility for parties that may face difficulties in achieving savings through direct actions, allowing them to contribute financially to the scheme instead.

Trading: Savings trading is permitted within the EEOS framework, allowing OPs to exchange excess savings to meet their targets. In some cases, a white certificate trading system may be established, providing a structured market where OPs and voluntary/eligible parties can buy and sell white certificates. This mechanism enhances cost-effectiveness and encourages investment in additional efficiency measures.

Penalty: Financial penalties are imposed on OPs that fail to meet their energy-saving targets. These penalties act as a deterrent against non-compliance and encourage active participation in the scheme. Cost-sharing mechanisms may be established to distribute the financial burden of EEOS implementation among end-users.

2.2 Implementation Experience

There are 15 active EEOS implementations in the EU. Country and scheme-specific features of existing EEOSs are given in Table 2.1 (ENSMOV, 2020; European Commission, 2022a & 2022b; IEA, 2022; MENR, 2018; World Bank, 2022).

Flexibility opportunities of existing EEOSs are given in Table 2.2 (ENSMOV, 2020; European Commission, 2022a & 2022b).

Table 2.1 : Country and scheme-specific features of existing EEOS.

Countries	Population (2019)	Final Energy Consumption (2019) (ktoe)	Energy Intensity[2] (2019) (TES/GDP) (MJ/2015 USD)	EEOS Establishment year	Obligated Parties	Responsible & Managing Authority	Target Sectors
Austria	8,879,920	28016	3.4	2015	All energy suppliers in Austria that sell more than 25 Giga Watt hour (GWh)/year energy to end users.	The Federal Ministry of Sustainability and Tourism and the Federal Ministry of Labor, Social Affairs, Health, and Consumer Protection & Austrian Energy Agency	All end-use sectors
Bulgaria	6,975,761	10058	13.2	2008	All companies that sell energy to final customers.	Ministry of Energy & Sustainable Energy Development Agency	All end-use sectors
Croatia	4,065,253	7271	6.4	2014	Energy suppliers of electricity, natural gas, heat, and oil products.	Ministry of Environmental Protection and Energy & National Energy Efficiency Authority	All end-use sectors
Denmark	5,814,422	13513	2.0	2006	All the energy distributors.	Ministry of Climate, Energy, and Utilities & Danish Energy Agency	All end-use sectors except transport
France	67,248,926	150074	3.9	2006	Energy suppliers of electricity, natural gas, oil products, heat (district heating).	Ministry for the Ecological and Solidary Transition & National Pole for White Certificates, The French Energy Agency	All end-use sectors
Greece	10,721,582	15980	4.5	2017	Electricity, gas, and oil products suppliers or retailers whose market share is higher than 1%.	Ministry of Environment and Energy & Centre for Renewable Energy Sources and Energy Savings	All end-use sectors
Hungary	9,771,141	20096	7.6	2021	Electricity and natural gas traders and providers, transport fuel companies.	Hungarian Energy and Public Utility Regulatory Authority	All end-use sectors
Ireland	4,934,340	11391	1.5	2014	All energy suppliers that sell more than 600 GWh/year.	Department of Communications, Climate Action & Environment & Sustainable Energy Authority of Ireland	All end-use sectors

[2] Energy intensity refers to the amount of energy consumed per unit of economic output, typically measured as energy use per unit of gross domestic product (GDP). It is an important indicator of how efficiently an economy uses energy to produce goods and services. Lower energy intensity generally signifies greater energy efficiency.

Table 2.1 (continued): Country and Scheme-specific Features of Existing EEOS.

Countries	Population (2019)	Final Energy Consumption (2019) (ktoe)	Energy Intensity (2019) (TES/GDP) (MJ/2015 USD)	EEOS Establishment year	Obligated Parties	Responsible & Managing Authority	Target Sectors
Italy	59,729,081	117718	3.3	2005	Electricity and natural gas distributors.	Ministry of Economic Development & Gestore dei Servizi Energetici, Gestore dei Mercati Energetici	All end-use sectors
Latvia	1,913,822	4020	6.2	2016	Electricity retailers that sell at least 10 GWh/year.	Ministry of Economics	All end-use sectors
Luxembourg	620,001	3836	2.6	2015	Electricity and gas suppliers.	Ministry for the Economy & The Energy Regulator, MyEnergy	All end-use sectors except transport
Malta	504,062	552	2.3	2009	The only distribution system and licensed electricity supply operator (Enemalta Corporation).	Ministry for Energy and Water Management & Energy and Water Agency	Residential sector
Poland	37,965,475	74493	7.5	2013	Electricity, heat (selling more than 5 MW_t), or natural gas suppliers and traders.	Ministry of Energy & Energy Regulatory Office	All end-use sectors except transport
Slovenia	2,088,385	4991	5.7	2010	Electricity, natural gas, heat (district heating), and liquid and solid fuels suppliers.	Ministry of Infrastructure & Slovenian Energy Agency	All end-use sectors
Spain	47,134,837	85524	3.8	2014	Electricity and natural gas suppliers, oil products, and LPG wholesale retailers.	Ministry for the Ecological Transition & Institute for Diversification and Saving of Energy	All end-use sectors
The United Kingdom	66,836,327	127306	2.3	1994	Electricity and gas suppliers who have more than 200,000 customers.	Department for Business, Energy & Industrial Strategy & Office of Gas and Electricity Markets	Residential sector
Türkiye	83,429,607	104394	6.2	-	Electricity, natural gas and petroleum distribution or retail companies based on their market shares.	Ministry of Energy and Natural Resources	All end-use sectors

Table 2.2 : Flexibility Opportunities of Existing EEOS.

	Austria	Bulgaria	Croatia	Denmark	France	Greece	Hungary	Ireland	Italy	Latvia	Luxembourg	Malta	Poland	Slovenia	Spain	The United Kingdom
Saving trading	+			+		+	+	+			+			+		+
Certificate trading					+				+				+		+	
Buy-out	+					+	+	+								
Banking		+	+		+									+		+
Borrowing		+	+										+			
National Energy Efficiency fund		+	+			+		+		+			+	+	+	
Penalty	+	+			+	+	+	+	+	+	+		+		+	

The implementation of EEOS varies across countries, with different structures, regulatory frameworks, and compliance mechanisms. The UK was the first country in Europe to establish an EEOS under the Supplier Obligations name, setting an example for other nations. Following the UK, Italy, Denmark, France, and Bulgaria introduced their EEOS frameworks. With the introduction of the first EU EED, the adoption of EEOS across the EU expanded significantly. Many EU Member States implemented EEOS as part of their strategies to achieve energy efficiency targets, aligning their national frameworks with the EED’s requirements. Countries such as Greece, Hungary, Spain, and Poland launched their EEOS in later years, ensuring compliance with evolving EU targets. Denmark, stopped its scheme in 2020, leaving 15 active EEOS schemes in the Europe.

Each country’s EEOS structure differs based on the design of OPs, target sectors, and available flexibility mechanisms. In some countries, all energy suppliers, distributors, or retailers are obligated, while others set specific thresholds based on market share, annual energy sales, or customer base. The responsible and managing authorities also vary, with ministries, national energy agencies, and regulatory bodies overseeing implementation and compliance.

The scheme flexibilities differ as well. Some schemes, such as those in Italy, France, Poland, and Spain, allow for white certificate trading, while others prioritize savings trading, banking, or borrowing options to enhance cost-effectiveness. Additionally, national energy efficiency funds are available in several countries, helping OPs finance energy-saving measures. Compliance is enforced through penalties, ensuring that OPs meet their energy-saving targets.

The diversity in EEOS structures across Europe highlights the adaptability of the scheme, demonstrating that different policy approaches can be effective in achieving energy efficiency goals. For countries like Türkiye, which is in the planning stages of EEOS consideration, learning from these varied implementations can help design a flexible, efficient, and well-integrated obligation scheme tailored to national needs.

2.3 Literature Review

After presenting the concept of EEOS and its implementation experiences, this section provides a review of the academic literature on EEOS, examining key studies, methodologies, and findings in the field.

Academic literature on EEOS was searched with the "energy efficiency obligations," "energy saving obligations," "white certificates," and "energy efficiency certificates" keywords from the "Web of Science" database. Studies published since 2010 were reviewed. Selected studies are listed in Table A.1 chronologically in Appendix A. In addition, the purpose and method of the studies are given in the same table. The articles in Table A.1 are divided into four groups: “Discussion on existing EEOSs,” “Proposing possible new EEOSs,” “Recommending improvements to EEOSs,” and “Interaction analyses of EEOSs with market or different mechanisms.” Figure 2.1 shows the distribution of studies and their rates in these groups. Figure 2.2 shows the number of studies in different groups over the years.

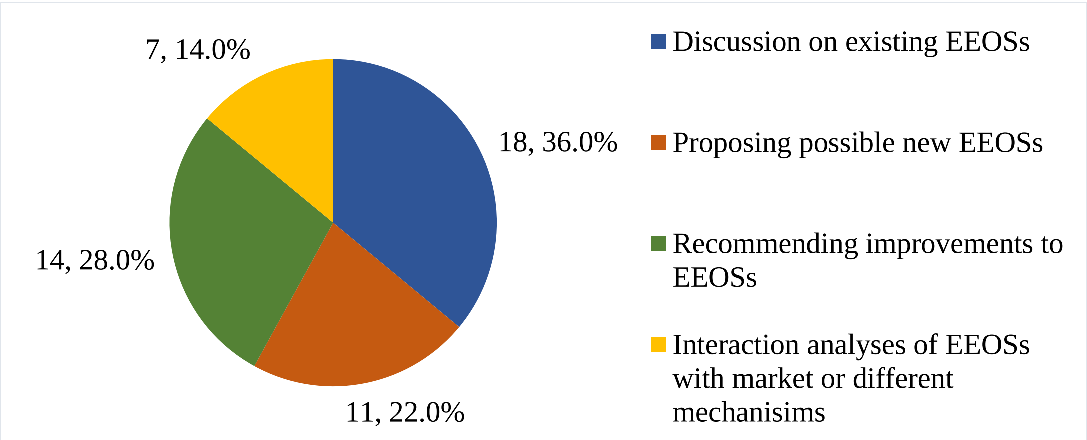

Figure 2.1 : The Number and Share of Studies in Different Groups.

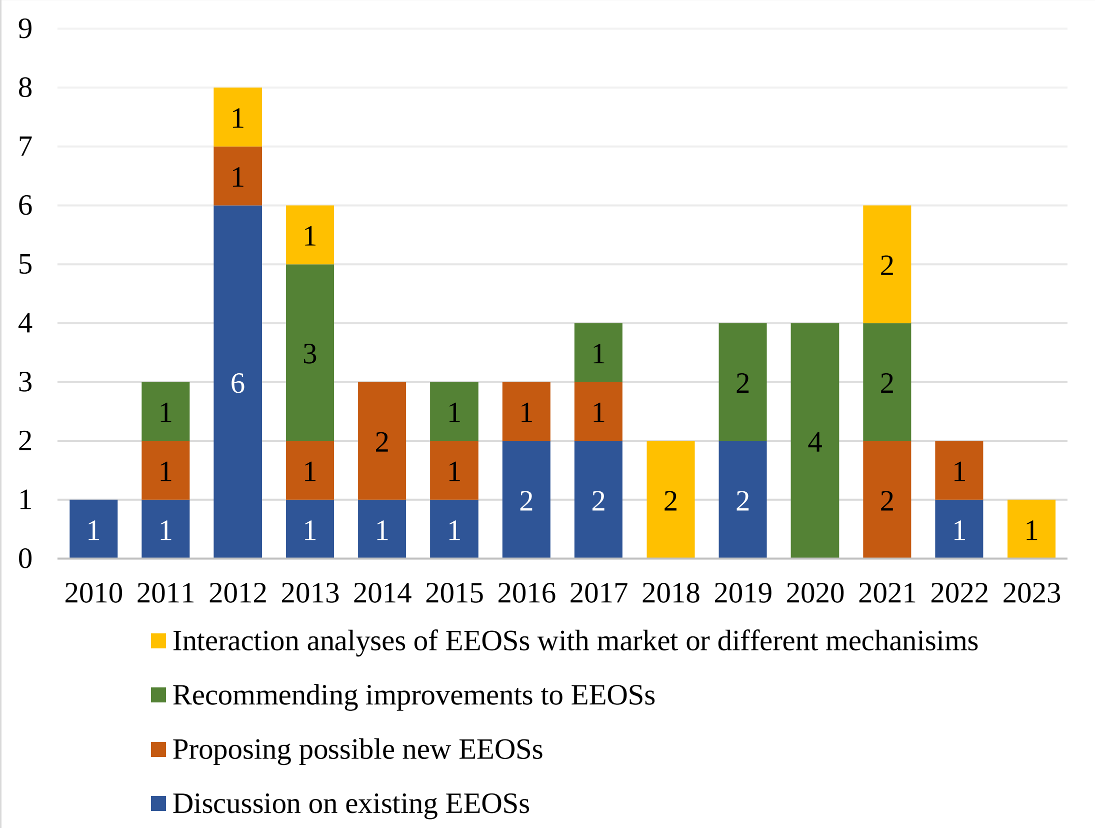

Figure 2.2 : The Number of Studies in Different Groups Over the Years.

As a result of the EEOS literature review, the following points stand out. Discussion on existing EEOS is the most studied group. Many studies introduce EEOS and examine and compare country practices (Bertoldi, 2010 & 2013; Fawcett et al., 2019; Pavan, 2012; Rosenow et al., 2016a; Rosenow et al., 2016b). Moreover, the evaluation of single national schemes is also one of the subjects studied in this category, such as France (Broc et al., 2011; Suerkemper et al., 2012), The United Kingdom (Rosenow, 2012), and Italy (Di Foggia et al., 2022; Petrella and Sapio, 2012). Some studies provide specific discussions, whether from an environmental perspective (Bányai and Fodor, 2014) or focusing on the behaviors of scheme participants (Oikonomou et al., 2012) or over-estimation of energy savings in the EEOS (Moser, 2017). Some studies used specific methodologies such as the cost-effectiveness analysis (Giraudet et al., 2012; Rosenow and Bayer, 2017; Suerkemper et al., 2012), and performance assessment (Rohde et al., 2015). Some studies also discuss EEOS as a market-based instrument (Di Foggia et al., 2022; Rosenow et al., 2019).

Recommending improvements to EEOSs is the second most studied group. Especially near the end of the first period of Article 7 (2020), it appears as the only group studied.

In this group, improvement in energy/fuel poverty issues was investigated several times. In these studies, how the issue of energy/fuel poverty should be handled in EEOS, how to address this issue (Moser, 2013; Rosenow et al., 2013), and monitoring methods (Arsenopoulos et al., 2020) are suggested. Improvements for single national schemes were studied, such as in Italy (Caragliu, 2021; Stede, 2017), Latvia (Blumberga et al., 2021; Locmelis et al., 2019), Poland (Rosenow et al., 2020). Some studies offer improvements on emission issues in the EEOS application (Rosenow and Eyre, 2013), white certificate trading timing for the ESCOs (Ahmadi et al., 2020), and liberal market competition in compliance (Giraudetet al., 2020). Moreover, specific subjects were in place in this group, such as transportation sector improvements in the EEOS (Bertoldi et al., 2011) and challenges in customer private information in the EEOS (Wirl, 2015).

Proposing possible new EEOS is a prevalent and relatively highly studied group. Countries such as Abu Dhabi (Afshari and Friedrich, 2016; Friedrich and Afshari, 2015), Germany (Schlomann et al., 2013), India (Harmsen et al., 2014), South Africa (Tyler et al., 2011), Sweden (Xylia et al., 2017), and Türkiye (Argun et al., 2021; Cin et al., 2021; Ünal et al., 2022) have studied how their potential EEOS should be. In this category, Türkiye is where the most studies were conducted.

The interaction of EEOS/white certificate schemes with other market mechanisms is another subject researched, as it is closely related to the market. It was studied the interaction between EEOS/white certificate schemes and the domestic offset (Oikonomou et al., 2012), retrofit programs (Miu et al., 2018), market forces (Morganti and Garofalo, 2022), energy efficiency support programs (Chlond et al., 2023) and other tradable instruments such as carbon certificates (Wittmann, 2013) and renewable energy certificates (Amundsen and Bye, 2018; Quirion, 2021)

2.4 Lesson Learned for Türkiye

In this section, a possible EEOS application for Türkiye is discussed in light of both implementation experiences and the findings of the literature review, aiming to derive key lessons learned for an effective scheme design.

Türkiye, 75% dependent on foreign energy, seeks to employ energy efficiency to ensure energy supply security. Since the 2007 Energy Efficiency Law, it has had extensive energy efficiency legislation. Although Türkiye has demonstrated strong enthusiasm for energy efficiency, supported by extensive regulations and ambitious national targets, it continues to face challenges in implementation. Notably, the EEOS implementation was one of the two actions that could not be realized during the first NEEAP period. However, the inclusion of EEOS adoption as a target in the second NEEAP indicates that Türkiye remains committed to establishing this mechanism despite the limited progress achieved in the first period. For the establishment of EEOS, administrative, infrastructural, and financial challenges must be addressed. An EEOS that is sensitive to changes under country conditions and can provide energy efficiency, economic efficiency, and social development is required for Türkiye, and a proper mechanism should be designed and established. To achieve this, it is essential to draw lessons from both successful and unsuccessful examples of existing EEOS implementations.

The design of EEOS should align with national policy priorities, considering factors such as the selection of OPs, end-use sector and energy type coverage, the obligation's amount and type, savings evaluation methods, and market conditions (Bertoldi et al., 2010). A well-structured EEOS can generate long-term energy savings while remaining adaptable to different policy mixes and national circumstances. Many countries have achieved significant energy savings through EEOS, and further improvements are expected. However, the risk of failure increases if a country lacks a preparatory voluntary phase or adopts a scheme model directly from another country without adapting it to its own context. This challenge arises due to the complexity of EEOS implementation and the lack of prior expertise with this policy instrument (Fawcett et al., 2019). To develop an effective EEOS, Türkiye must design a scheme tailored to its policy priorities and market structure. While existing international practices provide valuable insights, Türkiye should not directly replicate any specific EEOS model but instead develop a framework that best fits its national conditions.

Current EEOS designs highlight the role of national energy agencies, ministries related to energy, environment, sustainability, and economy, as well as regulatory authorities responsible for overseeing and managing these schemes. In Türkiye, energy efficiency programs are generally handled under the MENR, which was also designated as the responsible authority for EEOS in the first and second NEEAP. Cin et al. (2021) suggest that MENR should be the responsible authority, and a new energy agency should be established for managing the possible EEOS of Türkiye (Cin et al., 2021). On the other hand, SHURA (2022) proposes a broader administrative structure to oversee not only EEOS but also all energy and carbon-related programs, activities, and funds. According to this perspective, a more integrated structure could facilitate faster decision-making and implementation processes (SHURA, 2022). Although Türkiye's presidential system may provide the framework for such a centralized approach, no significant steps have been taken in this direction yet.

OPs are the key actors in EEOS. In European practices, all energy suppliers, distributors, retailers, and traders selling various types of energy can be designated as OPs. According to RAP (2016), the selection of OPs depends on the local energy market structure (liberalized or vertically integrated), the historical involvement of utilities in energy efficiency, and the cultural approach to energy efficiency implementation. While EEOS was initially introduced in countries with vertically integrated electricity utilities, its scope has expanded over time to include natural gas markets and is now also applied in liberalized energy markets. Additionally, EEOS obligations have extended beyond regulated energy sectors to cover unregulated fuels, such as heating oil, LPG, solid fuels, and road transport fuels (RAP, 2016).

In Türkiye, the electricity market has been liberalized, except for transmission system. However, there is monopolistic competition in the Turkish natural gas and oil market regarding import and wholesale. Energy prices are also affected by this situation. Compared to other energy markets, the electricity sector has a well-defined application structure and clearly identified actors, making it a more suitable starting point for an EEOS. For the initial stages of the Turkish EEOS, selecting OPs from the electricity market would be advantageous due to its regulatory clarity and market readiness. Over time, as the natural gas and oil markets evolve, gaining a more competitive structure and an increasing number of market participants, they can also be integrated into EEOS (SHURA, 2022).

A closer look at the Turkish electricity market reveals that Türkiye's electricity distribution is divided into 21 regions. Following the completion of privatization in 2013, all 21 distribution licenses were handed over to private companies under EMRA supervision. Also, distribution activities were separated from retail activities which are currently conducted by "incumbent suppliers/retailers" (IEA, 2021). According to the electricity market law, distribution companies and incumbent supply companies must operate as separate entities. However, despite this formal separation, these companies often belong to the same parent entity or holding. In addition to incumbent suppliers, the electricity market also includes wholesale and trading suppliers. Currently, there are 21 distribution companies and approximately 150 licensed suppliers in the market. Of these, 21 hold retail/incumbent supply licenses, while the rest operate as other suppliers. Despite their smaller numbers, incumbent supply companies dominate the market, holding a 70% market share.

In the Turkish electricity market, a minimum annual consumption threshold of 1,100 kWh is required for consumers to be eligible to choose their electricity suppliers. Eligible consumers can purchase electrical energy or capacity by bilateral agreement with all types of suppliers (EMRA, 2022). The incumbent suppliers provide electrical energy to the non-eligible consumers within their region, as well as to eligible consumers who choose not to switch suppliers, under a national tariff determined quarterly by EMRA (IEA, 2021). While theoretical market openness, based on the eligible consumer limit, stands at 98.1%, the actual share of eligible consumers in invoiced consumption was only 50.98% in 2022. This indicates that, although the Turkish electricity market has the potential to be almost fully liberalized in terms of consumer choice, awareness among end users regarding their eligibility remains relatively low. At the end of 2022, the number of consumers using the distribution system was 48.56 million, and the total invoiced consumption amount in the distribution regions was 192.61 TWh. In the sectoral distribution of total electricity consumption, industrial consumption has the highest share at 42.73%, followed by public and commercial buildings with 25.45%, residential buildings with 24.39%, and general lighting and agricultural activities with 7.43% (EMRA, 2022).

According to the first EED, energy companies were obligated to save 1.5% of their annual sales by 2020 (European Parliament, 2012). With the EED recast, the obligations are strengthened, with its annual end-use energy savings objective progressively rising from current 0.8% to 1.9% as of 2028 (European Commission, 2021). While obligations can be given to all selected energy companies, certain threshold values such as annual energy sales, number of customers, or market share can also be defined to reduce administrative costs and protect small companies. For example, the thresholds are sales of more than 600 GWh/year in Ireland, more than 1% market share in Greece, and more than 200,000 customers in the United Kingdom

(ENSMOV, 2020). The first NEEAP of Türkiye states that EEOS obligations will be distributed based on the market shares of companies. As mentioned earlier, 21 incumbent supply companies hold approximately 70% of the market share. Among them, two companies have a market share of more than 10%, six companies hold between 5-10%, and 13 companies have less than 5% market share (EMRA, 2022). To ensure a feasible and effective implementation of EEOS in Türkiye, realistic targets should be set at the initial stage. A phased approach could be adopted, starting with obligations assigned to larger companies, followed by a gradual expansion to smaller ones. Additionally, it should be defined which type of fuel savings will be eligible. To avoid complexity, each energy company can first focus on savings in its own fuel type.

Selecting the widest possible target sector can provide OPs with greater flexibility in meeting their energy-saving targets. A broader sectoral scope increases the range of eligible projects, allowing OPs to choose the most cost-effective and feasible measures. Including all project types and sectors may lead to complex and costly validation processes, particularly in assessing the additionality of projects and monitoring energy savings. Additionally, a broad scope places a significant administrative burden on regulators, as they must develop and oversee detailed M&V methodologies for various sectors and project types. Balancing flexibility for OPs with practical implementation considerations is crucial for designing an effective and manageable EEOS (Bertoldi et al., 2011).

In EEOS, the cost of energy efficiency measures can be passed on to customers through their energy bills. When these costs are distributed across society, distributional effects arise, impacting different consumer groups. To ensure a fair cost distribution, EEOS should cover as many final customers or as much final energy consumption as possible, while maintaining a balance between administrative efficiency and avoiding disproportionate burdens. The fact that all customers bear the costs and that only a part of the customers benefit from EEOS. This raises the need for policymakers to focus on cost minimization strategies to ensure that the scheme remains affordable and equitable (Moser, 2013). Additionally, there is an inherent tension between energy efficiency obligations and energy/fuel poverty objectives, particularly due to the potentially regressive effects of rising energy prices on residential/household sector. If these concerns are ignored, the increased financial burden on vulnerable consumers could undermine the program's overall effectiveness and public acceptance (Rosenow et al., 2013).

While the EEOS was initially motivated by promoting efficient energy consumption during market liberalization in the UK, other issues like climate change, energy prices, and energy/fuel poverty grew increasingly relevant. Then, the plan was enhanced with social equity targets, trading options, and other sub-targets like minimum quotas for some significant actions (Rosenow, 2012). The UK scheme was the first to include social aims and currently has the Carbon Savings Community Obligation and Affordable Warmth (Home Heating Cost Reduction Obligation). France secondly added social aim provisions into their scheme. In the French scheme, mandatory targets and bonuses are included. While Ireland set sub-targets for energy/fuel poverty, Austria and Greece have bonuses (Arsenopoulos et al., 2020). Moreover, EED recast includes ambitious energy-saving rates as well as specific requirements for alleviating energy poverty. It requires implementing policy measures as a priority among vulnerable customers and final users, people affected by energy poverty, and, where applicable, people living in social housing (European Commission, 2021).

Türkiye has comparatively low household electricity prices compared to other IEA member countries, while industrial prices are average (IEA, 2021). Household energy prices in Türkiye are partially subsidized with a lower tax rate. In 2022, the value-added tax (VAT) rate on the household electricity bills is 8.62%, while this rate is 15.25% on the industrial bill (EMRA, 2022). Therefore, if EEOS is adopted in Türkiye, it can be predicted that the government would not impose much burden on households. The increasing importance of energy/fuel poverty in EU should be a clue for Türkiye and for successful implementation of EEOS, the energy/fuel poverty effect should be considered, appropriate steps should be taken to prevent and/or mitigate energy/fuel poverty.

The first NEEAP of Türkiye includes plans to develop a standard action guide for EEOS implementation. A standardised list of energy efficiency actions offers several advantages. It increases the visibility and credibility of the scheme, ensuring that all efficiency measures are carried out in a consistent and high-quality manner. Additionally, such lists guide stakeholders toward cost-effective actions, helping OPs prioritize measures that deliver the highest energy savings at the lowest cost. However, relying on predefined standardised actions also introduces risks. If the energy-saving potential of an action is overestimated or underestimated, it can lead to undesirable consequences. Overestimation may result in lower actual savings than expected, weakening the scheme's effectiveness, while underestimation might discourage stakeholders from pursuing potentially impactful efficiency measures. Therefore, the accuracy of predefined savings estimates and regular updates to the standard action guide are essential to ensure the EEOS remains effective and fair (Broc et al., 2011).

Additionality is a fundamental principle in EEOS and plays a crucial role in ensuring that energy savings are truly incremental rather than just a reflection of existing market trends or regulatory requirements. To meet this principle, energy savings must exceed the EU minimum performance standards outlined in the Ecodesign Directive or any requirements under the Energy Performance of Buildings Directive (RAP, 2016). Additionality can be assessed from two key perspectives. Efficiency additionality refers to the extra efficiency achieved through a specific action, whereas volume additionality relates to the increased number of efficiency measures implemented beyond their baseline market penetration. For example, in the French EEOS, efficiency additionality is ensured through strict eligibility criteria, while volume additionality is promoted by encouraging the adoption of high-efficiency technologies that are otherwise costly. Another critical issue in EEOS implementation is double counting, where the same energy savings are claimed under multiple support mechanisms. In France, condensing boilers and insulation actions qualify for both tax credits and EEOS incentives, but adjustments are made to prevent an overestimation of actual savings (Broc et al., 2011). If Türkiye introduces a standard action list for EEOS, it is essential to integrate both types of additionalities and develop mechanisms to prevent double counting. In addition, the scheme design should consider Türkiye's existing regulatory minimum requirements and the historical evolution of energy efficiency in the market to ensure that the calculated savings reflect real, measurable improvements.

Compliance is a critical aspect of EEOS and is a key concern for OPs. Although there are flexibility opportunities in EEOS, ensuring energy efficiency should be the main priority. To maintain a balanced system, penalties and buy-out prices can be used to establish floor and ceiling prices, ensuring that OPs prioritize actual savings over financial alternatives (Bertoldi et al., 2010). The Latvian EEOS provides an example of how different compliance options influence outcomes. In this scheme, OPs could choose between information activities, direct energy efficiency actions, contributions to a fund, or paying a fine. The Ministry of Economics initially expected that 50% of total EEOS savings would come from information measures, with the remainder achieved through fund contributions or cost-effective efficiency actions. However, an ex-post study revealed that 95% of reported savings came from information activities, while only 5% resulted from consumer-side efficiency improvements. Since some measures were low-cost, OPs tended to avoid fund contributions (Blumberga et al. 2021). A similar challenge emerged during the transition of the Polish EEOS from its first to second phase, where the buy-out price was increased to provide stronger incentives for OPs to deliver actual energy savings instead of opting for the buy-out mechanism (Rosenow et al., 2020). To prevent similar issues in a Turkish EEOS, it is essential to limit the proportion of savings that can come from information measures or similar low-impact actions and to carefully regulate fund contribution options. Ensuring that energy efficiency actions remain the primary compliance method will help maximize actual energy savings and avoid distortions in the scheme's effectiveness.

EEOS is also referred to as a White Certificate Scheme, as defined in the 2006/32/EC Directive, where white certificates are described as "certificates issued by independent certifying bodies confirming the claims of market actors for savings of energy, as a consequence of energy end-use efficiency measures." OPs have the flexibility to comply with their obligations in different ways, depending on their marginal compliance costs. They can choose to implement energy efficiency measures directly, collaborate with third parties, purchase white certificates, or pay non-compliance penalties. This market-based approach allows those who achieve energy savings beyond their targets to sell excess white certificates to OPs that fall short of their savings requirements. By enabling this trading mechanism, white certificate schemes provide high flexibility and contribute to the implementation of more cost-effective energy efficiency measures. The ability to trade certificates ensures that energy savings are achieved at the lowest possible cost, making EEOS a dynamic and adaptable policy tool for promoting energy efficiency (Bertoldi et al., 2011). Certificate trading, saving banking options, long compliance, and validity periods of certificates decrease price risks but may discourage trade, reducing liquidity during the existing obligation period (Bertoldi et al., 2010). According to Morganti and Garofalo (2022), policymakers should view the white certificate mechanism as an economic tool that enhances transparency in industrial processes and technologies. This mechanism helps internalize the externalities associated with energy use, addressing market failures such as information asymmetries, credit limitations, and organizational bottlenecks. By overcoming these barriers, white certificate schemes not only drive energy efficiency improvements but also contribute to economic growth by fostering investment in cost-effective energy-saving measures (Morganti and Garofalo, 2022).

In the possible implementation of a Turkish EEOS, it is essential to ensure the continuity of energy efficiency efforts while providing sufficient flexibility for OPs to meet their targets and maintain strong motivation. To facilitate compliance and sustain energy efficiency practices, various flexibility opportunities may need to be introduced, allowing OPs to fulfil their obligations effectively and supporting the growth of the energy efficiency market (SHURA, 2022). Therefore, these flexibility opportunities should be carefully analysed, and the most suitable combination of mechanisms should be designed to align with Türkiye's market conditions, policy priorities, and long-term energy efficiency goals.

Under certain conditions, voluntary parties, such as ESCOs, can certify energy savings from the projects they implement and sell white certificates to OPs. The energy services sector has played a crucial role in the success of EEOS in Italy, where ESCOs have significantly contributed to energy savings. When industrial firms seek energy efficiency solutions, ESCOs step in to develop and implement projects, generating substantial energy savings. Their participation in the white certificate scheme has also enhanced their competencies and market presence (Stede, 2017). Similarly, EEOS has the potential to stimulate the growth of the energy service market in Türkiye. Through EEOS, Energy Performance Contracts (EPC) could be promoted via ESCO participation, fostering competition among energy efficiency market actors and ultimately benefiting end-users (Cin et al., 2021). Due to the requirements such as independent verifiers and the administrative burdens they bring, White Certificates can be adopted at the maturity stage of Turkish EEOS rather than its initial stage.

M&V is essential in EEOS, ensuring accurate energy savings calculations while reducing transaction costs for OPs and project developers. Standardised M&V procedures help streamline reporting and improve the credibility of reported savings. According to EU EED, there are four methods for calculating energy savings: (i) deemed savings, which are projected savings determined based on previous studies and used for standard actions; (ii) scaled savings, which apply proportional engineering estimates for more specific actions; (iii) metered savings, which measure energy consumption before and after implementation; and (iv) surveyed savings, which are used for behavioural actions only (RAP, 2016). While the metered approach offers greater accuracy, it is often more costly and complex compared to the deemed savings method, which provides a simpler and more cost-effective alternative. However, the effectiveness of deemed and scaled savings depends on the availability of sufficient, reliable, and extensive data. In Türkiye, the MENR has created a portal to collect energy efficiency project data in the building and industrial sectors, though it is not publicly accessible. Additionally, M&V expert training programs have been introduced. These efforts in data collection and expert training can serve as a foundation for establishing a robust M&V framework in a Turkish EEOS.

EEOS, or the white certificate scheme, can interact with other policy mechanisms, sometimes complementing them while at other times creating conflicts. The effectiveness of these interactions depends on the design and objectives of each policy. Oikonomou et al. (2012) analysed the interaction between White Certificates and Non-ETS Domestic Offset schemes using an interaction analysis method. Their findings suggest that an integrated policy approach combining these mechanisms could have positive effects on reducing greenhouse gas (GHG) emissions, improving energy efficiency and supply security, increasing political acceptance, creating employment opportunities, and raising environmental awareness. This indicates that EEOS can work effectively alongside non-ETS offset mechanisms to strengthen overall climate and energy goals (Oikonomou et al. 2012). On the other hand, several studies have reported negative interactions between white certificates and other market-based mechanisms, such as green (renewable energy) and black (carbon) certificates. Wittmann (2013), Amundsen and Bye (2018), and Quirion (2021) highlight concerns about the effectiveness and efficiency of integrating white certificates with these instruments. According to Amundsen and Bye (2018), it is uncertain whether introducing tradable white and green certificates into an existing electricity market would increase renewable electricity production or reduce electricity consumption. They argue that direct subsidies, such as feed-in tariffs, may be more effective in achieving these goals (Amundsen and Bye, 2018). Similarly, Quirion (2021) suggests that tradable instruments alone are not effective in combating climate change, as the interaction of multiple policy mechanisms can reduce additionality and weaken the impact of each instrument (Quirion, 2021).

Understanding the effectiveness of various policy mixes is crucial from both a theoretical and practical perspective. As energy efficiency targets become more stringent, the need for a well-designed and effective policy mix will increase. Ensuring that different mechanisms complement rather than contradict each other is essential for maximizing energy savings, reducing emissions, and maintaining economic feasibility (Rosenow et al., 2016a). Miu et al. (2018) evaluates three alternative policy options recommended to replace the UK's existing household retrofit program EEOS: variable council tax, variable stamp duty land tax, and green mortgage. Their findings indicate that a combination of these three policies is highly effective, offering strong potential for addressing consumer-related challenges, ensuring compatibility with business models of delivering organizations, and fostering expertise in a fragmented supply chain. However, the study also highlights a critical limitation: none of these proposed policy options guarantee the effective targeting of energy/fuel-poor households. Given the importance of addressing energy poverty, they suggest that this issue requires further discussion and consideration in future policy design (Miu et al., 2018). Chlond et al. (2023) assessed the performance of four types of financial schemes used to support retrofits (residential energy conservation works) implemented in France between 2014 and 2016: a grant scheme for low-income households, a reduction of the VAT, an income tax credit, and the White Certificates. They evaluated the programs' cost-effectiveness, additionality, redistribution, and ability to trigger private investment. Ultimately, they found that the White Certificates scheme is the most cost-effective, followed by the VAT reduction and the grant scheme. The VAT reduction triggers most additional private investment into conservation works, followed by the income tax credit and the White Certificates scheme (Chlond et al., 2023). These results highlight the strengths and limitations of different financial mechanisms and suggest that a combination of policies may be necessary to achieve both cost efficiency and market stimulation in energy efficiency programs. A key issue that requires further analysis is how EEOS can integrate with Türkiye's existing energy efficiency policies and how to design an effective energy efficiency policy mix that maximizes synergies between different mechanisms while avoiding overlaps or inefficiencies.

Countries that consider establishing new EEOSs should try to adapt the mechanisms according to their country's conditions by taking lessons from existing successful and unsuccessful experiences in other countries. Research on possible new EEOS establishments has been conducted in South Africa, Chile, Germany, Türkiye, India, Abu Dhabi, and Sweden. The findings indicating that all countries except Germany and Sweden could benefit significantly from EEOS. In Germany, studies suggest that EEOS alone would not be sufficient to achieve national energy efficiency targets, emphasizing the need for a broader mix of policy instruments to complement the scheme (Schlomann et al., 2013). Similarly, in Sweden, research indicates that EEOS would not have a major impact on meeting the country's 2020 energy efficiency goals. However, with a long-term perspective and more ambitious energy and climate policy objectives for 2030, it is estimated that a well-designed Swedish EEOS could deliver more substantial results (Xylia et al., 2017).

Türkiye is the most extensively studied country regarding proposed EEOS implementations, with four different studies conducted—two focusing on system design and two analysing application scenarios. Düzgün & Kömürgöz (2014) examined the applicability of the white certificate system in Türkiye, focusing on electricity and natural gas markets, scheme participants, and potential obstacles. Their study provided insights into the market structure and challenges that could arise in establishing a white certificate mechanism in Türkiye (Düzgün and Kömürgöz, 2014). Cin et al. (2021) analysed EEOS implementations in EU countries, identifying good practices and key considerations for adopting the scheme in Türkiye. Following this, they conducted an expert survey and applied Bayesian Belief Networks to propose an EEOS structure based on expert opinions. Their findings suggest that the proposed EEOS model has an 84% probability of success (Cin et al., 2021). Argun et al. (2021) developed optimization models for EEOS, aiming to achieve maximum energy savings at the lowest cost from the perspectives of regulators and electricity distribution companies. The study emphasized that a balanced approach to incentives and penalties is crucial for the successful adoption of EEOS in Türkiye (Argun et al., 2021). Ünal et al. (2022) created a guideline for standard energy efficiency activities applicable to residential, commercial, and industrial end-use sectors, assuming that electricity distribution companies would be the OPs in a potential Turkish EEOS. Their analysis demonstrated that if these companies fulfil their obligations by implementing standardised efficiency actions under different scenarios with varying targets and time frames, Türkiye's NEEAP total energy efficiency target could be achieved at a rate of 10% to 44%, depending on the scenario applied (Ünal et al., 2022).

These studies collectively provide a comprehensive foundation for designing and implementing an EEOS tailored to Türkiye’s energy market, highlighting key policy considerations, regulatory structures, and financial mechanisms necessary for a successful transition to an obligation-based efficiency scheme. However, despite these contributions, the literature on EEOS in Türkiye remains limited, and further research is needed to address critical gaps in both design and implementation aspects. Existing studies have primarily focused on the technical and regulatory aspects of EEOS. While Ünal et al. (2022) developed their model from the energy company perspective, Argun et al. (2021) considered both the energy company and scheme regulator perspectives. However, neither study incorporates an end-user perspective nor evaluates the broader social benefits of EEOS implementation. Future research should aim to integrate design and implementation approaches that also consider end-user participation and social impacts to create a more inclusive and equitable policy framework. Additionally, further studies should explore how EEOS can be designed to maximize benefits while minimizing costs for all stakeholders. Demonstrating the cost-effectiveness of EEOS would help policymakers in Türkiye mitigate political risks and accelerate the decision-making process for its adoption. Another crucial area for future research is the intersection of EEOS and energy/fuel poverty, which remains an unexplored issue in the Turkish context. Addressing this gap would ensure that EEOS not only drives energy efficiency improvements but also supports vulnerable households, enhancing its role as a socially inclusive energy policy tool.

The lessons learned from international EEOS experiences and academic studies emphasize the importance of adopting a gradual and well-structured approach for successful implementation of EEOS. A simple and manageable structure should be preferred in the initial phase to allow for an easier start and a learning period. Over time, the scheme should be adapted and refined, enabling it to develop organically based on real-world challenges and improvements. A fundamental challenge of EEOS is that it requires energy companies to reduce their energy sales through energy efficiency measures. Naturally, energy companies may be unwilling to reduce sales, the government may hesitate to increase the financial burden on suppliers, and end-users may resist additional energy-related costs. To create a balanced mechanism where all parties can benefit, the key issue is to reach the right balance between incentives, penalties, financing mechanisms, and consumer costs. The scheme should include financial support mechanisms to ease the burden on OPs while ensuring that end-users do not face disproportionate cost increases. To ensure effective implementation, the scheme should be designed with clear objectives and operational guidelines. This includes selecting appropriate target sectors and fuel types, structuring flexibility opportunities effectively, defining eligible energy efficiency measures, and ensuring that no party carries an excessive burden. Additionally, EEOS should be closely integrated with the issue of energy/fuel poverty, requiring dedicated studies to identify, monitor, and manage vulnerable households in Türkiye. Another critical factor is ensuring additionality, meaning that EEOS should generate energy savings that go beyond business-as-usual scenarios and align seamlessly with Türkiye’s existing energy efficiency policy mix. Lastly, for long-term success, the scheme must be built on transparency, stakeholder communication, and reliability. Establishing a well-governed and trusted mechanism will be crucial for gaining the support of energy companies, policymakers, and end-users, ensuring the sustainability and effectiveness of Turkish EEOS.

Energy efficiency is an essential way out when the climate and energy crisis is experienced and energy supply security concerns come to the fore again. EEOS is a proven and effective energy efficiency mechanism, and its objectives, design, and implementation strategies have continuously evolved in response to shifting energy and policy landscapes. The mechanism is further reinforced by the EU’s ‘energy efficiency first’ principle, and with the EED recast, EEOS has become more ambitious, indicating that it will remain a key policy tool for the foreseeable future. Although Türkiye has not yet established EEOS within the initially planned timeline, it is still not too late. As the country in the second period of the NEEAP (2024-2030), greater attention and effort should be dedicated to the establishment of EEOS to ensure long-term energy savings and policy alignment with global best practices.

Building on this foundation, the following chapters offer a comprehensive assessment of the potential implementation of EEOS in Türkiye, covering sector-specific feasibility analyses, social targeting strategies, compliance design, and policy integration.

3. AN EX-ANTE COST BENEFIT ASSESSMENT OF THE POSSIBLE EEOS TO BE IMPLEMENTED IN INDUSTRIAL AND COMMERCIAL BUILDINGS SECTORS[3]

In this chapter, an ex-ante cost-benefit assessment of a possible EEOS in Türkiye is conducted. A basic EEOS framework is established, where incumbent electricity suppliers act as obligated parties and industrial sub-sectors, and commercial buildings are end-users. The study applies a two-level distributed optimization approach, ensuring that OPs and end-users operate independently with their own objective functions, focusing on minimizing costs and maximizing benefits without interfering with each other. This structure enables an in-depth assessment of both cost distribution and financial feasibility while maintaining realistic market dynamics.

To examine the financial sustainability of EEOS, various case studies are conducted by changing obligation rates, EEOS fee rates, and penalty amounts. Cost-benefit ratios are calculated for each scenario, and win-win cases are identified where the scheme can fully finance itself. The impact of penalty mechanisms is also analysed to understand their role in ensuring compliance among OPs. Additionally, a sensitivity analysis using the Analysis of Variance method is performed to determine whether changes in obligation rates, EEOS fee rates, and penalty amounts have a statistically significant effect on achieved energy savings and cost-benefit ratios. Unlike traditional cost-benefit analyses that primarily focus on overall system evaluations, this study adopts a multi-stakeholder perspective to ensure that the scheme benefits both OPs and end-users, simultaneously. For the first time in Türkiye's EEOS discussions, an end-user perspective is integrated into the cost-benefit framework, offering a more inclusive and balanced analysis. The study also employs actual energy consumption, energy price, and efficiency investment data, ensuring that the policy evaluation is supported in real-world conditions.

[3] This chapter is based on the following publication: **Cin, R.,** Onaygil, S., & Gökçek, T. (2024). An ex-ante cost-benefit assessment of the possible Energy Efficiency Obligation Scheme in Türkiye. *Energy Policy*, *195*, 114398.

Additionally, this chapter contributes to the broader EEOS literature by combining cost-benefit analysis with an optimization-based approach, moving beyond simple financial evaluations to identify key equilibrium points where all participants benefit from the scheme without excessive financial burdens. The findings aim to provide valuable insights for policymakers in shaping a well-structured and effective EEOS framework for Türkiye aligns with its energy efficiency targets while ensuring economic feasibility for all parties.

3.1 The Proposed Energy Efficiency Obligation Scheme Structure

In this section, the cost and benefit features of EEOS is introduced and the determined structure of the possible Turkish EEOS for the study is explained.

Cost-benefit analysis is a method in which costs and benefits are expressed in monetary terms, enabling a direct comparison using a common unit of measurement. In the literature, several cost-effectiveness or cost-benefit studies are available on EEOS. The cost and benefit items determined for different parties are listed in Table 3.1. While Suerkemper et al. (2012) perform a measure-based ex-post cost-benefit analysis of a French energy company's program under EEOS, Giraudet et al. (2012) make a country-level ex-post cost-benefit evaluation of The United Kingdom (UK), France, and Italy (Giraudet et al., 2012; Suerkemper et al., 2012). Rosenow and Bayer (2017) make a comparative cost-benefit evaluation of several European countries (Rosenow and Bayer, 2017). Mundaca and Neij (2009) and Franzò et al. (2019) suggest different cost-benefit evaluation frameworks for Italy (Franzò et al., 2019; Mundaca & Neij, 2009). Different from these studies, Xylia et al. (2017) investigate whether the implementation of EEOS in energy-intensive industries in Sweden can be justified from the benefit-to-cost perspective (Xylia et al., 2017).

Since each application is unique and the scope of each study is different, the cost and benefit items may also vary. Some items vary due to differences in energy market structure or tax policies of countries. For instance, in a liberal market, there are different benefits for OPs. On the other hand, some items are common and found in almost all studies such as administrative and EE measure costs. The studies in Table 3.1 sometimes have difficulty measuring each item or expressing them in monetary terms. For example, some items under the social side were written symbolically but could not be evaluated.

Table 3.1 : Cost-Benefit Studies on EEOS.

Studies	Items	Regulator	Obligated Parties	End-users	Social
(Mundaca and Neij, 2009)	Cost	- Administrative costs	- Energy efficiency measures costs - Internal administration costs - Transaction costs	- Energy efficiency measures costs (partly)	n/a
	Benefit	n/a	n/a	- Energy cost saving	- Social and environmental benefits due to increased energy efficiency
(Suerkemper et al., 2012)	Cost	n/a	- Additional energy supply system costs (wholesale prices, Transmission & Distribution (T&D) tariffs) - Lost marginal revenue (net of taxes and T&D tariffs) - Incentive payments to program participants (bonus payments and capital costs of interest-free loans) - Program overhead costs	- (Incremental) costs of the energy efficiency improvement measure (including VAT)	- (Incremental) costs of the energy efficiency improvement measure (excluding VAT) - Program overhead costs
	Benefit	n/a	- Avoided energy supply system costs (wholesale prices, T&D tariffs) - Additional energy sales revenue (net of taxes and T&D tariffs) - Avoided penalties of the French - White Certificate scheme or avoided costs of acquiring white certificates	- Energy bill savings (including taxes) - Incentive payments (received bonus payments and avoided capital costs of interest-free loans) - Tax credits	- Avoided energy supply system costs (wholesale prices, T&D grid losses) - Avoided external environmental costs
(Giraudet et al., 2012)	Cost	- Administrative costs	- Direct costs (energy efficiency measures costs) - Indirect costs (expenditure on measure, transaction costs, information, and training costs)	- Energy efficiency measures costs (partly)	n/a
	Benefit	n/a	- Market share gains (in the free market)	- Reduction of energy expenditures - Tax credits	- Avoided carbon dioxide (CO_2) emissions - Alleviation of energy/fuel poverty - Employment in the energy efficiency industry

Table 3.1 (continued): Cost-Benefit Studies on EEOS.

Studies	Items	Regulator	Obligated Parties	End-users	Social
(Rosenow & Bayer, 2017)	Cost	- Administrative costs	- Energy efficiency measures costs - Internal administration	- Energy efficiency measures costs (partly) - Additional costs on bills	n/a
	Benefit	n/a	- Reduced costs in providing energy services - Reduced line losses resulting from load reduction (for electrical energy companies)	- Energy cost savings - Increased comfort (for residential end-users) - Increased values of their properties/ assets (for residential end-users)	- Carbon emission reduction - Air quality improvements
(Xylia et al., 2017)	Cost	Administrative costs	- Energy efficiency measures costs - Internal administration costs	- EE measures costs (partly) - Additional costs on bills	n/a
	Benefit	n/a	n/a	- Avoided energy use	- Avoided CO_2 emissions
(Franzò et al., 2019)	Cost	- Tax levies reduction related to an energy bill reduction	- Energy efficiency measures costs	- Additional costs on bills	n/a
	Benefit	- Energy import reduction - CO2 emission reduction	- Tax reduction - Energy import reduction - Tariff Contribution	- Energy bill reduction	n/a

In the second NEEAP of Türkiye, it is stated that energy efficiency obligations will be defined for all energy distribution and/or supply companies with an approach compatible with Türkiye's climate targets, and the obligation to be imposed on electricity distribution and/or supply companies will be defined as a quality performance criterion. Also, a pilot study is aimed at being carried out for the implementation of the white certificate market.

An EEOS that includes all energy types, and the white certificate market will have a more complex structure. On the other hand, the literature suggests that a simple structure should be preferred to make an easy start and allow the learning phase (Cin and Onaygil, 2024). Accordingly, in this study, a basic EEOS structure was created for an easy beginning. Items that are common to existing studies were selected and some items compatible with the Turkish scheme were added. Figure 3.1 shows the structure and Table 3.2 lists the cost and benefit items of the structure.

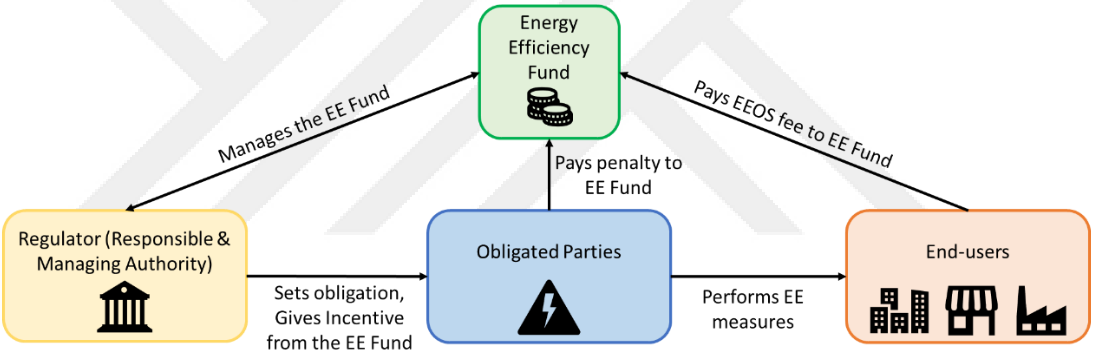

Figure 3.1 : EEOS Structure for Türkiye.

Table 3.2 : Cost and Benefit Items of EEOS Structure for Türkiye.

	Regulator	Obligated Parties	End-users
Costs	- Administrative costs: Tracking the OPs, managing the scheme, and Measurement &Verification.	- Energy efficiency costs: Cost of EE measures. - Internal costs: (internal administrative costs, labour costs, etc.) - Penalty: Fine to be paid for unfulfilled obligation.	- EEOS fee: a proportion included in energy bills.
Benefits	- Energy import reduction* - Carbon emission reduction*	- Energy cost reduction: Decrease in the amount of energy purchased by the supplier from the market. - Incentive: The amount to be received from the EE Fund.	- Energy bill reduction: Amount reduced in the bills due to energy saved.

* This benefit could not be included in the analysis since they are indirect benefits and cannot be measured.

In the Turkish EEOS structure, three levels are Responsible & Managing Authority, OPs, and End-users. In the structure, the Responsible & Managing Authority sets the obligations on OPs, OPs perform energy efficiency measures on end-users by bearing the energy efficiency investment cost and they have also internal costs for internal administration. There is an energy efficiency fund which is fed by EEOS fees included in the energy bills of end-users and penalties paid by OPs for unfulfilled obligations. The Responsible & Managing Authority manages the energy efficiency fund and gives incentives to OPs.

The second NEEAP states that the Responsible Authority of the Turkish scheme will be the Ministry of Energy and Natural Resources and the NEEAP does not define the managing authority. Therefore, in this study, Responsible and Managing Authorities are defined under a single title as "Regulator". The only cost item of the regulator is administrative costs which includes tracking the OPs, managing the scheme, and measurement & verification studies. The regulator also has indirect benefits from the scheme. Türkiye is a foreign-dependent country on primary energy sources around 75%, and energy imports constitute a significant part of Türkiye's current account deficit. The electricity savings provided by EEOS will indirectly reduce the primary energy need of Türkiye. However, it is not possible to add this decrease in monetary value directly to the regulator's benefit. Energy savings will also bring a certain reduction in carbon emissions, which will be an important contribution to Türkiye's 2053 vision. However, carbon reduction cannot be considered a direct monetary gain for the regulator. Similarly, since there is no mandatory carbon market in Türkiye, it is not possible to calculate the monetary benefit of carbon emission reduction for end-users. However, the carbon emissions that can be obtained at the end of the analysis are calculated and presented as an indirect scheme benefit.

While the second NEEAP envisages giving obligations to energy companies serving all energy types, it also highlights the electricity sector. The Turkish electricity market has been liberalized, except for the transmission system. On the other hand, there is monopolistic competition in the Turkish natural gas and oil markets in both import and wholesale. Therefore, for a simple start for the Turkish scheme, it would be useful to first focus on electricity companies. Türkiye's electricity distribution system is divided into 21 regions. Following the completion of privatization in 2013, all 21 distribution licenses were transferred to private entities supervised by the EMRA. Furthermore, distribution activities were separated from retail activity done by "incumbent suppliers" (IEA, 2021). According to the electricity market law, electricity distribution and incumbent supply companies must be separated. Despite these companies appearing independent, they are frequently part of the same umbrella company. While the distribution company is responsible for the infrastructure and physical distribution of electricity, incumbent supply companies are the ones that purchase electricity from the market and sell it to end-users. There are also other suppliers in the market for wholesale and trading. Among 150 supply license holders in the market, twenty-one incumbent supply companies’ market share is 70%. For the sake of protecting smaller companies and reducing administrative costs, it is assumed that the OPs are the incumbent electricity supply companies in this study.

OPs have the most cost items in the EEOS structure. Besides the EE investment costs, they also have internal costs. Besides, they must pay penalties if they cannot meet their yearly obligations. However, they can gain incentives from the fund when they fulfil at least half of their obligations. Thanks to the energy savings they provide, they also benefit from the reduction in the amount of electricity they purchase from the market. If distribution companies were chosen as OPs, there would be no benefit such as energy cost reduction.

For the target sector coverage of EEOSs, there are two ideas in the literature. With the wide selection of target sectors, OPs can have more options, however, including all sectors may lead to complicated and expensive scheme processes (Bertoldi et al., 2011). Besides, there is a contradiction between EEOS and energy/fuel poverty objectives. Especially, energy bill increases in the household sector may trigger energy poverty (Rosenow et al., 2013). Household energy prices in Türkiye are always partially subsidized with a lower tax rate. It can be expected that households may not be included in the possible Turkish EEOS, and even if they are, they will be treated differently regarding the EEOS fee. Therefore, by excluding the household sector, the industrial sub-sectors and commercial building sectors were covered in this study. The transportation sector also excluded from the sector coverage due to OPs’ selection on only electricity sector. In the structure, while end-users will bear the EEOS fee added to their electricity bills, a certain reduction in their electricity bills will be achieved thanks to the energy savings.

3.2 Materials

In this section, the necessary data for the calculation of the cost and benefit items in the EEOS structure for Türkiye is given.

3.2.1 Electricity sales and consumption

As mentioned, 21 electricity incumbent supply companies were selected as OPs for the basic Turkish EEOS structure. Electricity sales data of these companies is published every year by EMRA under the name "Electricity Sector Development Report" (EMRA, 2023a). In EEOSs, obligations are set according to certain base sales values. The average of the last three years' energy sales is a common practice for selecting a base value. In the Turkish EEOS to be carried out in the 2025-2030 period, the base sales value is calculated by taking the arithmetic average of the electricity sales of 2021, 2022, and 2023 (Table 3.3). Since the sector scope is industrial and commercial buildings, obligations will only be calculated based on sales belonging to these sectors.

In the annual electricity sector development reports published by EMRA, the sectoral division of the electrical energy invoiced in the distribution regions is given as industry, commercial building, household, public lighting, and agricultural irrigation. However, MENR annually publishes “National Energy Balance Tables” where the industry sub-sectors electricity consumption is given (MENR, 2023). By taking the arithmetic average of the last 3 years' electricity consumption values of the industrial sub-sectors from these tables, the percentage shares of each sub-sector in the total industrial consumption (again, average of the last 3 years) were calculated. These shares were multiplied by the average invoiced electrical energy consumption in the industrial sector in the last 3 years, and the electricity consumption of industrial sub-sectors was calculated. The purpose of these calculations is to ensure the equivalence of electricity sales and consumption and to have a more comprehensive look at the industrial sector. Unfortunately, the distinction made for industrial sub-sectors in the national energy balance tables is not available for commercial buildings. For this reason, commercial buildings remained under a single heading. Electricity consumption of end-use sectors is given in Table 3.4.

Table 3.3 : Electricity Sales Data of Incumbent Supply Companies.

Incumbent supply company	Average electricity sales from last 3 years (GWh)	Average electricity sales to industry and commercial building sectors from last 3 years (GWh)*	The share of Industry in the company's total average sales (%)	The share of the Commercial building sector in the company's total average sales (%)	Market share of companies in electricity sales to industrial and commercial building sectors (%)
Toroslar	31418.15	23072.81	56.65	16.79	13.43
Bogazici	28002.50	19817.67	30.90	39.87	11.53
Gdz	20865.03	14518.26	45.11	24.47	8.45
Uludag	19608.10	14893.60	56.87	19.09	8.67
Baskent	19562.13	13000.57	36.06	30.40	7.57
Sakarya	17845.09	14785.08	67.75	15.10	8.60
Dicle	14201.19	4997.68	16.80	18.40	2.91
Istanayak	13810.30	8790.49	26.04	37.61	5.12
Meram	12601.29	6687.97	31.44	21.63	3.89
Osmangazi	11385.81	8742.95	61.90	14.89	5.09
Akdeniz	11174.11	6459.32	17.94	39.86	3.76
Trakya	11120.05	9537.08	70.60	15.17	5.55
Adm	10581.55	6733.13	30.58	33.05	3.92
Yesilirmak	6755.42	4082.66	37.09	23.34	2.38
Akedas	4943.77	3744.71	60.97	14.77	2.18
Kcetas	4087.24	3721.08	66.49	24.55	2.17
Coruh	3800.77	2028.74	22.78	30.60	1.18
Firat	3364.90	2135.74	33.64	29.83	1.24
Camlibel	3042.02	886.58	13.85	15.29	0.52
Aras	2832.59	2142.30	26.19	49.44	1.25
Vangolu	2231.25	1066.11	12.40	35.38	0.62
Total	**253044.48**	**171844.54**	-	-	**100**

* The data in the column was used for calculating the obligations.

Table 3.4 : Electricity Consumption of End-use sectors.

Main Sector	Sub-sectors	Consumption ratio under its main sector	Average electricity consumption of industry sub-sectors and commercial building sectors from last three years (GWh)
Industry	Plastic	5.67%	6124.21
	Household Appliances	2.24%	2421.61
	Glass	1.53%	1652.08
	Cement	7.41%	7996.39
	Ceramic	1.99%	2147.57
	Metal Sector	27.05%	29193.04
	Food	7.39%	7974.81
	Pharmaceutical	0.49%	528.28
	Paper	3.16%	3411.37
	Chemistry & Petrochemistry	6.22%	6716.82
	Forest Products	2.04%	2204.75
	Automotive	2.31%	2492.46
	Textile	14.94%	16123.13
	Other Industries	17.54%	18930.45
Commercial Buildings		100.00%	63927.58
		Total	**171844.54**

3.2.2 Energy efficiency potential and investment cost

In 2022, a company, that has the reputation of being Türkiye's first energy service company, published a report called "Energy Efficiency Report of Turkish Industries", which compiled 434 investment-oriented energy studies' outputs. In the report, the EE potentials, unit EE investment costs, and carbon emission reduction data per unit EE of 13 industrial sub-sectors and the commercial building sector were presented. The outputs of the report were used in this study. In Table 3.5, carbon emission reductions per unit savings in end-use sectors and electricity saving potential of end-use sectors are given. Total electricity saving potential is calculated by multiplying sector consumptions and electricity saving potential ratio.

Table 3.5 : Electricity Saving Potential of End-users.

Main Sector	Sub-sectors	Carbon emission reductions (ton/MWh)	Electricity Saving Potential Ratio (%)	Total Electricity Saving Potential (GWh)
Industry	Plastic	0.291	6.0%	367.45
	Household Appliances	0.311	7.5%	181.62
	Glass	0.527	16.5%	272.59
	Cement	0.284	10.4%	831.62
	Ceramic	0.396	5.2%	111.67
	Metal Sector	0.369	17.0%	4962.82
	Food	0.328	15.5%	1236.09
	Pharmaceutical	0.466	11.3%	59.70
	Paper	0.306	29.9%	1020.00
	Chemistry & Petrochemistry	0.321	12.3%	826.17
	Forest Products	0.483	17.8%	392.45
	Automotive	0.413	11.4%	284.14
	Textile	0.394	7.1%	1144.74
	Other Industries*	0.376	12.9%	2444.94
Commercial Buildings	Commercial Buildings	0.418	33.9%	21671.45
			Total	**35807.46**

* There is not an electricity saving potential ratio data for the "other industries" sector in the related report. However, other industries have a certain consumption and to create a sales and consumption balance the potentials of remaining industry sub-sectors were averaged to determine the other industries' data.

In the report, the unit EE investment cost of the end-use sectors is given in USD per ton of oil equivalent (toe). For the analysis, cost values are converted to USD per Mega Watt hours (MWh)[4]. Since the analysis to be conducted covers the period 2025-2030, the cost values corresponding to each year were calculated with the future value method (Equation 3.1). The interest rate of 3% was used to calculate the future values[5]. In Table 3.6, the unit EE investment cost of end-use sectors and their future values are given.

[4] $1\ toe = 11.63\ MWh$

[5] Interest rate: https://think.ing.com/forecasts/ (Access date: January 2024)

$$Future\ Value = Present\ Value \times (1 + annual\ interest\ rate)^{number\ of\ period\ interest\ held} \quad (3.1)$$

Table 3.6 : Unit Energy Efficiency Investment Cost of End-use Sectors and Their Future Values.

Sub-sectors	Unit Energy efficiency investment cost in 2022 (USD/MWh)	2025	2026	2027	2028	2029	2030
Plastic	175.58	191.86	197.62	203.55	209.65	215.94	222.42
Household Appliances	101.81	111.25	114.58	118.02	121.56	125.21	128.96
Glass	220.03	240.44	247.65	255.08	262.73	270.61	278.73
Cement	265.09	289.67	298.36	307.31	316.53	326.03	335.81
Ceramic	65.78	71.88	74.03	76.25	78.54	80.90	83.33
Metal Sector	143.68	157.00	161.71	166.56	171.56	176.71	182.01
Food	121.15	132.39	136.36	140.45	144.66	149.00	153.47
Pharmaceutical	269.65	294.65	303.49	312.60	321.97	331.63	341.58
Paper	100.34	109.65	112.94	116.33	119.82	123.41	127.11
Chemistry & Petrochemistry	137.58	150.33	154.84	159.49	164.27	169.20	174.28
Forest Products	125.45	137.08	141.20	145.43	149.80	154.29	158.92
Automotive	190.63	208.30	214.55	220.99	227.62	234.45	241.48
Textile	124.85	136.43	140.52	144.73	149.08	153.55	158.16
Other Industries*	157.05	171.61	176.76	182.06	187.52	193.15	198.94
Commercial Buildings	267.84	292.68	301.46	310.50	319.82	329.41	339.29

* Since there is no unit energy efficiency investment cost data for the “other industries” group, the cost of remained industry sub-sectors were averaged.

3.2.3 Electricity prices

In this study, two types of electricity prices are considered for OPs and end-users. For the “Energy Cost Reduction” item of OPs’ benefits, Market Clearance Price (MCP)[6] data is needed. In the Transparency Platform of the Turkish Energy Exchange, MCP data is available. In this study, MCP was predicted for the next 6 years based on the linear trend analysis of the previous 6 years' data. MCP in Türkiye is expressed in Turkish Lira (TL), however, trend analysis was made in USD[7]. Historic and forecasted MCP values are given in Table 3.7.

[6] Market Clearance Price: Hourly electricity purchase-sale price determined as a result of matching the purchase and sale bids for all bidding zones in the day-ahead market for a certain hour.
[7]The exchange rate required for the calculation was determined by taking the value on the last business day of the relevant year from the Indicative Exchange Rates Data of the Central Bank of the Republic of Türkiye.

Table 3.7 : Historic and Forecasted Market Clearence Price.

Historic Arithmetic Averaged of MCP (USD/MWh)							Forecasted MCP (USD/MWh)					
2018	2019	2020	2021	2022	2023	2024*	2025	2026	2027	2028	2029	2030
43.73	43.76	37.49	38.05	134.03	74.24	62.36	92.44	100.06	107.68	115.31	122.93	130.55

* First two months of 2024

Table 3.8 : Historic and Forecasted Electricity Tariff Prices.

	Quarters	Industry (USD/MWh)	Commercial Building (USD/MWh)
Historic	2021-1	90.19	109.35
	2021-2	81.25	98.51
	2021-3	87.96	106.54
	2022-1	128.59	157.16
	2022-2	148.74	143.90
	2022-3	163.05	157.56
	2022-4	220.46	184.45
	2023-1	183.66	183.81
	2023-2	152.27	152.61
	2023-3	112.20	112.56
	2023-4	127.86	128.05
	Year	**Industry (USD/MWh)**	**Commercial Building (USD/MWh)**
Forecasted	**2025**	207.84	179.41
	2026	232.82	193.30
	2027	257.80	207.18
	2028	282.78	221.06
	2029	307.76	234.95
	2030	332.74	248.83

Note: Tariffs have not been published in the fourth quarter of 2021 by EMRA.

For the End-users' electricity prices, the national electricity tariff was considered. EMRA publishes the national electricity tariff four times a year, at the beginning of each quarter. In this study, medium voltage single-term tariff prices for industrial and commercial building sectors were taken from the tariff tables for simplicity. Electricity tariff prices were predicted for the next 28 quarters based on the linear trend analysis of the previous 3 years' quarterly data. By taking the average of the quarterly forecasted values in groups of four, the average electricity prices for the coming years were obtained. Electricity prices in the national electricity tariff are expressed in TL; however, trend analysis was made in USD[8]. Historic and forecasted electricity tariff prices are given in Table 3.8.

[8] The exchange rate required for the calculation was determined by taking the value on the beginning day of the quarters from the Indicative Exchange Rates Data of the Central Bank of the Republic of Türkiye.

3.2.4 Administrative and internal costs

The administrative cost rate of the regulator and the internal cost rate of the OPs were taken from the existing studies. Administrative costs typically cover the following: (i) setting energy savings target among the OPs; (ii) energy savings accreditation process; (iii) providing technical advice on eligible actions; (iv) accrediting energy savings; (v) setting up systems to track any trade or transfer of savings; and (vi) monitoring and verification (Rosenow & Bayer, 2017). Administrative costs borne by scheme authorities are 0.2% of the program's overall cost for the United Kingdom, 0.3% for Denmark, 0.4% for France, 1% for Sweden, and 1.4% for Italy (Giraudet et al., 2012; Xylia et al., 2017). In this study, the value of 0.66% will be used by taking the average of the existing administrative costs examples. OPs have internal costs other than EE investment costs when fulfilling their obligations such as internal administration, labour costs, etc. Internal costs of OPs are 21% of an obligated party's investment cost according to Mundaca and Neij (2009) and 18% according to Giraudet et al. (2012) (Giraudet et al., 2012; Mundaca & Neij, 2009). In this study, 19.5% will be used by taking the average of the existing internal cost examples of the OPs.

3.2.5 Obligation rates

In this study, there are obligation rates, the percentage of energy sales that need to be reduced, for OPs that must be filled every year in the 2025-2030 period. For obligation rates, three different fixed rate cases, low, medium, high, and an increased obligations case were selected by considering the EED practices (Table 3.9). Increased obligations case is similar to EED Recast obligations.

Table 3.9 : Obligation rates (%)

Cases	2025	2026	2027	2028	2029	2030
Low	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%
Medium	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
High	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%
Increasing	0.8%	1.3%	1.5%	1.5%	1.9%	1.9%

3.2.6 Penalties

OPs must pay penalties if they cannot meet their yearly obligations. In theory, if the penalty amount is lower than the EE investment cost, the OPs may choose to pay the penalty rather than fulfil their obligation. Similarly, they may choose to carry out EE actions in case of high penalty amounts. Therefore, it can be said that EE investment cost and penalty amount are closely related to each other. To measure the impact of the penalty amount, four different cases were determined by using the unit EE investment costs in Table 10: the average of the unit EE investment costs; the maximum unit EE investment cost; 1.5 times the maximum unit EE investment cost; 2 times the maximum unit EE investment cost (Table 3.10).

Table 3.10 : Penalty Amounts (USD/MWh).

Cases	2025	2026	2027	2028	2029	2030
Average	179.68	185.07	190.62	196.34	202.23	208.30
Max	294.65	303.49	312.60	321.97	331.63	341.58
1.5xmax	441.98	455.24	468.89	482.96	497.45	512.37
2xmax	589.30	606.98	625.19	643.95	663.26	683.16

3.2.7 EEOS fee rates

EEOS fees generally range from 2 to 5% of end-user consumer bills (RAP, 2016). In this study, four different cases were determined for annual EEOS fees for end-users' electricity bills. First, a 0% fee rate was determined to show how the scheme would work without placing any burden on end-users. In addition, three levels of fee rates are determined as low, medium, and high (Table 3.11).

Table 3.11 : Table 1. EEOS Fee Rates (%)

Cases	2025	2026	2027	2028	2029	2030
None	0%	0%	0%	0%	0%	0%
Low	1%	1%	1%	1%	1%	1%
Medium	3%	3%	3%	3%	3%	3%
High	5%	5%	5%	5%	5%	5%

3.2.8 Increase in consumption

In this study, it is assumed that there will be no increase in the electrical energy consumption of end-use sectors due to newly added subscribers or rebound effects during the EEOS period.

Looking at the electricity consumption data, it is seen that the electricity consumption of the industrial sector decreased by 7% and the consumption of the commercial building sector increased by 6.5% in the last 3 years. The total consumption remained almost constant. It is difficult to make predictions about Türkiye's future electricity consumption after the effect of the COVID-19 pandemic, sudden increases in electricity prices triggered by high inflation and exchange rates due to Türkiye's current economic situation, and the major earthquake disaster affecting 11 provinces of Türkiye. For these reasons, the mathematical model of this study was designed with the assumption that there will be no increase in electricity consumption.

The rebound effect is one of the awful consequences of energy efficiency policies. There are two types of rebound effects: direct and indirect. Due to a decrease in the energy price or increased comfort after energy efficiency implementation, an increase in energy consumption is defined as a direct rebound effect. The indirect rebound effect is related to macroeconomic effects and is hard to measure. The size of the direct rebound effect is expressed as the percentage of the potential savings taken back from the expected efficiency improvement. According to RAP, the direct rebound effects are measurable and are between 10-30% for households and 20-60% for industry (RAP, 2016). The rebound effect was not added to the mathematical model in this study, but the possible rebound effect is discussed in the results and discussion section of this chapter.

3.3 Methodology

In this section, utilized methodology is presented.

3.3.1 Main analysis: distributed optimization

Managing energy markets through decision-making mechanisms is a crucial issue and is commonly performed by centralized optimization algorithms. However, as the number of participants and operators in the energy sector increases, the problem-solving speed and hierarchical structure make it difficult to make reasonable decisions (Olivella-Rosell et al., 2020). In distributed optimization methods, instead of a single centralized problem, each participant has its own sub-problems. Since the model is divided into different participant levels, the constraints are simplified compared to the centralized model. Therefore, the speed issue, which would occur on a single model with many constraints, can be solved (Xu et al., 2022). Distributed optimization provides a reliable solution where participants can coordinate and solve their problems by agreeing on certain linkage points without manipulating or interfering with the other participant's level (Majumder et al., 2023).

The general representation of the distributed optimization model consisting of *Participant-A* and *Participant-B* is as follows:

The objective of the sub-problem of *Participant-A* $f(x)$, inequality constraints $g(x)$ and equality constraints $h(x)$ are represented in (3.2), (3.3), and (3.4), respectively, while x is the decision variable of *Participant-A* that will be obtained after the solution. The same modelling approach is shown in (3.5)-(3.7) for *Participant-B* while y is the decision variable.

$$\min: f(x) \tag{3.2}$$

$$g(x) \leq 0 \tag{3.3}$$

$$h(x) = 0 \tag{3.4}$$

$$\min: f(y) \tag{3.5}$$

$$g(y) \leq 0 \tag{3.6}$$

$$h(y) = 0 \tag{3.7}$$

The equation in (3.8) contains the shared variables that enable the transition from centralized optimization to distributed optimization, that is, the variables in which the decision is jointly determined. η and μ are the shared variables for the solution between *Participant-A* and *Participant-B*, respectively, and λ is the dual variable or Lagrange multiplier that realizes convergence for the joint decision of both participants.

$$\eta - \mu = 0 \quad ; \lambda \tag{3.8}$$

In (3.9) and (3.10), the final version of the distributed models of *Participant-A* and *Participant-B* are shared, respectively. As a result of relaxing the shared variable equations from the centralized solution, two separate sub-problems are created, and decentralized solutions are formed. Here, the operator (*) denotes the parameterized shared variable that a participant transmits to another participant after solving its own problem. In each iteration, the shared variable that participants transmit to each other updates the dual variable λ. When λ does not change in two consecutive (h) iterations as shown in (3.11), the optimization problem converges, and the problem is solved.

$$\min: \mathcal{L}^A = f(x) + \lambda.(\eta - \mu^*) + \frac{\sigma}{2}.\|\eta - \mu^*\|^2 \quad (3.9)$$

$$\text{s.t. } g(x) \le 0$$

$$h(x) = 0$$

$$\min: \mathcal{L}^B = f(y) + \lambda.(\eta^* - \mu) + \frac{\sigma}{2}.\|\eta^* - \mu\|^2 \quad (3.10)$$

$$\text{s.t. } g(y) \le 0$$

$$h(y) = 0$$

$$\lambda_{h+1}^{iter} = \lambda_h^{iter} + \sigma.(\eta_h^* - \mu_h^*) \quad (3.11)$$

3.3.2 Sensitivity analysis: analysis of variance

Analysis of Variance (ANOVA) refers to the process in which variances are used to assess if the means differ. The approach works by comparing the variance between group means to the variance within groups to determine if the groups are all part of the same larger population or represent separate populations with distinct characteristics. ANOVA determines the importance of one or more factors by comparing the response variable means at various factor levels. It uses F-tests to statistically evaluate the null hypothesis that all group means are equal against the alternative that at least one differs. For interpreting F-tests, p-values are used—lower probabilities indicate stronger evidence against the null hypothesis (Selvamuthu and Das, 2018). In this study, the 0.05 significance value is selected.

While classical ANOVA relies on replicated observations and assumes stochastic variability within groups, this study applies a variance-based sensitivity analysis within an ANOVA framework to evaluate the relative influence of policy design parameters (Obligation Rate, Penalty Amount, EEOS Fee Rate) on three model outcomes. Since the underlying data are derived from deterministic simulation outputs with no within-group variance, the resulting p-values should be interpreted as indicators of relative effect size rather than as strict tests of statistical significance.

3.4 Mathematical Model

In this section, the mathematical model, developed within the scope of the study, is explained for each level after giving the common features of the model. There are 3 different indexes in the model i, j, and t. “i” represents the OPs/incumbent supply companies which is up to 21. “j” represents the sectors which consist of 14 industrial sub-sectors and the commercial buildings sector. "t" represents each year in the 2025-2030 obligation period. For simplicity, OPs will be called “suppliers” in the rest of this section. The decision variable of the model is ES_{ijt} which is the energy-saving amount obtained by i^{th} supplier in the j^{th} sector in year t.

3.4.1 Mathematical model of obligated parties

In the study, 21 incumbent supply companies were selected as OPs. They implement energy efficiency actions in their end-use customers to fulfil their yearly obligations set for them by the regulator. They bear both the energy efficiency investment cost and the internal costs brought by this implementation. If they cannot fulfil their obligations in specific years, they pay a penalty to the energy efficiency fund; if they meet at least half of their annual obligations, they receive an incentive from the fund. Thanks to the energy savings they make, the amount of energy they purchase from the market will also decrease, thus reducing their energy costs. The objective function of the OPs (3.12):

$$Min\ OF_{OP} = \{C_{OP} - B_{OP}\} \tag{3.12}$$

C_{OP} represents the total costs of the OPs, and it is calculated in (3.13).

$$\begin{aligned} C_{OP} = \sum_t \sum_i CPB_{i,t}^{OP} + \sum_t \sum_j \sum_i DC_{i,j,t} + \sum_t \sum_i IC_{i,} \\ + \sum_t \sum_i P_{i,t} \end{aligned} \tag{3.13}$$

$CPB_{i,t}^{OP}$ is the total cost of the power bought from the wholesale electricity market of i^{th} supplier in year t by (3.14). Here, MCP_t is the market clearing price, while $PB_{i,t}^{OP}$ is the amount of power bought from the wholesale market. $DC_{i,j,t}$ is the direct energy efficiency cost of i^{th} supplier in the j^{th} sector in year t, and it is calculated using (3.15). As mentioned, $ES_{i,j,t}^{OP}$ is the energy saving amount obtained by the i^{th} supplier in the j^{th}

sector in year t. $C_{j,t}$ is the unit energy efficiency investment cost of the jth sector in year t. $IC_{i,t}$ is the internal/indirect cost of ith supplier in year t, and it is calculated by multiplying the direct cost of an obligated party with the internal cost rate η as in (3.16). $P_{i,t}$ is the penalty amount paid by ith supplier in year t due to unfulfilled obligations and is calculated by (3.17) where multiplies the failed saving amount $FS_{i,j,t}^{OP}$ with the determined unit penalty amount for each year ρ_t.

$$CPB_{i,t}^{OP} = MCP_t * PB_{i,t}^{OP} \ \forall i,t \tag{3.14}$$

$$DC_{i,j,t} = ES_{i,j,t}^{OP} * C_{j,t} \ \forall i,j,t \tag{3.15}$$

$$IC_{i,t} = \eta * \sum_j DC_{i,j,t} \ \ \forall i,j,t \tag{3.16}$$

$$P_{i,t} = \rho_t \times \sum_j FS_{i,j,t}^{OP} \ \ \forall i,j,t \tag{3.17}$$

B_{OP} in (3.12), represents the total benefit of the OPs calculated in (3.18).

$$B_{OP} = \sum_t \sum_i I_{i,t} + \sum_t \sum_i BPS_{i,t} \tag{3.18}$$

$I_{i,t}$ is the incentive gained by ith supplier in year t, and it is calculated via (3.19) and (3.20). MS_i is the market share of ith supplier in the base year. Furthermore, F_t is the total amount of money collected in the energy efficiency fund in year t, and it is calculated by (3.21). $BPS_{i,t}$, in (3.18), is the benefit of the power sold to the sectors by ith supplier in year t, and it is calculated by (3.22). Here, PMP_t is the pool market price in year t, while $PS_{i,j,t}^{OP}$ is the amount of power sold to the pool market.

$$I_{i,t} = F_t * \frac{MS_i}{\sum_i MS_i} \ \forall i,t;\ if \sum_j ES_{i,j,t}^{OP} \geq \sum_j FS_{i,j,t}^{OP} \ \forall i,t \tag{3.19}$$

$$I_{i,t} = 0 \ \forall i,t;\ if \sum_j ES_{i,j,t}^{OP} < \sum_j FS_{i,j,t}^{OP} \ \forall i,t \tag{3.20}$$

$$F_t = \sum_i P_{i,t} + \sum_j EF_{j,t} \ \forall i,t \tag{3.21}$$

$$BPS_{i,t} = PMP_t * \sum_j PS_{i,j,t}^{OP} \ \forall i,t \tag{3.22}$$

In (3.23), the obligations of suppliers, $O_{i,t}$, are calculated according to base energy sales, SB_i, which is the average of the last three years' sales and obligation rates of related years Θ_t. The summation of achieved energy savings and failed savings of a supplier is equal to its obligation for each year t, and it is calculated by (3.24). Both achieved ($ES_{i,j,t}^{OP}$) and failed ($FS_{i,j,t}^{OP}$) energy savings amount must be between zero and the obligation in the related year, as indicated in (3.25) and (3.26), respectively. Finally, the total energy cost reduction of each supplier can be determined as in (3.27).

$$O_{i,t} = SB_i \times \Theta_t \ \forall i,t \tag{3.23}$$

$$\sum_j ES_{i,j,t}^{OP} + \sum_j FS_{i,j,t}^{OP} = O_{i,t} \ \forall i,t \tag{3.24}$$

$$0 \leq \sum_j ES_{i,j,t}^{OP} \leq O_{i,t} \ \forall i,t \tag{3.25}$$

$$0 \leq \sum_j FS_{i,j,t}^{OP} \leq O_{i,t} \ \forall i,t \tag{3.26}$$

$$ECR_{i,t} = MCP_t * \sum_j ES_{i,j,t}^{OP} \ \forall i,t \tag{3.27}$$

3.4.2 Mathematical model of end-users

In the study, the targeted end-use sectors are 14 industrial sub-sectors and the commercial buildings sector. End-users must pay the EEOS fee as a percentage of their energy bill. On the other hand, due to the energy efficiency implementations by OPs in end-use sectors, the total energy consumption of end-users decreases accordingly the energy bills also decrease. The objective function of end-users (3.28):

$$Min\ OF_{EU} = \{C_{EU} - B_{EU}\} \tag{3.28}$$

C_{EU} represents the total cost of the end-users and is calculated by (3.29).

$$C_{EU} = \sum_t \sum_j \sum_i CPB_{i,j,t}^{EU} + \sum_j \sum_i EF_{j,t} \tag{3.29}$$

$CPB_{i,j,t}^{EU}$ is the total cost of the power bought from the pool market by the jth sector from ith supplier in year t by (3.30). $EF_{j,t}$ is the EEOS fee paid by jth end-use sector in year t, and it is calculated by (3.31). Here, $PMP_{j,t}$ is the energy price of the jth end-use sector in year t, while $PB_{i,j,t}^{EU}$ is the amount of power bought from the pool market, and μ is the fixed EEOS fee rate.

$$CPB_{i,j,t}^{EU} = PMP_{j,t} * \sum_j PB_{i,j,t}^{EU}\ \forall i,j,t \tag{3.30}$$

$$EF_{j,t} = \mu * T_{j,t} * PMP_{j,t}\ \forall j,t \tag{3.31}$$

$T_{j,t}$ is the energy consumption of the jth end-use sector in year t and calculated by (3.32) and (3.33). TB_j is the base electricity consumption of the jth end-use sector which is the average of the last three years' electricity consumption, and $ES_{i,j,t}^{EU}$ is the energy-saving amount of the end-user. Furthermore, TP_j is the total energy-saving potential of each sector and $RP_{j,t}$ is the remaining energy saving potentials of each sector in year t. Equations (3.34), (3.35), and (3.36) are used for calculating $RP_{j,t}$ and adjusting $ES_{i,j,t}^{EU}$. Finally, the total bill reduction (the benefit) of each sector can be determined as in (3.37).

$$T_{j,t} = TB_j - \sum_i ES_{i,j,t}^{EU}\ \forall i,j\ and\ t \in \{1\} \tag{3.32}$$

$$T_{j,t} = T_{j,t-1} - \sum_i ES_{i,j,t-1}^{EU}\ \forall i,j\ and\ t \in \{2,3,4,5,6\} \tag{3.33}$$

$$RP_{j,t} = TP_j\ \ \forall j,t\ and\ t \in \{1\} \tag{3.34}$$

$$RP_{j,t} = RP_{j,t-1} - \sum_{i} ES^{EU}_{i,j,t-1} \;\; \forall i, j \; and \; t \in \{2,3,4,5,6\} \tag{3.35}$$

$$\sum_{i} ES^{EU}_{i,j,t} \leq RP_{j,t-1} \quad \forall i, j, t \tag{3.36}$$

$$B_{EU} = EBR_{j,t} = PMP_{j,t} * \sum_{i} ES^{EU}_{i,j,t} \;\; \forall j, t \tag{3.37}$$

3.4.3 Mathematical model of regulator

In the study, the regulator has only administrative costs which is a proportion of the total cost of the OPs. The regulator does not have a level in the developed model. Because, within the scope of this study, it is desired that the regulator only aims for the scheme's success and does not harm the scheme.

The administrative costs of the regulator, AC, is calculated by multiplying the total cost of the OPs in year t with a fixed administrative costs rate (π) as shown in (3.38).

$$Min \; AC = \pi . \sum_{t} C^{OP}_{t} \;\; \forall t \tag{3.38}$$

3.4.4 Mathematical model of distributed solution

Apart from the centralized solution, the complicated constraints are removed in the distributed solution resulting relaxation of the whole model. The energy balance between the suppliers and the end-users is provided in (3.39). The power bought from the wholesale market, which is the power sold to the pool market, by ith supplier must be equal to the power bought from the pool market by the jth sector at each time t. In addition, the joint saved and failed energy decisions of the suppliers in the sectors should be the same as the end-user's decision as indicated in (3.40) and (3.41), respectively. As a result of the distributed implementation, the relaxed terms via the Lagrange variables are indicated in (3.42). Here, it is important to note that the $PMP_{j,t}$ is both the Lagrange variable and energy price of the energy transaction balance for the coordinate of the suppliers and end-users.

$$PB^{EU}_{i,j,t} = PS^{OP}_{i,j,t} \;\; \forall i, j, t \tag{3.39}$$

$$ES^{OP}_{i,j,t} = ES^{EU}_{i,j,t} \; \forall i,j,t \tag{3.40}$$

$$FS^{EU}_{i,j,t} = FS^{OP}_{i,j,t} \; \forall i,j,t \tag{3.41}$$

$$\begin{pmatrix} PMP_{j,t} \; ; (3.39) \\ \lambda^{1}_{i,j,t} \; ; (3.40) \\ \lambda^{2}_{i,j,t} \; ; (3.41) \end{pmatrix} \tag{3.42}$$

The last forms of the distributed solution for the suppliers, the end-users, and the regulator are presented in (3.43), (3.44) and (3.45), respectively. Additionally, each Lagrange variables in (3.42), which coordinate the relaxed equations to manage the overall problem in a decentralized manner, are updated at each iteration (h) and are indicated in (3.46), (3.47), and (3.48), respectively. Finally, the well-defined penalty parameter (σ) and step-length (β) in (3.49) are 1e-6 and 1.25, respectively, for the best solution of the distributed model, and σ is updated via (3.49) similar to the Lagrange variables.

$$\psi_{OP} = \sum_{i,t} CPB^{OP}_{i,t} + \sum_{i,j,t} DC_{i,j,t} + \sum_{i,t} (IC_{i,t} + P_{i,t}) - \sum_{i,t} I_{i,t} \tag{3.43}$$

$$+PMP_{j,t}.\left(PB^{EU,*}_{i,j,t} - PS^{OP}_{i,j,t}\right) + \frac{\sigma}{2}.\left(PB^{EU,*}_{i,j,t} - PS^{OP}_{i,j,t}\right)^2$$

$$+\lambda^{1}_{i,j,t}.\left(ES^{OP}_{i,j,t} - ES^{EU,*}_{i,j,t}\right) + \frac{\sigma}{2}.\left(ES^{OP}_{i,j,t} - ES^{EU,*}_{i,j,t}\right)^2$$

$$+\lambda^{2}_{i,j,t}.\left(FS^{EU,*}_{i,j,t} - FS^{OP}_{i,j,t}\right) + \frac{\sigma}{2}.\left(FS^{EU,*}_{i,j,t} - FS^{OP}_{i,j,t}\right)^2$$

s.t. (3.14)-(3.27)

$$\psi_{EU} = \sum_{i,j,t} CPB^{EU}_{i,j,t} + \sum_{j,t} EF_{j,t} \tag{3.44}$$

$$+PMP^{*}_{j,t}.\left(PB^{EU}_{i,j,t} - PS^{OP,*}_{i,j,t}\right) + \frac{\sigma}{2}.\left(PB^{EU}_{i,j,t} - PS^{OP,*}_{i,j,t}\right)^2$$

$$+\lambda^{1}_{i,j,t}.\left(E^{OP,*}_{i,j,t} - ES^{EU}_{i,j,t}\right) + \frac{\sigma}{2}.\left(ES^{OP,*}_{i,j,t} - ES^{EU}_{i,j,t}\right)^2$$

$$+\lambda^{2}_{i,j,t}.\left(FS^{EU}_{i,j,t} - FS^{OP,*}_{i,j,t}\right) + \frac{\sigma}{2}.\left(FS^{EU}_{i,j,t} - FS^{OP,*}_{i,j,t}\right)^2$$

s.t. (3.30)-(3.37)

$$\psi_{AC} = \pi . \sum_t C_t^{OP} \quad (3.45)$$

$$PMP_{j,t,h+1}^{*} = PMP_{j,t,h}^{*} + \sigma_h^{*} . (PB_{i,j,t,h}^{EU,*} - PS_{i,j,t,h}^{OP,*}) \quad (3.46)$$

$$\lambda_{i,j,t,h+1}^{1,*} = \lambda_{i,j,t,h}^{1,*} + \sigma_h^{*} . (ES_{i,j,t,h}^{OP,*} - ES_{i,j,t,h}^{EU,*}) \quad (3.47)$$

$$\lambda_{i,j,t,h+1}^{2,*} = \lambda_{i,j,t,h}^{2,*} + \sigma_h^{*} . (FS_{i,j,t,h}^{OP,*} - FS_{i,j,t,h}^{EU,*}) \quad (3.48)$$

$$\sigma_{h+1}^{*} = \beta . \sigma_h^{*} \quad (3.49)$$

3.5 Results and Discussion

In this study, the two-level distributed optimization model was developed and solved. A total of 64 different case studies were created by four different alternatives of the obligation rate, the EEOS fee, and the penalty amount parameters. Changes in energy-saving amount obtained from different scenarios are shown in Figure 3.2.

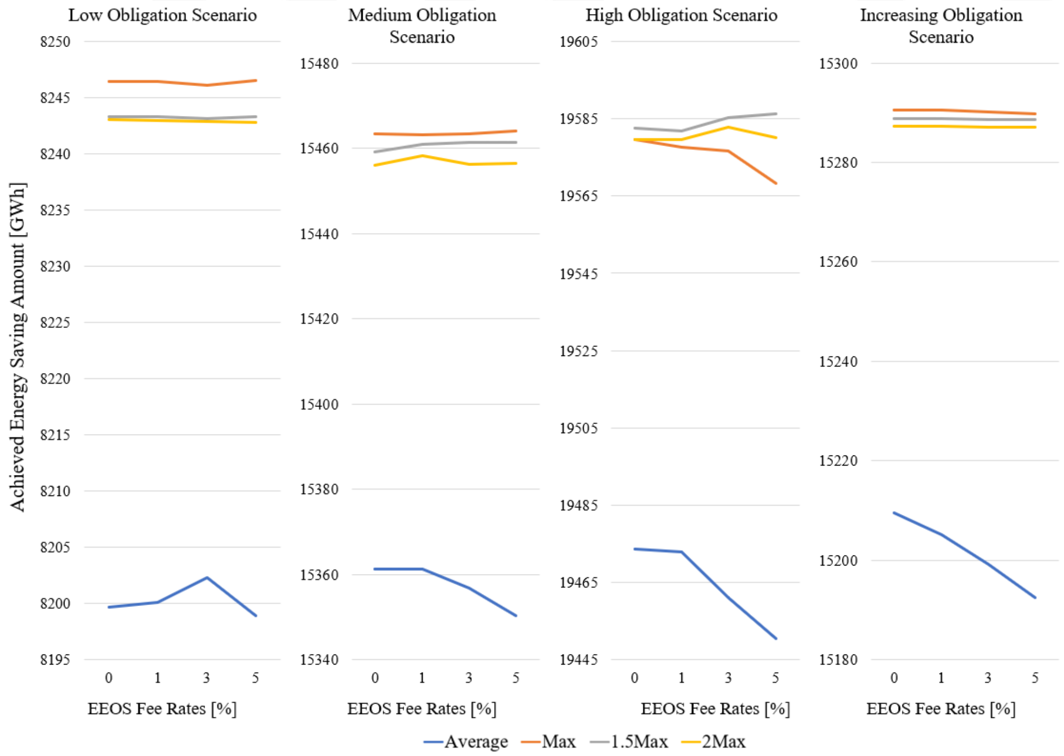

Figure 3.2 : Changes in Energy Saving Amount Obtained from Different Scenarios.

The energy-saving values in the graphs show the total values obtained at the end of the 6 years. From the broadest perspective, the achieved energy savings increase with the obligation ratio. The more ambitious obligation ratio triggers the achievement of more savings. On the other hand, Figure 3.2 shows that there is no direct proportional relationship between the energy savings achieved in terms of penalty amount and EEOS fee rate in the different obligation scenarios. In all types of obligation scenarios, the “Average” penalty amount scenario leads to the least energy savings. The “Max” penalty amount scenario leads to the most energy savings in all EEOS fee rates and obligation scenarios except the “high obligation” scenario. In the “high obligation” scenario, the "1.5Max" penalty amount provides the most energy savings in all EEOS fee rates.

In terms of cost-benefit ratios, interesting outputs were obtained under different scenarios. Changes in the cost-benefit ratios of OPs and end-users under different scenarios are shown in Figure 3.3.

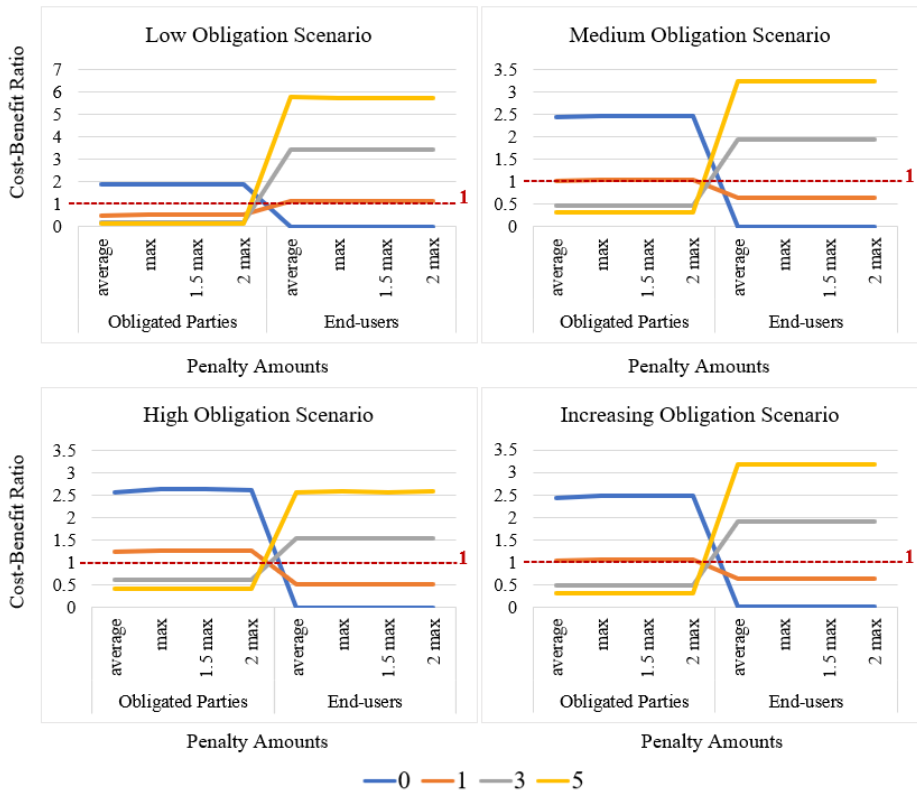

Figure 3.3 : Changes in Cost-Benefit Ratios under Different Obligation Scenarios.

The cost-benefit ratio is obtained by dividing the total cost value by the total benefit value. The cost-benefit ratio should be less than “1”, indicating that the benefit is greater than the cost. Since the cost of end-users is “0” in the "0%" EEOS fee rate scenario, their cost-benefit ratio is also calculated as “0”, which means there are only benefits. Figure 3.3 shows that different penalty amounts do not seem to affect the cost-benefit ratios. In all case studies, OPs fulfilled their obligations at least 99.8%. It might be said that the existence of a penalty has a deterrent effect on the OPs, and they choose to provide energy efficiency also considering the other benefits they will receive.

According to Figure 3.3, if the EEOS fee is absent, OPs’ costs are much higher than their benefits under all obligation scenarios. While around the "1%" EEOS fee rate is beneficial for OPs in only the "low obligation" scenario, it is the only beneficial fee rate for end-users besides the “0%”. On the other hand, “3%” and “5%” EEOS fee rates impose excessive costs on the end-users and more than cover the costs of the OPs.

Figure 3.4 shows the rate at which the money collected in the fund covers the OPs' net costs under different obligation scenarios. OPs’ net costs are obtained by subtracting the energy cost reduction amount from the total cost of the OPs. Thus, it can be examined whether the incentive amount that the OPs will receive from the fund covers its net costs.

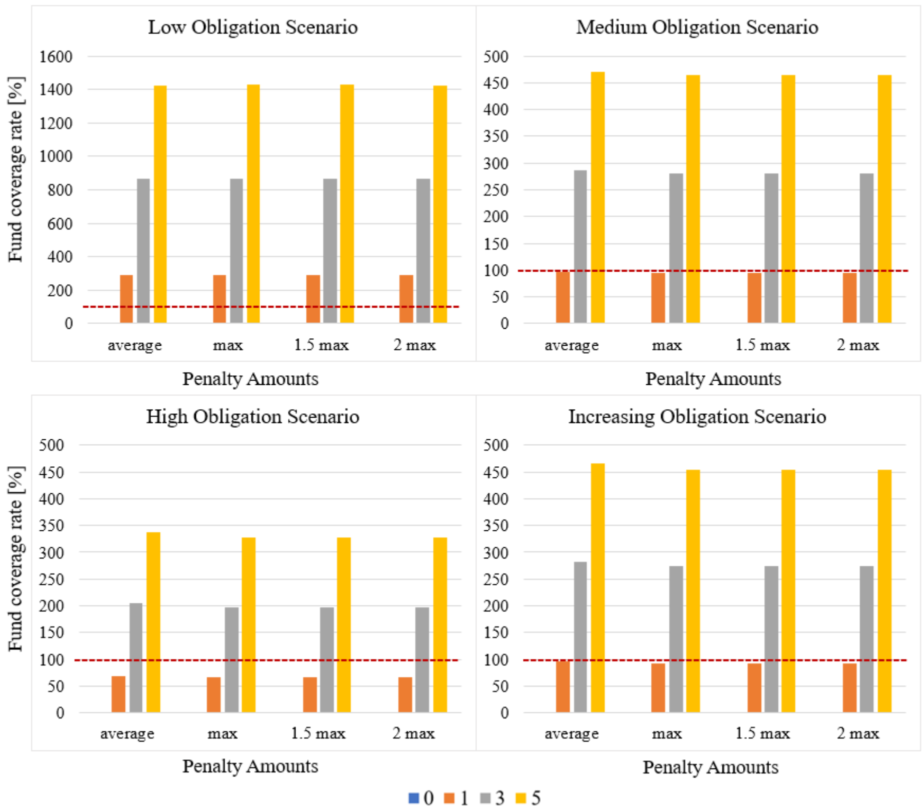

Figure 3.4 : The Fund Coverage Rate of Obligated Parties’ Net Costs.

According to the results, since OPs tend to fulfil their obligations under all scenarios, it is impossible to cover the mechanism with penalties alone without imposing an EEOS fee on the end-users. The “1%” EEOS fee rate is not enough to cover all the costs of OPs in most obligation scenarios except “low obligation". On the other hand, with the “3%” and “5%” EEOS fee rates, more than the necessary amount of money is collected. Somewhere between 1-3% EEOS fee rate would be sufficient for “medium”, “high”, and “increasing” obligation scenarios. The mathematical model was re-run for several values between 1-3% to prove this. As can be seen from Figures 3.3 and 3.4, the change in the penalty amount does not cause a significant change in the cost-benefit and fund coverage ratios. To reduce the computational time, the mathematical model was re-run by selecting the penalties that provide the highest energy efficiency for each obligation scenario, that is, the “1.5Max” penalty amount for the “high obligation” scenario and the “Max” penalty amount for the “medium” and “increasing” scenarios. Figure 3.5 shows the changes in cost-benefit ratios under new cases.

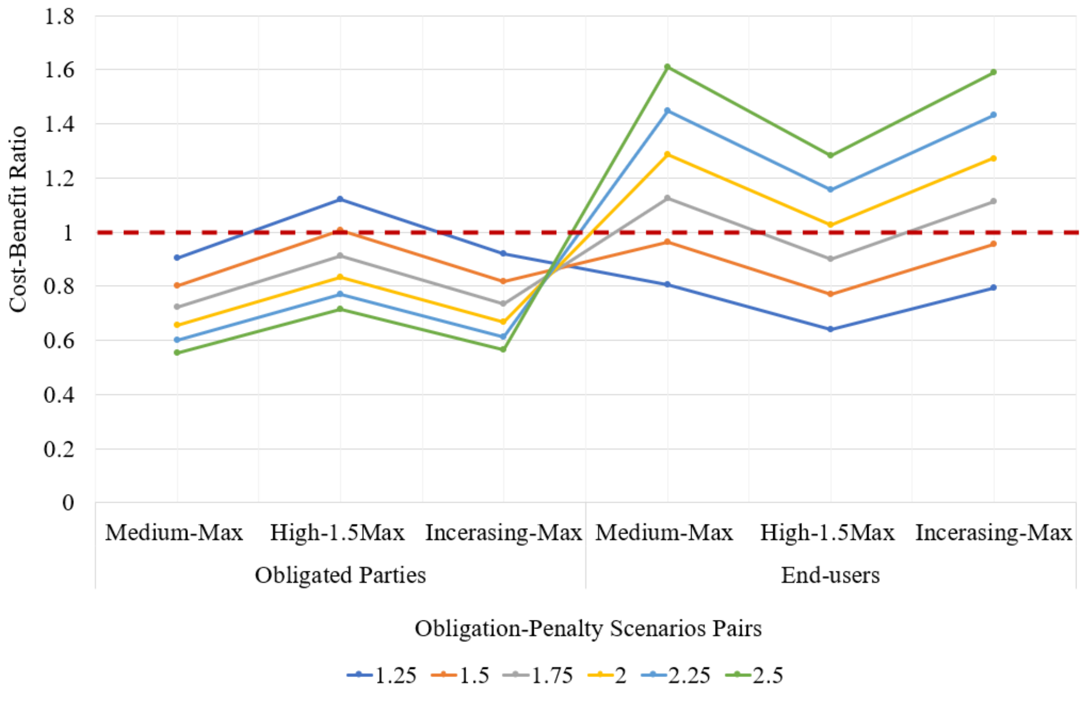

Figure 3.5 : Changes in Cost-Benefit Ratios under Different Obligation-Penalty Scenarios Pairs.

Figure 3.5 shows that around 1.25% EEOS fee can be imposed on end-users to balance the OPs’ cost-benefit ratio under the “medium” and “increasing” obligation scenarios. If the obligation is to be more ambitious, like the “high obligation” scenario, at least a

1.5% EEOS fee rate is required. However, more than 1.75% EEOS fee rate disrupts the cost-benefit balance of the end-user except for the “high obligation” scenario.

To sum up, to ensure the cost-benefit balances of both OPs and end-users in the possible Turkish EEOS, up to 1% EEOS fee rate should be determined for the "low" obligation scenario, up to 1.5% for the "medium" and "increasing" obligation scenarios, and between 1.5%-2% for the "high" obligation scenario. Considering these results, the EEOS fee rate parameter was fine-tuned for the obligation scenario, and the penalty amount pairs with the best energy-saving results. Table 3.12 summarizes win-win cases with lower and upper limits of EEOS fee rates for obligation scenario and penalty amount pairs.

Table 3.12 : The Lower and The Upper Limits of EEOS Fee Rates.

Limits	Obligation Scenario-Penalty Amount	EEOS Fee Rate	Achieved Energy Savings (GWh)	Cost-benefit ratio of Obligated Parties	Cost-benefit ratio of End-users	The fund coverage rate of obligated parties' net costs	Administrative Costs of the Regulator (Millon USD)
Lower	Low-Max	0.35%	8246.46	0.99	0.40	102.9%	5.5
Upper	Low-Max	0.87%	8246.43	0.58	0.99	254.8%	5.5
Lower	Medium-Max	1.10%	15463.17	0.98	0.71	103.7%	16.8
Upper	Medium-Max	1.55%	15463.44	0.79	1.00	145.8%	16.8
Lower	High-1.5Max	1.52%	19585.29	1.00	0.81	100.5%	23.6
Upper	High-1.5Max	1.94%	19585.26	0.85	1.00	128.1%	23.6
Lower	Increased-Max	1.10%	15290.42	0.99	0.70	101.2%	17.3
Upper	Increased-Max	1.55%	15290.38	0.80	0.99	142.4%	17.3

While lower limits express the minimum EEOS fee rate that can cover the costs of OPs, upper limits refer to the maximum EEOS fee rate that will be charged to end-users whose costs do not exceed their benefits. At lower limits, the money accumulated in the fund fully covers the net costs of the OPs. At the upper limits, more money accumulates in the fund than necessary, and the OPs get back more than their costs as incentives. The point to emphasize here is not to give more incentives to OPs, but to show that more contributions can be made to the fund without disrupting the cost-benefit balance of end-users. If a cost item not covered in this study is added to the possible Turkish EEOS, this cost can be covered up to a certain amount. For example, the excess funds accumulated can cover the administrative costs or it can be directed to energy efficiency investments in the household sector. Thus, the administrative costs to be undertaken by the regulator will not be a burden, the cost-benefit balance of the OPs and the industrial and commercial building sectors will be achieved, and finally, energy efficiency will be increased within the framework of the scheme without imposing an EEOS fee on the household sector.

If the lower limit cases are examined closely, the distribution of achieved energy savings in different sectors is given in Figure 3.6.

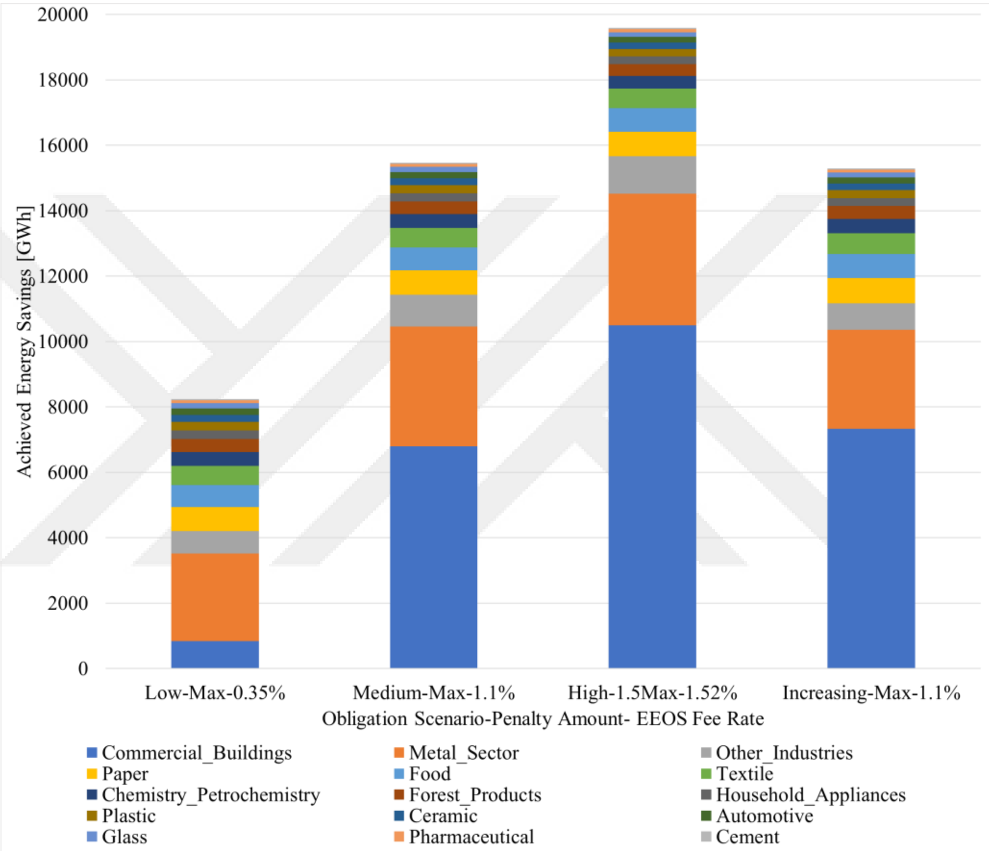

Figure 3.6 : The Distribution of Achieved Energy Savings in Different Sectors under The Best Cases.

Figure 3.6 shows that the most energy savings achieved come from the commercial buildings under best cases except the low-max-0.35%. In all best cases, although energy savings are recorded in all sectors, there is a domination of commercial buildings, metal, other industries, paper, food, and textiles sectors. The sectors where the most energy savings are achieved are not the sectors with the lowest energy efficiency investment costs. If only the costs of OPs wanted to be minimized, OPs would concentrate on the sectors with the lowest energy efficiency investment costs, as in the study of Ünal et al. (2022). In this study, end-users also aim to balance costs and benefits. For this reason, energy efficiency is being tried to be achieved in all end-use sectors in return for the EEOS fee received from the sector. Therefore, more energy efficiency is achieved in sectors with higher electricity consumption. Here the importance of considering the different level participants of the scheme becomes evident.

As mentioned, the second NEEAP aims to make a 20.2 billion USD investment between 2024-2030 and to achieve 37.1 Mtoe cumulative primary energy saving. In addition, with the Paris Agreement, Türkiye has committed to achieving net zero emissions by 2053. The contribution of the possible Turkish EEOS to be implemented in the 2025-2030 period described in this study to Türkiye's national goals is given in Table 3.13.

Table 3.13 : The Contributions of The Best Cases of The Possible Turkish EEOS to Türkiye's National Goals.

	Low-Max-0.35%	**Medium-Max-1.1%**	**High-1.5Max-1.52%**	**Increasing-Max-1.1%**
Achievable Final Energy (Electricity) Savings (Mtoe)	0.71	1.33	1.68	1.31
Contribution to NEEAP's Primary Energy Saving Goal (%)	2.24%	4.19%	5.31%	4.15%
Energy efficiency investment to be fully financed within the possible Turkish EEOS (Billion USD)	1.75	4.26	5.75	4.37
Share of the Regulator's administrative costs in the NEEAP investment budget (%)	0.03%	0.08%	0.12%	0.09%
Possible carbon emission reduction (kton CO_2 equivalent)	3063.8	6017.8	7716.7	5974.7
The share of carbon emissions to be reduced within the scope of possible Turkish EEOS in Türkiye's total greenhouse gas emissions* (%)	0.54%	1.07%	1.37%	1.06%

*According to the latest official data announced by the Ministry of Environment, Urbanization, and Climate Change, Türkiye's total greenhouse gas emissions in 2021 were 564.4 million tons of CO_2 equivalent.

Table 3.13 shows that between 2.2-5.3% of the energy savings targeted in the Second NEEAP can be met with the possible Turkish EEOS described in this study. In the Second NEEAP, primary energy saving is targeted, but the results obtained in this study are final energy savings. The primary equivalent of final energy savings is higher due to losses. Especially, the primary energy equivalent of final electricity savings will be much higher in Türkiye, which has a high fossil fuel rate in the electricity generation mix. Therefore, the contribution of the possible Turkish EEOS to Türkiye’s national energy efficiency targets will be higher than the calculated values. Energy import costs of Türkiye, which is a country dependent on foreign sources for around 75% of primary energy, will also decrease thanks to the electrical energy savings to be achieved.

On the other hand, there is a reality called the rebound effect that is based on the logic that improvements in energy efficiency encourage greater use of the services (Sorrell, 2007). According to different studies, there is a rebound effect of up to 60%, which varies by sector (RAP, 2016; Sorrell, 2007). Although the direct rebound effect has positive impacts such as improved health, reduced energy poverty, or improved productivity, it reduces the expected results of energy efficiency policies. According to the EED, when calculating the actual reductions in energy consumption for the individual measures, direct rebound effects must be estimated and the reduced value must be used (RAP, 2016). If the rebound effect is considered in this study, the energy efficiency that can be achieved will be less than calculated. An average rebound effect value of 30% can eliminate an average of 0.9 Mtoe of energy savings which is more than the achieved energy saving in the low obligation scenario.

Administrative burdens that the regulator must bear have a very small share in the planned NEEAP budget. However, if it is desired, EEOS fee rates can be adjusted not to exceed the upper limits in Table 3.12, ensuring that the administrative costs are covered.

In addition, thanks to the savings to be achieved in the possible Turkish EEOS, between 3064-7717 kton CO_2 equivalent carbon emission reduction can be achieved, which means that up to 1.4% of Türkiye’s carbon emissions can be reduced. Thus, a contribution to Türkiye's 2053 Net Zero Emission goal will be made with the possible Turkish EEOS.

In this study, carbon emission reduction is not considered as a variable since there is neither a carbon tax nor a mandatory carbon market in Türkiye. If these existed, different cost and benefit items could be added to the model, such as avoided carbon tax for end-users, and reduction in carbon tax revenues for regulators. If the avoided carbon tax was a benefit for end-users, sectors with higher carbon emission reductions per unit savings could come to the fore. The parameter of the EEOS fee rate seems to define the future of the possible Turkish EEOS. The upper and lower limits of this parameter were determined for different obligation scenarios to ensure a win-win for different levels of participants.

So far, it has been observed that the penalty amount affects the achieved energy savings, but does not affect the cost-benefit ratios, as the OPs fulfil almost all their obligations. What if there is no penalty mechanism in the model, how do the results of best cases change? Table 3.14 summarizes the changes in the best cases without a penalty mechanism.

Table 3.14 : Changes in the Best Cases Without Penalty Mechanism.

Best cases	Fulfilled obligation rate (%)	Change compared to the case with penalty	Cost-benefit ratio of Obligated Parties	Change compared to the case with penalty	Cost-benefit ratio of End-users	Change compared to the case with penalty
Low-0.35%	90.5	-9.48	1.20	+0.21	0.45	+0.05
Medium-1.1%	88.1	-11.98	1.03	+0.05	0.81	+0.10
High-1.52%	87.3	-12.68	1.02	+0.02	0.90	+0.09
Increasing-1.1%	82.5	-17.45	0.95	-0.04	0.86	+0.16

If a penalty parameter is excluded, OPs are less likely to fulfil their obligations, even if they have other benefits. OPs, which try to fulfil almost all their obligations while there is a penalty factor, fulfil an average of 13% fewer obligations when there is no penalty. In the scheme without penalty, since the OPs make less energy efficiency investment, there is an increase in cost-benefit ratios on the end-user side due to the decrease in energy bill reduction benefit. In the low, medium, and high obligation cases, the cost-benefit ratios of OPs increase compared to cases with penalty factors. In the increasing obligation case, the large decrease in the fulfilled obligation causes the energy efficiency investment cost of the OPs, therefore, there is a decrease in the cost-benefit ratio of the OPs.

o investigate the optimization results systematically, a variance-based sensitivity analysis using an ANOVA framework was performed. Obligation rate, penalty amount, and EEOS fee rate are factors/independent variables and the achieved energy savings, cost-benefit ratio of OPs, and cost-benefit ratio of end-users are response/dependent variables. ANOVA was conducted on the results of 64 case studies. The summary of factors used in the analysis is shown in Table 3.15.

Table 3.15 : The Summary of Factors.

Factors	Levels	Values
Obligation Rate	4	Low, Medium, High, Increasing
Penalty Amount	4	Average, Max, 1.5Max, 2Max
EEOS Fee Rate	4	0, 1, 3, 5

Since there are three dependent variables the analysis was conducted three times for each dependent variable separately. The results of the three analyses are given in Table 3.16.

Table 3.16 : ANOVA Results.

Dependent Variable	Factor	Degree of Freedom	Sequential Sums of Squares	Adjusted Sums of Squares	Adjusted Mean Squares	F	p-value
Achieved Energy Saving	Obligation Rate	3	1059036509	1059036509	353012170	1985489.03	0.000
	Penalty Amount	3	91724	91724	30575	171.96	0.000
	EEOS Fee Rate	3	129	129	43	0.24	0.866
	Error	54	9601	9601	178		
	Total	63	1059137963				
Cost/Benefit Ratio of Obligated Parties	Obligation Rate	3	2.4750	2.4750	0.8250	117.16	0.000
	Penalty Amount	3	0.0039	0.0039	0.0013	0.19	0.905
	EEOS Fee Rate	3	42.3544	42.3544	14.1181	2004.89	0.000
	Error	54	0.3803	0.3803	0.0070		
	Total	63	45.2136				
Cost/Benefit Ratio of End-users	Obligation Rate	3	18.951	18.951	6.317	24.71	0.000
	Penalty Amount	3	0.000	0.000	0.000	0.00	1.000
	EEOS Fee Rate	3	127.733	127.733	42.578	166.57	0.000
	Error	54	13.803	13.803	0.256		
	Total	63	160.488				

As mentioned, a 0.05 significance value is selected. If the calculated p-value is less than 0.05, the null hypothesis is rejected, and it can be said that there is a statistically significant difference in response variables according to changes in a factor’s levels.

ANOVA results show that changing the obligation rate has a statistically significant effect (strong and consistent influence) on the achieved energy saving and cost-benefit ratios of OPs and end-users. It is the only factor that demonstrates a clear effect across all response variables. The obligation rate and penalty amount explain a notable portion of the variation in achieved energy savings. On the other hand, the penalty amounts meaningfully influence the cost-benefit ratios of OPs and end-users. The ANOVA results support that the effect of no penalty and different penalty levels on the achieved energy savings as seen in Figure 3.2 and Table 3.14 is statistically significant. While the EEOS fee rate has minimal effect on achieved energy savings, it plays a major role in shaping the cost-benefit ratios of both OPs and end-users. A significant part of the change in the cost-benefit ratios of both levels of participants was explained by the EEOS fee rate. In other words, this analysis shows that the key influencing factor on cost-benefit outcomes is the EEOS fee rate.

3.6 Summary of Key Findings and Insights

The primary goals of this chapter are to set an EEOS implementation example for stakeholders, especially policymakers, from an academic perspective by evaluating the future of the possible Turkish EEOS with its cost and benefit features and its potential contribution to Türkiye's goals. While conducting this evaluation, it is also aimed to go beyond the existing EEOS literature and make a significant contribution to them. For these purposes, an ex-ante cost-benefit assessment of the possible Turkish EEOS is conducted. Unlike the existing EEOS studies for Türkiye, the end-user perspective is considered for the first time in this study. Besides this, OPs and end-users are first evaluated together at different levels by utilizing a two-level distributed optimization approach. Thanks to the methodology, each level has its own objective function that seeks to ensure a cost-benefit balance without interfering with the other level. Therefore, reaching a win-win point can be possible.

In this chapter, a basic Turkish EEOS structure is created with its cost and benefit items. For the structure, incumbent electricity suppliers are selected as OPs, and industrial sub-sectors and commercial buildings are covered as end-users. 2025-2030 was determined for the EEOS implementation period, and actual energy consumption, energy price, and energy efficiency investment data were collected for analysis, and the mathematical model was developed. Multiple case studies were created with varying levels of obligation scenarios, penalty amounts, and EEOS fee rates. Cost-benefit ratios were calculated for each case. After getting all results, penalty amounts that led to the most energy efficiency were determined in each obligation rate scenario.

With determined obligation-penalty pairs, more detailed cases were investigated for different levels of the EEOS fee rate to reveal cases in which the benefit outweighed the cost for both OPs and end-users. Then, the lower and upper limits of the EEOS fee rate were specified, in which the cost-benefit balance was achieved for both level participants. After that, to better see the effect of the penalty, the mathematical model was rerun for the best cases without the penalty parameter, and the change in the results was observed. It was seen that in the absence of a penalty mechanism, OPs fulfil their obligations less. To support the study results statistically, three ANOVA were performed for obligation rate, penalty amount, and EEOS fee rate factors on the different response variables of achieved energy savings, and cost-benefit ratios of both levels of participants. In the end, it is revealed that the obligation rate has a statistically significant effect on all response variables, the penalty amount has a statistically significant effect on only the achieved energy saving, and the EEOS fee rate has a statistically significant effect on the cost-benefit ratios of both levels of participants.

The main outcomes of this assessment are to find the win-win points where the goals and rules to be determined while designing an EEOS provide benefits for all scheme participants and to express mathematically the effect of these goal and rule parameters on the results of the possible Turkish scheme. In other words, this assessment offers practical suggestions for determining the obligation rate, EEOS fee rate, and penalty amount when designing the EEOS.

According to the results, if the obligation rate is more ambitious, the energy savings to be achieved will be greater in a scheme as can be expected. Besides the obligation rate, it has been mathematically proven that the penalty plays a very critical role at this point. The penalty has a deterrent effect, and it creates a motivation for the OPs to fulfil their obligations almost completely. Although the collected penalties are expected to feed the fund, it should be considered that the only penalty revenues will be insufficient to finance the whole scheme. Therefore, when designing the Turkish EEOS, it is necessary not to rely on penalty revenues to fund the scheme. The priority of the EEOS is to ensure energy efficiency implementations. The penalty amount that will trigger OPs to reach their obligations at the maximum level must be determined. According to the results, at least the maximum value of the current energy efficiency investment costs should be determined as the penalty amount. However, if there are high obligation rates, the penalty amount should be above the maximum energy efficiency investment cost. To determine the correct penalty amount, the development in the energy efficiency market can be continuously monitored, and the penalty amount can be readjusted on a regular basis.

The EEOS fee rate is the key parameter of the cost-benefit assessment. With an EEOS fee rate set in the right range according to the obligation rate, the Turkish scheme can fully finance itself while the benefits of both levels of participants outweigh their costs. With upper limits fee rates, administrative costs can be covered, and an additional budget can be created for other energy efficiency activities. Additional budget may be dedicated to energy efficiency investments in the household sector, which were not included in this assessment due to the possible energy poverty risk. Although the issue of combating energy poverty is not currently one of Türkiye's priorities, it is an important part of the EEOS concept. In addition, the new EED mandates to make exceptional efforts to address energy poverty and take additional actions. Over time, the political awareness on the energy poverty issue will be raised in Türkiye, which follows EU policies, albeit from behind. Therefore, energy poverty should be considered by policymakers in Türkiye before the adoption of the EEOS, and solutions should be incorporated into the scheme's scope. For instance, a definition of energy poverty and its indicators suitable for Türkiye should be determined. Energy retail companies could collect detailed data from household customers through surveys. In this way, a nationwide energy poverty mapping for Türkiye can be created using actual household data. Also, energy-poor priority groups can be determined as well as vulnerable consumers who are at risk of energy poverty. Tailored strategies to mitigate energy poverty can be developed for specific regions. Currently, detailed data is not available on household energy efficiency in Türkiye. Obtaining this missing data through energy retail companies will provide an important basis for Türkiye’s future energy poverty policies. In the possible Turkish EEOS, the energy poverty sub-target could include not only electricity savings but also savings from other energy types, such as natural gas.

Results show that most of the energy efficiency investments were made in the sectors that have the most electricity consumption rather than having minimum energy efficiency investment costs. This result was reached because of not only the cost minimization of the OPs but also the costs and benefits for both the end-users and the OPs in the model. Since the total EEOS fee paid by the sector is higher, the energy efficiency achieved in that sector is also higher, in accordance with the win-win principle. If more homogeneous energy savings across sectors or the prioritization of certain sectors is desired, sub-targets can be defined for different sectors in alignment with Türkiye's national energy efficiency policies. For example, sectors with a high need and potential for energy efficiency could be evaluated, or focus could be placed on sectors where carbon emissions reduction per unit of energy efficiency is higher. In Türkiye, the industrial sector has always been a leader in energy efficiency efforts due to the availability of skilled labour and easier access to financing. However, commercial and public buildings are increasingly gaining prominence in energy efficiency initiatives. When selecting the sectoral scope of the EEOS, Türkiye's current energy efficiency vision should be carefully evaluated.

With the proposed EEOS structure, focusing on electricity fuel type, 0.7-1.7 Mtoe final energy saving is possible in the analysis period of 5 years. Besides, between 1.75-5.75 billion USD investment can be covered by EEOS fees, which change between 0.35%-1.52%, without disrupting the cost-benefit ratio of end-users. These results were obtained when the EEOS fee was imposed on all industrial sub-sectors and the commercial building sector. Similar to the household sector, there may also be a group that should be protected in covered sectors. Small and Medium-Sized Enterprises (SMEs) may need specific attention in the Turkish scheme. Approximately 4 million of around 45 million industrial and commercial electricity subscribers are SMEs in Türkiye. While there are different energy efficiency supports for SMEs in Türkiye, it is uncertain whether EEOS fees will be applied to SMEs in the Turkish scheme. Similarly, the electricity consumption of public buildings is included in the commercial buildings’ consumption data. There may also be exceptions for this group regarding EEOS fee imposition. It is not possible to exclude the SMEs’ and public buildings' consumption from the model since the detailed electricity consumption data is missing. There is a great need to collect more detailed energy consumption data in Türkiye.

The results show that the proposed Turkish EEOS can contribute to the Türkiye’s climate commitments. Despite having set a high national carbon reduction target, Türkiye's existing carbon reduction initiatives are insufficient. Besides, its carbon-intensive industry is at a disadvantage under the EU’s Carbon Border Adjustment Mechanism (CBAM). To mitigate the negative effects of the CBAM on Türkiye's carbon- and energy-intensive industries, efforts are underway on key issues such as national carbon pricing, clean energy transition, and sectoral decarbonization roadmaps. Simultaneously, preparations for Climate Law are also ongoing. The EEOS can be an effective tool for the energy efficiency part in the decarbonization steps of energy-intensive sectors. Specific targets can be defined in the possible Turkish EEOS for the sectors (cement, iron and steel, aluminium, fertilizers, electricity, and hydrogen) covered by the CBAM. Although the carbon reduction target or sub-target is not a common practice in EEOS, it can be considered for Türkiye, especially for sectors within the scope of CBAM. Furthermore, electrification and renewable energy integration measures implemented in sectors covered by the CBAM could also be considered eligible within the EEOS framework. In this case, necessary adjustments may need to be made in the EEOS fees to be imposed on these sectors to protect justice among end-users.

According to results, the best cases were obtained in which more energy efficiency investments were made in end-use sectors than the total fees received from those sectors. However, when looking at details, while all end-users pay fees, some of them benefit from energy efficiency investments. To reduce the cost imposed on the end-user, different cost recovery mechanisms and flexibility options can be added to the possible Turkish scheme. For example, transfer of savings between OPs can be possible in the scheme or a certificate trading platform can be created for all energy efficiency market players. Also, buy-out, banking, and borrowing options can be included. Moreover, Energy Performance Contracts, where obliged parties, ESCOs, and end-users meet on common ground for large energy efficiency projects, can be a solution. However, the interaction and/or overlap between different cost-recovery and flexibility options of the scheme should be investigated.

EEOS can activate the entire energy efficiency market in Türkiye. However, due care should be taken to ensure that the energy savings achieved within the scope of the Turkish EEOS are additional and do not overlap with existing energy efficiency policies. A properly functioning reporting system and appropriate M&V mechanism are very important for EEOS to achieve its purpose. Before EEOS adoption, it is essential to establish the reporting and monitoring platforms and to meet the necessary infrastructure and expert personnel needs for M&V. Besides additionality issues, one of the undesirable consequences of energy efficiency policies is the rebound effect.

Unfortunately, Türkiye does not define additionality and rebound effects within energy efficiency policies. For energy efficiency policies to be effective in Türkiye, additionality must be ensured, and energy efficiency calculations must be made by foreseeing the rebound effect.

In this study, the rebound effect is ignored, and it is assumed that all the achieved energy savings are additional. Other assumptions are also made such as forecasting energy prices and calculating the future value of investment costs. Türkiye is not a predictable country due to its economic situation, high inflation, and exchange rates. Despite the limitations and assumptions, the results of this study draw a framework for the future of the Turkish scheme. EEOS, which Türkiye has been postponing for years, can be strong enough to finance itself under favourable conditions. It is desired that this study will be useful and guiding for all sector stakeholders, especially policymakers. With the proper implementation, EEOS can contribute to Türkiye's energy efficiency and climate goals, stimulate the entire energy service market with its opportunities, and create new employment areas.

In this study, the household sector was excluded due to potential energy/fuel poverty impacts. The following three chapters delve deeper into this issue.

4. ENERGY POVERTY AND ITS RELATIONSHIP WITH EEOS

In this chapter, the relationship between energy poverty and EEOS is explored. The discussion first clarifies the distinction between energy poverty and fuel poverty and explains why energy poverty is the preferred term for Türkiye. The chapter then provides an overview of the historical development of energy poverty in academic and policy discussions, highlighting key definitions and measurement approaches.

Next, the chapter examines how EEOS can interact with energy poverty, drawing on international experiences from various countries that have incorporated social provisions into their schemes. It discusses different policy mechanisms and potential risks to consider.

Finally, Türkiye's current energy efficiency policies and energy poverty research are reviewed, identifying gaps and opportunities for future policy development. This chapter provides the background information needed for the next two chapters, outlining key concepts, policy frameworks, and international experiences related to energy poverty and its connection to EEOS.

4.1 Energy Poverty

Energy poverty or fuel poverty? Although they are closely related and often used interchangeably, they also have their own distinctions. Energy poverty, defined as the lack of access to adequate, reliable, affordable, quality, and environmentally acceptable energy services, is often used in underdeveloped and developing countries to describe problems arising from a lack of physical access to energy services (Castaño-Rosa et al., 2019; Parajuli, 2011; Primc et al., 2021). On the other hand, fuel poverty is often used in developed countries to refer to the inability to afford modern energy services to live a comfortable life. In other words, fuel poverty is the situation where households do not have the disposable income to meet their basic energy needs, and this concept is built on the interactions of energy prices, low incomes, and household energy inefficiencies (Castaño-Rosa et al., 2019; Primc et al., 2021; Shihab et al., 2018). While the term 'fuel poverty' is mostly found in the UK literature, "energy poverty" has a broader usage in the overall literature, comprising the definition of fuel poverty. Recently determined EU level definition combines the definitions of energy and fuel poverty under the name of “energy poverty”. Therefore, the term “energy poverty” is selected for Türkiye in this study. However, in the rest of the paper, "energy/fuel poverty" is used when mentioning the studies carried out under the name of fuel poverty.

Energy/fuel poverty emerged in academic and policy discussions following the oil crisis in the 1970s. Its initial focus was on the vulnerability of low-income households to rising energy costs, a concern that led Isherwood and Hancock to introduce the concept of energy (or fuel) poverty in 1979 (Primc et al., 2021). In 1991, Brenda Boardman published her pioneering work defining fuel poverty, arguing that this problem was linked to household income, energy costs, and the energy efficiency of housing. In this context, she defined it as a situation where a household's fuel expenditure for all energy services exceeds 10% of its income to maintain an acceptable indoor temperature (Boardman, 1991). The definition and its indicators have changed and evolved over the years. Today, it is one of the key drivers of national and international energy policies.

Households experiencing energy/fuel poverty are unable to adequately heat their homes and struggle to pay their fuel bills. If they pay, they must allocate a large portion of their income to energy costs. Some households are even forced to choose between spending money on energy bills or food (heat or eat situation) (Frank et al., 2006; Walker and Day, 2012). There are consequences of insufficient warmth on physical and mental health and well-being. Energy-poor households are more likely to be hospitalized in winter for respiratory and cardiovascular conditions and are more likely to die prematurely in winter than those living in more efficient housing. In the cases where indoor temperatures were increased and/or living conditions were improved by reducing energy/fuel poverty, residents reported better physical and mental health (Gilbertson et al., 2012; Howden-Chapman et al., 2012; Walker and Day, 2012). Therefore, the benefits of tackling energy/fuel poverty include improved health, less stress, increased comfort, full use of the home, and better building maintenance (Boardman, 2012). Addressing energy poverty can also complement climate change mitigation efforts (Ürge-Vorsatz and Tirado Herrero, 2012). Therefore, dealing with this problem is crucial for achieving Sustainable Development Goal (SDG)-7, which ensures access to affordable, reliable, sustainable, and modern energy for all. It is also important to SDG-1 (ending poverty), SDG-3 (good health and well-being), and SDG-10 (reduced inequalities).

Energy/fuel poverty has drivers of low income, high energy prices, energy-inefficient dwellings, and household characteristics (age, ethnicity, location, etc.). To measure it, new definitions and indicators have been developed since Broadman's 10% approach. It is crucial to precisely target the right energy/fuel-poor group to employ limited government resources more efficiently to solve the problem. For this reason, various nuanced indicators are being developed (Galvin, 2024). When energy/fuel poverty provisions are included in EEOS, the program's overall cost rises due to higher subsidy requirements for energy-poor households and costs associated with targeting eligible households. If the policy is not properly designed and has low targeting efficiency, regressive outcomes can be possible (Rosenow et al., 2013). Therefore, Türkiye should be aware of the energy poverty issue while designing EEOS and take appropriate policy steps for a fair and successful implementation.

Energy efficiency improvements provide a long-term, sustainable solution for tackling energy/fuel poverty rather than financial assistance, which provides only temporary relief and must be repeated regularly (Hills, 2012; Rosenow et al., 2013). The buildings sector offers a high potential for cost-effective emissions reduction, and improving energy efficiency in buildings can also alleviate or eliminate energy/fuel poverty. This creates a valuable alignment between short-term social goals and long-term environmental objectives, rather than treating energy/fuel poverty as a separate issue (Ürge-Vorsatz and Tirado Herrero, 2012). Since EEOS is an energy efficiency mechanism, it can mitigate energy poverty by improving dwellings’ inefficiencies. Energy poverty is a broad issue with many different drivers. It should be noted that the aim of this study is not to show that energy poverty can be solved only by energy efficiency improvements but to show that EEOS can be a tool in addressing one of the key drivers of the issue.

4.2 Energy Poverty and Energy Efficiency Obligation Scheme

The EU is dedicated to reducing energy poverty and ensuring access to energy for vulnerable consumers since the Electricity Market Directive (2009/72/EC) in 2009 aims to take structural and targeted measures to address the root causes of energy poverty. Recently, the revised EED (EU/2023/1791), published in 2023, brought a stronger focus on tackling energy poverty (European Commission, 2024a).

In the revised EED, the first ever EU-level energy poverty definition was made: *"Energy poverty means a household's lack of access to essential energy services, where such services provide basic levels and decent standards of living and health, including adequate heating, hot water, cooling, lighting, and energy to power appliances, in the relevant national context, existing national social policy and other relevant national policies, caused by a combination of factors, including at least non-affordability, insufficient disposable income, high energy expenditure and poor energy efficiency of homes".*

In addition to the first EU-level energy poverty definition, the revised directive brought a requirement to the Member States to prioritization, higher protection, and empowerment of vulnerable customers. In this direction, Member States may require obligated energy companies to achieve a share of their energy savings obligation among people affected by energy poverty, vulnerable customers, people in low-income households, and, where applicable, people living in social housing (European Parlement, 2023).

Although EEOS was introduced with the first EED in 2012, the UK has been implementing it since 1994 under the name of Supplier Obligations (SO), which seeks to deliver energy and carbon savings in the household sector. In the initial periods, obligation targets were given in terms of energy savings but were later updated with the carbon saving metric. Until 2002, the SO scheme did not establish specific targets for energy/fuel poverty. However, the 2000 Warm Homes and Energy Conservation Act, alongside the Utilities Act, established a legal commitment for the UK to eliminate energy/fuel poverty, with a goal to eradicate it in vulnerable households by 2010 and in all households by 2016, as outlined in the UK Fuel Poverty Strategy. In 2002, a target was set for the so-called priority group, which included energy/fuel-poor customers. Under the scheme, 50% of all energy savings were required to be achieved within the priority group. As a result, SO came to be viewed as a scheme capable of achieving dual objectives: reducing carbon emissions while also contributing to the alleviation of energy/fuel poverty (Rosenow, 2012). While there are synergies, tensions also arise. Since SO is funded by energy suppliers who pass the costs on to consumers, creating a conflict when using this policy instrument to address energy/fuel poverty. Additionally, SO is typically seen as a tool to reduce energy consumption, whereas energy-poor households often under-consume energy services. While consumers who get energy efficiency improvement benefit from overall bill reductions, those who do not receive such improvements face increased energy bills. Consequently, if the scheme is not designed carefully and with poor targeting efficiency, regressive outcomes can increase.

For many years, Boardman's 10% approach was used to determine the priority group in the UK scheme, with a particular focus on households receiving certain benefits and containing people aged over 70. However, the targeting efficiency of the priority group determined in this way achieved a 1/4 between 2005 and 2012 (Rosenow et al., 2013).

In 2011, John Hills was invited to review the energy/fuel poverty definition by the UK Department of Energy and Climate Change. He proposed the "low income/high costs" (LIHC) definition in which households "living on a lower income in a home that cannot be kept warm at reasonable cost" to be classed as energy/fuel poor. The low-income threshold for each household is defined as 60% of the median equivalized income (the official poverty line), after housing costs plus fuel costs after equivalization. The high energy cost threshold is set at the median equivalized fuel cost for all households (Hills, 2011). However, while this new definition has advantages over the 10% definition, it has been criticized for masking fuel price increases and being insensitive to price fluctuations of fuels (BEIS, 2021; Moore, 2012). In 2021, the LIHC definition was updated to "Low Income Low Energy Efficiency" (LILEE) by the UK Department for Business, Energy and Industrial Strategy. According to LILEE, a household is energy/fuel-poor if its residual income is below the poverty line and it lives in a home that has an energy efficiency rating band D and below (BEIS, 2021).

Apart from the official definitions, there are also proposals on how to target energy/fuel-poor households. For instance, households are classified as energy/fuel-poor if their energy expenditures exceed twice the national median share of income (2xMedian approach). In 2009, Moore proposed "minimum income standards" and stated that a household is energy/fuel-poor if its residual net income (after housing costs and after all other minimum living costs) is not sufficient to cover its required fuel costs (Moore, 2009 & 2012). In 2013, Rosenow et al. offered the "Low Income, Low Efficiency Area" (LILEA) approach, which includes the energy efficiency of dwellings and location proxies to improve targeting efficiency. This approach claims that energy/fuel poverty is geographically concentrated and energy efficiency improvements should be provided to all homes in an area that is known to include a large proportion of low-income households and include energy inefficient dwellings (Rosenow et al., 2013).

In addition to the objective indicators explained above, there are also subjective indicators, which involve collecting self-assessments from households on whether they consider themselves affected by energy/fuel poverty. This can be done by asking if they feel they can afford adequate energy services for heating, lighting, and cooking. Although subjective surveys have limitations, they offer two key advantages over objective measures. First, they allow for cross-country comparisons without needing compatible data sources on household energy spending and income. Second, combining subjective and objective measures can identify households that feel energy/fuel poor but do not spend excessively on energy because they ration their usage, a group that is particularly hard to identify (Maxim et al., 2016). Many households that spend over 10% of their income on energy do not necessarily perceive themselves as energy/fuel-poor, while some people who feel energy/fuel-poor may not actually spend more than 10% of their income on energy. While raising incomes and lowering energy costs can reduce energy/fuel poverty based on objective definitions, such policies may have little impact on how many households feel unable to afford adequate heating. Due to the differences between these measures, addressing objective energy/fuel poverty will not necessarily reduce the number of households who feel they cannot afford adequate heating (Waddams Price et al., 2012).

Comprehensive energy poverty indexes that include both objective and subjective indicators have been produced. These indexes are produced for a cross-country analysis of energy poverty at an aggregated level. Nussbaumber et al. (2013) proposed the Multidimensional Energy Poverty Index (MEPI), which is designed to capture and evaluate a set of energy deprivations (cooking fuel, indoor pollution, electricity access, household appliances ownership, entertainment and communication appliances ownership) that affect a person or household (Nussbaumer et al., 2013). Bouzarovski and Tirado Herrero (2015) constructed the Energy Poverty Index (EPI), which takes into account the inability to keep homes adequately warm, having arrears on utility bills, and living in a home with a leaking roof, or the presence of damp and rot (Bouzarovski and Tirado Herrero, 2015). Maxim et al. (2016) included additional indicators of inadequate living conditions, that are dwellings not comfortably cool during summertime (not cool) and dwellings with low lighting levels (dark), to EPI, and they created the Compound Energy Poverty Index (CEPI) (Maxim et al., 2016). Gouveia et al. created Energy Poverty Vulnerability Index (EPVI) combining socio-economic indicators of population (e.g. presence of elderly and young people; unemployed; income and education level); climate variables (heating degree days, external outdoor temperature, heating and cooling seasons duration); energy consumption levels (e.g. electricity, natural gas, biomass); calculated energy demand for space heating and cooling (per square meter, per household); climatization technologies details (efficiency, ownership); and construction characteristics of several building typologies (e.g. height, area, bearing structure, type of wall, windows, roofs) distinctive for each of the country's regions (Gouveia et al., 2019).

The new EED requires Member States to achieve a portion of their cumulative end-use energy savings, specifically among people affected by energy poverty, vulnerable customers, low-income households, and, if applicable, social housing. This share must match the proportion of energy-poor households identified in each country's national energy and climate plans. The new EED also recommends objective and subjective indicators together. To assess energy poverty, the following indicators should be considered: (a) the inability to keep the home adequately warm; (b) the arrears on utility bills; (c) the total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor; (d) at-risk-of-poverty rate (cut-off point: 60 % of median equivalized income after social transfers). If a Member State has not provided its energy poverty assessment, it must use the average share of these indicators (European Parlement, 2023).

To reduce the potential negative distributional impacts of EEOS, several countries have introduced measures aimed at low-income or energy/fuel-poor households. These measures fall into two categories, which are a mandatory sub-obligation, requiring energy suppliers to achieve a portion of energy savings in energy/fuel-poor households, and a bonus system, where OPs multiply their energy savings come from energy efficiency investments in these households with a determined factor or earn extra certificates. The UK scheme is specifically designed for energy/fuel-poor households. After the UK, France added the social aim to their EEOS. In the French scheme, mandatory sub-obligation targets and bonuses are included. Ireland also sets mandatory sub-obligation targets for energy/fuel poverty, whereas Austria, Greece and Croatia have bonuses (Arsenopoulos et al., 2020; Darmais et al., 2024).

In the French EEOS, the so-called French White Certificate Scheme, every four years, new individual obligations are allocated to electricity, gas, and gasoline retailers based on their sales, with varying coefficients depending on the fuel type. OPs get energy savings certificates, known as CEEs, upon proof of energy efficiency investments. OPs can generate certificates themselves or subcontract the work to other firms. They can also purchase certificates on the CEE market. At the end of each four-year period, OPs must submit the required certificates to the regulator to demonstrate compliance. Any surplus certificates can be carried over for use in future compliance periods. The program's cost is entirely funded by the OPs, who cover it by passing compliance costs to all customers' energy bills. This situation may exacerbate fuel poverty and economic inequalities. To mitigate that, the French scheme implemented both types of measures: a mandatory sub-obligation and a bonus system. OPs must obtain at least 25% of their certificates by supporting energy/fuel-poor households. The scheme established two separate certificate categories: "Précarité" certificates, which reward investments made by low-income households, and standard certificates. The eligibility criteria for households to receive Précarité certificates are determined by per capita income thresholds. According to the ex-post analysis of the French scheme, the scheme successfully targeted the households in the lowest income group. However, because of the bonus system, OPs produced a high volume of "Précarité" certificates in the 2018–2021 compliance period. This surplus could hinder new investments in low-income households for the 2022–2025 period. Although the regulator increased obligations for the next period, the surplus still represented 40% of the new requirement, meaning nearly half had already been met before the new compliance period began. This may slow energy renovations for low-income households (Darmais et al., 2024). Therefore, countries should be aware of the negative consequences of using different types of social provisions together in EEOSs.

In the Irish obligation scheme, started in 2014, OPs are all energy suppliers of all energy types selling more than a certain amount of energy. The Energy Poverty Strategy in Ireland, launched in 2016, introduced a pilot scheme aimed at implementing deep energy efficiency interventions for energy/fuel-poor households with individuals suffering from severe health conditions and residing in poorly insulated homes. For 2017, the obligation target was set with mandatory sub-targets of 20% for the residential/household sector and an additional 5% for the “energy/fuel poverty” scope. OPs can meet some or all of their targets by collaborating with existing government grant schemes, contributing up to 30% of the funding for residential measures and up to 95% for homes experiencing energy/fuel poverty (ENSMOV, 2020). In the Irish scheme, energy/fuel-poor households are targeted based on whether households are eligible for certain government benefits and live in social housing or pre-determined areas (Arsenopoulos et al., 2020).

Austria and Greece include bonuses in their schemes to mitigate energy poverty. The EEOS of Austria started in 2015, and the OPs of the scheme are all energy suppliers selling more than a certain amount of energy to end-users. In the scheme, OPs’ energy savings come from energy efficiency actions on households experiencing energy poverty are multiplied by a factor of 1.5. In the Greece scheme, started in 2017, OPs are electricity, gas and oil products suppliers or retailers, whose market share is above a certain percentage. Actions tackling energy/fuel poverty are eligible to get a bonus factor of 40% (energy savings are multiplied by 1.4). In both countries’ schemes, eligibility criteria for targeting energy/fuel-poor households are that the household’s eligibility for special electricity tariffs (Arsenopoulos et al., 2020; ENSMOV, 2020). In Greece, addressing energy poverty and protecting vulnerable households primarily involves special measures for at-risk consumers, such as partial and interest-free bill payments and suspending suppliers' rights to disconnect services due to late payments during critical periods, like winter and summer (Arsenopoulos et al., 2021).

In the scheme of Croatia, started in 2014, obliged parties are energy suppliers of electricity, natural gas, heat and oil products. Obliged parties are encouraged to tackle energy poverty with bonuses in the Croatian scheme. If energy efficiency measures are implemented in underdeveloped areas, energy savings may increase by 10% (energy savings are multiplied by 1.1). When applied in vulnerable energy consumers' households, savings may rise by 20% (energy savings are multiplied by 1.2). The scheme aimed at tackling energy poverty through a grant scheme (ENSMOV, 2020).

While energy/fuel poverty sub-targets or bonuses are less common in EEOS, their prevalence is likely to increase in many EEOS following the new EED. Countries looking to add a social aim to their schemes need to learn from the existing, albeit limited, experiences. In this sense, ex-post analyses of countries that have added social purpose to their schemes are important and valuable.

In summary, for the accurate targeting of energy/fuel-poor households under EEOS, countries must establish appropriate indicators based on local conditions and data availability. It may be possible to collect data on a local scale and determine target group-specific measures. If multiple social benefit provisions are to be added to the scheme, their interactions, overlaps, or potential redundancies should be anticipated in the planning process. Energy/fuel poverty should not be treated solely with financial aid; efforts must be made to address the root cause of the problem, which is inefficient dwellings (Anderson et al., 2012; Brunner et al., 2012). It should not be forgotten that the primary goal under EEOS is to ensure energy efficiency and appropriate steps must be taken to encourage obligated participants to contribute to social benefits. Tackling energy/fuel poverty under EEOS shifts the responsibility for identifying and addressing the issue from the state to the private sector, where cost efficiency may take priority, potentially reducing accountability in how energy/fuel-poor households are selected and treated (Walker and Day, 2012). Policymakers should be cautious at this point and not neglect to monitor the OPs.

4.3 Current Status of Türkiye

Türkiye has created comprehensive legislation on energy efficiency since the Energy Efficiency Law (Law No. 5627) came into force in 2007. In Türkiye, the industrial sector has historically led energy efficiency efforts, thanks to skilled labor and better access to financing. In recent years, there has been significant progress in the building sector. Notably, important steps have been taken in implementing energy efficiency measures and energy performance contracts, particularly in public buildings. However, household energy efficiency has been overshadowed by public and commercial buildings. Nevertheless, the household sector has a significant level of energy consumption. In 2023, of the 255 Tera Watt hours (TWh) of billed electricity, 25.95% was consumed by households, 25.86% by commercial and public buildings, and 40.76% by the industrial sector. In the same year, of the 50 billion standard cubic meters of natural gas consumed, 33.79% was by households, 10.61% by commercial and public buildings, and 24.48% by the industrial sector (EMRA, 2023a & 2023b).

In the electricity consumption, the total buildings sector (households and commercial and public buildings) has surpassed the industrial sector. In natural gas consumption, the household sector holds by far the largest share. Due to the high energy consumption of the total buildings sector, it is understandable that this sector group recently stood out in Türkiye's energy efficiency policies. However, the lack of attention given to the household sector within this group highlights a gap in Türkiye's just/fair energy transition. In line with the principle of leaving no one behind, new energy efficiency policies should be developed, or existing policies should be improved for the household sector.

There is a Regulation on Energy Performance in Buildings (2008) based on the Energy Efficiency Law, which includes energy efficiency for the household sector as well. The regulation aims to ensure the efficient use of energy and energy resources in buildings, prevent energy waste, and protect the environment. It also defines the Building Energy Performance Certificate (BEPC) as a document that includes, at a minimum, information regarding the building's energy needs and consumption classification, insulation characteristics, and the efficiency of heating and/or cooling systems. Under the current BEPC system in Türkiye, both new and existing buildings must obtain an BEPC. New buildings must achieve at least a C-class rating. Existing buildings registered before January 2011 are required to obtain an BEPC following the 2017 version of the regulation. For existing buildings, there is no minimum rating they need to meet. The BEPC remains valid for ten years, and without a documented BEPC in the registration, the building cannot receive occupancy permission. Additionally, as of January 1, 2020, it is mandatory to present the BEPC before selling or renting a property. Despite the existing requirements of regulation, the lack of sufficient control in practice means that not all requirements of the regulation are being met (Yıldırım and Önder, 2014). While the system works better for new buildings, there are issues in implementing the requirements of the regulation for the BEPC assessment of existing buildings.

In 2022, to encourage homeowners to insulate their homes, long-term and low-interest insulation loans of up to 50,000 Turkish Liras per apartment have been made available by state-owned banks. Eligible expenses for the loan include insulated window frame systems, door and roof systems, external facade insulation, and insulation of the floors, walls, and ceilings of the residence for heat, water, sound, and/or fire protection

(MENR, 2022). The specified loan amount has not been updated since 2022, and under today's economic conditions of high inflation and exchange rates, the designated credit amount is no longer sufficient.

The second NEEAP of Türkiye defines three actions for existing buildings, including households. "*B5: Rehabilitation of Existing Buildings and Improvement of Energy Efficiency"* highlights the need to evaluate the current insulation loan program for households to enhance its effectiveness. Efforts will also be made to expand this loan program to include funding for other energy-efficient technologies. Additionally, real estate advertisements will be required to disclose the BEPC, alongside increased awareness initiatives in partnership with civil society organizations within the real estate sector. "*B6: Encouraging the Use of Central and Regional Heating/Cooling Systems"* aims to create incentive programs to promote efficient heating and cooling solutions for both new and existing buildings. "*B10: Defining Financial Incentives for the Renovation of Existing Buildings"* focuses on developing financial and fiscal incentives to support the installation of heat pumps in existing structures. A working committee will also be established to evaluate potential financial incentives for homes with a BEPC, encouraging energy-efficient renovations in the household sector.

These actions outlined in the second NEEAP confirm the existing issues related to the BEPC system and the insulation loan program. Furthermore, introducing heat pumps appears to be a step that Türkiye, which is heavily dependent on external sources for primary energy, particularly natural gas, is taking to reduce its high natural gas consumption in households.

In Türkiye, no specific policy has been developed to address energy poverty. The perception of energy poverty is characterized by the inability to access modern energy services, reflecting the most basic definition of the issue. The electricity network covers all over the Türkiye with transmission and distribution lines. Compared to the electricity network, there are some rural areas that the natural gas network has not yet reached. By the end of 2023, the natural gas supply had reached all 81 provincial centres, 757 districts (from 922) and 89 towns (from 405) (EMRA, 2023a & 2023b). However, energy poverty comprises more than physical access. Following the EU-level definition and emphasis, the issue will soon come into focus in Türkiye, especially with the potential adoption of EEOS.

Although there is no political awareness regarding energy poverty in Türkiye, this issue has been addressed in several academic studies. Köse (2019) investigated the relationship between a health status index and a self-reported energy poverty indicator (inability to keep home adequately warm) using the TurkStat 2014 Income and Living Conditions Microdata. According to the self-reported energy poverty indicator, 15.8% of households in 2014 stated that they could not keep their homes adequately warm. At the end of the analysis, he found a negative association between the energy poverty indicator and individual health index, indicating that energy poverty and poor health are more likely to occur together. According to his analysis, sociodemographic factors and housing conditions are significantly linked to the health outcomes of individuals (Kose, 2019).

Selçuk et al. (2019) investigated energy poverty conceptually and examined the socioeconomic characteristics of energy-poor households in Türkiye using the TurkStat 2003-2017 Household Budget Survey and 2006-2016 Income and Living Conditions Survey microdata. They used the 10% approach to identify energy-poor households. According to the analysis results, between 2003 and 2017, the percentage of energy-poor households spending more than 10% of their income on energy to heat up sufficiently in Türkiye dropped from 36% to 23%. However, the most impoverished households saw little improvement in that period. In 2017, 72% of energy-poor households lacked access to natural gas, 63% did not have floor heating, 11.5% had no hot water, and 10.3% lacked a toilet. Additionally, 90% of these energy-poor households were in debt, 76.5% could not save money, 34% did not own their homes, and 82% rarely dined out (Selçuk et al., 2019).

Ucal and Günay (2022) explored the relationship between happiness and energy/fuel poverty, while also considering other housing characteristics in their analysis. They used TurkStat 2014-2018 Life Satisfaction Survey microdata for their analysis and selected the "issue of heating" variable for defining energy/fuel-poor households. According to the analysis, 21% of households in Türkiye struggle to heat their homes. The results revealed a negative relationship between household happiness and energy/fuel poverty, indicating that households experiencing energy/fuel poverty are less likely to report higher happiness levels (Ucal and Günay, 2022).

Doğan et al. (2021) explored the impact of financial inclusion on energy poverty using the 2018 TurkStat Household Budget Survey microdata. The study measured energy poverty in Türkiye using three approaches: the 10% approach, the 2x median approach, and the LIHC approach. They found 17%, 18% and 7% energy poverty rates according to these approaches, respectively. They examined the financial inclusion of households by considering factors such as savings, insurance possession, credit card ownership, and online shopping habits. The results indicate that financial inclusion decreases the likelihood of energy poverty. Additionally, age, higher education levels, and employment status reduce the probability of experiencing energy poverty. Ultimately, they highlighted the importance of implementing policies encouraging financial inclusion as an effective strategy to alleviate energy poverty (Dogan et al., 2021).

Günay and Kayacan (2023) reviewed the level of the energy poverty issue in Türkiye using the TurkStat 2002-2018 Household Budget Survey and the 2006-2018 Income and Living Conditions Survey microdata. They found that 19.2% of households cannot keep their home adequately warm, 36.9% of households have leaking roofs, damp walls, floors or foundations, or rot in window frames or floors, etc., 39.3% of households experience an inability to heat their dwelling due to insufficient insulation, and 26.6% of households have arrears on their utility bills. They claimed that the lack of insulation and poor-quality housing stock are the most important underlying factors pushing households into energy poverty in Türkiye. They also compare Türkiye's energy poverty rate with that of European countries, finding that energy poverty in Türkiye is higher than the average levels observed across Europe (Günay and Kayacan, 2023).

Lastly, Ucal and Günay (2023) examined the impact of working-age females' economic precarity and other risk factors influencing their perceptions of energy poverty in Türkiye using the TurkStat 2018-2020 Income and Living Conditions Survey microdata. As indicators of energy poverty perception, they used the inability to keep homes adequately warm and arrears on utility bills, and they revealed that 19% of women of working age could not heat their homes adequately, and 20% have arrears on utility bills. Their findings showed that women are more likely to feel insecure about keeping their homes adequately warm and paying utility bills when they perceive their living conditions as precarious, influenced by their perceptions of poverty, employment status, and other factors (Ucal and Günay, 2023).

4.4 General Assessment

Given the distributional effects of EEOS and the strong emphasis on energy poverty in the Recasted EED, it becomes clear that EEOS cannot be considered independently from energy poverty. Therefore, policymakers in Türkiye should be aware of the energy poverty aspect of EEOS while designing the scheme. In Türkiye, no specific policy has been developed to address energy poverty. However, even the limited number of energy poverty literature in Türkiye confirms the existence of energy poverty, with up to 23%.

To avoid the possible energy poverty impact of EEOS in Türkiye, totally excluding the household sector from the scope might seem like a solution. However, for a country like Türkiye, which lacks an energy poverty policy, the need for awareness and a dedicated policy mechanism to address the existing energy poverty problem is evident. Moreover, Türkiye's candidacy for EU membership makes it inevitable that developments in EU policies will be reflected in Türkiye's policy agenda sooner or later. In this context, turning a blind eye to energy poverty and keeping it out of the scheme's scope may not be the right strategy in the long run. If Türkiye desires EEOS implementation, EEOS can be seen as an opportunity to fill this energy poverty policy gap. Furthermore, investigating the impact of EEOS on energy poverty and designing the scheme accordingly would be far more beneficial than ignoring it and facing it later in a more aggravated level.

Studies in the energy poverty literature of Türkiye have typically analysed energy poverty using a specific definition and investigated the relationship between energy poverty and other issues without addressing the methodological differences between definitions. Furthermore, the relationship between energy efficiency policies and energy poverty has been neglected in these studies. This Ph.D. thesis aims to contribute to the literature in those aspects. Moreover, it represents a first step in addressing energy poverty within the EEOS framework, a topic that will inevitably gain prominence as Türkiye aligns with EU energy policies.

If Türkiye sets social aims within the scope of EEOS, these aims must be aligned with local conditions, clearly defined, and data driven. Given that Türkiye may integrate energy poverty objectives into EEOS, policymakers may first rely on income- and energy expenditure-based definitions. However, recognizing the limitations of these definitions is essential for designing more targeted and inclusive policies. To support this, the next chapter compares income- and energy expenditure-based energy poverty definitions and examines the potential impact of EEOS on energy poverty in Türkiye. Then, the following chapter develops an eligibility index for Türkiye and cluster households to effectively target energy-poor households and investigates how energy poverty can be addressed within EEOS.

As Türkiye moves toward EEOS implementation, incorporating social considerations will be crucial to prevent regressive impacts and address the energy poverty policy gap. This study initiates a much-needed discussion on the intersection of EEOS and energy poverty. A well-structured EEOS, informed by a broader understanding of energy poverty, will not only enhance its effectiveness but also contribute to a fair and sustainable energy transition in Türkiye. As energy poverty gains more attention, ensuring that EEOS is socially equitable and that no vulnerable households are left behind will be essential. This requires carefully designed policies, effective targeting mechanisms, and a holistic approach that balances energy efficiency goals with social considerations.

5. COMPARATIVE ANALYSIS OF INCOME- AND ENERGY EXPENDITURE-BASED ENERGY POVERTY DEFINITIONS: ASSESSING THE IMPACT OF POSSIBLE EEOS ON ENERGY POVERTY IN TÜRKİYE

In this chapter, a comparative analysis of income- and energy expenditure-based energy poverty definitions is conducted to assess their effectiveness in identifying energy-poor households in Türkiye. This analysis serves as a foundation for evaluating the potential impact of EEOS on energy poverty. Using the 2022 Household Budget Survey (HBS), key indicators such as income levels, fuel types, energy bills per square meter, and dwelling age are examined to determine which definition better captures energy-poor households. Additionally, the chapter simulates the effect of a 5% EEOS fee on energy poverty, incorporating updated energy prices and economic conditions in 2024. The findings provide insights into how different definitions influence policy outcomes and highlight considerations for integrating energy poverty measures into a possible Turkish EEOS.

The starting point of this study is to understand “What is the potential effects of EEOS on energy poverty in Türkiye?” and to simulate the economic consequences of this policy. This required a dataset that included household energy expenditure, leading to the use of HBS. To analyse the impact of EEOS, it was first necessary to establish a baseline energy poverty rate. During the analysis process, it was observed that the identification of energy-poor households is significantly shaped by the differentiation of energy poverty definitions. This finding emphasized the importance of evaluating these definitions to determine their effectiveness in capturing energy-poor households. Consequently, a new research question emerged: Which energy poverty definition is more effective in identifying energy-poor households in the context of Türkiye? This shift in focus led to a comparative analysis to better understand the advantages and limitations of income- and energy expenditure-based energy poverty definitions, ensuring a more nuanced assessment of EEOS's potential impact.

The analysis is based on the 2022 HBS, a nationally representative dataset collected by the Turkish Statistical Institute (TurkStat) and obtained in October 2024 as the most up-to-date version available at that time. The comparison criteria were selected based on key drivers of energy poverty, such as low income, high energy prices, and energy-inefficient dwellings. To operationalize these drivers within the scope of this study, energy poverty definitions were compared using four criteria available in the HBS dataset: their ability to target the lowest income group, the fuel type used by households (conventional or modern), energy bills per square meter, and the age of the dwelling. Chi-square Independence Tests and Post-hoc Analyses were applied to reveal the association between energy poverty definitions and these criteria. These methods made it possible to explain in which contexts the definitions are more effective and which groups they cover better.

To account for Türkiye’s recent economic changes, the data were updated to reflect 2024 year-end values, incorporating revised energy unit prices, inflation rates, and TurkStat statistics on income change of households. The analyses highlight the changes in energy poverty definitions and household vulnerabilities over time, emphasizing the dynamic nature of energy poverty. In addition, the simulation of the 5% EEOS fee was conducted for both 2022 and 2024 to evaluate its impact on energy poverty.

Furthermore, this study sheds light on critical considerations for integrating a social aim addressing energy poverty into a possible EEOS in Türkiye. It explores which energy poverty definitions align better with Türkiye's local conditions, providing insights that could guide the development of a nationally relevant energy poverty indicators. Additionally, the study identifies areas where existing datasets could be improved, highlighting the need for more comprehensive and context-specific data to effectively address energy poverty in Türkiye. These insights are not only relevant for Türkiye but also provide a methodological framework for other countries aiming to develop their own locally adapted indicators of energy poverty while balancing energy efficiency goals with social equity.

Although energy poverty can be defined in various ways, income- and energy expenditure-based definitions remain important for a clear analysis of its direct impact on households' energy costs, especially in the context of energy efficiency policies. In recent years, the link between energy inefficiency and energy poverty has gained more attention, leading to definitions that incorporate dwellings' energy efficiency as a key factor. Since the primary goal of EEOS is to ensure energy efficiency, it is reasonable to use energy efficiency related indicators under scheme. On the other hand, income- and energy expenditure-based approaches continue to play a fundamental role in capturing the economic dimensions of energy poverty, particularly when evaluating the social implications of energy efficiency policies. To observe both the effectiveness of these definitions and the potential impact of EEOS, this study focuses on income- and energy expenditure-based approaches as a common ground. However, ultimately, this study concludes by recognizing and emphasizing the importance of energy efficiency-related indicators.

5.1 Data: Household Budget Survey

To obtain the 2022 Household Budget Survey dataset used in this study, a research proposal was submitted to TurkStat. TurkStat reviewed the proposal and approved the data request. As of the approval date, October 2024, the 2022 dataset was the most recent available.

TurkStat has conducted the HBS annually since 2002. By uncovering consumption patterns and income levels across different socio-economic groups, the survey provides detailed information on households' spending habits, types and diversity of expenditures on goods and services, employment status of household members, total household income, and income sources (TurkStat, 2023).

All settlement areas within Türkiye were included in the scope of the survey. However, institutionalized populations, such as individuals living in elderly homes, rest homes, correctional facilities, military barracks, specialized hospitals, nurseries, and nomadic populations, were excluded. The 2022 HBS employed a stratified two-stage cluster sampling method. In 2022, the survey captured indicators of consumption expenditures across Türkiye by sampling 1,296 households monthly, resulting in a total of 15,552 households surveyed over the year, spanning the period from January 1st to December 31st. For the 2022 Household Budget Survey, the non-response rate for Türkiye was 23.3%. Therefore, the final household count of the HBS is 11,922 (TurkStat, 2023).

It should be noted that each household was surveyed only once, and the data collection spanned the entire calendar year, including both winter and non-winter months. Consequently, a significant portion of the surveyed households were sampled during non-winter months, when energy costs and heating needs are typically lower. This seasonal limitation may lead to an underestimation of energy poverty, as households that struggle to meet their energy needs during colder months might not be fully represented in the results. Therefore, the findings should be interpreted with caution, considering the potential for higher energy poverty rates. While the HBS has been used in previous studies on energy poverty in Türkiye, this limitation has generally not been addressed. Acknowledging this issue is critical to ensure a more accurate interpretation of the results.

5.2 Methodology

In this section, the methodology used for the analysis is outlined. It begins with an explanation of the dataset preparation process. Next, the energy poverty calculation methods are introduced. Finally, the section presents the statistical analysis techniques, including Chi-square Independence Tests and Post-hoc Analyses.

5.2.1 Preparing the dataset for the analysis

There are three main data sets in the HBS: "household", "individual", and "consumption expenditure". There is also a "codes and definitions" file that explains the codes of the items in the consumption expenditure dataset. The primary dataset used in this study is the "household" dataset, which contains detailed information about household profiles, characteristics, and income related variables. To incorporate energy expenditure data into the analysis, energy-related items from the "consumption expenditure" dataset were extracted and merged with the "household" dataset. This process allowed for the creation of a comprehensive dataset, where household variables and energy expenditures are combined, enabling a more thorough examination of energy poverty dynamics.

It was observed that 360 households reported no energy expenditures. This situation may be attributed to the monthly data collection process, where some households might not have incurred energy costs during the surveyed month, or due to missing data entries. To ensure the accuracy and reliability of the analysis, these households were excluded from the dataset. As a result, the analyses were conducted using data from a total of 11,562 households.

20% income quintiles were created to analyse differences among income groups. To reflect Türkiye's recent economic situation, the dataset was adjusted to include updated 2024 year-end values, incorporating changes in energy unit prices, inflation rates, and data from TurkStat. To update the 2022 HBS dataset to reflect the year-end values of 2024, unit prices for electricity and natural gas were adjusted based on data from the EMRA and the Petroleum Pipeline Transportation Joint Stock Company (BOTAŞ), respectively. During this period, electricity unit prices increased 20%, while natural gas unit prices rose 40% (BOTAŞ, 2024; EMRA, 2024). For other fuel types, which do not have regulated tariffs, energy expenditures were updated using inflation rates published by TurkStat. Specifically, the average annual inflation rate for 2023 was 64.8%, and the average annual inflation rate for 2024 was 44.4% (TurkStat, 2024a). To update annual disposable income to 2024 year-end values, TurkStat's statistics on household average annual disposable income growth by 20% income quintiles were utilized. The growth rates are as follows: Q1 = 269%, Q2 = 273%, Q3 = 278%, Q4 = 281%, and Q5 = 285% (TurkStat, 2024b). While these disposable income growth rates may appear substantial, they reflect the economic challenges Türkiye has faced, particularly after 2022. As indicated by the inflation rates, Türkiye has experienced significant economic instability during this period. For example, the minimum wage increased by 3.4 times from 2022 to 2024. These economic conditions underline the necessity of updating the dataset to reflect current circumstances, ensuring a more accurate and relevant analysis.

For computational efficiency, parameters deemed unnecessary for the analysis were removed from the dataset. Additionally, the remaining parameters were renamed to ensure clarity and consistency in their content, facilitating easier interpretation during the analytical process. R programming language was used in this study as a tool for data analysis and statistical computing.

5.2.2 Energy poverty calculation methods

The energy expenditure and income-based energy poverty definitions selected from the literature for this study are explained below.

- **10% Approach:** Household's expenditure of more than 10% of its income on energy/fuel. It is calculated as in equation (5.1).

$$\frac{En}{Inc} > 0.1 \quad (5.1)$$

- **2x Median Share Approach:** Household's energy expenditures exceed twice the national median share of income. It is calculated as in equation (5.2).

$$\frac{En}{Inc} > 2 \times Median\left(\frac{En}{Inc}\right) \quad (5.2)$$

- **LIHC Approach:** Household's energy expenditure exceeds the national median value while household's disposable income falls below the poverty line (60% of the median income). It is calculated as in equation (5.3).

$$Inc < 0.6 \times Median(Inc)\ \&\ En > Median(En) \quad (5.3)$$

Where *En* is the total energy expenditure and *Inc is* disposable income of a household. The HBS dataset included an annual disposable income variable, which was directly used, while the monthly total energy expenditure values were multiplied by 12 to convert them into annual format.

5.2.3 Statistical analysis

To evaluate the associations between energy poverty definitions and household profiles and income quintiles, a Chi-square test of independence was employed. This test examines whether there is a statistically significant association between categorical variables by comparing observed and expected frequencies. The test statistics are calculated as in equation (5.4).

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (5.4)$$

Where O_i represents the observed frequency in cell i and E_i represents the expected frequency in cell i in a contingency table. E_i calculated as in equation (5.5).

$$E_i = \frac{(RowSum_i * ColumnSum_i)}{Total} \quad (5.5)$$

Where $RowSum_i$ is the row total, $ColumnSum_i$ is the column total, and $Total$ is the grand total of the contingency table.

A significant Chi-square test ($p<0.05$, 95% confidence level) indicates an association between the categories. However, this test does not reveal which specific categories contribute to the differences. Post-hoc analyses are used to perform pairwise comparisons between categories and further explore significant findings from the Chi-square tests.

To identify specific associations within the contingency table, Post-hoc pairwise comparisons are conducted using standardised residuals. Standardised residuals are calculated as in equation (5.6).

$$R = \frac{(O_i - E_i)}{\sqrt{E_i}} \quad (5.6)$$

Standardised residuals (R) are calculated to identify significant contributions of specific cells to the Chi-square statistic. A threshold of $|R| > 1.96$ was used in this study, corresponding to a 95% confidence level. Residuals exceeding this threshold are considered statistically significant, indicating cells with observed frequencies significantly higher or lower than expected.

Additionally, Bonferroni correction was applied to control for Type I (false-positive) errors caused by multiple comparisons. The Bonferroni-adjusted significance level is computed as in equation (5.7):

$$\alpha_{adjusted} = \frac{\alpha}{k} \quad (5.7)$$

Where α is the original significance level and k is the number of pairwise comparisons.

Cells with significant residuals ($|R| > 1.96$) and adjusted p-values below 0.05 were identified as contributing significantly to the observed association. This approach ensures that meaningful patterns are detected while minimizing the risk of false-positive findings.

By integrating the Chi-square test with Post-hoc analysis and Bonferroni correction, this study provides a robust framework for understanding the associations between energy poverty definitions and selected criteria.

5.3 Results and Discussions

This section presents the findings of this study, including a snapshot of households in the dataset, a comparative analysis of energy poverty definitions, and the results of the EEOS fee simulation. The implications of these findings are discussed in the context of EEOS, focusing on mitigating energy poverty and ensuring social equity.

5.3.1 Snapshot of households

The heating systems of households, and the types of fuels used are shown in Figure 5.1.

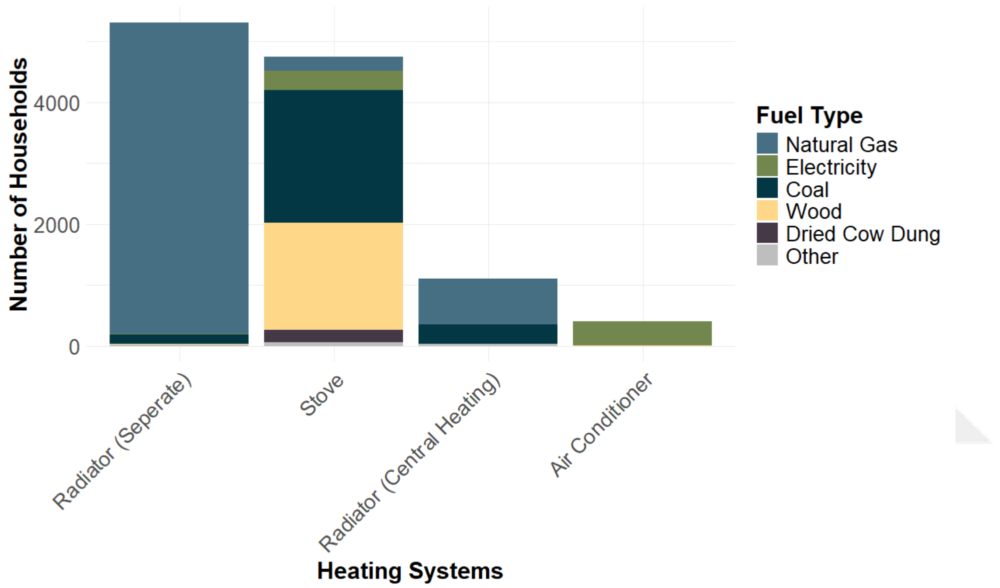

Figure 5.1 : Heating Systems and Fuel Types of Households.

The separate radiator system stands out as the most used heating method among households and is largely supported by natural gas. Central heating systems are mostly fuelled by natural gas however, coal has a visible share in this heating system. In households where stoves are used, there is a diversity of traditional fuel types such as wood and coal have a significant share. Also, biomass-based fuels such as dried cow dung also have a considerable usage rate in stove heating system. Air conditioning is a less commonly used heating system among households. The prevalence of traditional fuel types among stove users highlights a lack of access to modern energy services in these households, indicating their potential vulnerability to energy poverty.

Figure 5.2 compares different dwelling types vs household types. Multi-unit buildings have the highest number of dwelling type, and it is seen that nuclear families consisting of couples with children are concentrated mostly in this type of dwelling.

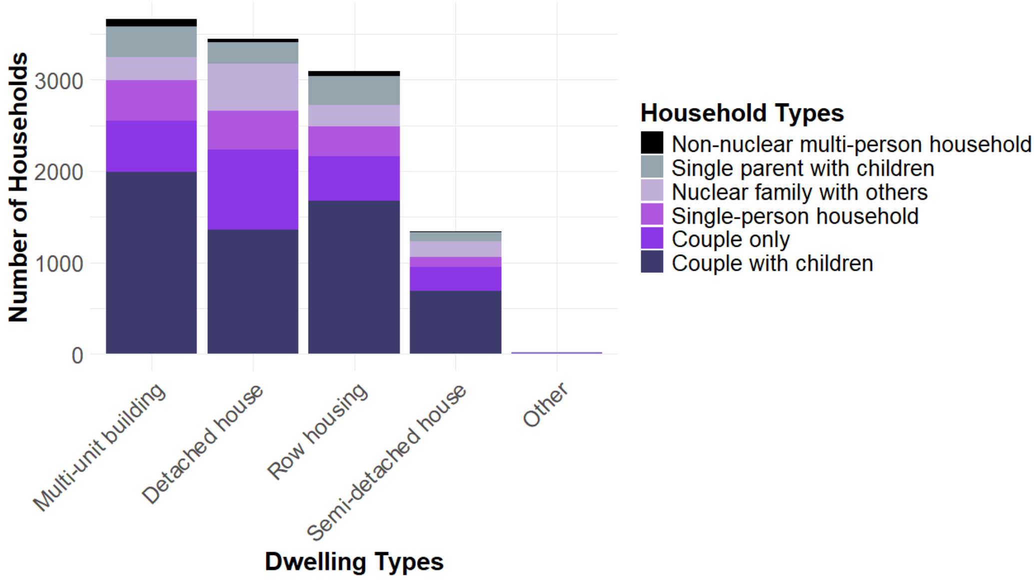

Figure 5.2 : Dwelling Types vs Household Types.

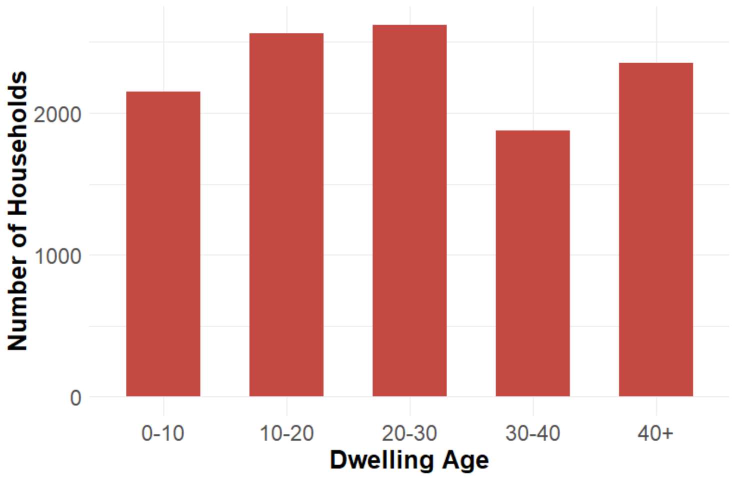

Figure 5.3 : Dwelling Age Distribution.

Figure 5.3 shows the distribution of households according to dwelling age. While 20-30 years old buildings host the largest number of households, 30-40 years old buildings are seen to be relatively less preferred. However, it is noteworthy that the number of households living in buildings older than 40 years is increasing again. This situation provides important clues about the diversity of housing age, household preferences and housing stock. When evaluated from an energy poverty perspective, it is predicted that older buildings generally have lower energy efficiency and therefore may have higher heating energy costs.

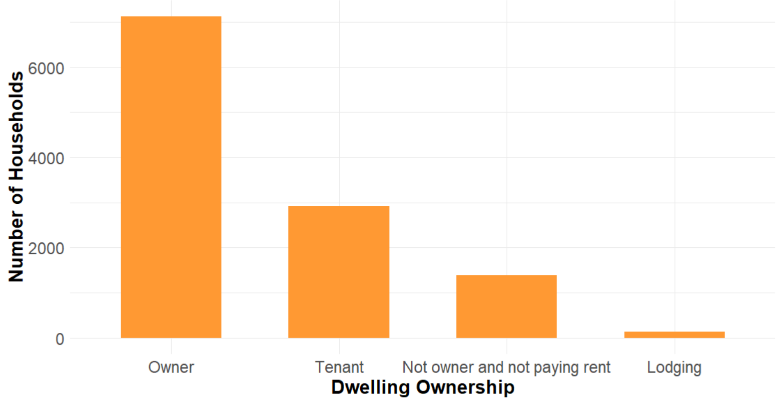

Figure 5.4 : Ownership Status of Dwellings.

Figure 5.4 shows the ownership status of the dwellings. Owner households constitute the vast majority, while tenant households are represented at a lower rate. Households that do not pay rent but do not own property and households living in housing such as lodgings have a very low share. In terms of energy poverty, it should be noted that owner households, especially those living in older buildings, may have the potential to make energy efficiency investments, but such investments are often neglected in low-income groups. Tenant households, on the other hand, may not have control over improvements such as energy efficiency or insulation, and this may increase the difficulties related to energy costs. The limited influence of tenant households, especially on factors that directly affect energy costs, may cause this group to be in a more vulnerable position in terms of energy poverty.

Figure 5.5 shows the availability of basic infrastructure amenities in dwellings.

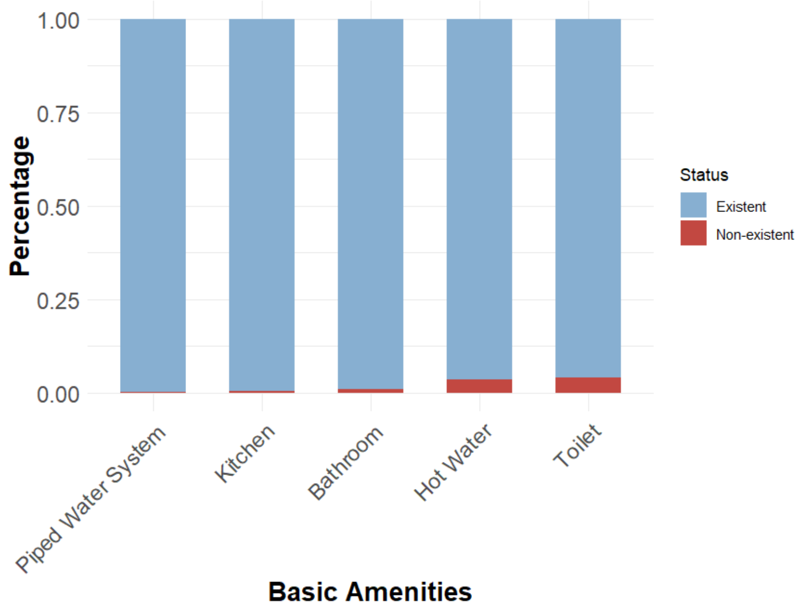

Figure 5.5 : Basic Infrastructure Amenities in Dwellings.

In general, it is seen that basic infrastructure amenities are largely available. However, there are a few households that are deficient in some amenities such as Hot Water and Toilet. When evaluated in the context of energy poverty, it can be thought that households without access to hot water have difficulty in accessing energy use or cannot afford these services due to energy costs. Similarly, situations where access to a basic service such as a toilet is lacking may indicate not only energy poverty but also the general level of poverty. Such infrastructure deficiencies indicate a multidimensional poverty problem that needs to be addressed with general social policies as well as energy policies.

Figure 5.6 shows the ownership of household appliances. It is seen that basic household appliances such as refrigerators and washing machines are available in almost all households. However, it is noteworthy that the ownership rates of appliances such as dishwashers, deep freezers, air conditioners and clothes dryers are significantly low. When evaluated in the context of energy poverty, these differences in ownership rates can be associated with the income levels and energy consumption capacities of households. These findings provide important clues for understanding the energy consumption profiles of households and developing policies aimed at increasing energy efficiency.

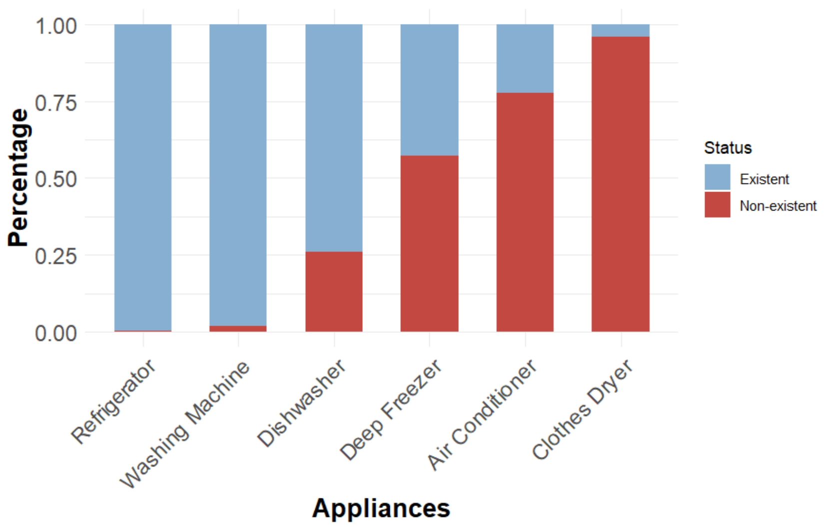

Figure 5.6 : Ownership of Household Appliances

Before starting the comparative analysis, to better understand household financial capacity and spending patterns in the context of energy poverty, Figure 5.7 is created which shows the distribution of Annual Energy Expenditure, Annual Total Expenditure, and Annual Disposable Income across income quintiles (Q1-Q5). The y-axis uses a logarithmic scale to accommodate the wide range of incomes. This helps in visualizing the distribution more clearly but also emphasizes the disparity between Q1 and Q5.

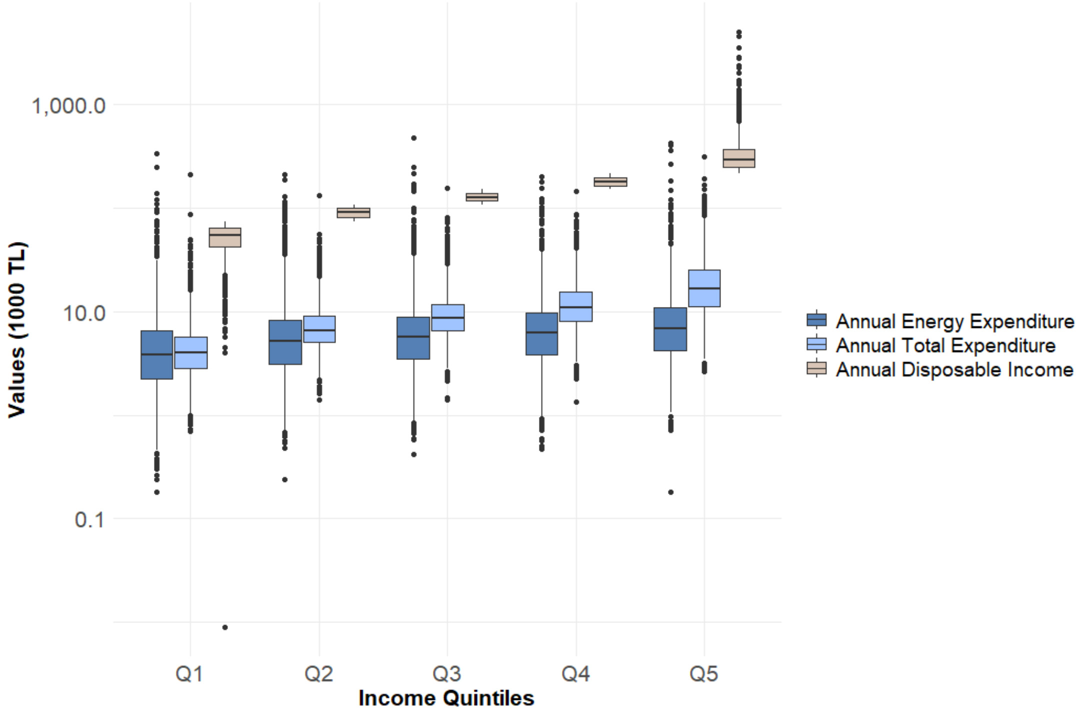

Figure 5.7 : Box Plots of Income Quintiles' Annual Disposable Income and Energy Expenditures

As expected, the median income increases steadily from Q1 to Q5, reflecting the ascending nature of income quintiles. In the lowest income quintile (Q1), many households clustered near the lower end of the income scale. On the other hand, the highest income quintile (Q5) displays many outliers at the upper end, indicating the presence of exceptionally high-income households within this group. Annual Energy Expenditure remains relatively stable across income quintiles, indicating a saturation effect; higher-income households may spend more on energy, but the increase is not proportional to income growth. In the lowest income quintiles (Q1 and Q2), energy expenditures represent a substantial proportion of disposable income, highlighting a potential vulnerability to energy poverty. Notably, energy expenditures exhibit substantial variability in lower quintiles, with some households reporting disproportionately high energy costs. Conversely, in Q5, energy expenditures constitute a minor fraction of disposable income. This disparity indicates the regressive nature of energy costs and underscores that energy poverty alleviation policies should prioritize lower-income households, where energy costs pose a disproportionate burden. Annual Total Expenditure follows a clearer upward trend, mirroring the increase in disposable income. The gap between total expenditure and disposable income is more pronounced in lower quintiles, suggesting a higher proportion of income is allocated to expenditures, including energy, possibly indicating financial constraints.

5.3.2 Comperative analysis of energy poverty definitions

According to different energy expenditure and income-based energy poverty definitions, energy poverty rates in Türkiye were calculated. Table 5.1 shows the energy poverty rates of Türkiye according to different energy poverty definitions.

Table 5.1 : Energy Poverty Rates of Türkiye.

Energy Poverty Definition	Energy Poverty Rates
10%	15.75%
2x Median Share	20.54%
LIHC	7.28%

Since each approach defines energy poverty differently, the results vary from each other. Türkiye has an energy poverty rate ranging from 7.28% to 20.54%.

Table 5.2 provides a comparative analysis of energy-poor households in Türkiye based on different energy poverty definitions. The rows represent energy poverty status and “n” column reflects the number of households in each combination.

Table 5.2 : Comparative Energy Poverty Analysis of Türkiye.

10%	2xMedian Share	LIHC	n
FALSE	FALSE	FALSE	9151
FALSE	FALSE	TRUE	36
FALSE	TRUE	FALSE	462
FALSE	TRUE	TRUE	92
TRUE	TRUE	FALSE	1107
TRUE	TRUE	TRUE	714

A total of 714 households satisfies all the definitions, highlighting them as the most vulnerable in terms of energy poverty. Analysis reveals that 2,411 households (20.8%) meet at least one energy poverty definition. Among them, 1,199 households (10.4%) fulfil at least two definitions. These layers of inclusion highlight the variations in household categorization depending on the chosen definitions. This analysis can help to understand more clearly the level of inclusiveness of energy poverty definitions. Table 5.3 shows the energy poverty rates in the income quintiles.

Table 5.3 : Energy Poverty Rates in Income Quintiles.

Energy Poverty Definitions	**Energy Poverty Rates (%)**				
	Q1	**Q2**	**Q3**	**Q4**	**Q5**
10%	37.01	20.71	12.54	6.23	2.25
2xMedian Share	44.44	28.53	17.6	9.13	2.98
LIHC	33.42	2.98	0	0	0

As expected, energy poverty rates are highest in Q1 and decrease as income increases. The 10% and the 2x Median Share approaches show relatively higher energy poverty rates for low-income households. These rates decrease in higher income quintiles, indicating that these definitions capture a broader sense of energy poverty among lower-income groups. The LIHC shows a steeper drop across quintiles, with Q1 at 33.42% but virtually no energy poverty beyond Q2. While each approach captures different dimensions of energy poverty, all approaches show that the lowest-income households are the most vulnerable. However, the differences in the results indicate that the definition used plays a crucial role in identifying energy poverty.

While different energy poverty definitions have some overlaps, they also target distinct households. But which of these definitions better identifies energy-poor households? To address this question, the definitions were compared based on specific criteria. These criteria were determined by considering the key drivers of energy poverty and the variables available in the dataset. For the low-income driver, the ability to capture lower-income quintiles was used as a criterion. For high energy prices, energy bills per square meter were selected, which also served as an indicator of the energy inefficiency of dwellings when considered alongside the age of the dwelling. Additionally, to capture access to modern energy sources, a key element in the fundamental definition of energy poverty, fuel class (conventional or modern) was included as a comparison.

To compare energy poverty definitions statistically, Chi-square tests and Post-hoc analyses were conducted. To create contingency tables, it was necessary to categorize households into a single column based on the energy poverty definition that the household met. However, some households met more than one energy poverty definition. Therefore, the categorization was prioritized by starting with the definition that covered the fewest households and progressing to the one that covered the most. Therefore, sequential categorization started with LIHC and continued with 10%, and 2x Median Share, respectively. This categorization allows for the examination of the unique effects of each definition while enabling a clear comparison of the differences between the definitions. After the sequential categorization, the final household counts of definitions are 842, 1,107, and 462 for LIHC, 10%, and 2x Median Share, respectively. In addition, 9,151 households that do not meet any of the energy poverty definitions were added to the comparison as "No Energy Poverty" to increase the efficiency of the analysis.

- **Income Quintiles**

Firstly, the association between energy poverty definitions and income quintiles is examined. Table 5.4 gives the contingency table of this analysis. Tables 5.5 gives the Chi-square test results, while Table B.1 gives the Post-hoc analysis results in the Appendix B. Figure 5.8 shows the residual heat map of the analysis.

Table 5.4 : Contingency Table of Energy Poverty Definitions vs Income Quintiles.

			Income Quintiles				
			Q1	**Q2**	**Q3**	**Q4**	**Q5**
Energy Poverty Definitions	**10%**	Observed Counts	183	438	290	144	52
		Expected Counts	221.46	221.46	221.36	221.36	221.36
	2x Median Share	Observed Counts	94	167	117	67	17
		Expected Counts	92.42	92.42	92.38	92.38	92.38
	LIHC	Observed Counts	773	69	0	0	0
		Expected Counts	168.44	168.44	168.37	168.37	168.37
	No Energy Poverty	Observed Counts	1263	1639	1905	2101	2243
		Expected Counts	1830.67	1830.67	1829.88	1829.88	1829.88

Table 5.5 : Chi-square Results of Energy Poverty Definitions vs Income Quintiles.

Chi-square value	Degree of Freedom	Significance
3597.8	12	0.000

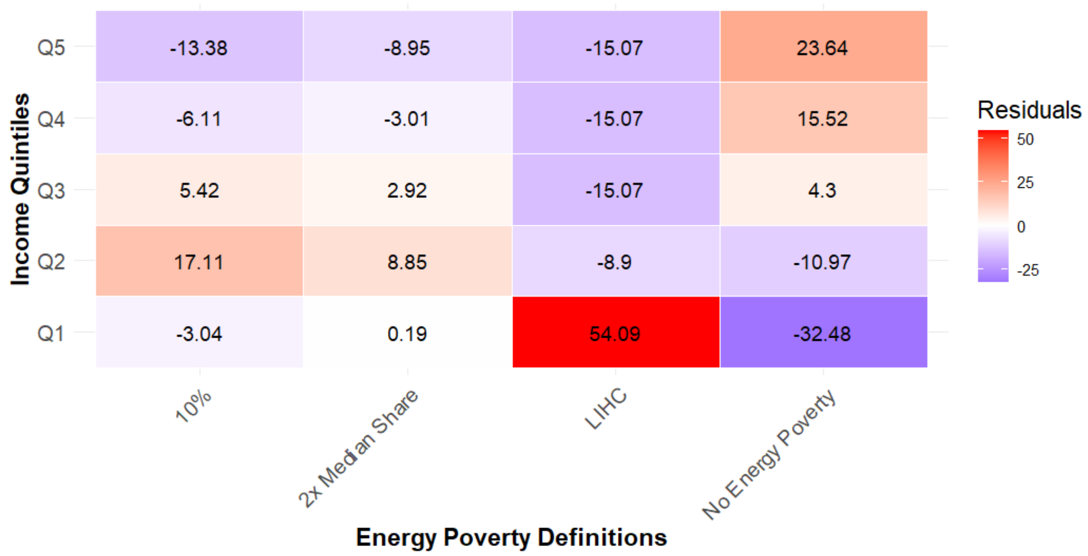

Figure 5.8 : The Residual Heat Map of Energy Poverty Definitions vs Income Quintiles.

The chi-square test reveals a statistically significant association between income quintiles and energy poverty definitions, indicating that income level plays a role in determining energy poverty. To determine which energy poverty definition is more effective in capturing this association, it is necessary to examine the Post-hoc analysis results and the residual heat map visualizing these outcomes.

The heat map highlights associations visually, and the residuals indicate whether observed values are higher or lower than expected under the assumption of independence. While positive residuals say that the observed count is higher than expected, negative residuals say that the observed count is lower than expected. Residual values close to zero indicate no strong deviation from expectation. The absolute value of a residual is higher than 1.96, which means it is statistically significant. Darker colours on the heat map correspond to stronger residuals.

The standardised residuals highlight important findings. As expected, the No Energy Poverty category is strongly associated with the highest income quintiles, as evidenced by high positive residuals, while showing significant negative residuals in the lowest quintile. This indicates that households in higher income quintiles are predominantly free from energy poverty, while those in the lowest quintile are less likely to fall into this category.

The residual heatmap reflects the impact of the sequential categorization process on energy poverty classification across income quintiles. As households meeting multiple definitions were assigned to the least populated category first, the LIHC definition appears to capture the broadest range of energy-poor households in Q1, evident in its strong positive residual. This supports that LIHC includes not only its unique cases but also households classified as energy-poor under all definitions, making it statistically dominant in energy poverty identification.

The 10% definition shows a notable positive residual in Q2 (+17.11), indicating that it classifies a significant number of middle-low-income households as energy-poor. However, its presence in Q1 is weak (-3.04), likely because many of the lowest-income households had already been assigned to LIHC due to the sequential categorization process. Ideally, capturing more Q1 households outside of LIHC would have strengthened its ability to identify energy-poor households in the lowest income group. Instead, its remaining classifications appear more dispersed across Q2 and Q3, reflecting previous critiques that it sometimes includes households that may not be among the most vulnerable.

The 2x Median Share definition, which was the last step in the sequential categorization, had the chance to highlight its unique cases; households that were not classified as energy-poor under either LIHC or 10%. However, its residuals remain relatively weak across all quintiles, suggesting that it failed to provide strong additional insights beyond the other definitions. While it captures some households in Q2 (+8.85), its presence in Q1 is minimal, indicating that the households it identifies as energy-poor are more scattered across different income levels. This outcome shows that, despite having an independent role in classification, the 2x Median Share definition does not effectively distinguish energy-poor households in a way that sets it apart from the other definitions.

- **Fuel Class**

The association between energy poverty definitions and fuel class, categorized as Conventional and Modern, was examined. Modern fuels refer to natural gas and electricity, while conventional fuels include coal, wood, dried cow dung and other. Table 5.6 gives the contingency table of this analysis. Tables 5.7 gives the Chi-square test results, while Table B.2 gives the Post-hoc analysis results in the Appendix B. Figure 5.9 shows the residual heat map of the analysis.

Table 5.6 : Contingency Table of Energy Poverty Definitions vs Fuel Class Analysis.

Energy Poverty Definitions			Fuel Class	
			Conventional	Modern
	10%	Observed Counts	618	489
		Expected Counts	454.88	652.12
	2x Median Share	Observed Counts	204	258
		Expected Counts	189.84	272.16
	LIHC	Observed Counts	510	332
		Expected Counts	345.99	496.01
	No Energy Poverty	Observed Counts	3419	5732
		Expected Counts	3760.28	5390.72

Table 5.7 : Chi-square Results of Energy Poverty Definitions vs Fuel Class Analysis.

Chi-square value	Degree of Freedom	Significance
285.64	3	0.000

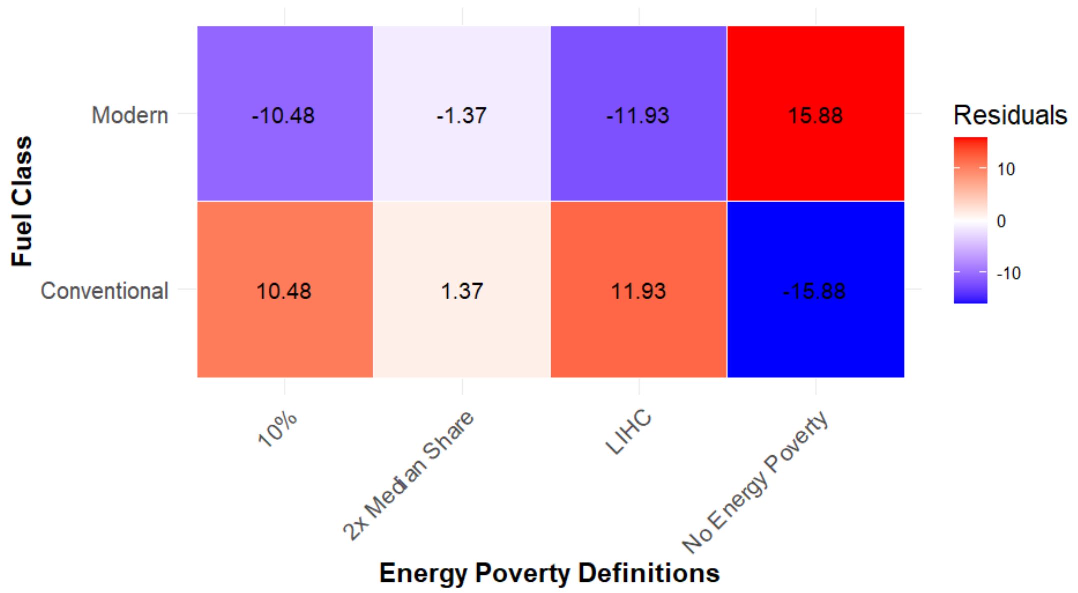

Figure 5.9 : Residual Heat Map of Energy Poverty Definitions vs Fuel Class Analysis.

The Chi-square results indicate a significant association between energy poverty definitions and fuel classes. This means that the type of fuel a household uses is not randomly distributed across energy poverty definitions; rather, certain definitions are more likely to classify households using specific fuel types as energy-poor.

The 10% and LIHC definitions showed a significant positive association with conventional fuel usage and a negative association with modern fuels. This means that households falling under these definitions rely more on conventional fuels. However, it should be noted that energy poverty is not solely limited to households using conventional fuels; even with access to modern energy services, affordability remains a critical factor in determining energy poverty.

Households in the No Energy Poverty category showed a strong positive association with modern fuel usage and a negative association with conventional fuels. However, this category includes a significant number of households using conventional fuels (3202), alongside those using modern fuels (5585). This could be due to several factors: their incomes may exceed the thresholds set by energy poverty definitions, or their energy expenditures might be low. For instance, in rural areas, households may access conventional fuels at little or no cost, reducing their overall energy expenses. Additionally, if the survey was conducted during non-winter months, their energy consumption, especially for heating, might have been lower than usual, potentially masking seasonal energy burdens. However, this situation raises the possibility of “hidden energy poverty”. Similarly, there may be households that tend to under consume modern fuel types due to affordability considerations. This is again the issue of hidden energy poverty. Further analysis of seasonal energy consumption and income levels is needed to assess whether these households are truly free from energy poverty or simply exhibit suppressed energy demand.

On the other hand, the presence of modern fuel users within energy poverty definitions indicates that affordability also remains a determinant of energy poverty. Simply having access to modern energy sources does not guarantee affordability, as high energy costs relative to household income push households into energy poverty. In contrast with the 10% and LIHC, 2x Median Share definition showed no significant associations with either fuel class, shows a more neutral distribution of fuel types for households under this definition. Therefore, 2x Median Share definition also failed to bring significancy to the fuel class criteria.

Designing effective interventions requires a multifaceted approach that considers income levels, fuel types, and seasonal energy consumption dynamics. These findings emphasize the need for energy poverty definitions and policies that are sensitive to the complex interplay of affordability and fuel type.

- **Energy Bill per Square Meter**

The association between energy poverty definitions and energy bill per square meter is investigated. To create energy bill per square meter categories total energy expenditure values divided to 5 quintiles. The comparison was conducted to ensure a more equivalent and standardised evaluation of energy expenditures across households. Larger homes typically consume more energy, which could obscure affordability challenges if energy costs were assessed without accounting for the size of the household. By normalizing energy expenditures to a per-square-meter scale, this analysis aimed to provide a clearer perspective on energy costs relative to household size and evaluate how effectively different energy poverty definitions capture this issue. Table 5.8 gives the contingency table of this analysis. Tables 5.9 gives the Chi-square test results, while Table B.3 gives the Post-hoc analysis results in the Appendix B. Figure 5.10 shows the residual heat map of the analysis.

Table 5.8 : Contingency Table of Energy Poverty Definitions vs Energy Bill per Square Meter.

			Energy Bill per Square Meter				
			Lowest	**Low**	**Medium**	**High**	**Highest**
Energy Poverty Definitions	**10%**	Observed Counts	29	54	78	151	795
		Expected Counts	221.46	221.36	221.46	221.27	221.46
	2x Median Share	Observed Counts	15	36	71	146	194
		Expected Counts	92.42	92.38	92.42	92.34	92.42
	LIHC	Observed Counts	2	24	164	313	339
		Expected Counts	168.44	168.37	168.44	168.30	168.44
	No Energy Poverty	Observed Counts	2267	2198	2000	1701	985
		Expected Counts	1830.67	1829.88	1830.67	1829.09	1830.67

Table 5.9 : Chi-square Results of Energy Poverty Definitions vs Energy Bill per Square Meter.

Chi-square value	Degree of Freedom	Significance
3320.3	12	0.000

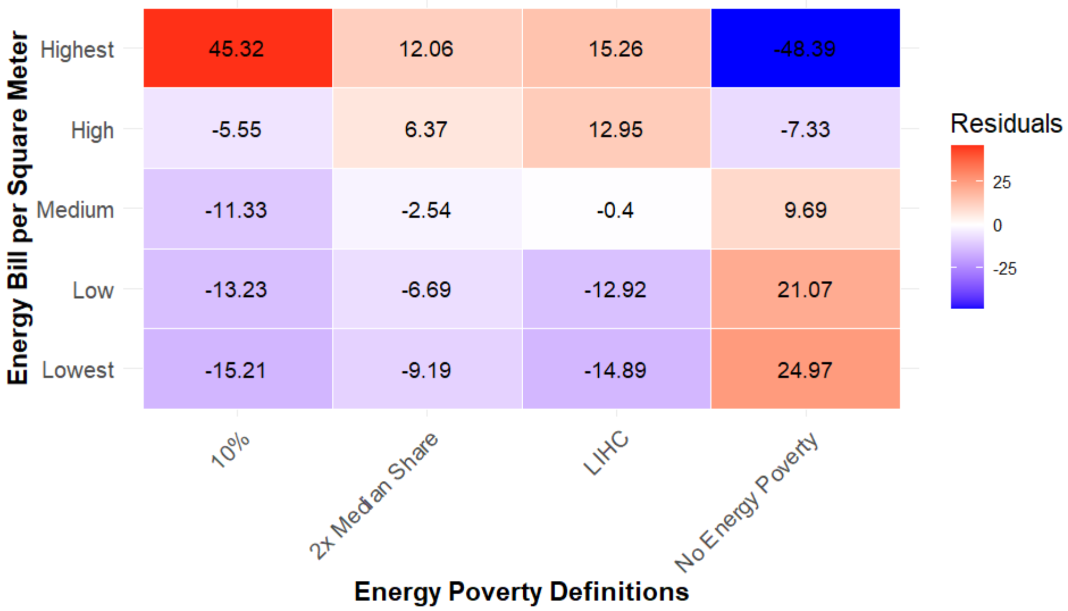

Figure 5.10 : Residual Heat Map of Energy Poverty Definitions vs Energy Bill per Square Meter.

The Chi-square test result indicates a statistically significant association between energy poverty definitions and energy bill per square meters categories. This means that energy poverty classifications are not randomly distributed across different levels of energy bill per square meter. Certain energy poverty definitions are more likely to capture households with higher or lower energy costs relative to their living space.

Residual heat map shows that all definitions demonstrated positive significant associations with households in the highest energy bill per square meter category and negative significant associations with households in the lowest energy bill per square meter category.

The 10% definition has a strong positive residual (+45.32) in the highest category, meaning it classifies far more high-energy-cost households as energy-poor than expected. The 10% definition has often been criticized in the UK context for misclassifying large households or mansions with high total energy consumption as energy-poor. This critique highlights the definition's reliance on total energy expenditures relative to income, which can overlook the influence of household size. However, in the Turkish context, the analysis shows that the 10% definition performs well. Despite the sequential categorization process favouring LIHC, the 10% definition still demonstrates a strong ability to capture households with the highest energy bills per square meter. Given that high energy bills per square meter can also indicate poor energy efficiency, the strong presence of these households under the 10% definition suggests that this measure is sensitive to identifying households facing financial strain due to inefficient dwellings. Meanwhile, 2x Median Share, categorized last, still includes some high-energy-cost households (+12.06), indicating that a portion of energy-inefficient or high-cost households remained uncaptured by previous definitions and were uniquely classified under this category.

The No Energy Poverty category predominantly includes households with lower energy bill per square meter values. This aligns with expectations, as such households typically have manageable energy expenditures relative to their income. However, underrepresentation in the highest quintile (residual = -48.39) indicates that some households manage to avoid energy poverty despite high energy costs, likely due to higher income levels. However, this approach may still overlook households that deliberately under consume energy due to affordability constraints. Households that restrict their energy use may not exhibit high expenditures per square meter despite struggling with energy poverty. This finding highlights the need for a broader perspective in energy poverty measurement that encompasses both high-cost burdens and suppressed energy demand.

- **Dwelling Age**

The association between energy poverty definitions and dwellings age is examined. Table 5.10 gives the contingency table of this analysis. Tables 5.11 gives the Chi-square test results, while Table B.4 gives the Post-hoc analysis results in the Appendix B. Figure 5.11 shows the residual heat map of the analysis.

Table 5.10 : Contingency Table of Energy Poverty Definitions vs Dwelling Age.

			Dwelling Age				
			0-10	**10-20**	**20-30**	**30-40**	**40+**
Energy Poverty Definitions	**10%**	Observed Counts	185	213	253	189	267
		Expected Counts	206.04	245.11	251.04	179.71	225.09
	2x Median Share	Observed Counts	75	101	108	76	102
		Expected Counts	85.99	102.29	104.77	75.00	93.94
	LIHC	Observed Counts	122	135	188	145	252
		Expected Counts	156.72	186.43	190.95	136.69	171.21
	No Energy Poverty	Observed Counts	1770	2111	2073	1467	1730
		Expected Counts	1703.25	2026.17	2075.24	1485.59	1860.75

Table 5.11 : Chi-square Results of Energy Poverty Definitions vs Dwelling Age.

Chi-square value	Degree of Freedom	Significance
93.018	12	0.000

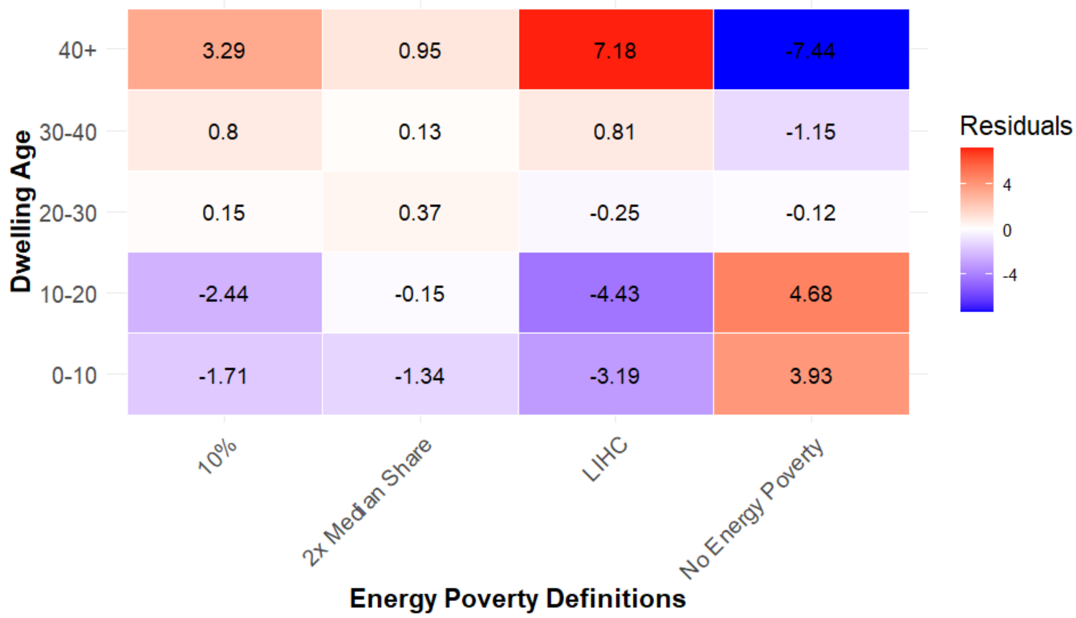

Figure 5.11 : Residual Heat Map of Energy Poverty Definitions vs Dwelling Age.

The significant Chi-square test shows an association between energy poverty definitions and dwelling age, indicating that certain dwelling age categories are more likely to be associated with energy poverty.

According to results, LIHC shows strong positive association with older (40+ years) potentially less efficient dwellings and negative associations with newer dwellings (0–10 years and 10–20 years). Similarly, the 10% definition also shows overrepresentation (+3.29) for the 40+ category. Despite LIHC's advantage in the sequential categorization, the 10% definition still demonstrates a significant capacity to capture potentially energy-poor households. Conversely, the 2x Median Share definition presents a more neutral relationship with dwelling age compared to other energy poverty definitions and it fails to provide additional differentiation. The No Energy Poverty category exhibits a strong connection to newer dwellings, emphasizing the role of energy-efficient construction in reducing energy poverty risks. These findings highlight the importance of retrofitting older housing stock and advancing energy-efficient building practices to address energy poverty more effectively.

The comparative analysis of energy poverty definitions in Türkiye highlights critical differences in their ability to identify and address energy-poor households. The LIHC definition stands out as the most precise and impactful, capturing the most vulnerable households, particularly those in the lowest income quintile (Q1). Its strong association with affordability indicators highlights its ability to target energy poverty effectively. On the other hand, the 2x Median Share definition consistently provides the weakest results, showing minimal statistical significance across comparison criteria. These outcomes can be partially attributed to the sequential prioritization used in the categorization process. LIHC covers an intense range of energy-poor households, making it statistically stronger. Although the 2x Median Share definition may appear disadvantaged in the sequential categorization process, it had the opportunity to highlight its unique aspect by identifying households classified as energy-poor solely under its criteria. However, its neutral associations with comparison criteria demonstrate that this definition remains insufficient in providing distinctive insights beyond other energy poverty definitions. Between those extremes, 10% definition performs reasonably well. The 10% definition, often critiqued in other contexts, works fine in Türkiye, especially when adjusted for energy bill per square meter. Even after LIHC has absorbed a significant portion of energy-poor households, the 10% definition still provides meaningful insights, effectively capturing additional cases.

In summary, the LIHC definition provides the most robust insights into energy poverty. The 10% definition complements this with broader but meaningful coverage. The 2x Median Share definition, while inclusive in theory, struggles to provide unique insights. These findings emphasize the importance of understanding both the strengths of each definition and the methodological impacts of categorization when analysing energy poverty. However, these definitions still fall short in capturing hidden energy poverty, particularly for households that deliberately under-consume energy due to affordability constraints. The inability to measure suppressed demand means that some energy-poor households may remain overlooked. Additionally, relying on assumptions about energy inefficiency rather than actual data limits the accuracy of identifying households struggling with inefficient dwellings. Incorporating direct indicators of energy deprivation and verified efficiency metrics would provide a more comprehensive understanding of energy poverty and improve the targeting of policy interventions. A nuanced approach combining the strength of these definitions, while also incorporating indicators for under-consumption patterns and energy inefficiency, could enhance the effectiveness of future energy poverty analyses and interventions.

5.3.3 2024 year-end update

To reflect 2024 year-end values, the 2022 HBS dataset was updated by adjusting energy expenditures and disposable income based on official data. Electricity and natural gas unit prices increased 20% and 40%, respectively. For other fuels without regulated tariffs, energy expenditures were updated using TurkStat's inflation rates (64.8% for 2023 and 44.4% for 2024). Disposable incomes were adjusted using TurkStat's income growth rates for 20% income quintiles. The average disposable income increase rate is 277% among income quintiles. Table 5.12 gives the estimated change in energy poverty rates in Türkiye between 2022 and the projected values for 2024 (2024e) across energy poverty definitions.

Table 5.12 : Estimated Change in Energy Poverty Rates of Türkiye.

Energy Poverty Definitions	Energy Poverty Rates		
	2022	2024e	Change
10%	15.75%	4.23%	-11.52%
2x Median Share	20.54%	24.33%	+3.79%
LIHC	7.28%	8.86%	+1.58%

Significant variations in the rates are observed, reflecting the impact of Türkiye’s economic and energy price dynamics during this period. The variations reflect the combined effects of rising energy prices, inflation, and significant growth in household disposable incomes during this period. Figure 5.12 shows the Venn diagrams of energy poverty definitions in 2022 and 2024e household counts.

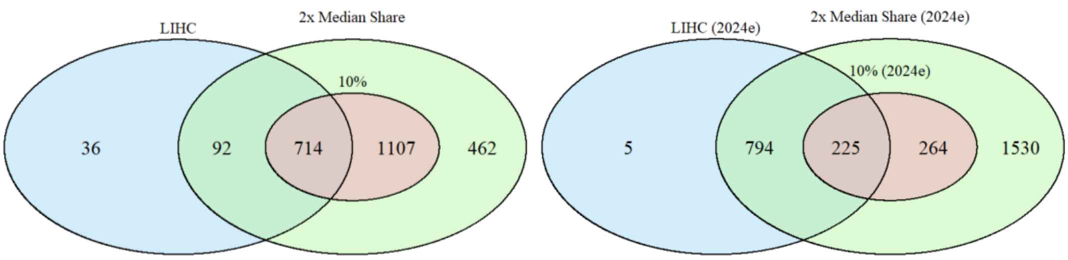

Figure 5.12 : Venn Diagrams of Energy Poverty Definitions in 2022 and 2024e.

Table 5.12 and the Venn diagrams provide complementary insights into how energy poverty definitions interact and how energy poverty rates change between 2022 and 2024e. Together, they highlight the combined effects of economic dynamics on different energy poverty definitions. The key point is that disposable incomes have grown more rapidly than energy expenditures between 2022 and 2024e.

The 10% definition displays a sharp decline in energy poverty rates and its overlap with other definitions is reduced in 2024e. This substantial decrease can be attributed to the fact that disposable incomes grew significantly faster than energy costs, causing fewer households to exceed the 10% energy cost threshold. As a result, this definition appears highly sensitive to relative changes in income- and energy expenditure proportions.

The 2x Median Share definition, on the other hand, shows the biggest increase in energy poverty rates. It captures a different reality: it identifies a broader range of households affected by rising energy prices, despite overall income growth. This is evident in its increased unique group in the Venn diagram (1,530 households in 2024e). The LIHC definition maintains their role and its modest changes highlights that households facing high energy burdens remained vulnerable, even with increased incomes.

The smaller overlap of 225 households across all definitions in 2024e, compared to 714 in 2022, suggests that the imbalance between rising disposable incomes and increasing energy costs has diversified the profiles of energy-poor households, leading to a more fragmented classification across different definitions. While all definitions incorporate both income- and energy expenditure, their differing weighting mechanisms have caused them to capture increasingly distinct groups over time. The sharp decline in unique cases of LIHC and 10% classifications reflects how rapid income growth has shifted affordability-based classifications, whereas the expansion of 2x Median Share shows that high relative energy costs remain a persistent issue. This fragmentation highlights the evolving nature of energy poverty under changing economic conditions and emphasizes the need for a more integrated approach that captures both absolute and relative energy cost burdens in future policy considerations.

These results emphasize the need to rethink energy poverty definitions for Türkiye's evolving economic conditions, ensuring that policy interventions capture the full extent of energy vulnerability.

5.3.4 EEOS fee simulation

EEOS has been recognized for its potential distributional impacts to create or exacerbate energy poverty. As Türkiye plans to implement an EEOS, assessing its potential effects on energy poverty is critical for both households and policymakers.

In this study, the impact of a 5% increase in total energy bills on energy poverty rates was simulated using data from both 2022 HBS and 2024e values. The 5% fee rate was chosen based on findings from the literature, where EEOS fee rates are typically reported to range between 2% and 5% (RAP, 2016). Table 5.13 provides a simulation of energy poverty rates after adding a 5% EEOS fee to household energy bills.

Table 5.13 : 5% EEOS Fee Simulation.

Energy Poverty Definitions	**Energy Poverty Rates**					
	Base line 2022	**5% EEOS Fee 2022**	**Change**	**Base line 2024e**	**5% EEOS Fee 2024e**	**Change**
10%	15.75%	17.15%	+1.4%	4.23%	4.47%	+0.24%
2xMedian Share	20.54%	20.54%	0%	24.33%	24.33%	0%
LIHC	7.28%	7.28%	0%	8.86%	8.86%	0%

Table 5.13 shows that the 5% EEOS fee has a slight impact on energy poverty in Türkiye. Only the 10% definition, reveals a modest distributional impact, particularly in 2022. This means that the 10% definition is highly sensitive to proportional increases in energy costs. The lack of sensitivity in 2x Median Share is expected, as the definition is based on relative energy expenditures compared to the median. Since the EEOS fee uniformly increases energy bills across households, the relative distribution remains unchanged, leaving energy poverty rates unaffected. The LIHC definition is less sensitive to uniform fee increases because they incorporate additional thresholds. The proportional increase in energy costs does not shift households across these thresholds significantly, resulting in stable energy poverty rates.

Given that the EEOS fee did not drastically change energy poverty rates, policymakers should be cautious when interpreting these results, as they may underestimate the real financial strain on vulnerable households. The 5% EEOS fee imposes an additional financial burden on low-income households, which are already struggling with high energy bills and limited disposable income, even a modest fee increase may exacerbate financial difficulties. In this context, the stable energy poverty rates observed in the simulation might mask underlying challenges. While these households may not cross the thresholds of standard energy poverty definitions, the higher energy bills resulting from the EEOS fee could contribute to increased living costs, reducing their capacity to afford other essential goods and services.

Furthermore, the concept of "hidden energy poverty" highlights a critical limitation of income- and energy-expenditure-based energy poverty measures. The results of the EEOS fee simulation support this concern, as the 5% increase in energy bills did not significantly change measured energy poverty rates under most definitions. This implies that some households may have absorbed the additional cost by further reducing their energy consumption, potentially worsening living conditions without being captured by energy poverty definitions. Consequently, the simulation results may underestimate the true financial burden imposed by the EEOS fee, particularly for households already experiencing constrained energy use.

In recent years, high inflation rates have significantly shaken purchasing power, making it increasingly difficult for households to manage basic expenses. The rise in energy prices, coupled with persistent inflation, has placed additional pressure on low-income and vulnerable households. While the 5% EEOS fee may appear negligible in isolation, it adds to a broader economic strain, particularly for those already grappling with hidden energy poverty.

Reassessing the EEOS simulation to incorporate broader energy poverty definitions, including hidden energy poverty, would provide a more accurate understanding of the scheme's potential impact. Current income- and energy expenditure-based definitions may fail to capture households that limit their energy use, leading to an underestimation of the policy's true burden. To mitigate these effects, policies should not only address energy costs but also consider fuel types, household energy efficiency levels, and the actual living conditions of vulnerable populations. This approach would ensure that households experiencing hidden energy poverty are not overlooked in EEOS program design, thereby strengthening the scheme's effectiveness in targeting those most in need of energy efficiency interventions.

5.4 Summary of Key Findings and Insights

This chapter provided a comparative analysis of income- and energy expenditure-based energy poverty definitions for Türkiye, assessing their implications in the context of a possible EEOS. Using the 2022 HBS and projected 2024 values, the analysis revealed that energy poverty classifications vary significantly depending on the definition used, leading to different interpretations of energy vulnerability. The findings highlight the strengths and weaknesses of different definitions and their ability to capture vulnerable households. The LIHC definition emerged as the most precise in identifying energy-poor households, while the 10% definition, despite its broad scope, demonstrated meaningful coverage. The 2x Median Share definition, however, struggled to provide unique insights and appeared less effective in targeting energy-poor households. These findings emphasize the importance of carefully selecting energy poverty definition when designing policies to mitigate energy vulnerability.

Furthermore, the results emphasize the importance of considering hidden energy poverty, which remains a limitation in current income- and energy expenditure-based definitions. Households that deliberately under consume energy due to affordability constraints may not be fully captured under existing definitions, leading to underestimations of energy poverty rates. Additionally, energy inefficiency emerges as a critical factor, as households with high energy bills per square meter or older dwellings are disproportionately classified as energy-poor. However, relying on assumptions rather than actual efficiency data presents a challenge in accurately identifying households struggling with energy-inefficient dwellings.

The 2024 year-end economic update revealed significant shifts in energy poverty rates, demonstrating the impact of rising disposable incomes and fluctuating energy costs. While the 10% definition showed a sharp decline in energy poverty rates due to income growth, the 2x Median Share approach captured a broader range of households affected by increasing energy costs. The divergence of energy poverty definitions over time indicates that energy vulnerability is a dynamic issue, requiring flexible and adaptive policy measures.

The EEOS fee simulation further points out the complex relationship between energy affordability and policy interventions. While a 5% EEOS fee increase on energy bills did not drastically shift measured energy poverty rates, it placed an additional burden on low-income households, reducing their financial flexibility. Simulation results also emphasize the need for policies that go beyond a narrow focus on energy expenditure thresholds. This highlights the risk of underestimating the real burden of such policies when only standard definitions are applied.

Given these insights, to ensure that EEOS is equitable and effective, a comprehensive approach to energy poverty measurement is essential. This includes: (i) integrating hidden energy poverty indicators to capture households that suppress energy consumption due to affordability constraints; (ii) incorporating energy efficiency parameters rather than relying on assumptions about dwelling inefficiencies; (iii) developing policy mechanisms within EEOS that address both affordability and efficiency concerns, ensuring that energy efficiency interventions reach those most in need.

While the HBS provides a valuable dataset for analysing energy poverty, certain limitations should be acknowledged. Seasonal biases remain a key concern, as the survey is conducted throughout the year, potentially underestimating energy poverty linked to heating costs. Additionally, the dataset lacks location-specific details and indicators of dwelling inefficiency, making it challenging to fully capture the structural drivers of energy poverty. However, despite these limitations, the HBS remains the only available national dataset containing household energy expenditure data, making it invaluable for initiating discussions on energy poverty in Türkiye. To build upon these findings and address the gaps in household characteristics and locational data, the next chapter leverages the Survey of Income and Living Conditions (SILC) dataset, which provides a richer socio-economic perspective on energy poverty.

6. ADDRESSING, TARGETTING AND TACKLING ENERGY POVERTY UNDER POSSIBLE EEOS IN TÜRKİYE

In the previous chapter, the limitations of income- and energy expenditure-based energy poverty definitions in accurately capturing energy-poor households in Türkiye were demonstrated. While these definitions provide a foundational understanding, they fail to account for hidden energy poverty and inefficiency-related factors which are critical in effectively identifying and supporting vulnerable households under EEOS. A more comprehensive and context-sensitive approach is needed to ensure that EEOS implementation targets the right households and delivers meaningful social benefits.

To address these gaps, this chapter leverages the TurkStat SILC dataset, which offers detailed socio-economic and housing characteristics, as well as location data variables missing in the HBS. Additionally, SILC includes indicators relevant to energy inefficiency and hidden energy poverty, making it a valuable resource.

Given the evolving energy poverty literature, various new methodologies, indicators, and indexes have been developed to better capture the complexity of the issue. Traditional energy poverty definitions, such as income- and energy expenditure-based approaches, have limitations, particularly in identifying hidden energy poverty and accounting for housing inefficiencies. To address these gaps, recent approaches have sought to incorporate both affordability constraints and structural inefficiencies, recognizing that energy poverty is shaped by a combination of financial, infrastructural, and behavioural factors. In this context, composite indexes integrating both objective and subjective indicators offer a more nuanced perspective.

This chapter presents a data-driven approach to identifying inefficient households and prioritizing energy-poor ones within the EEOS framework. Rather than relying on predefined energy poverty definitions or existing indexes, this study develops a custom eligibility index, ensuring that households in need of prioritized interventions are effectively targeted.

The first step involves identifying all inefficient households based on selected inefficiency indicators. Following this, a set of carefully chosen financial difficulty indicators is incorporated into the eligibility index to distinguish energy-poor households within the inefficient group. The index and inefficiency indicators cluster these households into three categories: priority energy-poor, at-risk, and regular households, each of which will be treated differently under the EEOS to ensure targeted and efficient policy implementation.

To determine the weights of financial difficulty indicators for the eligibility index, a broad set of candidate variables is initially considered. The variable selection process is guided by a combination of correlation analysis, frequency distributions, and contextual relevance, ensuring that the most meaningful and distinct indicators are retained without redundancy. Once the set of six core indicators is finalized, Multiple Correspondence Analysis (MCA) is used to assign weights based on their contribution to the underlying data structure. This method allows for a consistent and statistically informed weighting scheme.

Households are grouped into three distinct clusters (priority energy-poor, at-risk, and regular) based on their eligibility index scores, inefficiency categories and regions using the k-prototypes clustering method. This approach enables a more nuanced and empirically grounded clustering, enhancing the targeting strategy under the EEOS framework. Overall, the study integrates statistical and machine learning methods to create a robust and data-oriented analytical design.

Finally, the spatial distribution of these household groups and the corresponding required energy efficiency measures will be mapped across Türkiye. This approach provides policymakers with a localized and actionable framework for implementing equitable and effective energy efficiency interventions.

Last but not least, this study offers a transferable methodology through SILC data, providing a replicable framework for other European countries to target energy-poor households.

6.1 Energy Poverty Indexes

Objective or calculation-based energy poverty definitions, such as income- and energy expenditure-based approaches, are widely used to measure energy poverty. However, as demonstrated in the previous chapter, these definitions have significant limitations, particularly in capturing hidden energy poverty and housing inefficiencies. Households that deliberately restrict their energy consumption due to affordability concerns may not be classified as energy-poor under these definitions, leading to underestimations of energy vulnerability. Additionally, these approaches fail to account for energy inefficiency, which is a key driver of energy poverty. To address these gaps, subjective indicators have been used. Subjective indicators rely on self-assessments from households regarding their ability to afford adequate energy services, providing valuable insights into hidden energy poverty. These indicators help identify households that do not necessarily spend a high proportion of their income on energy but still experience energy deprivation due to financial constraints. Additionally, subjective measures enable cross-country comparisons without requiring harmonized household energy expenditure data (Maxim et al., 2016).

Building on both objective and subjective measures, composite energy poverty indexes have been developed to provide a more nuanced understanding of the issue and offer a more comprehensive assessment. These indexes incorporate multiple factors, including housing conditions, energy efficiency levels, affordability constraints, and socio-economic characteristics, to capture the complexity of energy poverty. Among them, Multidimensional Energy Poverty Index (MEPI) is designed by Nussbaumer et al. (2013) to assess the broader deprivation of energy services beyond affordability. It includes indicators such as access to modern cooking fuels, exposure to indoor air pollution, access to electricity, and ownership of essential household appliances for daily activities, entertainment, and communication. MEPI is commonly used in developing countries where energy poverty is strongly linked to the lack of energy infrastructure (Nussbaumer et al., 2013). Bouzarovski & Tirado Herrero (2015) created Energy Poverty Index (EPI) which is one of the most widely recognized indexes for assessing energy poverty in developed regions. It focuses on housing-related deficiencies, incorporating indicators such as inability to keep homes adequately warm, arrears on utility bills, and living in substandard housing with structural problems like leaking roofs, damp walls, or rotting window frames. This index captures the direct economic and physical impacts of energy poverty (Bouzarovski and Tirado Herrero, 2015). Maxim et al., (2016) expands the EPI by introducing additional living condition indicators, such as dwellings that are uncomfortably hot during summer and dwellings with poor lighting conditions, and proposed Compound Energy Poverty Index (CEPI). By highlighting seasonal and non-thermal aspects of energy deprivation, making CEPI a more holistic index (Maxim et al., 2016a). With Energy Poverty Vulnerability Index (EPVI), Gouveia et al., (2019) provides a regionalized approach to assessing energy poverty risks by integrating socioeconomic, climatic, energy consumption, and building characteristics. It considers factors such as age and income level, unemployment rates, heating degree days, energy demand per square meter, efficiency of heating and cooling systems, and building typologies. EPVI is particularly useful for identifying energy-poor households in different geographic and climatic conditions (Gouveia et al., 2019). Last but not least, the Recasted EED recommends a mix of objective and subjective indicators, including inability to keep homes warm, utility bill arrears, poor housing conditions, and at-risk-of-poverty rates, to estimate energy poverty levels in Member States (European Parliament, 2023).

By integrating these diverse indicators, composite indexes provide a more holistic approach to energy poverty measurement, allowing policymakers to design more effective and targeted interventions. A key challenge in developing composite indexes lies in selecting appropriate indicators and determining their relative importance. The choice of indicators significantly influences the outcomes, as different datasets, regional conditions, and policy priorities shape how energy poverty is addressed. Each energy poverty index incorporates a unique combination of objective and subjective indicators, reflecting the diverse factors contributing to energy deprivation. The selection of these indicators often depends on data availability and the policy focus of the country or region implementing the index.

Once the indicators are chosen, determining their relative importance within the index becomes the next challenge. Various weighting methods exist in the literature, each with its own strengths and limitations (Siksnelyte-Butkiene et al., 2021). For example, in the predefined weighting approach, weights are assigned to indicators without empirical validation. These weights may be equal (each indicator has the same influence) or different (fixed but arbitrarily assigned based on policy logic) (Bouzarovski and Tirado Herrero, 2015; Charlier and Legendre, 2019; Maxim et al., 2016; Nussbaumer et al., 2013; Recalde et al., 2019). There is also expert judgment-based weighting method which assigns weights based on expert opinions (Gouveia et al., 2019; März, 2018). Statistical weighting method applies data-driven techniques to assign weights based on the variance explained by each indicator, effectively capturing the strongest differentiators of energy poverty but requiring extensive and reliable datasets (Recalde et al., 2019). Machine learning-based weighting method, including clustering and predictive modelling, represents an emerging approach that optimizes indicator selection and weighting based on real-world energy poverty patterns, potentially improving accuracy in identifying at-risk households (Al Kez et al., 2024; Gawusu et al., 2024; Pino-Mejías et al., 2018; Spandagos et al., 2023).

By integrating objective and subjective indicators with refined weighting methodologies, composite energy poverty indexes provide a robust framework for energy poverty assessment. The diversity of approaches highlights the importance of selecting the most appropriate methodology based on the national context, policy priorities, and available data. Building on this foundation, this study aims to develop an eligibility index to accurately identify energy-poor households eligible for support under a potential EEOS in Türkiye.

6.2 Data and Methodology

This section introduces the dataset, outlines the data preparation steps undertaken for the analysis, and presents the methodological framework applied in the study.

6.2.1 Survey of income and living conditions

To obtain the 2023 SILC dataset used in this study, a research proposal was submitted to TurkStat. TurkStat reviewed the proposal and approved the data request. As of the approval date, June 2024, the 2023 dataset was the most recent available.

TurkStat has conducted the SILC annually since 2006. SILC is an important source for compiling information about income distribution, level, and composition of poverty, living conditions, and social exclusion in the country (TurkStat, 2024).

All settlement areas within Türkiye were included in the scope of the SILC. However, institutionalized populations, such as individuals living in elderly homes, rest homes, correctional facilities, military barracks, specialized hospitals, nurseries, and nomadic populations, were excluded. SILC employed a stratified two-stage cluster sampling method. In 2023, the total sample consisted of 27,825 households, of which 24,932 were successfully interviewed, while the remaining 2,893 could not be reached due to various reasons (TurkStat, 2024).

The SILC dataset includes various variables related to energy poverty, allowing for a more comprehensive analysis of household vulnerabilities. Table 6.1 lists the energy poverty-related variables available in the SILC dataset. The variable categories are taken from the survey guide. Additionally, the table includes a category of newly constructed variables, which have been created by the authors using certain existing variables from the SILC dataset to serve as energy poverty indicators.

Table 6.1 : Energy Poverty-related Variables Available in the SILC Dataset.

Variable Name	Description	Category
leak_problem	Having leaking roof, damp walls, or rotting in window frames problems	Problems with dwelling
insulation_problem	Having heating problems due to insulation	Problems with dwelling
arrears_utility	Having arrears on utility bills in the last 12 months	Financial situation
arrears_rent_mort	Having arrears on mortgage, loan repayments, or rent payments in the last 12 months	Financial situation
arrears_debt	Having arrears on instalments, credit cards, or other loan payments in the last 12 months	Financial situation
sufficiency	Ability to make ends meet with total household income	Financial situation
d_burden	Financial burden of the total housing cost (Repayment of a loan or credit on dwelling or rent, utility bills, heating expenses, penalties for utility bills, collective expenses of apartments, and regular repair and maintenance costs are all covered.)	Financial situation
o_burden	Financial burden of the repayment of debts from hire purchases or loans excluding housing costs	Financial situation
vacation	Ability to afford a one-week annual holiday away from home	Financial situation
nutrition	Ability to afford a meal with meat, chicken, or fish every second day, including vegetarian alternatives.	Financial situation
unexp_exp	Ability to cover an unexpected expense of approximately 1,400 TL using own financial resources, excluding borrowing.	Financial situation
keep_adeq_warm	Ability to afford adequate heating for the household.	Financial situation
mat_dep	Ability to renew worn-out or old furniture, including second-hand options, with responses indicating financial difficulty or other reasons for not replacing them.	Material deprivation
low_income	The total disposable household income variable was divided into 20% income quintiles, with households in the lowest two quintiles (Q1 and Q2) classified as low-income households.	Newly constructed
conv_heating_system	The variable representing "Heating system available in the dwelling" was adjusted to distinguish between dwellings that use conventional heating systems and those that do not.	Newly constructed

6.2.2 Preparing the dataset for the analysis

The SILC dataset initially comprised 24,932 households. To ensure its suitability for energy efficiency and energy poverty assessments, several preprocessing steps were applied. Irrelevant columns were removed, and households lacking essential amenities such as a toilet, bathroom, kitchen, or piped water system were excluded, reducing the dataset to 24,015 households.

Since direct building age data was unavailable, an alternative approach was used to estimate it. The survey provided information on the year since which each household had been residing in its current dwelling. By subtracting this year from the survey year, an estimate of building age was derived, and households were categorized accordingly. Those residing in buildings estimated to be 50 years or older were excluded, resulting in a final dataset of 23,427 households. However, this approach has an inherent limitation, as it does not account for households that have recently moved into older buildings, potentially leading to an underrepresentation of such cases. These filtering steps were essential to ensure that the analysis targeted households that could realistically benefit from energy efficiency interventions.

Households lacking basic amenities represent the most structurally inadequate segment of Türkiye's housing stock, where energy efficiency improvements would not be a feasible policy option. Similarly, older buildings, particularly those over 50 years old, pose significant safety risks due to Türkiye's location in a high-seismic zone. Unlike European energy efficiency schemes, where historical structures may still be considered for retrofits, Türkiye's earthquake-prone conditions make such buildings more suitable for urban renewal programs rather than efficiency upgrades. As a result, these dwellings are typically addressed under separate housing and infrastructure policies, rather than through energy efficiency measures. By refining the dataset through these exclusions, the analysis aims to identify households that are both vulnerable in terms of energy poverty and structurally suitable for efficiency interventions.

To systematically analyse energy poverty and vulnerability, selected variables were recoded into a binary format, where a value of 1 indicates the presence of vulnerability in a given dimension, while 0 signifies its absence. The selected energy poverty-related variables and their binary coding structure are presented in Table 6.2.

Table 6.2 : Energy Poverty-related Variables' and Their Coding Structure.

Variable Name	Previous Coding	Revised Coding
leak_problem	1: Yes, 2: No	**1:** Yes, **0:** No
insulation_problem	1: Yes, 2: No	**1:** Yes, **0:** No
arrears_utility	1: Yes, once, 2: Yes, twice or more, 3: No, 4: There is no such payment	**1:** Yes, once & twice or more, **0:** No & there is no such payment
arrears_rent_mort	1: Yes, once, 2: Yes, twice or more, 3: No, 4: There is no such payment	**1:** Yes, once & twice or more, **0:** No & there is no such payment
arrears_debt	1: Yes, once, 2: Yes, twice or more, 3: No, 4: There is no such payment	**1:** Yes, once & twice or more, **0:** No & there is no such payment
sufficiency	1: With great difficulty, 2: With difficulty, 3: With some difficulty, 4: Fairly easily, 5: Easily, 6: Very easily	**1:** With great difficulty & with difficulty **0:** With some difficulty & fairly easily & easily & very easily
d_burden	1: A heavy burden, 2: A slight burden, 3: Not burden at all	**1**: A heavy burden **0:** A slight burden & not burden at all
o_burden	1: A heavy burden, 2: A slight burden, 3: Not burden at all	**1**: A heavy burden **0:** A slight burden & not burden at all
vacation	1: Yes, 2: No	**1**: No, **0**: Yes
nutrition	1: Yes, 2: No	**1**: No, **0**: Yes
unexp_exp	1: Yes, 2: No	**1**: No, **0**: Yes
keep_adeq_warm	1: Yes, 2: No	**1**: No, **0**: Yes
mat_dep	1: Yes, 2: No - Financial difficulty, 3: No - Other reasons	**1:** No - Financial difficulty **0:** Yes & no - other reasons
low_income	-	**1:** Q1 and Q2 income level households **0:** Others
conv_heating_system	-	**1:** Households using conventional heating systems (Stove) **0:** Households using Modern heating systems (Radiator, Air Conditioning, and others)

Figure 6.1 illustrates the distribution of annual disposable income across the five income quintiles (Q1–Q5). The selection of Q1 and Q2 for identifying low-income households is based on both statistical and policy considerations. A significant portion of Q2 (approximately 25%) falls below the poverty threshold, defined as 60% of the median income. Additionally, the distribution of Q2 closely aligns with the annualized value of the minimum wage for the respective year, indicating that many households

in this group are at the lower bound of economic security. Given these factors, Q1 and Q2 represent the most financially vulnerable households, making them the most relevant groups for assessing energy poverty within the eligibility framework.

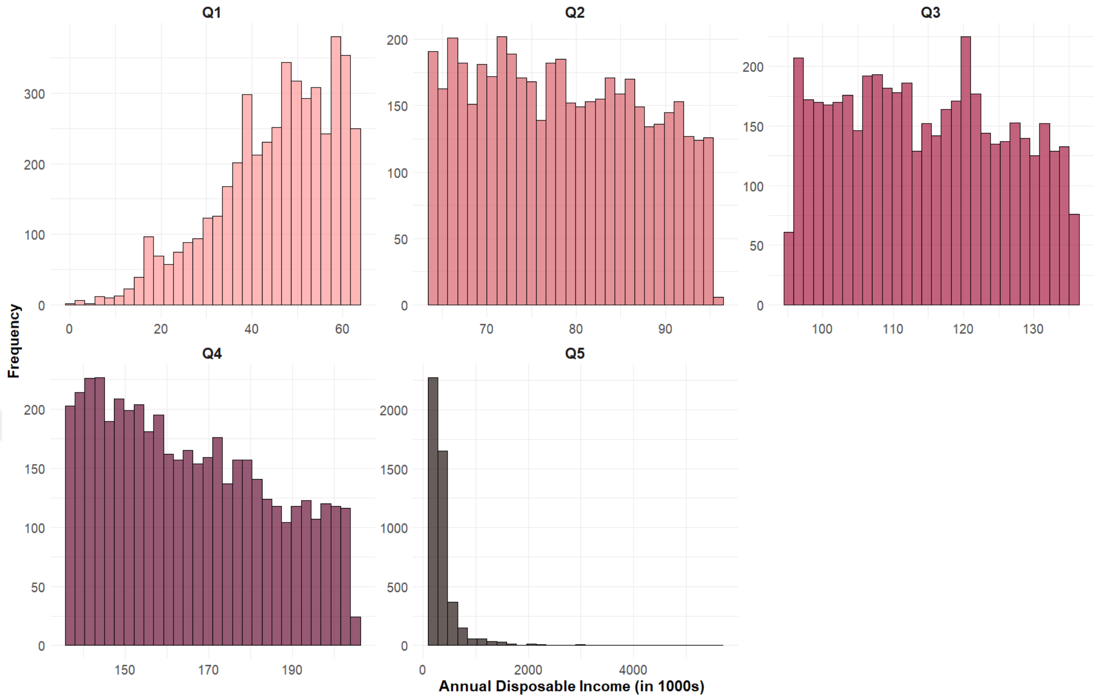

Figure 6.1 : Annual Disposable Income Distribution among Income Quintiles

6.2.3 Methodology

The methodological framework of this study is structured in three main phases.

In the first phase, an exploratory data analysis was conducted to examine the distributional properties and interrelationships among the financial difficulty indicators. Correlation analyses were applied to identify highly related variables and to guide the initial selection of indicators. Additionally, descriptive statistics such as frequencies, proportions, and cross-tabulations were used to understand the prevalence of each indicator. By reducing redundancy, it is ensured that the most informative and distinct variables were retained.

In the second phase, MCA was employed to assign weights to the selected financial difficulty indicators for the construction of the eligibility index. MCA is a multivariate statistical method used for analysing and visualizing patterns in categorical data. It is particularly suitable for analysing datasets in which variables are nominal or binary, and it extends the logic of correspondence analysis to more than two variables. MCA projects categories and individuals into a reduced-dimensional space, making it possible to identify associations, groupings, and underlying structures within the data. The method relies on the chi-square distance and operates on an indicator matrix, where each category of each variable is represented by a binary column. The method relies on the chi-square distance and operates on an indicator matrix, where each category of each variable is represented by a binary column (Greenacre & Blasius, 2006; Kassambara, 2017).

MCA outputs a set of dimensions (also referred to as factors or axes) derived from the eigenvalues of the decomposition of the indicator matrix. Each eigenvalue corresponds to a dimension’s inertia, which represents the amount of total variation (or "explained variance") captured by that dimension. The sum of the eigenvalues equals the total inertia in the data, and the proportion of each eigenvalue reflects how much of the underlying structure is explained by the corresponding axis. These dimensions are often visualized through a factor coordinate map, where variables and categories are plotted according to their contributions to the first two or three dimensions. In this map, the distance between points reflects their level of association—categories that appear close to each other are more likely to co-occur, while those that are far apart are less related. To interpret the relevance of variables on these axes, two additional measures are crucial: $\cos^2$ (squared cosine) and contribution. Cos^2 values indicate the quality of representation of a point on a given dimension—higher values mean the category is well represented in that axis. In contrast, contribution values show how much a variable or category has influenced the construction of the dimension itself (Greenacre & Blasius, 2006; Kassambara, 2017).

In this study, the contribution values of the selected financial difficulty indicators were combined with the variance explained by each dimension to assign statistically grounded and meaningful weights. This weighting strategy ensures that the constructed eligibility index captures the underlying structure of financial vulnerability in a manner that is both methodologically rigorous and empirically relevant. Based on these weights, the eligibility index is constructed and eligibility scores calculated for each household in the dataset.

In the third phase, an unsupervised clustering analysis was conducted to group households based on their eligibility index scores, inefficiency categories, and regions. The machine learning algorithm k-prototypes was used for clustering. This method is specifically designed for mixed-type data, allowing simultaneous analysis of continuous and categorical variables. It operates by minimizing a combined dissimilarity measure that integrates both numerical distance and categorical mismatch (Szepannek, 2018). In this study, the algorithm identified three distinct household groups that reflect varying levels and patterns of energy-related vulnerability, offering a more nuanced segmentation than threshold-based approaches. This approach enhances the policy relevance of the findings by allowing for more targeted and differentiated interventions under a potential EEOS framework.

R programming language was used as the main environment for conducting all data analysis and statistical procedures in this study.

6.3 Exploratory Data Analysis

This section provides an overview of the exploratory data analysis conducted to understand the structure, distribution, and relationships among key financial and housing-related variables used in the construction of the eligibility index.

The distribution of selected energy poverty variables, illustrating the proportion of households experiencing vulnerability in each dimension, is presented in Figure 6.2. The binary-coded variables categorize households as either facing a specific energy poverty-related issue (coded as 1, shown in red) or not (coded as 0, shown in green). The most prevalent indicator is the inability to afford a vacation, affecting 56.6% of households, followed by low-income households at 40.0%. Material deprivation (37.7%), inadequate nutrition (36.9%), and reliance on conventional heating systems (31.2%) are also common vulnerabilities. Issues related to housing conditions, such as insulation problems (29.9%) and leakage problems (27.9%) highlight structural inefficiencies contributing to energy poverty. The inability to keep the home adequately warm (17.6%), while frequently considered a key subjective indicator of energy poverty, primarily reflects an affordability issue. Additionally, utility arrears (16.5%), high dwelling related financial burdens (15.8%), and difficulties paying rent or mortgage (6.7%), indicate economic constraints limiting household resilience.

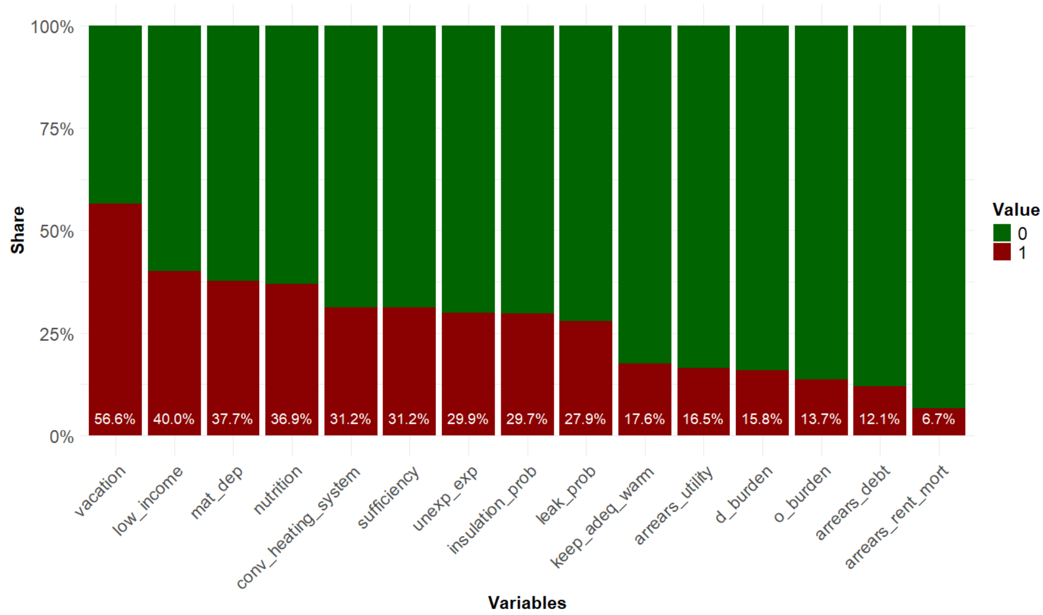

Figure 6.2 : The Share of Selected Energy Poverty Variables.

6.3.1 Selecting inefficiency indicators

The choice of the starting point is crucial when defining energy poverty, as it significantly impacts the identification of vulnerable households and the effectiveness of targeted policy measures. In Türkiye, many studies use the inability to keep the home adequately warm (keep_adeq_warm) as a primary criterion for energy poverty. While this subjective indicator is valuable in capturing hidden energy poverty, particularly cases where households underheat their homes due to financial constraints, it can be misleading if used in isolation. Figure 6.3 supports this argument by illustrating the difference between subjective energy poverty and structural inefficiencies.

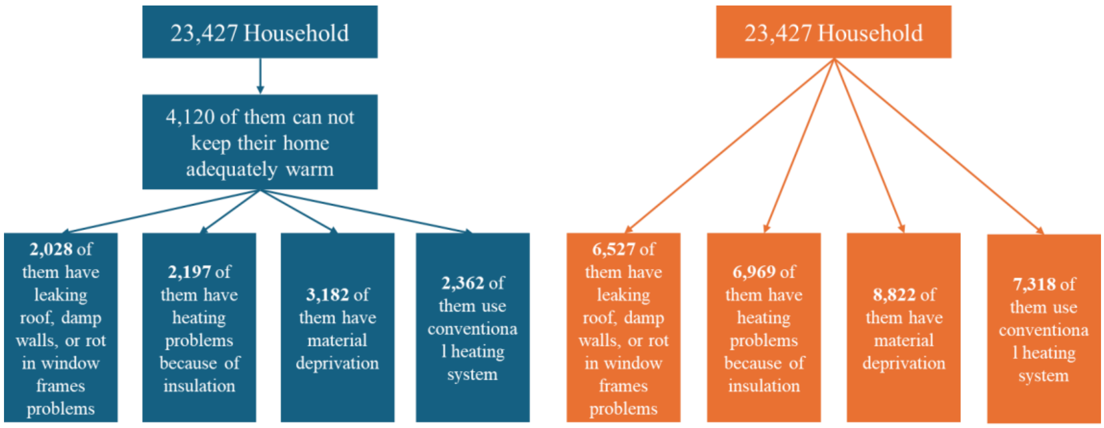

Figure 6.3 : Comparison of Energy Poverty Identification Approaches.

Since the EEOS is an energy efficiency mechanism, it can be designed to address the inefficiency dimension of energy poverty rather than its broader financial aspects. Energy poverty is a multidimensional issue, and some households may struggle to afford adequate heating despite living in energy-efficient homes. These cases stem from financial difficulties rather than structural deficiencies, meaning they fall outside the direct scope of an efficiency-based policy like EEOS.

The approach taken in this study prioritizes identifying inefficient households first and then assessing energy poverty within this group. This ensures that EEOS interventions are directed toward households that are both energy-poor and suffer from inefficiency-related vulnerabilities, making the mechanism more effective in achieving its intended impact.

The four key energy inefficiency indicators selected for identifying households with structural and operational inefficiencies relevant to energy poverty:

- **"leak_prob"** and **"insulation_prob"** represent structural inefficiencies that contribute to high energy loss and increased heating demand. Dwellings with these deficiencies require more energy to maintain thermal comfort, making them particularly vulnerable to energy poverty.

- **"conv_heating_system"** refer to stove-based heating, which is inherently inefficient for whole-house heating. Due to data limitations in the SILC dataset, the exact fuel type used for stoves cannot be determined. Stoves in the dataset may include those powered by electricity, natural gas, coal, wood, or even dried cow dung, all of which have different efficiency levels. However, regardless of the fuel source, stoves generally heat only a single room rather than an entire dwelling, leading to uneven heating, energy inefficiency, and increased vulnerability to cold indoor temperatures. Households relying on stove heating are more likely to experience energy poverty due to inefficiencies in heat distribution.

- **"mat_dep"**, though not directly related to heating, reflects a household's inability to replace worn-out or outdated furniture, may including inefficient household appliances (white goods). Given that older appliances consume more energy, households experiencing material deprivation are likely to face higher electricity costs. Energy poverty discussions often focus on thermal inefficiency, but electrical inefficiency also plays a critical role. Households struggling with both thermal and electrical inefficiencies may need to limit their energy usage, affecting their overall well-being and financial stability.

By incorporating both structural and operational inefficiencies, this selection serves as a filtering mechanism to identify households with energy inefficiencies, forming the foundation for a more in-depth energy poverty analysis. Rather than directly classifying these households as energy-poor, this approach distinguishes those facing efficiency-related vulnerabilities, allowing for a layered assessment of energy poverty within this subset. The Venn diagram in Figure 6.4 illustrates the overlap between four key energy inefficiency indicators.

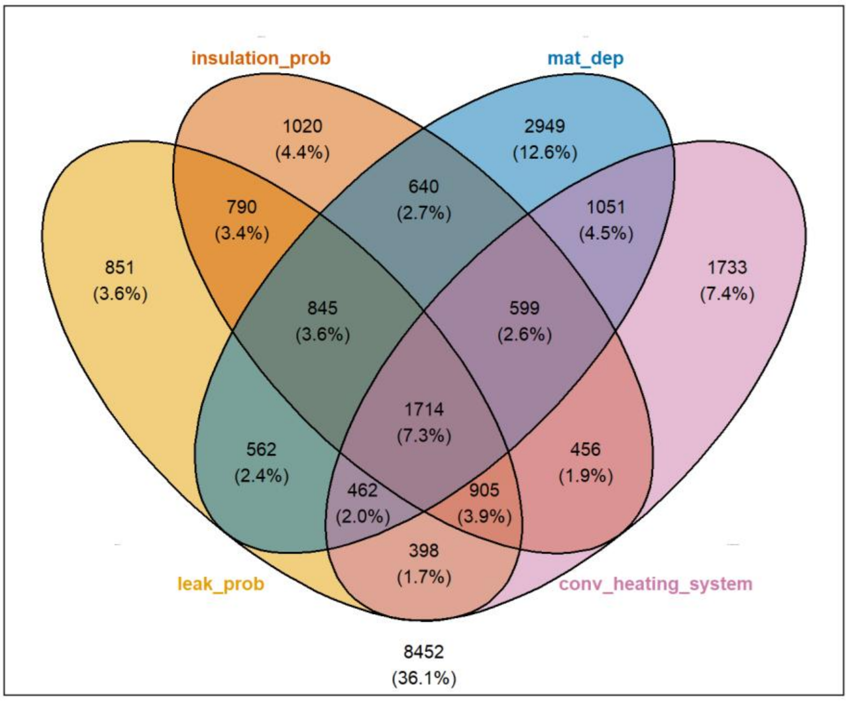

Figure 6.4 : Venn Diagram of Selected Inefficiency Indicators.

Households with at least one inefficiency (leak_prob, insulation_prob, mat_dep, or conv_heating_system) account for 63.9% (14,975 out of 23,427) of the dataset. These households exhibit structural or operational inefficiencies that can contribute to energy poverty and are potential candidates for energy efficiency interventions under EEOS. Households without any inefficiency make up 36.1% (8,452 out of 23,427). These households do not show clear signs of structural or operational inefficiency, indicating that their energy-related challenges, if present, are more likely linked to affordability rather than inefficiency. Among the 8,452 households without inefficiencies, 280 report being unable to afford adequate heating. These households do not face direct inefficiency-related problems but still struggle with energy costs, likely due to financial constraints. The remaining 8,172 households (34.9% of the total dataset) experience neither inefficiency nor affordability problems. These households are neither structurally vulnerable nor financially constrained in terms of energy affordability.

The selected inefficiency indicators are not only used to filter the initial sample, but also to categorize households based on the type and severity of their inefficiencies in subsequent stages of the analysis.

6.3.2 Selecting financial difficulty indicators

After applying the inefficiency filtering, the remaining 14,975 households exhibit varying degrees of financial difficulties, as shown in Figure 6.5.

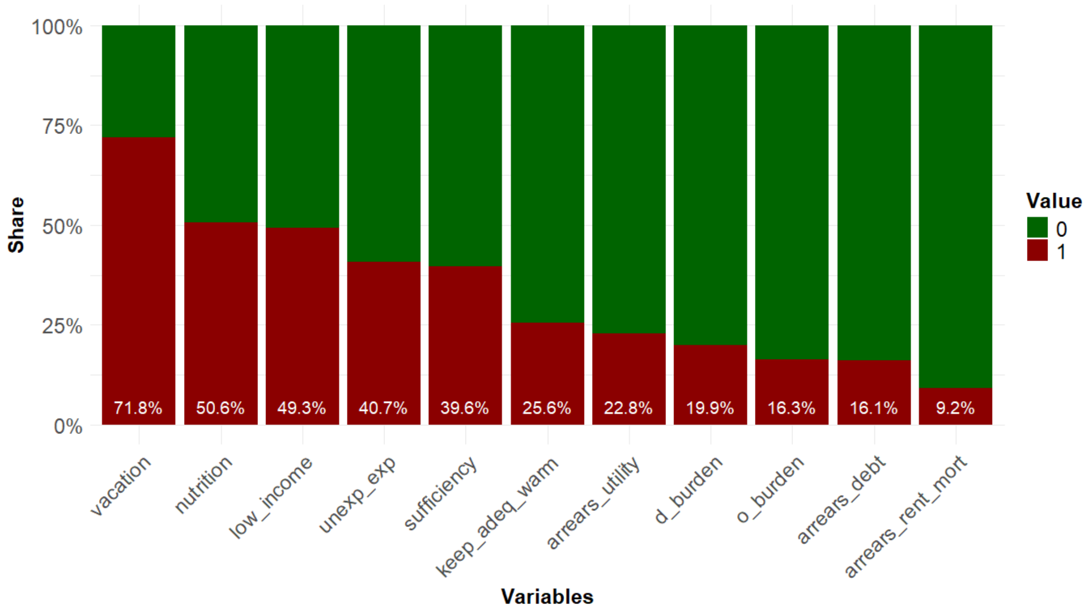

Figure 6.5 : The Share of Financial Difficulty Variables Among Households with Inefficiencies.

The most prevalent indicators are inability to afford a vacation (71.8%), nutritional deprivation (50.6%), and low income (49.3%), highlighting widespread economic constraints. Additionally, utility arrears (22.8%), and difficulty keeping the home adequately warm (25.6%) imply that financial struggles further exacerbate energy poverty.

Given the large number of financial difficulty variables, selecting the most meaningful and distinct indicators is crucial for practical application. Additionally, identifying highly correlated variables is essential to avoid redundancy and improve the robustness of the analysis. To achieve this, firstly, a tetrachoric correlation matrix was constructed. The heatmap in Figure 6.6 visually represents the relationships between financial difficulty variables.

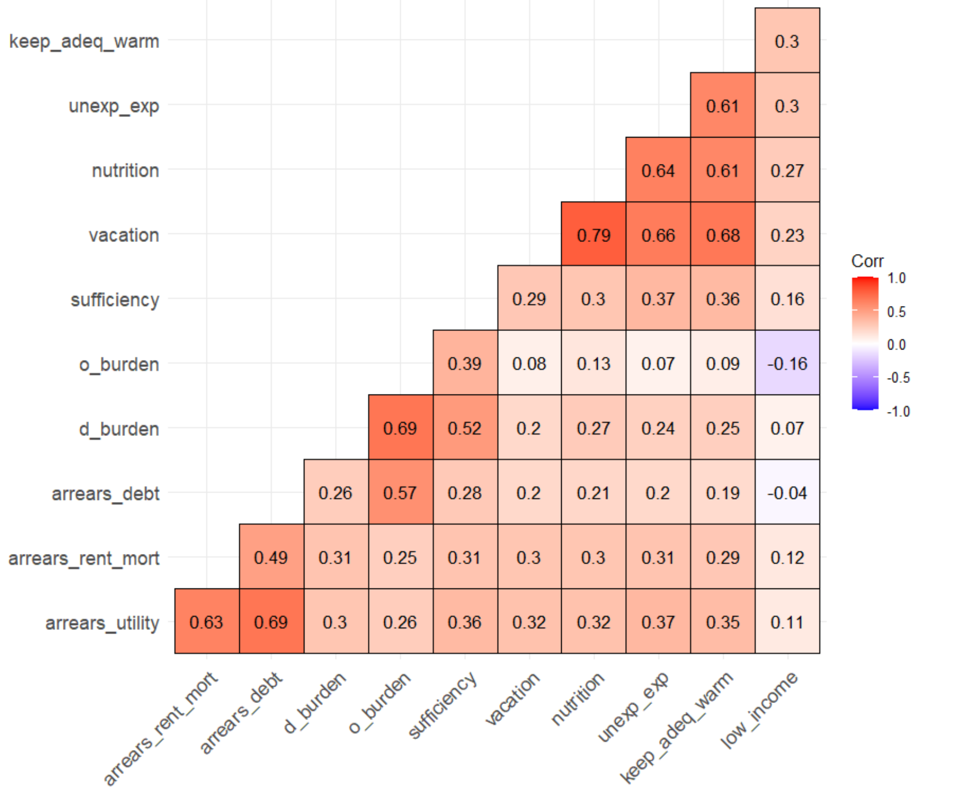

Figure 6.6 : Tetrachoric Correlation Matrix of Financial Difficulty Indicators.

A tetrachoric correlation matrix estimates the correlation between binary variables under the assumption that they represent underlying continuous distributions. Unlike Pearson correlation, which is used for continuous variables, tetrachoric correlation is specifically designed for dichotomous (0/1) variables, making it useful for identifying relationships among binary variables. By using this approach, the analysis ensures that highly correlated variables are detected, and redundant ones can be removed, improving the clarity and efficiency of the final indicator selection.

The tetrachoric correlation matrix reveals several highly correlated variables (above 0.6), indicating potential redundancy in financial difficulty indicators. The strongest relationships are observed among variables that capture consumption-related financial difficulty, such as nutrition, vacation, unexpected expenses, and ability to keep the home adequately warm. These indicators tend to move together, indicating that households struggling in one of these areas are likely to experience difficulties in others as well. Similarly, arrears-related indicators, including utility arrears, rent/mortgage arrears, and debt arrears, exhibit strong correlations, reflecting a pattern where households falling behind on one type of financial obligation are more likely to struggle with others. Additionally, subjective financial burden indicators, such as debt burden and overall financial burden, also show notable correlations, indicating that households perceiving financial strain often face multiple overlapping financial difficulties.

Given these strong correlations, reducing the number of indicators by selecting only one variable from each highly correlated pair would help minimize redundancy, simplify the analysis, and enhance the clarity of financial difficulty assessments while preserving the accuracy of the results. Further investigation is required to determine which variables provide the most distinct and meaningful contribution to assessing energy poverty.

In the process of reducing the number of variables while maintaining the most informative indicators, careful consideration was given to minimizing information loss. First, an assessment was conducted on four highly correlated variables which are "vacation", "nutrition", "unexp_exp" and "keep_adeq_warm". Table 6.3 shows their distribution across households.

Table 6.3 : Distribution of Highly Corelated Variables Across Households.

vacation	nutrition	unexp_exp	keep_adeq_warm	n
0	0	0	0	3637
0	0	0	1	33
0	0	1	0	239
0	0	1	1	9
0	1	0	0	196
0	1	0	1	33
0	1	1	0	56
0	1	1	1	14
1	0	0	0	2198
1	0	0	1	243
1	0	1	0	714
1	0	1	1	321
1	1	0	0	1896
1	1	0	1	637
1	1	1	0	2199
1	1	1	1	2550

"keep_adeq_warm" was prioritized as it is a key indicator of energy poverty. However, selecting only this variable would result in the omission of 4,347 households that struggle to meet basic dietary needs, as captured by "nutrition". Additionally, including nutrition helps retain a substantial number of households that also report financial difficulties in affording “vacation” and “unexp_exp”. Given this, “keep_adeq_warm” and “nutrition” were selected as the most representative indicators from this group.

To refine the selection of arrears-related indicators, an evaluation was conducted on “arrears_utility”, “arrears_debt”, and “arrears_rent_mort” (Table 6.4). “arrears_utility” was prioritized, as it is another key indicator for energy poverty evaluations. Examining the distribution of households across these three indicators reveals that excluding “arrears_debt” and “arrears_rent_mort” does not lead to significant information loss. Most households identified by these two indicators are already covered under “arrears_utility”, ensuring that financial distress related to arrears is still well represented. Therefore, “arrears_utility” was selected as the most representative variable from this group.

Table 6.4 : Distribution of Highly Corelated Variables Across Households.

arrears_utility	arrears_debt	arrears_rent_mort	n
0	0	0	10432
0	0	1	307
0	1	0	704
0	1	1	116
1	0	0	1402
1	0	1	427
1	1	0	1062
1	1	1	525

Finally, the distribution of “o_burden and d_burden” across households was examined (Table 6.5).

Table 6.5 : Distribution of Highly Corelated Variables Across Households.

o_burden	d_burden	n
0	0	11043
0	1	1496
1	0	946
1	1	1490

While “d_burden” initially appeared to be a more representative indicator, its moderate correlation with “sufficiency” raised concerns regarding redundancy. In contrast, “o_burden” provided distinct information that was not strongly overlapping with “sufficiency”, making it a more suitable choice for inclusion. Therefore, “o_burden” was selected as the representative variable from this group.

As a result of the variable selection process, six key financial difficulty indicators were identified to construct the eligibility index. These indicators were chosen based on their ability to capture financial vulnerability and energy poverty while minimizing redundancy.

The selected indicators are: **“low income”**, **“sufficiency”**, **“keep_adeq_warm”**, **“nutrition”**, **“arrears_utility”**, and **“o_burden”**. These six indicators will form the basis of the eligibility index, ensuring that the most financially and energy-vulnerable households are accurately identified under EEOS.

6.4 Creating the Eligibility Index

The preparation for the eligibility index began by establishing energy inefficiency as the starting point, filtering households with at least one inefficiency indicator. Then, financial difficulty indicators were refined through correlation analysis, household coverage, and contextual relevance, resulting in a final selection of six key variables.

With the indicators for the eligibility index finalized, the next step is to determine their weights, ensuring that each variable's contribution reflects its significance in capturing financial vulnerability and energy poverty. To ensure that the weight assignment is meaningful, data-driven, and statistically robust, the MCA method was utilized.

The scree plot (Figure 6.7) illustrates the percentage of variance explained by each dimension, while the eigenvalues table (Table 6.6) presents the exact variance contribution and cumulative variance percentages.

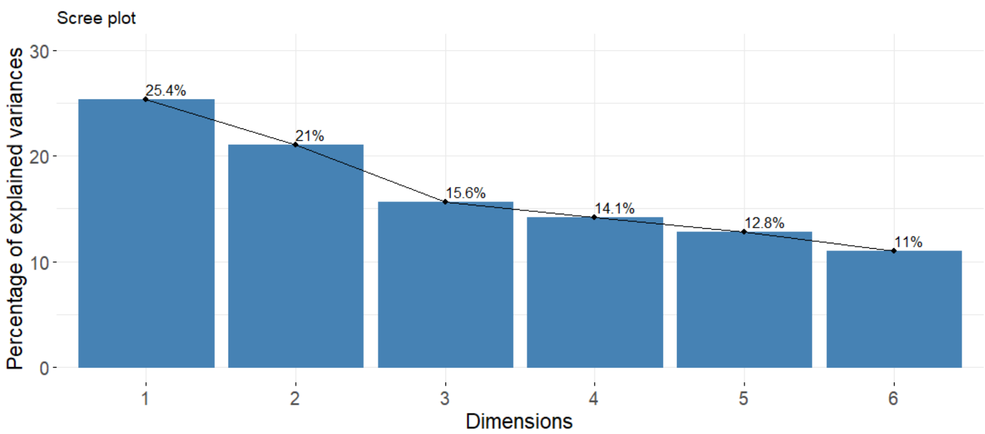

Figure 6.7 : Scree Plot.

Table 6.6 : Eigenvalues Table.

Dimensions	Eigenvalues	Variance (%)	Cumulative Variance (%)
Dim1	0.2537	25.37	25.37
Dim2	0.2104	21.04	46.41
Dim3	0.1562	15.62	62.03
Dim4	0.1414	14.14	76.16
Dim5	0.1282	12.82	88.98
Dim6	0.1101	11.01	100.00

The two-dimensional (2D) MCA factor map (Figure 6.8) visualizes the relationships between financial difficulty indicators along the first two dimensions, which together explain 46.4% of the total variance (Dim 1: 25.4%, Dim 2: 21%). Each category's position on the plot reflects its relationship with other variables and how it contributes to differentiating household financial conditions. In this plot, vulnerable category values such as "keep_adeq_warm_1", "sufficiency_1", "nutrition_1", and "arrears_utility_1" are clearly positioned on the right side of the graph, indicating their strong association with financial and energy-related difficulties. In contrast, categories such as "keep_adeq_warm_0", "sufficiency_0", "nutrition_0", and "arrears_utility_0" and cluster around the left side, representing financially stable households.

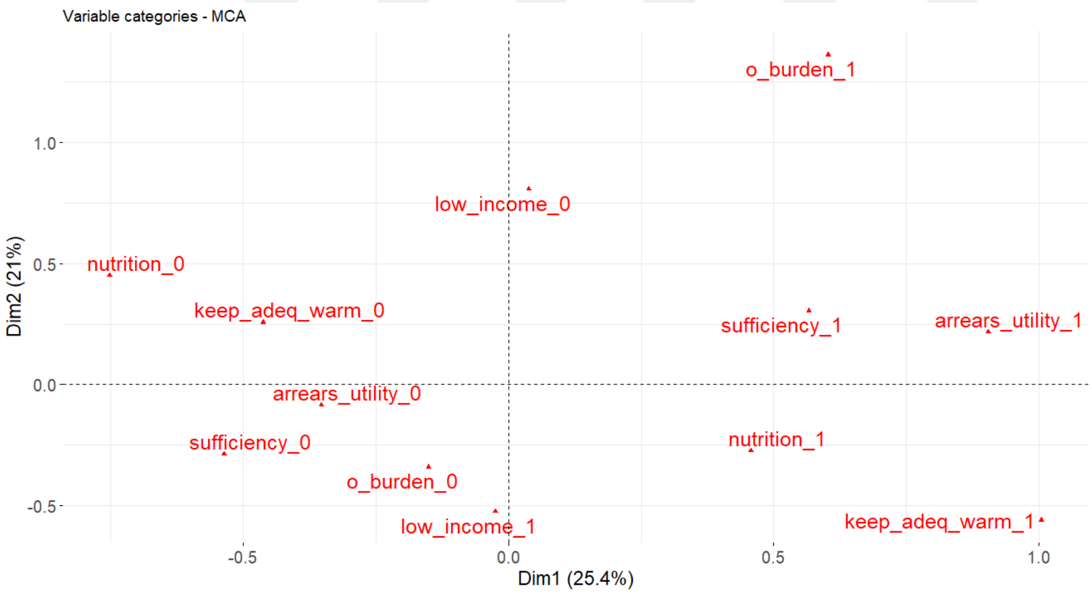

Figure 6.8 : MCA 2D Factor Map.

However, the three-dimensional (3D) MCA factor map (Figure 6.9), which incorporates the third dimension (Dim3: 15.6% additional explained variance), reveals new spatial relationships that were not visible in the 2D projection. For instance, low_income_1, which appears near the origin in the 2D map, distinctly separates along the third dimension, highlighting its contribution to a hidden structure of financial vulnerability.

Similarly, categories like nutrition_0 and keep_adeq_warm_1 show clearer divergence across the vertical Dim3 axis, reflecting different combinations of deprivation not captured in the first two dimensions. This enhanced spatial understanding supports the use of MCA in weight construction, as it helps uncover latent patterns in financial difficulty and energy poverty.

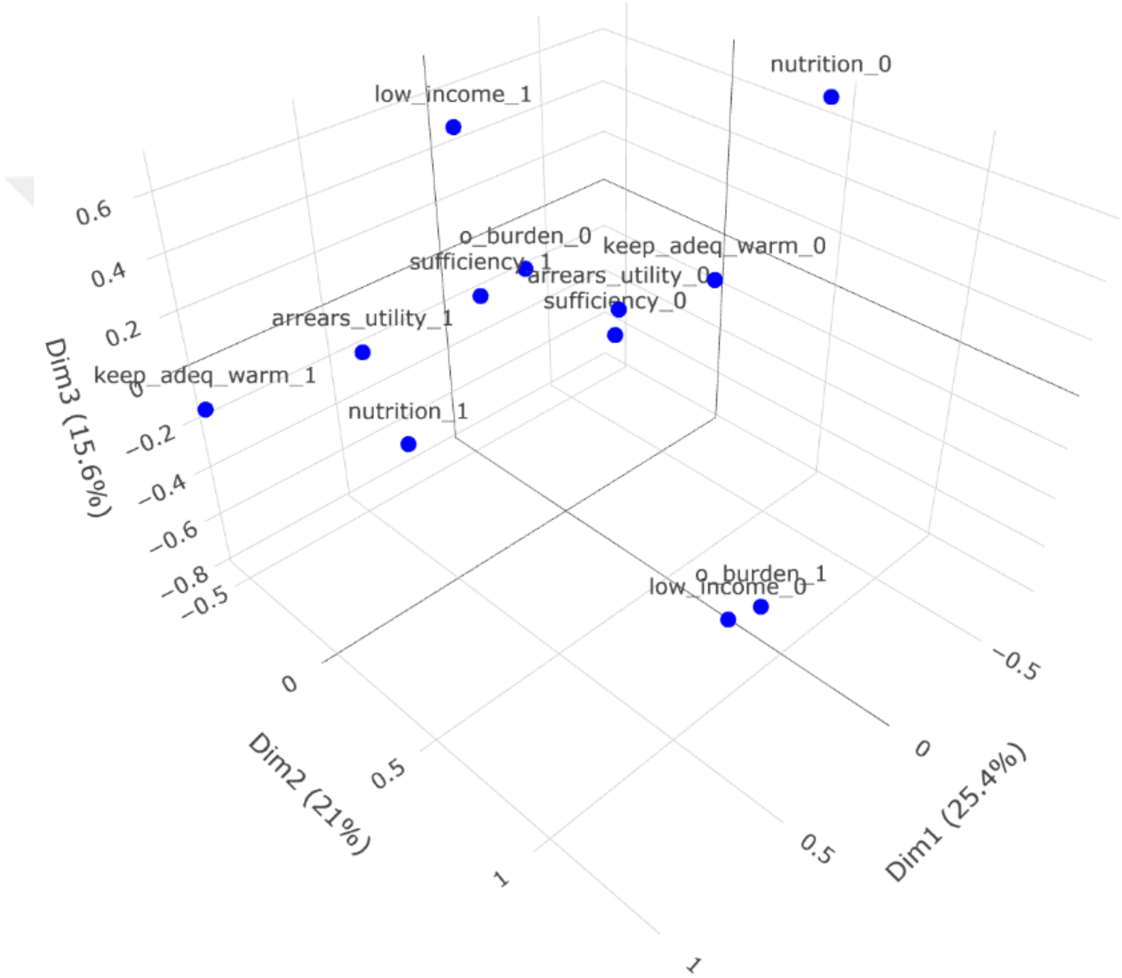

Figure 6.9 : MCA 3D Factor Map.

The selection of dimensions for the eligibility index was based on three key criteria: (i) “explained variance”: dimensions that contribute significantly to the total variance were prioritized; (ii) “cumulative contribution”: the cumulative percentage of explained variance was assessed to ensure that the retained dimensions captured the majority of the dataset’s structure; (iii) “interpretability”: the contribution of variables to each dimension was examined to verify whether the selected dimensions aligned with financial difficulty and energy poverty characteristics.

As shown in Table 6.6, six dimensions together account for 100% of the total variance, with the first three dimensions capturing 62% of the variance. Specifically, Dimension 1 explains 25.4% of the variance, followed by Dimension 2 (21%) and Dimension 3 (15.6%). These three dimensions were retained for weighing, as they collectively provide the most substantial explanatory power in representing financial difficulty. The remaining dimensions were excluded due to their relatively lower contribution and limited added value in distinguishing households for the eligibility index. Indicator-specific contributions were then extracted from each retained dimension to assign weights proportionally to their empirical influence.

Table 6.7 presents the contribution and cos² values of each indicator across the first three MCA dimensions retained for index construction. Contribution values indicate the importance of the variable for defining each dimension. Cos² values reflect the quality of representation of the variable on the respective dimension.

Table 6.7 : Contribution and Cos² Values of Each Category.

Categories	Dim1 Contrib. (%)	Dim1 Cos²	Dim2 Contrib. (%)	Dim2 Cos²	Dim3 Contrib. (%)	Dim3 Cos²
low_income_0	0.039	0.001	20.354	0.424	24.851	0.384
low_income_1	0.025	0.001	13.231	0.424	16.155	0.384
keep_adeq_warm_0	9.625	0.465	3.603	0.144	0.288	0.009
keep_adeq_warm_1	20.913	0.465	7.830	0.144	0.625	0.009
nutrition_0	14.038	0.344	6.092	0.124	18.699	0.282
nutrition_1	8.524	0.344	3.699	0.124	11.354	0.282
sufficiency_0	9.696	0.303	3.376	0.088	10.450	0.201
sufficiency_1	10.236	0.303	3.564	0.088	11.031	0.201
o_burden_0	1.191	0.091	7.357	0.464	0.011	0.001
o_burden_1	4.767	0.091	29.440	0.464	0.045	0.001
arrears_utility_0	5.873	0.319	0.408	0.018	1.820	0.061
arrears_utility_1	15.075	0.319	1.046	0.018	4.671	0.061

To proceed with weighting, each indicator must be assigned to a specific dimension. This assignment is based on the dimension where the indicator demonstrates the highest contribution value along with a sufficiently high quality of representation. As a preliminary step, the total contributions of each indicator were considered. That is calculated by summing up the contributions of their response categories as shown in Table 6.8. This ensures that indicators are associated with the dimension where they are most statistically informative.

Except for “sufficiency”, the dimension assignments of the indicators are relatively clear based on their highest contribution values. While “sufficiency” shows its highest contribution in Dimension 3, its contribution to Dimension 1 is very close. Given that its Cos² value is higher in Dimension 1 and Dimension 1 explains a larger share of total variance, the “sufficiency” indicator is assigned to Dimension 1. As a result, Dimension 1 consists of “keep_adeq_warm”, “sufficiency”, and “arrears_utility”; Dimension 2 includes “o_burden”; and Dimension 3 includes “low_income” and “nutrition”.

Table 6.8 : Contribution and Cos² Values of Each Indicator.

Indicators	Dim1 (25.4%)		Dim2 (21%)		Dim3 (15.6%)	
	Contrib. (%)	Cos²	Contrib. (%)	Cos²	Contrib. (%)	Cos²
low_income	0.064	0.001	33.585	0.424	41.006	0.384
keep_adeq_warm	30.538	0.465	11.433	0.144	0.913	0.009
nutrition	22.562	0.344	9.791	0.124	30.053	0.282
sufficiency	19.931	0.303	6.941	0.088	21.481	0.201
o_burden	5.958	0.091	36.797	0.464	0.057	0.001
arrears_utility	20.948	0.319	1.454	0.018	6.491	0.061

Total contribution values of indicator categories were used to assign each indicator to a specific dimension. However, for the construction of the eligibility index, only the contribution values of the “1” category, representing the presence of financial difficulty, were considered.

To calculate the final weights of indicators included in the eligibility index, let:

- i: index of the indicator category, i={low_income, keep_adeq_warm, nutrition, sufficiency, o_burden, arrears_utility}
- j: index of the dimension, j={1, 2, 3}
- c_{ij}: contribution (%) of indicator *i* (category “1”) to dimension *j*,
- c_{ij}^{norm}: normalized contribution (%) of indicator *i* to dimension *j*,
- D_j: set of indicators assigned to dimension *j*,
    - $for\ j = 1,\ D_1$= {keep_adeq_warm, sufficiency, arrears_utility}
    - $for\ j = 2,\ D_2$= {o_burden}
    - $for\ j = 3,\ D_3$= {low_income, nutrition}
- v_j: explained variance of dimension *j*, $v_j = \{0.254, 0.21, 0.156\}$
- w_i: weighted contribution of indicator *i*.
- w_i^{norm}: weight assigned to indicator *i*.

First, the normalized contribution of each indicator to corresponding dimension is calculated as shown in (6.1).

$$c_{ij}^{norm} = \frac{c_{ij}}{\sum_{i \in D_j} c_{ij}} \quad for\ i \in Dj \tag{6.1}$$

For each indicator, the contribution value from its corresponding dimension is normalized so that the sum of contributions within each dimension equals 100%. Table 6.9 gives the contribution values and their normalized forms for each indicator, organized by their assigned dimensions. This normalization ensures comparability across dimensions and allows for consistent weighting in the final eligibility index construction.

Table 6.9 : Previos and Normalized Contribution Values of Each Indicator.

Indicators	Dim1 (25.4%)		Dim2 (21%)		Dim3 (15.6%)	
	Contrib. (%)	Normalized Contrib. (%)	Contrib. (%)	Normalized Contrib. (%)	Contrib. (%)	Normalized Contrib. (%)
low_income	-	-	-	-	41.006	57.707
keep_adeq_warm	20.913	45.243	-	-	-	
nutrition	-	-	-	-	30.053	42.293
sufficiency	10.236	22.144	-	-	-	-
o_burden	-	-	36.797	100.000	-	-
arrears_utility	15.075	32.613	-	-	-	-

Then, the weighted contributions of all indicators are calculated by multiplying their normalized contribution within a dimension by that dimension's explained variance. This procedure ensures that indicators from dimensions with higher explanatory power are given proportionally greater influence in the index. The weighted contribution of each indicator is obtained using (6.2).

$$w_i = c_{ij}^{norm} \times v_j \quad for\ i \in Dj \tag{6.2}$$

After that, the final normalization is performed to ensure that the sum of all indicator weights equals 1. This step guarantees that the index is properly scaled. The final normalized weight of indicators is calculated as in (6.3)

$$w_i^{norm} = \frac{w_i}{\sum w_i} \quad \forall i \tag{6.3}$$

Table 6.10 shows the weighted contributions and final weights of indicators.

Table 6.10 : Weights of Each Indicator.

Weights	low_income	keep_adeq_warm	nutrition	sufficiency	o_burden	arrears_utility
w_i	0.090	0.115	0.066	0.056	0.210	0.083
w_i^{norm}	0.145	0.185	0.106	0.091	0.339	0.134

Finaly, the eligibility index is calculated by combining binary indicator values with their corresponding normalized weights. Let:

- x_i: Binary value of indicator i for a given household (1 if the household experiences the corresponding difficulty, 0 otherwise).
- w_i^{norm}: Normalized weight of indicator i,
- EI: Eligibility index score for a given household.

The EI score is computed as shown in (6.4):

$$EI = \sum_{i=1}^{6} x_i \times w_i^{norm} \quad \forall i \tag{6.4}$$

Explicitly, it is calculated as shown in (6.5)

$$\begin{aligned} EI = 0.339 \times x_{o\_burden} + 0.185 * x_{keep\_adeq\_warm} \\ + 0.145 \times x_{low\_income} + 0.134 \times x_{arrears\_utility} \\ + 0.106 \times x_{nutrition} + 0.091 \times x_{sufficiency} \end{aligned} \tag{6.5}$$

The EI scores range between 0 and 1, where higher scores indicate greater vulnerability. 1 represents the highest level of combined financial difficulty, and 0 indicates no reported financial hardship.

Although MCA does not produce component loadings in the same manner as Principal Component Analysis (PCA), the normalized contribution of each binary indicator to the retained dimensions can be used as an approximation of its relative importance. In this chapter, these contributions are combined with the variance explained by each dimension to derive approximate indicator weights. While this approach involves a methodological simplification, it offers a statistically informed weighting scheme that is well suited to the nature of the data. Statistically, MCA is appropriate for the binary nature of the indicators and ensures internal consistency. Practically, the method allows for a structured weighting scheme using available data without relying on subjective assumptions, making it suitable for applied policy analysis. Despite being an approximation, it remains reliable due to its internal consistency, lack of redundancy, and its ability to capture meaningful variation in the data. Moreover, it upholds transparency and reproducibility as key qualities for constructing robust composite indices in applied policy research.

With the construction of the eligibility index complete, the first part of the next section applies this index to examine the overall situation and spatial distribution of inefficient and financially vulnerable households across Türkiye.

6.5 Results and Discussions

This section presents the key findings of the analysis, including the distribution of eligibility index scores and the clustering results used to group households based on their energy poverty profiles.

6.5.1 Distribution of eligibility index across Türkiye

Following the methodological steps outlined earlier, EI scores were calculated for each household. Figure 6.10 illustrates the distribution of the constructed EI scores among the 14,975 households that meet at least one inefficiency indicator.

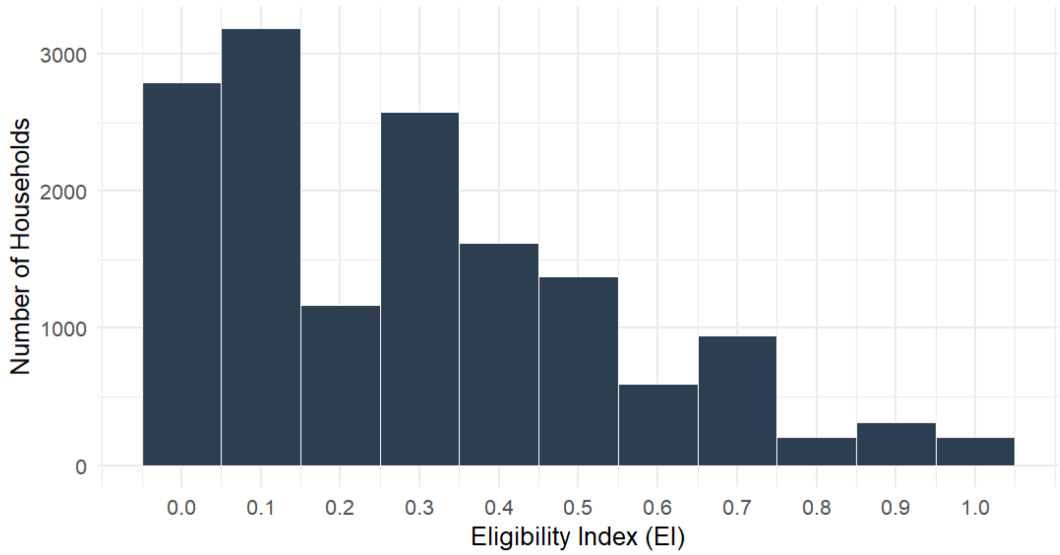

Figure 6.10 : EI Distribution Across Households with At Least One Inefficiency Indicator.

The distribution is right-skewed, with most households concentrated in the lower EI ranges. Notably, the most populated group (6,413 households) falls within the 0-0.2

interval, followed by the 0.2-0.4 intervals (3,808 households). Less households (1,740 households) exhibit high EI scores (above 0.6), indicating that severe vulnerability. In contrast, Figure 6.11 presents the EI distribution among households that report no inefficiency problems.

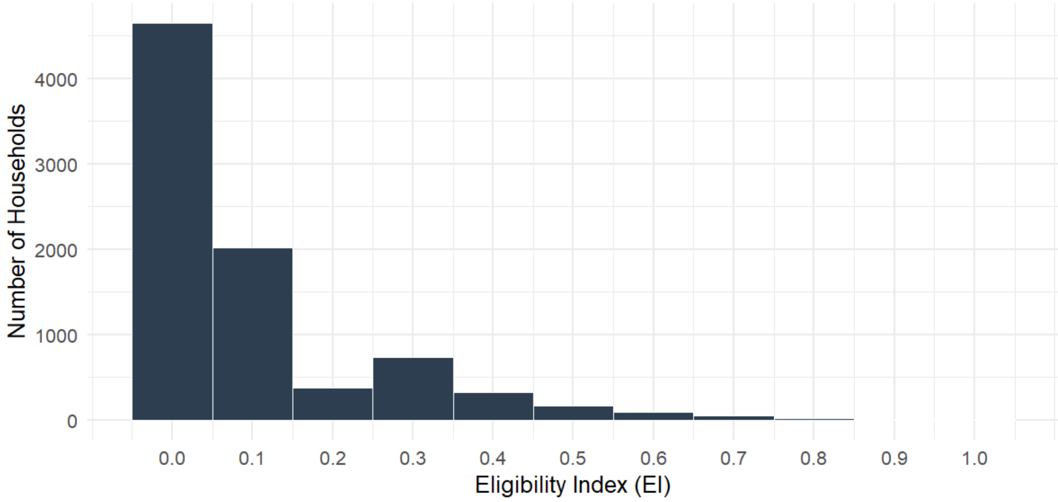

Figure 6.11 : EI Distribution Across Households without Inefficiency Problems.

In this group, index values are heavily concentrated below 0.2 (6,776 households), and very few households exceed an EI score of 0.6 (94 households). This sharp difference confirms the relevance of the inefficiency filter: when applied prior to the index calculation, it enhances the model's ability to identify households that are both financially and structurally vulnerable. The comparison supports the use of a two-stage approach, first isolating inefficient households, then creating the eligibility index, which significantly improves targeting precision for energy poverty interventions.

Table 6.11 presents descriptive statistics of the EI for households categorized according to their combinations of selected energy inefficiency indicators. Four primary inefficiency categories are represented: L (having roof/wall/window leakage problems), I (having insulation problems), M (in material deprivation, potential electrical inefficiency), and C (using conventional heating systems). Households are grouped based on whether they experience one or more of these inefficiencies, with the corresponding inefficiency categories combining the initials (e.g., LIMC indicates a household has leakage and insulation problem, experiences material deprivation, and has conventional heating system). The table shows that as the number of inefficiency indicators increases, so does the average EI score, highlighting a cumulative effect on financial vulnerability.

Table 6.11 : Number of Households and Summary Statistics of the EI Scores Across Inefficiency Combinations.

Inefficiency Category	Number of Households	Mean EI Scores	Median EI Scores	Min EI Scores	Max EI Scores
C	1733	0.157	0.145	0	0.909
I	1020	0.147	0.091	0	1.000
IC	456	0.208	0.145	0	0.909
IM	640	0.349	0.331	0	1.000
IMC	599	0.430	0.425	0	1.000
L	851	0.147	0.091	0	0.909
LC	398	0.199	0.145	0	0.866
LI	790	0.180	0.134	0	1.000
LIC	905	0.250	0.236	0	1.000
LIM	845	0.406	0.385	0	1.000
LIMC	1714	0.483	0.476	0	1.000
LM	562	0.333	0.331	0	1.000
LMC	462	0.388	0.382	0	1.000
M	2949	0.308	0.251	0	1.000
MC	1051	0.371	0.342	0	1.000

To visualize the distribution of EI across inefficiency categories, Figure 6.12 provides boxplots that further illustrate the variation within each group.

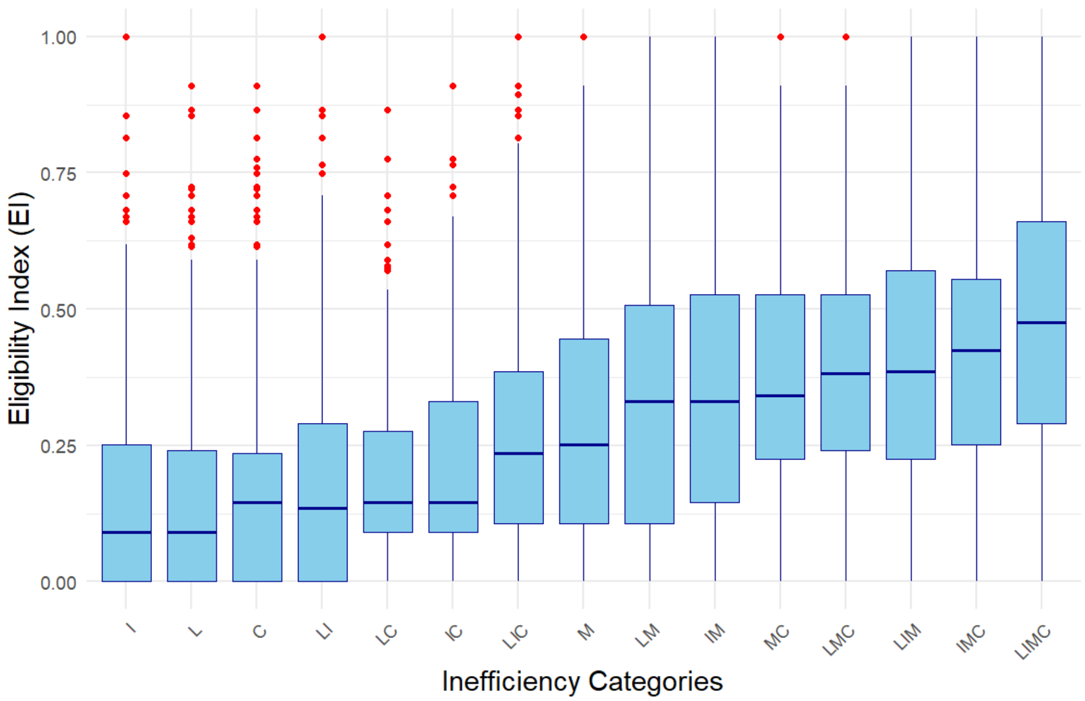

Figure 6.12 : Boxplot of distribution of EI Scores across these categories.

Households experiencing only one inefficiency problem tend to have lower EI scores with relatively narrower distributions. As the number of inefficiency indicators increases, so does the EI scores, reflecting higher levels of financial vulnerability. Notably, households with all four inefficiency problems (LIMC) exhibit the highest median and overall distribution of EI, highlighting the compounding nature of multiple inefficiencies in determining eligibility.

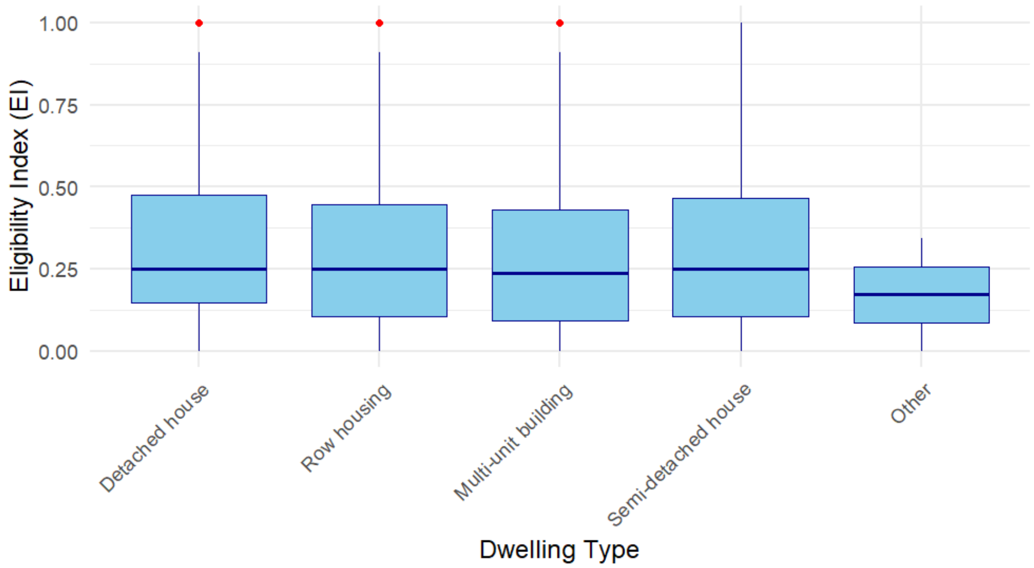

Figure 6.13 : The Distribution of EI Scores Across Different Dwelling Types.

Figure 6.13 presents the distribution of EI scores across different types of dwelling. While there are slight variations among categories, the overall differences appear relatively modest. Households residing in detached, semi-detached, and row housing types tend to show slightly higher EI scores, indicating a marginally elevated risk of energy poverty. However, no single dwelling type stands out as significantly more vulnerable than others. This indicates that although physical structure may influence household vulnerability to some extent, it is not a dominant factor on its own within the current index framework.

Figure 6.14 presents the distribution of the EI scores across households by dwelling ownership status. Households that rent their homes (Tenants) exhibit the highest median EI scores, indicating a higher likelihood of experiencing financial and energy-related hardships. In contrast, owners show lower EI scores overall, reflecting more stable conditions. The category "Not owner but not paying rent" shows a wider spread, suggesting diverse conditions within this group. Meanwhile, Lodging households have lower median values but a few extreme cases with high EI scores, possibly pointing to isolated but severe vulnerabilities. The tenure status can play an important role in household vulnerability and should be considered when designing targeted interventions under a potential EEOS.

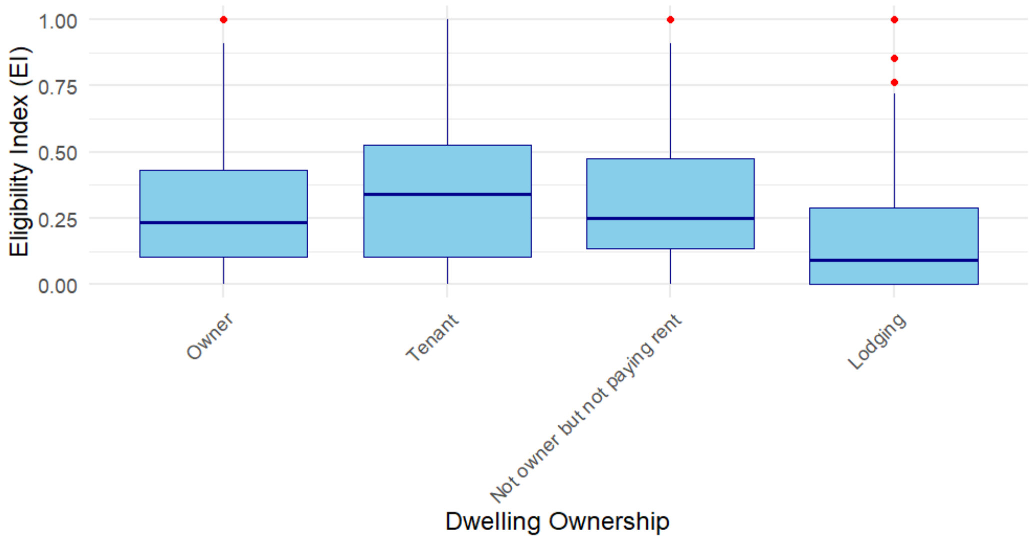

Figure 6.14 : The Distribution of EI Scores Across Different Dwelling Ownership Status.

Figure 6.15 shows the distribution of the EI scores across different household types. Among all categories, single-parent households with children and non-nuclear multi-person households tend to have higher median EI scores, suggesting greater financial stress and energy poverty risk. In contrast, couples only and single-person households exhibit relatively lower EI levels, though some outliers indicate extreme vulnerability even within these groups.

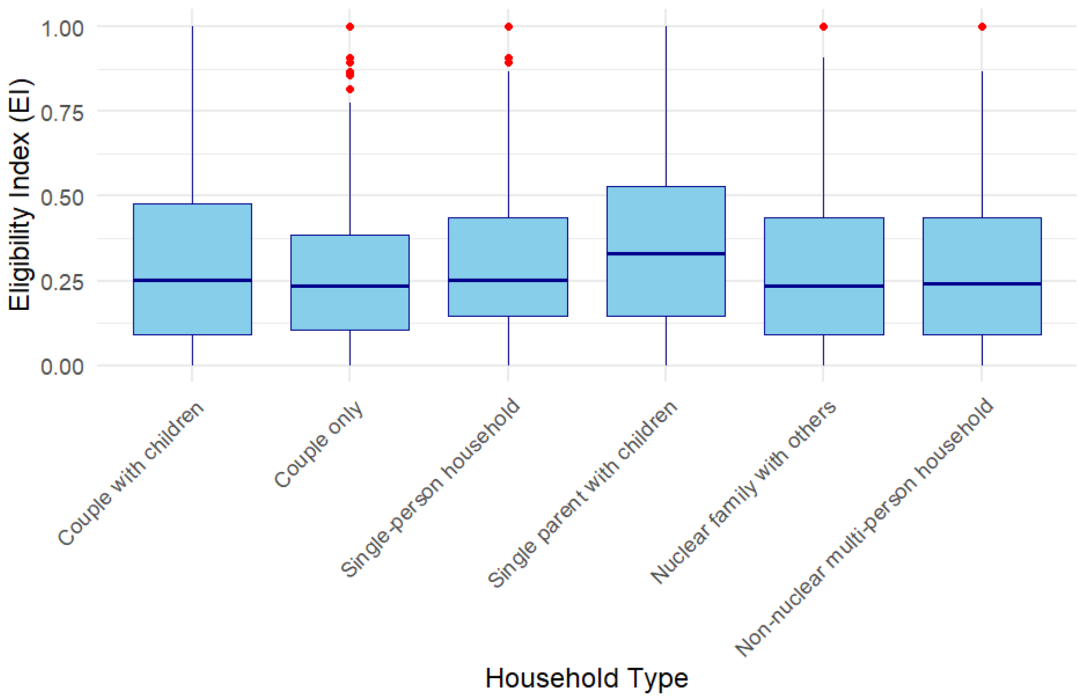

Figure 6.15 : The Distribution of EI Scores Across Different Household Types.

The SILC dataset includes geographic identifiers based on the Nomenclature of Territorial Units for Statistics (NUTS) classification system, which enables regional comparisons. This classification system is widely used in the European statistical framework and divides countries into hierarchical levels for policy and planning purposes. At the NUTS1 level, Türkiye is divided into 12 large statistical regions, while the NUTS2 level consists of 26 subregions. This structure allows for both broad and detailed spatial analyses of household vulnerability. The list of NUTS2 codes and the provinces they correspond to is provided in Appendix C.

Figure 6.16 presents the distribution of the EI scores across the NUTS1 regions. Western regions such as West Marmara, West Black Sea, Aegean, and East Marmara generally exhibit lower median EI scores, indicating lower levels of vulnerability. In contrast, eastern regions such as Central East Anatolia, Southeast Anatolia, and Northeast Anatolia tend to have higher medians and wider interquartile ranges, suggesting both higher vulnerability and greater within-region inequality. Istanbul displays a notably wide spread of EI scores, ranging from zero to the upper bound of the index. While the median EI score in Istanbul remains moderate compared to other regions, the presence of extreme scores and the broad interquartile range indicates an explicit level of internal inequality. This finding reflects the dual structure of Istanbul's socioeconomic landscape, where high-income households and severely vulnerable groups coexist within the same metropolitan area.

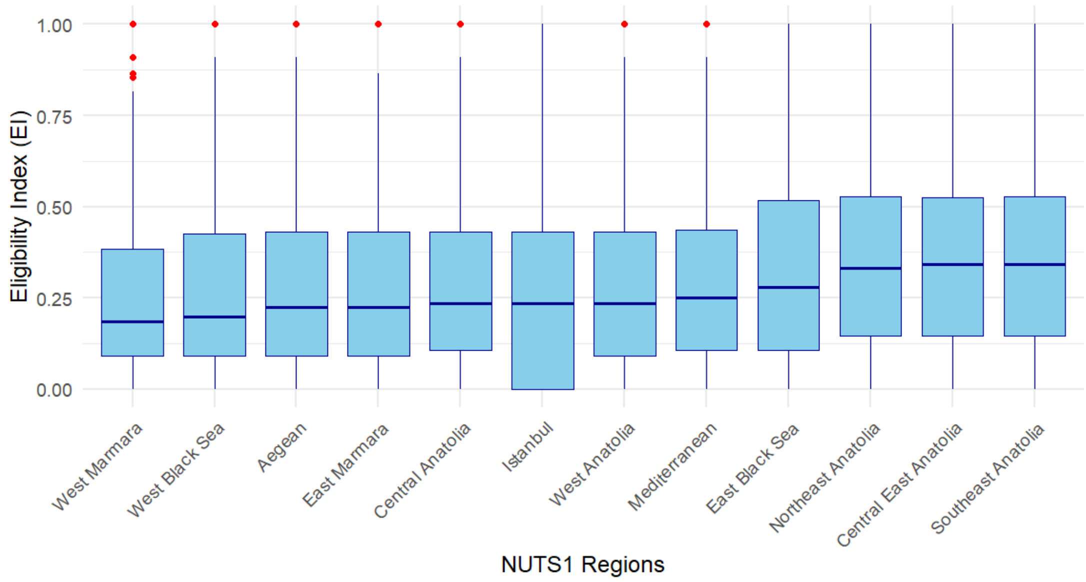

Figure 6.16 : Distribution of the EI Scores Across the NUTS1 Regions.

Figure 6.17 presents the spatial distribution of household counts across different EI score categories at the NUTS2 regional level in Türkiye. Each colored dot represents EI scores, ranging from 0–0.2 (very low vulnerability) to 0.8–1.0 (very high vulnerability), while the size of the dots indicates the number of households in that category within each region. The TR63 region (Hatay, Kahramanmaraş, Osmaniye) appears empty in the visualization due to the absence of household-level data in the 2023 SILC dataset. This gap is most likely attributed to the severe disruptions caused by the devastating earthquakes that struck the region in February 2023.

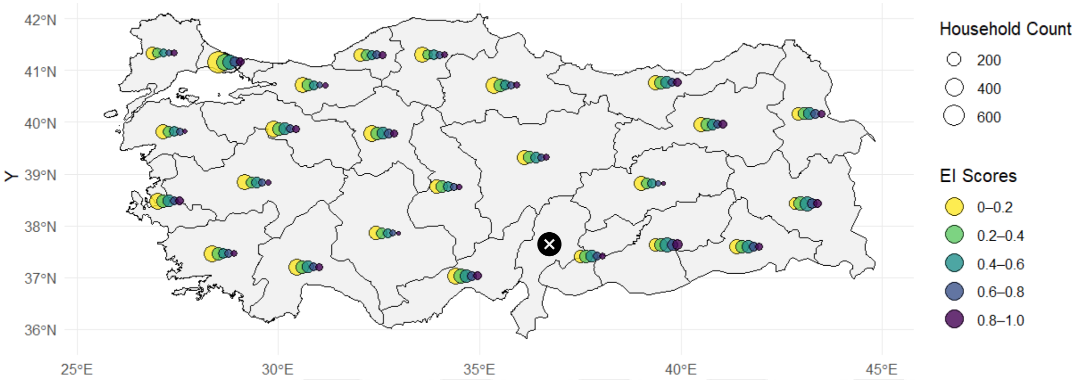

Figure 6.17 : Distribution of the EI Across the NUTS2 Regions.

In Figure 6.17, a clear regional pattern emerges: many western and northwestern regions are characterized by a higher concentration of households in the lower EI ranges, reflecting relatively lower financial and energy-related vulnerability. In contrast, eastern and southeastern regions exhibit larger bubbles in the higher EI ranges. It is also important that Istanbul stands out prominently on the map due to its large population size and high number of households.

Figure 6.18 illustrates the regional variation in the proportion of households with high EI scores, between 0.6 and 1.0. The darker red shades represent higher shares of such households within each NUTS2 region, while lighter tones indicate lower concentrations. The TR63 region is displayed in grey due to the absence of data. The map reveals a noticeable east-west divide in the distribution of high EI score households. Southeastern and eastern regions of Türkiye exhibit the highest concentration of households facing significant financial and infrastructural vulnerability. In contrast, most western and northwestern regions have comparatively lower shares of high EI scores.

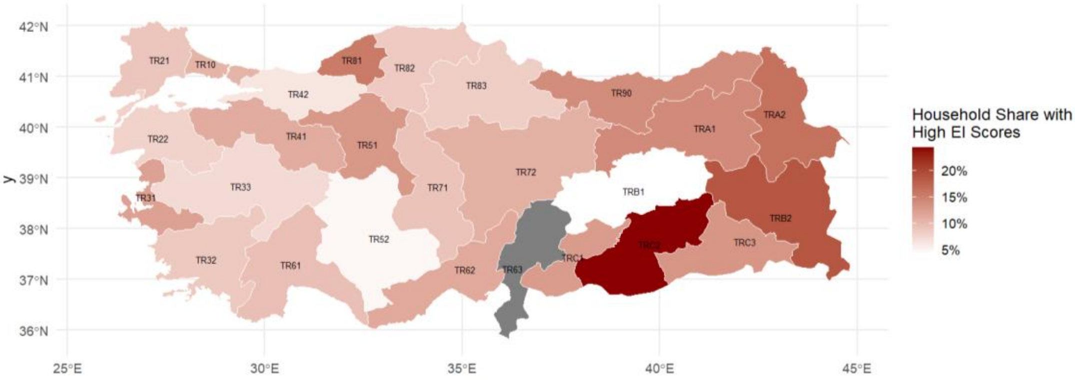

Figure 6.18 : Household Share with High EI Scores (0.6–1.0) Across the NUTS2 Regions.

The overall spatial pattern in Figure 6.17 and 6.18 not only highlights regional disparities in vulnerability but also reinforces the need for geographically targeted energy efficiency interventions under a potential EEOS framework.

6.5.2 Clustering results

To segment households based on their vulnerability and suitability for targeted energy efficiency interventions under EEOS, an unsupervised clustering analysis was conducted using the k-prototypes algorithm. This method was selected due to its ability to handle mixed-type data, combining both numerical and categorical variables, which reflect key dimensions of energy poverty in Türkiye. The clustering was performed using three variables: the EI scores, the inefficiency categories, and the NUTS2 regions. Together, these three variables were chosen to reflect a balance of household-level vulnerability, technical inefficiency, and regional equity considerations, aligning with the broader goal of designing a socially just EEOS.

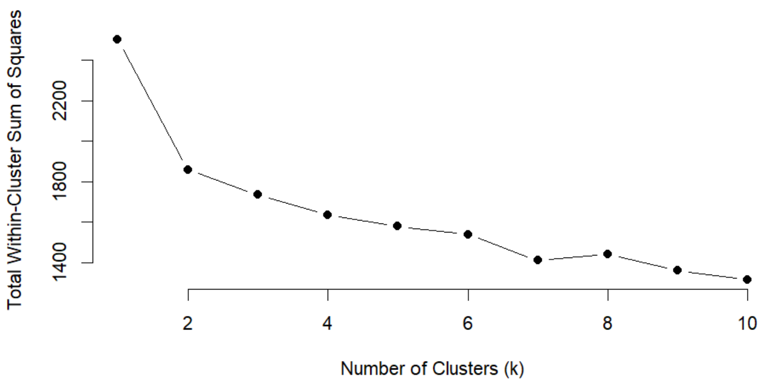

Figure 6.19 : Elbow Method for K-Prototypes Clustering.

The Elbow Method was used to decide the best number of clusters by plotting the total within-cluster sum of squares (WSS) for different values of k. This method looks for the point where increasing the number of clusters brings only a small improvement in how tightly grouped the clusters are.

In Figure 6.19, “elbow” was seen at k = 3, where the decrease in WSS started to slow down. Although k = 4 also looked reasonable, k = 3 was chosen to make the results easier to interpret and to support clearer visualizations. This decision balances statistical accuracy with practical use, especially when the aim is to define household groups clearly for energy efficiency policy.

Figure 6.20 presents the 3D visualization of the clustering results based on three key variables. The k-prototypes algorithm, applied with k = 3, successfully separates households into three distinct groups that reflect different combinations of vulnerability, technical inefficiency, and geographic distribution. Each cluster presents specific patterns that can inform differentiated energy efficiency strategies.

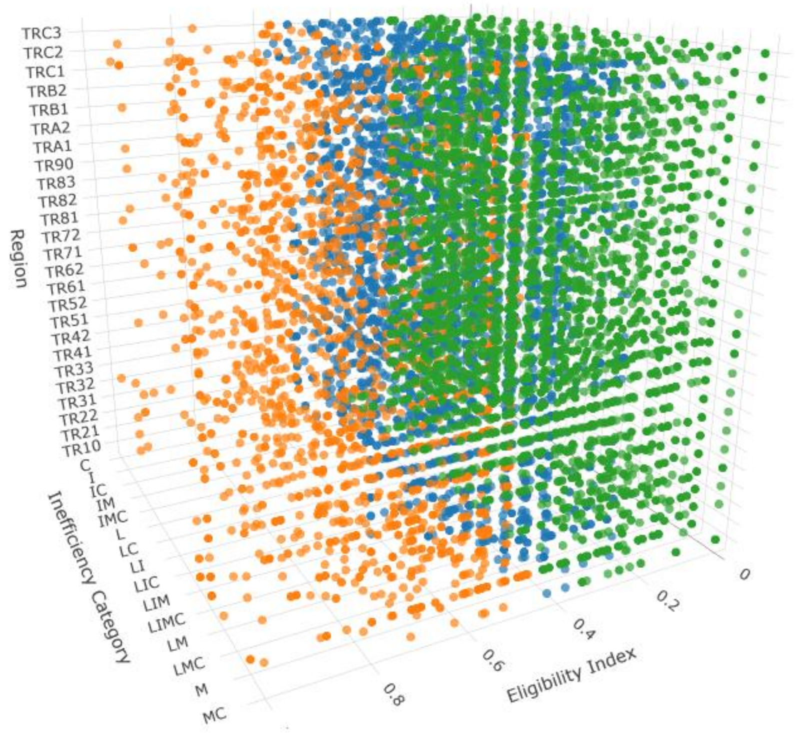

Figure 6.20 : 3D Cluster Visualization.

At first glance, the 3D visualization of the clustering results reveals a clear stratification of clusters along the EI dimension. Orange-coloured households appear to be concentrated at the higher end of the EI scale, suggesting greater vulnerability, while green points are mostly located at the lower end, and blue households are more centrally distributed. Although this spatial distribution offers useful insight into the relationship between EI and the cluster structure, a more precise comparison across clusters requires examining the statistical distribution of EI. Therefore, a boxplot was generated to compare EI levels across the three clusters.

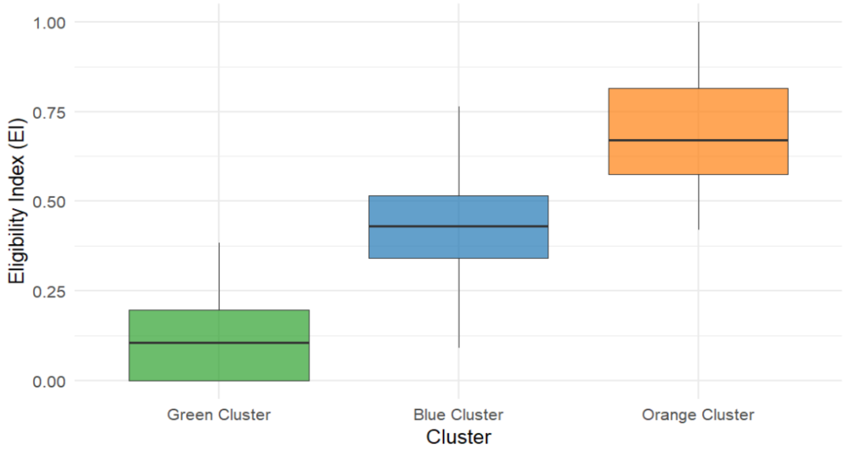

Figure 6.21 : Distribution of EI by Cluster.

Figure 6.21 supports the initial visual interpretation of the cluster structure by showing the distribution of the EI across the three clusters. The green cluster (consist of 8,374 households, represent 55.92%) has the lowest median EI, followed by the blue cluster (consist of 4,395 households, represent 29.35%), while the orange cluster (consist of 2,206 households, represent 14.73%) shows the highest values. This ordering confirms that the clustering outcome reflects a meaningful stratification in terms of household vulnerability.

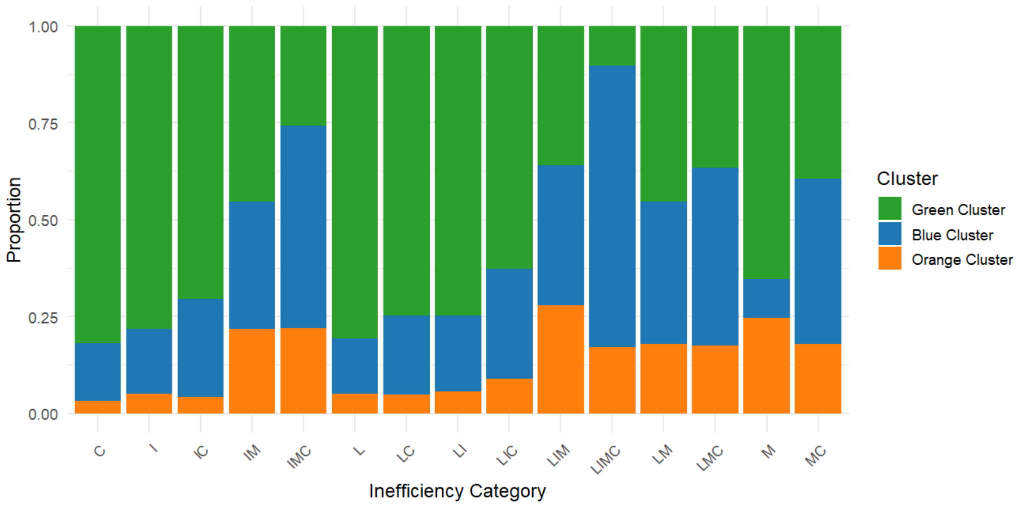

Figure 6.22 : Distribution of Inefficiency Categories by Cluster.

Figure 6.22 illustrates the composition of each inefficiency category by cluster. Green Cluster dominates the technically simpler categories, while Orange Cluster becomes increasingly prevalent in categories that reflect multiple inefficiency dimensions (such as LIMC, LMC, and LM). Blue Cluster is more evenly spread and may represent households in a transitional or moderate condition.

The clustering outcome aligns well with the conceptual framework proposed at the beginning of this study, which aimed to segment households into three main groups: priority energy-poor, at-risk, and regular households. The orange cluster, characterized by high eligibility index scores and complex inefficiency patterns, clearly reflects the priority energy-poor group. The blue cluster represents at-risk households with moderate eligibility levels and a mix of inefficiency types. Meanwhile, the green cluster largely comprises regular households with relatively low EI scores. This consistency between the theoretical categorization and empirical clustering results strengthens the credibility of the approach and shows that the selected variables effectively capture household-level energy vulnerability.

The spatial patterns of the Priority Energy-Poor, At-Risk, and Regular household groups are presented in Figures 6.23, 6.24, and 6.25, respectively.

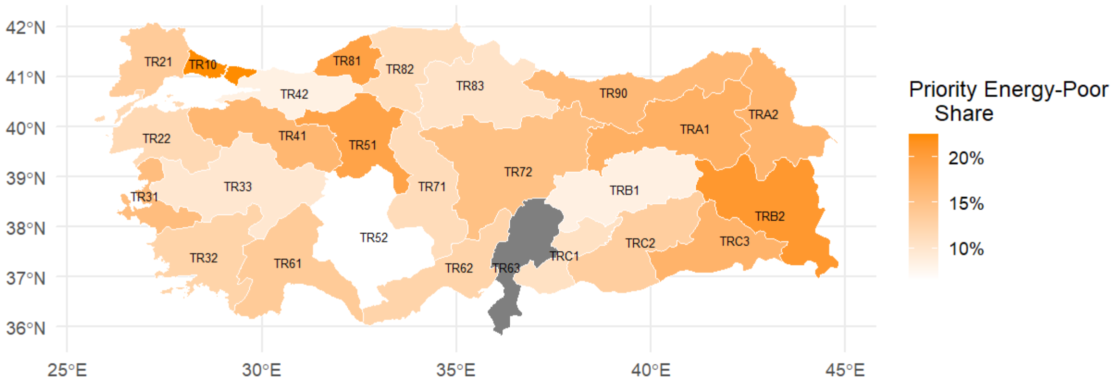

Figure 6.23 : Regional Distribution and Share of Priority Energy-Poor Group.

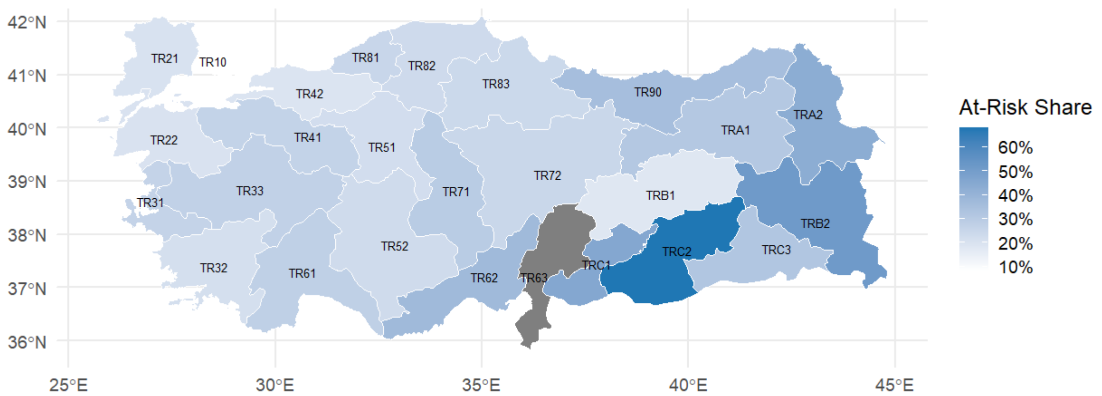

Figure 6.24 : Regional Distribution and Share of At-Risk Group.

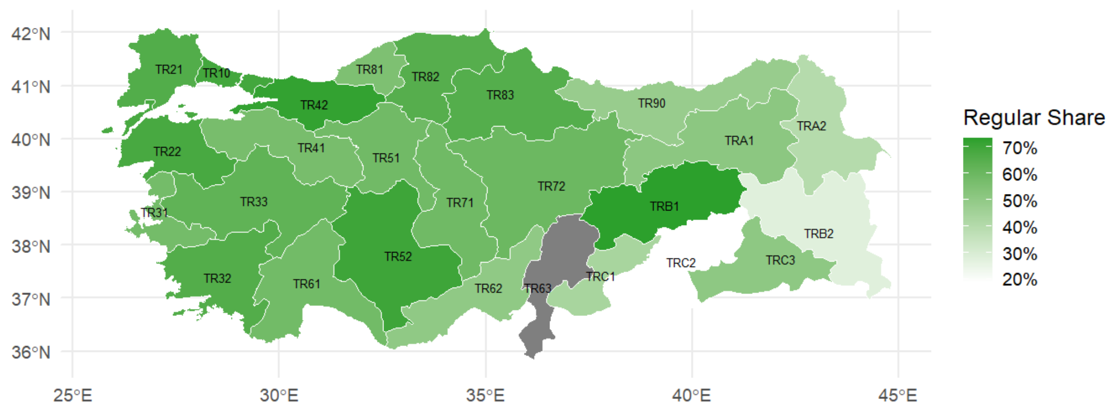

Figure 6.25 : Regional Distribution and Share of Regular Group.

The spatial distribution of household groups shows clear regional patterns across Türkiye. The share of Priority Energy-Poor households is highest in eastern and southeastern regions such as TRB2 and TRC3, which shows a strong concentration of energy poverty. At-risk households are prominent in TRC2 and TRB2, indicating a transitional group vulnerable to falling into deeper energy poverty if not supported. Conversely, Regular households dominate the central and western parts of the country. One notable case is Istanbul (TR10), which shows a polarized distribution: it has a visible share in both the Priority Energy-Poor and Regular groups, while the At-risk group is nearly absent. This suggests a sharp socioeconomic divide among households, where many are either clearly vulnerable or relatively well-off, with fewer households falling in between. These findings emphasize the importance of spatially differentiated policy tools under any future EEOS, particularly if the objective is to target and reduce energy poverty in a precise and effective manner.

The regional distribution and share of inefficiency categories, along with a detailed breakdown of EI ranges for priority energy-poor and at-risk households across inefficiency categories and regions, are presented in Appendix C.

6.6 Summary of Key Findings and Insights

This chapter presents a comprehensive, data-driven approach to identifying and prioritizing energy-poor households within a potential EEOS in Türkiye. This study first identifies inefficient households using structural and operational inefficiency indicators. Within this subset, carefully selected financial difficulty indicators are used to construct a custom EI, with weights assigned through MCA. Based on the EI scores, inefficiency categories, and regional variation (at the NUTS2 level), households were clustered into three groups, Priority Energy-Poor, At-Risk, and Regular, using the k-prototypes algorithm.

The findings of the study highlight that energy poverty is not solely a financial phenomenon but is closely intertwined with inefficiency-related vulnerabilities. Households with multiple inefficiency problems consistently exhibit higher EI scores, underlining the cumulative burden of physical inadequacies. Among households with no inefficiency problems, high EI scores (above 0.6) are virtually absent, indicating that financial difficulty alone (without inefficiency consideration) does not sufficiently identify households at high risk of energy poverty.

The clustering results reveals a conceptually aligned segmentation and highlight the need for differentiated policy responses. Priority Energy-Poor households, the highest eligibility scores and most complex inefficiency profiles, require immediate and comprehensive interventions. These households should receive the highest level of support under an EEOS. At-Risk households show moderate vulnerability and more mixed inefficiency patterns. This group would benefit from preventive, targeted measures before their conditions worsen. Finally, Regular households, while less vulnerable, still face inefficiency problems and can be addressed through general EEOS measures. For this group, co-financing approaches such as low-interest loans or credit-based programs can be designed, enabling household contribution and promoting cost-effective upgrades.

Moreover, clear spatial disparities in household vulnerability were observed across Türkiye. The Priority Energy-Poor group is predominantly concentrated in the eastern and southeastern regions, where both financial difficulty and structural inefficiencies are more pronounced. In contrast, the Regular group, characterized by relatively low vulnerability, is more common in the western and central parts of the country. The At-Risk group tends to cluster in transitional regions, particularly those situated between eastern and central Türkiye, where moderate levels of both economic and structural challenges coexist. A particularly notable case is Istanbul, which exhibits a polarized distribution of households: while the city includes both highly vulnerable and relatively well-off groups, it hosts very few households in the intermediate, At-Risk category. This sharp divide highlights significant internal inequality within metropolitan areas and emphasizes the need for differentiated and location-specific policy responses.

The areas where the Priority Energy-Poor group is predominantly concentrated, Türkiye's eastern and southeastern regions, are also those with the highest levels of electricity theft and non-technical losses. This dual reality presents a complex challenge for policy design. For EEOS to be fair and effective, such regional dynamics must be considered, ensuring that support reaches genuinely vulnerable households while also addressing structural issues related to enforcement, infrastructure, and accountability.

Energy efficiency programs in the household sector have traditionally focused on thermal retrofits, such as insulation and heating system improvements. In this Ph.D. thesis study, electricity incumbent suppliers are considered the obligated parties under the possible Turkish EEOS. However, since the focus is on the household sector, this institutional setup needs to be reconsidered. Whether natural gas distribution or supply companies should also be included in the obligation scheme is another important question. These issues are further discussed in the ninth chapter, with an emphasis on creating a more balanced and effective EEOS design.

In conclusion, the results highlight the necessity of moving beyond narrow, single-dimensional definitions of energy poverty. By incorporating structural, financial, and spatial dimensions, the proposed methodology offers a robust and replicable framework for identifying vulnerable households. Importantly, since EEOS is fundamentally an energy efficiency mechanism, this study was designed to align with that purpose by first identifying inefficiency as a starting point and then layering financial vulnerability through the eligibility index. The results confirm the effectiveness of this approach in targeting energy poor households within the scope of an EEOS.

However, it is important to acknowledge that the analysis is constrained by the scope and granularity of the national SILC dataset. For instance, the dataset does not include detailed information on household appliances, making it necessary to rely on assumptions when considering operational inefficiencies related to appliance use. Moreover, since the dataset lacks direct energy expenditure data, the identification of energy-poor households in this chapter cannot be empirically compared with those defined through expenditure-based metrics in Chapter 5, which uses the HBS. This limits the ability to cross-validate findings across different data sources. Additionally, the absence of a heating fuel type variable in the SILC dataset prevents a clear assessment of which obligated energy suppliers, such as electricity or natural gas companies, should be responsible for targeting specific households under the EEOS framework. These limitations should be considered when interpreting the results and designing future data collection strategies. To strengthen future research and enable more accurate targeting mechanisms within a potential EEOS, it is essential that national datasets be enhanced accordingly. The results of this study highlight the urgent need to include additional variables in national surveys, particularly those capturing household appliance ownership and efficiency levels, detailed energy expenditure breakdowns, and the primary heating fuel types used by households. Incorporating such variables would significantly improve the accuracy of vulnerability assessments and enable the alignment of EEOS design with real household energy profiles. Therefore, it is recommended that the findings of this study be taken into account in the revision and expansion of future rounds of national surveys such as SILC or HBS, ensuring that energy poverty and efficiency policies are supported by richer and more targeted data infrastructure.

Despite the limitations of the national SILC dataset, the study employed robust, data-driven methods and statistically grounded interpretations to produce meaningful and policy-relevant results. It introduces the first comprehensive framework for identifying and prioritizing energy-poor households within the scope of a potential EEOS in Türkiye. As such, the study provides proactive and actionable insights to support policymakers in designing an inclusive, targeted, and socially equitable scheme, making it a significant and timely contribution to Türkiye’s energy efficiency and energy poverty policy agenda.

7. FLEXIBILITY OPTIONS AND WHITE CERTIFICATES

In the previous chapters, the rationale for introducing an EEOS in Türkiye was established, followed by a detailed assessment of its sectoral applications. The analysis covered the cost-benefit assessment of implementing the scheme in industrial and commercial building sectors, as well as an in-depth examination of its potential social implications in the household sector, particularly through the lens of energy poverty. While the chapter presenting the cost-benefit assessment of the EEOS structure focused on a basic end-user-financed obligation model, it was also noted that incorporating flexibility options and market-based components could ease the burden on end-users and improve overall cost-effectiveness. This chapter builds on that insight by exploring key design features that enhance the adaptability and economic efficiency of EEOS: flexibility options and white certificates.

In this chapter, the flexibility options, including buy-out, banking, borrowing, and saving trading, are examined in detail, along with the practical experiences from their implementation. Following this, the focus shifts to the market-based feature of the scheme: white certificates. Particular attention is paid to the structure of white certificate schemes, including a historical overview of existing European schemes, a typology of institutional and trading structures, and lessons learned from both successful and unsuccessful implementations. Finally, the chapter develops a reference framework tailored to Türkiye's context, grounded in international best practices but adapted to national policy conditions and institutional capacity. This framework is intended to support the effective design and launch of Türkiye's pilot white certificate program, ensuring alignment with energy efficiency goals, equity considerations, and market readiness.

7.1 Flexibility Options

EEOS is designed with embedded flexibility mechanisms to enhance cost-effectiveness, responsiveness, and administrative feasibility of compliance. These flexibility options enable obligated parties to meet their targets through alternative compliance routes, mitigate temporal and financial constraints, and better align savings delivery with market dynamics.

7.1.1 Buy-out

Buy-out mechanisms allow obligated parties to fulfil a portion of their energy efficiency targets by making a financial payment instead of delivering actual savings. While such mechanisms may be referred to differently across jurisdictions, such as administrative contributions, non-compliance penalties, pay-to-save option, compensation fee, or fund payments, they share the same underlying concept. All of them offer an alternative compliance pathway that substitutes monetary input for physical energy savings under specific conditions. The primary rationale for introducing a buy-out option is to provide flexibility in meeting obligations, especially in contexts where the delivery of savings is constrained by market immaturity, limited technical capacity, or high marginal costs. Buy-out mechanisms can especially help stabilize the scheme in its early phases by avoiding strict non-compliance penalties while still generating financial resources that can be redirected into verified efficiency programs. In this way, they maintain momentum in energy-saving efforts while acknowledging practical constraints on delivery.

Buy-out mechanisms must be tightly regulated to avoid becoming an easy substitute for physical energy savings delivery. To ensure credibility, buy-out contributions should be set at a level higher than the typical cost of fulfilling the obligation, thereby maintaining a deterrent effect. Transparency and regular price adjustment are also essential. Importantly, all funds collected through buy-out payments must be reinvested directly into verified energy efficiency actions, ideally targeting underserved or vulnerable groups. Buy-out should be clearly distinguished from penalties and should function as a compliance tool rather than a punitive measure. However, this distinction does not rule out the use of enforcement mechanisms to ensure timely and complete contributions. The case of Slovenia illustrates this balance: although the buy-out is not a penalty, late payments accrue interest and unpaid amounts are legally enforceable, thereby reinforcing compliance without altering the voluntary nature of the mechanism. Similarly, in Latvia's EEOS, obligated parties may opt to make a buy-out payment at a fixed rate of €70 per MWh. However, if they fail to meet at least 80% of their target, the payment becomes mandatory and is increased by a multiplier of 1.5. This two-tiered structure allows flexibility for early compliance while applying greater financial pressure on underperformance. Both cases highlight that voluntary compliance pathways can coexist with firm enforcement provisions, provided that the rules are transparent, proportional, and well-communicated (EBRD, 2019; ENSMOV, 2020).

In Poland, energy efficiency targets for obligated parties are set in the form of white certificates, which represent verified energy savings. To comply, obligated parties must submit these certificates to the regulator. As an alternative, they can pay a substitution fee to the National Fund for Environmental Protection and Water Management. Although only a proportion of the obligation could be met through the substitution fee in earlier years, since 2019 this option has been restricted and can only be used when white certificates are not available on the market, making it a limited and conditional compliance pathway. The substitution fee is set each year in advance. In 2017, it was around €350 per toe and increases by 5% annually. This design helps prioritize certificate trading while keeping the buy-out as a last resort (ENSMOV, 2020).

In Austria, obligated parties have the option to fulfil their energy efficiency targets through a “pay to save” mechanism. This allows them to meet their obligations by paying a fixed compensation fee of €0.20 per kWh of first-year energy savings, instead of directly implementing efficiency measures. The scheme offers a cost-transparent alternative to physical delivery and serves as a formal buy-out option. While it provides flexibility, the system also includes a strong enforcement component: in cases of non-compliance beyond the accepted mechanisms, administrative penalties of up to €100,000 may be imposed (ENSMOV, 2020).

Ireland’s EEOS includes a clearly defined and strictly controlled buy-out mechanism, designed to offer a limited degree of compliance flexibility. The buy-out option allows obligated parties to meet a portion of their targets by making a financial contribution to the Energy Efficiency National Fund and used to support approved energy efficiency measures. The mechanism is not a general alternative to target delivery, but a last-resort flexibility subject to strict eligibility and procedural conditions. To qualify for buy-out, obligated parties must apply to the Sustainable Energy Authority of Ireland (SEAI), specifying the number of energy credits they wish to buy out, the relevant sub-target category (e.g. residential, commercial, energy poverty), and the compliance year. Each “energy credit” corresponds to 1 kWh of final energy savings, and the buy-out price per credit is pre-set annually by SEAI. For the 2023 obligation year, the buy-out prices were set at €0.69 per kWh for residential targets, €2.19 per kWh for energy poverty targets, and €0.24 per kWh for cross-sector targets. The notably higher unit price for energy poverty obligations reflects the scheme’s commitment to ensuring that social equity goals are not bypassed through the use of financial flexibility mechanisms. Buy-out applications must be submitted by 31 March of the year following the relevant compliance year, and upon SEAI approval, the full contribution must be paid within 28 days. Importantly, the use of buy-out is capped at 30% of each annual sub-target. That is, no obligated party may buy out more than 30% of their assigned obligation for any single sector, and this limit applies independently to each compliance year. SEAI also evaluates whether the party has previously used the buy-out option and may reject applications based on underperformance or overuse across years. Once approved and paid, the corresponding energy credits are added to the obligated party’s record in the Energy Credit Management System. However, these credits cannot be transferred or traded; they are non-transferable and valid only to satisfy the applicant’s own obligation for that specific year. This restriction reinforces the principle that buy-out is a compliance flexibility, not a market instrument. A key strength of the Irish approach is that buy-out contributions are reinvested through the Energy Efficiency National Fund, administered by SEAI. These funds are allocated to eligible projects, often with a focus on vulnerable households or public sector buildings. As such, even when physical delivery is substituted by financial contribution, the system ensures that verified energy savings are still achieved elsewhere in the economy, thus maintaining policy integrity and delivering public value (SEAI, 2023).

In the UK, a different type of buy-out mechanism has been proposed under the Energy Company Obligation (ECO) scheme. Unlike traditional buy-out used to cover delivery shortfalls, this version is designed to support medium-sized energy suppliers who are just above the obligation threshold which is currently set at 150,000 domestic customers or 500 GWh per year. These companies are expected to meet the same requirements as much larger suppliers, which can create financial and operational challenges. The proposed buy-out would allow them to remain in the scheme by making fixed payment instead of delivering energy-saving measures themselves. This payment would then be used to fund ECO activities through a central program. Although not yet implemented, this model shows how buy-out can be used not for compliance relief, but to reduce pressure on smaller actors while still contributing to national targets (BEIS, 2022).

7.1.2 Banking and borrowing

Banking and borrowing mechanisms are often considered in the design of EEOS to introduce temporal flexibility. In the EEOS context, banking refers to carrying forward excess savings from one obligation period to the next, while borrowing refers to using expected future savings to meet current-period targets. Among European schemes, banking is relatively common and generally accepted within defined limits, whereas borrowing is largely avoided due to its adverse effects on delivery momentum and scheme credibility. Allowing a moderate degree of banking can help avoid “stop-go” cycles in energy efficiency activity. Without banking, obligated parties may be discouraged from over-delivering in one period if those efforts are not recognized in future targets. This can lead to market instability and disruption in project pipelines. Banking supports continuous investment and encourages early action, if carry-over volumes are capped and used within a short timeframe to avoid speculative behaviour or double counting. In contrast, borrowing is considered a high-risk mechanism. While it may provide short-term flexibility, it can enable parties to delay actual savings delivery and slow down the overall pace of progress. Moreover, allowing borrowing may conflict with the scheme’s penalty structure and undermine the credibility of compliance enforcement. For these reasons, borrowing is rarely used in practice and is not recommended in most design guidelines. The consensus in international experience is to allow banking within well-defined boundaries, while discouraging or prohibiting borrowing, to maintain both delivery certainty and market stability (RAP, 2016).

In Austria, the EEOS allows banking but prohibits borrowing. If obligated parties exceed their annual targets, they may carry over the excess savings to subsequent years within the obligation period. However, if they fail to meet their target in a given year, borrowing from future periods is not permitted. Instead, obligated parties have two options to ensure compliance: they can either purchase additional eligible energy savings from the same year on the market or pay a compensation fee of €0.20 per kWh of the shortfall. This structure encourages early action through banking while maintaining delivery discipline by excluding borrowing and providing clear alternative compliance pathways (RAP, 2016).

In Croatia, banking and limited borrowing are permitted under EEOS. Obligated parties may transfer overachieved savings to future years within the current cumulation period or even to the next period. Additionally, if an obligated party falls short in a given year, up to 10% of the annual target may be compensated in the following year. This structure provides temporal flexibility while maintaining a clear boundary to prevent long-term underperformance. By capping the extent of borrowing, the Croatian model aims to balance delivery reliability with practical feasibility (RAP, 2016).

7.1.3 Saving trading

In several EEOS, obligated parties are allowed to trade surplus energy savings directly with one another. This type of inter-party saving trading or exchange typically takes place through bilateral agreements and administrative reporting, rather than through formal market platforms. The goal is to enhance compliance flexibility and reduce the marginal cost of meeting obligations, especially for smaller suppliers who may face limited internal delivery capacity. Real-world experience shows that inter-party saving trading volumes remain low and market liquidity is limited. Obligated parties often prefer to deliver savings in-house to maintain control, simplify administration, and avoid transaction-related uncertainties. The lack of price transparency and limited standardization across trades further restricts the potential for broad market participation. In most cases, traded savings are tracked through internal registries or oversight by scheme administrators, but without centralized pricing or liquidity mechanisms. Inter-party saving trading can still be a useful complementary mechanism within an EEOS framework if supported by clear rules on transferability, robust M&V procedures, and transparent accounting systems. In the absence of these, trading may introduce coordination challenges and limit scalability. As such, inter-party saving trading is best viewed as a complementary compliance option rather than a core delivery pathway within EEOS. Many EEOS designs exempt smaller energy companies to avoid placing disproportionate administrative and financial burdens on them. In schemes where inter-party trading is allowed, this can partially alleviate challenges for small suppliers by enabling them to purchase savings from others rather than deliver them directly (RAP, 2016).

In Ireland, obligated parties are allowed to exchange validated energy credits with one another, provided that both parties complete and submit a formal Energy Credit Exchange Form to the SEAI. This form must include details such as the names of the parties involved, the amount of energy credits exchanged, the relevant sector, and the applicable target year. The SEAI reviews each application to ensure that the transferring party holds a sufficient credit balance, and that the transaction will not cause non-compliance with minimum achievement requirements. If approved, SEAI updates the Energy Credit Management System, accordingly, deducting credits from the sender and adding them to the receiver’s account. Exchanges are only allowed between obligated parties and must occur within the same sectoral category (e.g., residential to residential). Credits acquired through financial contributions, such as buy-out payments, are not eligible for exchange. Importantly, SEAI does not involve itself in the commercial terms of the exchange, and the original obligated party retains responsibility for the quality of the associated energy efficiency measures (SEAI, 2023).

In Luxembourg’s scheme, bilateral transfers of energy savings are allowed between obligated parties under certain conditions. Energy savings projects can also be delivered by third parties (such as installers or energy advisors) but only if they are directly subcontracted by the obligated parties through project calls, bilateral agreements, or negotiated contracts. This structure preserves a degree of operational flexibility while ensuring that obligated parties retain full accountability for the savings claimed and reported (ENSMOV, 2020).

In the United Kingdom, trading of obligations between obligated parties is permitted under the ECO framework, but only under a set of predefined conditions. The trading process is overseen by the scheme administrator, and each transaction is assessed on a case-by-case basis. Obligated parties must submit formal applications demonstrating that all regulatory criteria are met and that the exchange does not undermine the scheme’s integrity or delivery expectations. While this allows for some compliance flexibility, the system remains tightly controlled to ensure transparency and accountability (ENSMOV, 2020).

In Austria, both public and private entities can register for an energy savings account and transfer their verified savings to obligated parties through civil contracts. These transfers are contractual rather than market-based and must be reported through the national system. Entities without an obligation are also allowed to bank savings they have implemented until February 14th of the following year, enabling them to transfer these savings to obligated parties within the obligation periods. This approach broadens participation while maintaining administrative control and ensuring traceability of savings transfers (ENSMOV, 2020).

Although different from saving trading, Ireland offers an additional flexibility mechanism through which obligated parties can transfer part of or all their annual targets to another obligated party. This process involves the formal reallocation of the responsibility to achieve energy savings, rather than the exchange of completed savings, between two consenting entities. This mechanism allows obligated parties to rebalance their compliance obligations based on operational capacity or strategic preference, while still ensuring overall target delivery remains within the obligated group (SEAI, 2023).

7.2 White Certificates

White certificates, also referred to as energy efficiency certificates or energy savings certificates, are tradable instruments that represent a quantified and verified amount of final energy savings. They form the basis of a more structured and formalized version of saving trading, in which the exchange of certified savings is extended beyond obligated parties to include third-party actors, typically within a regulated market framework. In white certificate schemes, energy savings achieved by accredited actors, such as ESCOs, installers, or aggregators, are validated and then converted into certificates, which can be bought and sold to help obligated parties meet their compliance targets. The inclusion of non-obligated participants, along with formal registry and trading procedures, distinguishes white certificates from simpler bilateral exchanges. In fact, some national EEOS frameworks, such as those in Italy, France, and Poland, are commonly referred to as White Certificate Schemes, reflecting the central role of tradable savings in their design. White certificate schemes function by issuing tradable certificates that correspond to a verified and standardised amount of final energy savings, typically measured in kWh or toe. These certificates are awarded by a designated authority following the validation of eligible energy efficiency measures and may be used by obligated parties to demonstrate compliance with their assigned savings targets (RAP, 2016).

White certificates are market-based instruments that combine regulatory obligations with price signals. Unlike command-and-control regulations, well-designed tradable permit systems equalise marginal compliance costs across market actors by encouraging competition to deliver energy efficiency measures where they are most cost-effective. This enables the achievement of energy savings at the lowest aggregate cost. Moreover, unlike subsidy schemes, white certificate programmes operate independently of state budgets and create incentives for the private sector to finance energy efficiency investments (Stede, 2017).

Having outlined the general structure and functioning of white certificate schemes, it is important to recognise that their implementation varies significantly across countries. While the core principles, such as the issuance of tradable energy savings certificates, the use of accredited measures, and compliance by obligated parties, are broadly shared, each national scheme reflects a distinct institutional, regulatory, and market context. Differences in how certificates are generated, who can participate, how trading is conducted, and how the schemes interact with other policy instruments result in a diverse set of models across countries.

There are currently four active white certificate schemes in Europe: those in Italy, France, Poland, and Spain. Among them, Italy, France, and Poland have been in operation for a much longer time and offer deeper insights in terms of market maturity, institutional learning, and policy evolution. In contrast, Spain's scheme is still very recent, and no academic evaluation is yet available. The following subsections provide a detailed examination of Italy, France, and Poland cases.

7.2.1 Case of Italy

Italy launched its white certificate scheme (Titoli di Efficienza Energetica – TEE) in 2005, marking the first fully operational market-based EEOS in Europe. The initial obligation was placed on electricity and natural gas distribution companies with more than 100,000 customers. In 2008, the threshold was lowered to 50,000 customers, broadening the scope of the obligated parties significantly. Each year, obligated distributors are required to submit a number of white certificates corresponding to their annual targets, which are calculated in proportion to their distributed energy volumes. Targets have been set in toe primary energy savings and increase annually. Each white certificate represents 1 toe of verified energy savings. Certificates are awarded for duration, referred to as the white certificate lifetime, depending on the complexity and expected persistence of the intervention. Importantly, only additional savings, those exceeding baseline trends and existing regulatory requirements, are considered eligible. Beyond obligated distributors, a wide range of accredited non-obligated actors are eligible to generate certificates by implementing eligible energy efficiency measures. These include energy service providers such as Energy Service Provider Companies (ESPCs) and ESCOs. Moreover, companies that have appointed an energy manager, those certified under the ISO 50001 energy management system, and non-obligated smaller distributors below the obligation threshold are also permitted to participate. This inclusive structure has played a significant role in developing a competitive and diverse market for energy services, expanding delivery capacity and encouraging innovation across sectors (Bertoldi et al., 2015; Di Santo et al., 2016; Di Santo and Chicchis, 2022; Stede, 2017)

The Italian white certificate scheme is governed through a multi-level institutional framework, involving several key public bodies with distinct roles and responsibilities. At the core of the system is the Energy Services Operator (Gestore dei Servizi Energetici - GSE), a publicly owned company responsible for managing the overall operation of the scheme. GSE oversees project approval, certificate issuance, registry management, and compliance tracking. Complementing GSE's operational role is the Energy Markets Operator (Gestore dei Mercati Energetici - GME), which manages the electronic trading platform where white certificates can be exchanged, either through spot market sessions or bilateral contracts. This trading infrastructure enables liquidity and price discovery but is also subject to fluctuations in market volume and transparency challenges. On the regulatory side, the Ministry of Economic Development (Ministero dello Sviluppo Economico - MiSE) sets the overall policy direction and issues national guidelines in coordination with the Ministry of the Environment (Ministero dell'Ambiente). Since 2021, following an institutional restructuring, these responsibilities have been transferred to the newly established Ministry of Ecological Transition, which was formed through the merger of the Ministry of the Environment and relevant departments of MiSE. The new ministry is now in charge of defining the national energy efficiency policy and issuing guidelines for the White Certificate Scheme. The Regulatory Authority for Energy, Networks and Environment (Autorità di Regolazione per Energia Reti e Ambiente - ARERA) is tasked with enforcing compliance, defining obligations, and overseeing tariff reimbursements to obligated parties. It also applies sanctions when targets are not met. In terms of technical oversight, the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (Agenzia Nazionale per Le Nuove Tecnologie, L'energia e Lo Sviluppo Economico Sostenibile - ENEA) and Research on the Energy System Institution (Ricerca sul Sistema Energetico) Research on the Energy System Institution) provide methodological support and scientific validation for savings calculations and measurement protocols. Together with GSE, they ensure the reliability of project evaluations (Di Santo et al., 2016; Di Santo and Chicchis, 2022).

In the Italian white certificate scheme, project developers (obligated parties or eligible/third-party actors) submit their project proposals directly to GSE. Each project must demonstrate compliance with the scheme's regulatory framework, particularly in terms of additionality, baseline assumptions, and energy savings calculation methodology. Project developers are required to carry out an ex-ante analysis before submitting an energy efficiency project for approval. This analysis involves a detailed assessment of the expected energy savings, considering technical parameters, operational conditions, measurement methodologies, and potential external factors such as climate or production variability. A core element of this process is the definition of the project's energy baseline, which serves as the reference point against which future savings are measured. The baseline is initially established based on the actual energy consumption of the existing system, typically using at least 12 months of real measurement data. This reference value is then adjusted to reflect the specific operational conditions expected during the project's implementation period. Factors such as daily operating hours, system load, or seasonal variations may lead to a refined baseline that better represents the project's context. However, in order to ensure additionality, the scheme goes further by comparing the adjusted baseline with existing market trends and regulatory standards. If the technology being replaced is already outdated compared to the average efficiency level in the market, the baseline is corrected downward to reflect what would have occurred anyway through spontaneous market evolution. Similarly, if legal minimum performance standards apply to the intervention, the baseline may be further reduced to exclude savings that would have resulted from regulatory compliance alone. The lowest of these adjusted values is then compared to the projected energy use of the new system, and the difference is considered the net eligible savings for which white certificates may be issued. This multi-layered approach to baseline definition ensures that only actual additional savings, which is beyond market and legal trends, are credited under the scheme. While it provides a high level of integrity, it also places a significant burden on project developers, who must collect extensive technical documentation, reference data, and metered consumption records. Particularly for industrial projects, this often requires a sophisticated level of engineering analysis and long-term measurement infrastructure. As a result, baseline definition in the Italian scheme is not only a technical exercise but also a regulatory and market-aligned validation of project impact. Once the project is reviewed and approved, GSE issues white certificates corresponding to the verified amount of energy savings. All participants hold accounts within the national market platform managed by GME. Verified certificates are credited to the project developers' accounts and may be used for compliance or traded. Obligated parties must obtain a sufficient number of certificates each year to fulfil their obligation. They can do so either by implementing their own projects or by purchasing certificates from third parties. To comply with their obligations, obligated parties submit the required number of certificates to GSE by May 31 of the year following the obligation period. GSE then officially cancels these certificates and credits them toward the party's annual target. Third-party actors, generate certificates through eligible projects and monetise them by selling to obligated parties. These transactions can occur via two main channels: bilateral agreements and the spot market managed by GME. Bilateral agreements remain the dominant trading mechanism, allowing parties to negotiate price and volume privately, often based on ongoing business relationships and project-specific factors. These agreements offer flexibility but are not transparent to the wider market. Alternatively, the spot market enables open trading sessions in which prices are set through supply-demand matching. While the spot market provides greater price transparency, its overall liquidity remains limited. Prices in both channels are determined by market conditions and are influenced by factors such as annual target levels, project approval volumes, regulatory changes, and certificate availability. Each white certificate carries a unique identification code and is associated with a specific project and compliance year, meaning it can only be used to meet obligations for that designated year. Certificates not used for compliance may be traded, but they cannot be reused once submitted and cancelled by GSE. Obligated parties must therefore ensure that the certificates they acquire or generate match the correct compliance year, as certificates from earlier or later years cannot be applied retroactively or in advance (Di Santo et al., 2016).

Over time, the Italian white certificate scheme has experienced a significant transformation in terms of the types of projects and sectors contributing to energy savings. In its early years, the scheme was dominated by small-scale, standardised measures such as the widespread installation of Compact Fluorescent Lamps (CFLs), efficient electric motors, and circulation pumps. These measures were attractive due to their low cost and ease of implementation, often promoted through partnerships between energy distributors and equipment retailers. However, over time, concerns were raised about the additionality, durability, and verification of these low-cost actions. To address additionality concerns, the Italian energy market regulator progressively tightened the eligibility criteria for CFLs, ultimately leading to their full exclusion from the white certificate scheme in 2011. Following this regulatory shift, the scheme experienced a substantial reorientation toward industrial and customized energy efficiency projects. The share of savings from industrial projects increased dramatically from just 6% in 2007 to 75% in 2015. This shift marked a transition from mass-market, standardised interventions to tailor-made, high-impact projects, often requiring detailed engineering assessments and more rigorous M&V procedures. This evolution reflects both the maturing of the Italian energy services market and the increasing demand for high-quality, verifiable energy savings. It also highlights the need for regulatory frameworks to adapt over time, ensuring that savings are not only cost-effective but also technically robust and aligned with long-term decarbonization goals (Stede, 2017).

In 2012, the tau coefficient, introduced in the Italian white certificate scheme. It was a lifetime multiplier designed to account for the expected duration of energy savings generated by projects. This “lifetime” refers to the number of years for which the project is eligible to receive certificates, based on the durability and persistence of its energy savings. Before the introduction of tau coefficient, white certificates were issued only for the first five years of savings, which penalized long-lived and capital-intensive interventions, particularly in the industrial sector. The tau coefficient aimed to address this by discounting future energy savings at a fixed 2% annual rate and awarding a proportionate number of certificates for savings achieved over a lifespan of up to 30 years. Depending on project lifetime, tau values ranged from 1.00 to 4.58 (Di Santo et al., 2016; Stede, 2017).

In 2017, during a period of high certificate prices, the Italian white certificate scheme attracted the attention of criminal organizations, which attempted to profit from the system by submitting illegitimate applications under standardised project protocols. A major case, uncovered through joint efforts by GSE and the Guardia di Finanza (Italy's financial law enforcement agency), revealed a large-scale fraud involving approximately €700 million worth of certificates, of which €105 million had already been claimed and transferred abroad before detection. Evidence from multiple evaluations indicates that fraudulent activity and procedural irregularities have occurred particularly in the residential and building sectors. Several cases involved false documentation and overstated savings, leading to significant numbers of project rejections by GSE and ENEA, the scheme's main verification bodies. Notably, some of these frauds were linked to companies established specifically to exploit regulatory loopholes, many of which were registered outside of Italy. To mitigate the fraud risk, the Italian regulator introduced stricter validation procedures and restructured the approval process around two main project typologies: Simplified Projects (SPs) and Monitoring Plan Projects (MPPs). SPs are based on predefined deemed savings values listed in a standardised catalogue, allowing faster evaluation for routine measures with low risk of manipulation (e.g. LED lighting, insulation). These projects require minimal documentation but are limited in scope and savings potential. In contrast, MPPs are designed for customized, complex, or large-scale interventions, especially in industrial processes. They demand detailed engineering calculations and involve ex-post verification, typically through sampling and on-site inspections, following methodologies aligned with the International Performance Measurement and Verification Protocol (IPMVP). While more resource-intensive, MPPs provide higher certainty in savings estimation and are less prone to fraudulent reporting due to their rigorous technical and administrative requirements. The Italian experience underscores the critical need for differentiated project pathways with risk-adjusted verification protocols, ensuring both administrative efficiency and system integrity.

These reforms helped re-establish trust in the scheme and strengthened its alignment with long-term energy efficiency and decarbonization objectives (Di Santo et al., 2016; Stede, 2017).

While these corrective measures, particularly the introduction of MPPs, initially helped re-establish trust in the system, they were not sufficient to reverse deeper market dysfunctions that had taken root. By the late 2010s, the Italian white certificate scheme was facing a widespread crisis marked by a persistent imbalance between supply and demand. The number of newly approved projects declined sharply due to the complexity of administrative procedures, inconsistent evaluation standards, and uncertainty surrounding project eligibility. At the same time, annual savings targets for obligated parties remained high, causing a widening gap between the volume of certificates required and those available on the market. As a result, certificate prices increased, reaching nearly €500 per unit in 2017, undermining both market stability and cost-effectiveness. In an attempt to control this volatility, the regulator introduced a price cap of €250 per certificate in 2018. However, this intervention also weakened investment signals and discouraged new project development, leading to further stagnation. In response to this slowdown, the regulator introduced temporary flexibility measures to ease the compliance burden on obligated parties. One such measure was the introduction of virtual certificates, a mechanism allowing distributors to fulfil part of their annual obligation using certificates not linked to actual savings but issued administratively to avoid non-compliance in times of certificate scarcity. In parallel, an additional compliance flexibility was introduced, allowing obligated parties to meet a portion of their targets (ranging between 40% and 50% depending on the year) with a delay of one or two years. While these measures provided short-term relief and helped prevent immediate sanctions, they did not address the underlying causes of market slowdown. Instead, they signalled a system under strain that was unable to deliver sufficient new savings to match rising policy ambition. As the gap between real project delivery and compliance obligations continued to widen, it became clear that a more structural and forward-looking reform was required to restore the scheme's credibility, predictability, and long-term effectiveness. In light of these systemic challenges, the Italian government enacted a major reform of the White Certificate Scheme through a Ministerial Decree issued on 21 May 2021. The reform aimed to restore balance to the mechanism by addressing supply constraints, regulatory complexity and demand-side pressure simultaneously. It introduced a revised target trajectory for obligated parties, expanded the scope of eligible interventions and simplified administrative procedures to reduce the risk of project rejection. Several outdated elements were removed, including the tau coefficient and the SPs pathway. The tau coefficient, which had previously been used to reward long-lived savings with more certificates, was replaced by a simpler system in which certificates are issued annually based on the project's verified savings over a defined lifetime. Depending on the type of intervention, this lifetime now ranges from 3 to 10 years. New features were also introduced, such as integrated efficiency projects that combine retrofit and new installations, bonus mechanisms for audit-based projects in ISO 50001-certified firms and front-load certificates for specific sectors. A preliminary assessment process was created to help applicants resolve issues before submission, and GSE was given a stronger technical support role, including the development of sector-specific reference values and tools. Taken together, these measures were designed to reactivate investment flows, rebuild confidence in the scheme and realign it with national and EU-level energy efficiency targets (Di Santo and Chicchis, 2022).

The 2021 reform brought important changes to the Italian white certificate scheme, aiming to stabilize a market previously affected by supply shortages and high certificate prices. On the demand side, annual targets were significantly reduced: the 2020 obligation was revised down from 7.0 to 2.8 Mtoe, and targets for the 2021–2024 period were set on a more gradual scale, starting at 1 Mtoe and reaching 2.4 Mtoe by 2024. This helped ease pressure on obligated parties and contributed to rebalancing the market. On the supply side, the volume of certificates issued increased notably. In 2023, over 245,000 certificates were granted (more than twice the 2022 level) driven by higher project approval rates and a rise in applications. The reform also influenced the type of projects submitted. While earlier phases of the scheme were dominated by residential and commercial measures, industrial projects now represent the majority of new applications and issued certificates. This is partly due to the complex and costly M&V procedures still required in sectors like transport and buildings. The pre-submission process introduced by the reform has been widely adopted, with around 600 preliminary notifications submitted in 2023. This has helped reduce rejections and improve transparency. Additionally, GSE has strengthened its technical support through clearer documentation, standardised reference values, and digital tools to assist project developers. By the end of 2023, the scheme had entered a “long market” phase, with certificate supply exceeding demand for the first time in several years (Di Santo et al., 2024).

Italian white certificate scheme stands out as one of the most experienced and mature systems in Europe. Over nearly two decades, it has undergone multiple phases of expansion, regulatory tightening, crisis, and recovery. The system has moved from supporting small, standardised measures to encouraging large, tailored industrial projects, reflecting both market development and institutional learning. Challenges such as fraudulent activity, administrative complexity, and market imbalances have triggered major reforms, including stricter verification rules, clearer project categories, and more flexible compliance tools. The Italian experience shows that while white certificate schemes can be powerful tools for promoting energy savings, they require strong institutions, well-designed rules, and the ability to adjust over time. As such, Italy offers not only a technical model but also valuable lessons from its successes and setbacks for other countries considering similar approaches.

7.2.2 Case of France

France introduced its white certificate scheme (Certificats d’Économies d’Énergie - CEE) with implementation starting in July 2006. Since then, the scheme has evolved through several multi-year obligation periods, marked by increasing ambition, broadened scope, and policy refinement.

The French scheme operates under a multi-institutional governance framework, involving both regulatory and technical bodies. At the core of the scheme is the General Directorate for Energy and Climate (DGEC) of the Ministry for Ecological Transition, which holds overall policy and regulatory responsibility. This ministry defines the legal framework, sets the energy savings obligations, enforces penalties, and issues official decrees that guide the implementation of the scheme. Administrative management is carried out by the National Pole for Energy Savings Certificates (Pôle National des Certificats d'Économies d'Énergie – PNCEE), a dedicated body within the ministry. PNCEE oversees the entire operational process: it manages the electronic registry of certificates, receives and verifies applications, validates declared energy savings, and issues the corresponding white certificates. PNCEE is also responsible for monitoring compliance and performing controls. On the technical side, the scheme is supported by the French Agency for Ecological Transition (Agence de la Transition Écologique - ADEME). ADEME contributes to the development of standardised energy-saving action sheets, provides methodological support. In cases involving fraud within the scheme, the Ministry has the authority to impose a temporary ban on the offending party from submitting further certificate applications, in addition to cancelling the fraudulent certificates and applying financial penalties. Other types of fraud or complaints (such as those related to poor-quality installers) are handled by the General Directorate for Competition Policy, Consumer Affairs, and Fraud Control (ENSMOV, 2020).

The French scheme placed savings obligations on energy suppliers delivering electricity, natural gas, district heating and cooling, LPG, and domestic fuel. To ensure proportionality, specific thresholds were applied: 400 GWh/year for electricity, gas, and heat/cool, and 100 GWh/year for LPG. There was no threshold for domestic fuel suppliers under the scheme, which resulted in the inclusion of a large number of small entities, approximately 2,300 out of a total of 2,350 obligated companies fell into this category. The obligation was distributed among obligated suppliers based on their 2005 market share. Despite the high number of obligated parties, the savings target was heavily concentrated: the largest electricity supplier in France was responsible for 63% of the national obligation, while the main natural gas supplier held 28%. This structure highlights the highly asymmetric distribution of the compliance burden in the scheme’s first phase. The first compliance period spanned from 2006 to 2009 and set a total energy savings obligation of 54 TWh cumac. This cumac unit refers to the cumulative and discounted final energy savings over the lifetime of an action, using a 4% annual discount rate. A financial penalty of €0.02 per cumac/kWh was levied on obligated parties failing to meet their targets, reinforcing the compliance requirement. The scheme allows for the banking of surplus certificates, whereby overachievements from a previous obligation period can be applied toward compliance in the following period. The scheme aimed to generate diffuse energy savings at the end-user level by incentivizing suppliers to co-finance energy efficiency investments. Estimated investment contributions from obligated parties were projected at approximately €150 million per year. Importantly, the system was not designed as a subsidy tool but rather as a new instrument to implement energy and climate policy by leveraging market logic to deliver low-cost savings (Tabet, 2007).

Like Italy, energy efficiency projects had to demonstrate energy savings compared to market-average baseline technologies, thereby ensuring additionality principle. Only savings beyond current market norms or regulatory standards were eligible. Renewable energy actions were eligible only when replacing fossil fuel-based heating systems. Energy savings actions were standardised through 93 predefined methodologies across various sectors. These methodologies were heavily concentrated in the residential and commercial building sectors, which together accounted for 72 of the 93 records. In the residential sector (39 methodologies), the majority focused on thermal improvements such as heaters and coolers (29), followed by insulation (6), appliances (3), and training-related services (1). The commercial sector (33 methodologies) similarly emphasized thermal systems (16), insulation (7), electrical equipment upgrades (8), and services (1). In grids, eight methodologies were approved, with four focused on heating and cooling grids and the other four on public lighting. The industry sector included 9 methodologies, covering both industrial buildings and process/utilities improvements. Finally, the transport sector had 4 approved actions, including intermodal equipment (e.g. bus tires, logistics hubs) and training services. A separate procedure allowed for non-standardised project submissions, in which the technical components of the application were reviewed and validated by ADEME experts (ENSMOV, 2020; Tabet, 2007).

While obligated suppliers could generate certificates directly through their own programs, eligible bodies were also allowed to implement projects and earn certificates. Eligible bodies included local authorities, building owners, and eligible companies. Furthermore, local communities were also eligible if their savings exceed a threshold of 1 GWh cumac. These actors can generate white certificates by implementing approved energy-saving actions. However, eligible companies must meet two key conditions: the energy savings must be outside their core business activity, and the measures must not generate direct commercial income. These restrictions effectively may excluded ESCOs and other energy service providers from participating as eligible actors in the early years of the scheme. To claim a certificate, an entity had to demonstrate a minimum savings volume of 1 GWh cumac. Once savings actions are verified and approved, white certificates are issued and credited to the registrants' accounts. These certificates can then be transferred, held, or used to fulfil compliance obligations. Although the scheme was designed as a "market-driven obligation," certificate trading remained limited during the first period. There was no formal exchange platform; instead, interactions between obligated and eligible parties were enabled through direct sale contracts, meaning that certificate transfers were governed by bilateral agreements. A national registry facilitated the tracking of issued and exchanged certificates, ensuring transparency and accountability within the decentralized trading environment (Tabet, 2007).

An official evaluation of the first compliance period of the French scheme (2006–2009) revealed that the total certified energy savings reached 65.2 TWh cumac, exceeding the initial target of 54 TWh cumac. When adjusted for the average measure lifetime (estimated at 13 years and corresponding to a discount coefficient of 10.39) this volume of certificates equates to approximately 5 TWh of actual energy savings per year. The majority of savings, which was about 87%, originated from the residential sector, where the most common measures included condensing and low-temperature boilers, various types of heat pumps, roof insulation, and double-glazed windows, reflecting the scheme's strong emphasis on improving thermal efficiency in buildings (Broc et al., 2011). Despite its formal market-based design, the French white certificate scheme has displayed limited trading activity, with only around 4% of certificates exchanged between parties. Most obligated suppliers have relied on delivering their own end-use energy efficiency projects rather than purchasing certificates, reflecting a preference for vertically integrated compliance strategies. During the first compliance period, the scheme resulted in an estimated an average cost of €0.037 per kWh, yet supplier contributions accounted for only about 10% of the total investment. One reason for this low contribution was that, due to regulated energy tariffs, suppliers were unable to fully pass compliance costs onto end-users. Nevertheless, the regulator estimated that the obligation resulted in moderate increases of around 1% for electricity tariffs and 0.5% for natural gas tariffs, indicating that partial cost recovery was achieved through indirect price adjustments. This dynamic encouraged suppliers to prioritize low-cost, short-payback actions, primarily through heating system upgrades such as condensing boilers and heat pumps, while more capital-intensive measures like insulation remained underutilized. Moreover, many eligible actions under the French scheme were also supported by parallel public incentives, particularly tax credits and zero-interest loans, which covered a significant share of investment costs. As a result, obligated parties often acted more as facilitators or co-financiers than as primary funders, further reducing their financial exposure. Although the scheme fostered new partnerships between energy suppliers and installation firms and expanded advisory services, it fell short of triggering systemic market transformation. Overlaps with other incentive schemes and the absence of robust verification mechanisms further limited its long-term impact, particularly regarding installation quality and persistent energy savings (Giraudet and Finon, 2015).

2010 was a transitory period followed with no new obligations, yet still saw 99.1 TWh cumac delivered, mainly from previously initiated actions. The second period (2011-2013) marked a major expansion, with obligations rising to 345 TWh cumac, including 90 TWh cumac specifically targeting fuel wholesalers, marking the first time transport fuels were included in the obligation. This expansion aimed to broaden the scheme's sectoral coverage and strengthen its impact. In this period, 317.4 TWh cumac certificates were delivered. Owing to administrative and market delays, the second period was extended by one year (2014) with an added obligation of 115 TWh cumac, during which 153.2 TWh cumac were delivered. This extra year was added to stabilize the scheme and prepare for upcoming expansions. This trajectory laid the groundwork for an even more ambitious third period (2015-2017) with a target of 700 TWh cumac, reflecting France's commitment to scaling up energy efficiency across sectors. During the third obligation period, France undertook a major revision of its standardised action sheets to comply with the EU's Energy Efficiency and EcoDesign directives. This period was marked by a significant tightening of rules, especially concerning deemed savings methodologies and verification procedures. Only marginal energy savings beyond regulatory baselines were considered eligible for equipment covered by EcoDesign standards, such as condensing boilers and heat pumps, resulting in a 20 to 50% decrease in their associated certificate values. In contrast, insulation measures, which were not subject to such directives, saw increases of 20 to 35% due to updated reference data and improved performance assumptions. These adjustments led to an estimated 13% reduction in overall certified savings for identical actions, effectively shifting market incentives toward building envelope improvements. While the revision enhanced additionality and regulatory consistency, it also raised concerns about transparency and policy clarity, since similar measures began receiving different certificate values depending on their technical eligibility. Another major change in the third period was the integration of energy/fuel poverty considerations through a dedicated energy/fuel poverty target, paving the way for broader inclusion of vulnerable households in the scheme. To operationalize this objective, a specific sub-obligation was established, requiring obligated parties to achieve part of their savings through actions targeting low-income households. Projects implemented under this component generated a distinct category of white certificates (known as précarité certificates) which were tracked separately and could be used to fulfil the social sub-target. In addition to this mandatory channel, a bonus mechanism (Coups de pouce) was introduced to further encourage investments in priority actions such as heating system replacements and insulation measures when delivered to eligible households. This bonus mechanism significantly boosted the number of certificates generated under the social objective, particularly in the residential sector. While the third period maintained a strong emphasis on insulation and heating-related actions, it also faced challenges. Overachievement in this period led obligated parties to reduce their activity temporarily, resulting in a "stop and go" dynamic that disrupted project delivery and investment planning. Despite these difficulties, the period served as a transition toward more ambitious obligations and stronger administrative oversight, setting the foundation for the fourth period's scaling-up of both targets and controls (Darmais et al., 2024; ENSMOV, 2020; Osso et al., 2015).

Fourth period of the scheme began in 2018 and was initially planned to run through 2020 but was later extended to the end of 2021. The total obligation for this period was set at 2,133 TWh cumac, maintaining the same annual target in 2021 as in previous years. Notably, 400 TWh cumac of this target was for households experiencing energy/fuel poverty, marking a significant shift toward social equity objectives. A key development during this period was the extension of eligibility to include certain actions within sectors covered by the EU Emissions Trading System (ETS), which expanded the scope of the scheme while requiring strict compliance with defined performance criteria and technical requirements. In total, 199 standardised operations were officially recognized, covering a broad range of eligible measures. The period also saw improvements in monitoring and control mechanisms, including mandatory third-party inspections and large-scale on-site verifications, aimed at addressing past issues like fraud and ensuring better documentation. The ecosystem around the scheme had by this time matured significantly, enabling more ambitious goals (ENSMOV, 2020). However, this increased maturity, and the intensification of activity also led to unintended consequences. Most notably, the volume of précarité certificates exceeded the target by nearly 60%, creating a surplus that could be carried over into the next obligation period. This reduced the need for new investment in low-income households during the fifth period and weakened the intended social impact of the scheme. In response, the bonus mechanism was significantly revised and its scope narrowed to deep renovation projects and its contribution capped at 25% of total certified savings (Darmais et al., 2024; ENSMOV, 2020).

In anticipation of the fifth obligation period (2022–2025), the French energy agency ADEME commissioned a prospective study to assess the technical energy savings potential achievable through standardised actions, particularly in the residential and tertiary building sectors. The results revealed a substantial mismatch between potential and policy ambition: under the most realistic scenario, the savings potential was estimated at only 1,029 TWh cumac, far below the official target of 1,770 TWh cumac. This shortfall highlighted the need for structural adjustments in the scheme's design and implementation capacity. In response, the fifth period introduced several key reforms, including a greater role for accompanying programmes, a revision of bonus mechanisms to better target priority interventions, and the gradual exclusion of fossil fuel-related actions. The study also emphasized that while insulation and heat pump installations remained major contributors to savings, many promising actions (such as domestic hot water control and advanced building systems) remained underutilized due to the rigid and outdated structure of standardised action sheets. As a result, recommendations were made to update these sheets in order to better reflect deep renovation strategies, integrate more accurate deemed savings values, and capture a broader range of technical possibilities. Furthermore, certain fossil fuel-based measures, such as high-efficiency gas boilers, were flagged for potential removal from the catalogue in light of their misalignment with the revised EED. These developments reflect a broader policy shift toward climate compatibility and long-term decarbonisation goals (ENSMOVPlus, 2022).

Over nearly two decades, the French white certificate scheme has evolved from a relatively simple market-based obligation into a complex and multi-dimensional policy instrument. It has progressively expanded its scope, integrated social equity objectives, and continuously adapted its methodologies to align with both EU directives and national decarbonisation targets. The successive obligation periods have demonstrated the scheme's ability to deliver large-scale energy savings, mobilize private investment, and target vulnerable households, albeit with mixed outcomes in terms of market efficiency and policy coherence. While the growing technical sophistication and institutional maturity of the scheme are evident, recurring challenges such as administrative complexity, fluctuating investment signals, and unintended consequences of overachievement highlight the importance of careful calibration. As one of the most established and socially oriented white certificate systems in Europe, the French case offers valuable lessons on balancing ambition, flexibility, and social targeting within a market-based framework.

7.2.3 Case of Poland

Poland introduced its white certificate scheme in 2012 as the primary mechanism for fulfilling its obligations under Article 7 of the EU EED. The legislative foundation of the Polish scheme was established through the first Energy Efficiency Act in 2011. The scheme mandates that energy suppliers, which are selling electricity, natural gas, and district heat (selling more than 5 MW heat) to final customers, submit a volume of white certificates proportional to their revenue of energy sales. Specifically, obligated parties were required to obtain white certificates equivalent to 1% of their revenue from energy sales in 2013, rising to 1.5% in both 2014 and 2015. The scheme covers a broad group of end-use sectors excluding transport and energy-intensive industries, mainly those not covered by the EU ETS. If obligated parties fail to meet their obligations through white certificate redemption, they must either pay a predefined buy-out fee to the National Fund of Environment Protection and Water Management or face penalties. From an institutional standpoint, the scheme is governed by the Ministry of Energy, which holds overall supervisory authority, while the Energy Regulatory Office (ERO) is tasked with administration. ERO is responsible for granting certificates, maintaining compliance, and verifying project outcomes. Additionally, the Polish Power Exchange (TGE) provides a trading platform where white certificates can be exchanged, enabling obligated parties to purchase certificates in order to fulfil their targets. Any actor is eligible to submit energy savings projects to obtain the white certificates (ENSMOV, 2020; Rosenow et al., 2020)

During the first phase of Poland's white certificate scheme (2013 to 2016), energy efficiency projects were selected through competitive auctions managed by ERO. Rather than evaluating projects on a case-by-case basis or using deemed savings, the scheme allocated certificates based on a centralized bidding process. ERO determined energy savings quota for each round of auctions. For instance, the first auction had a limit of 1 TWh of annual savings, meaning that certificates would be awarded only up to this cumulative cap. To ensure project significance, each eligible application was also required to deliver at least 10 toe in annual savings. To prevent market distortion and protect smaller players, ERO introduced separate auction slots for different categories of energy efficiency projects. At least 80% of the certificates were reserved for end-use energy savings at final consumer premises, while no more than 10% could be allocated to power companies' internal energy efficiency measures. An additional 10% cap applied to savings from reducing energy losses in transmission and distribution networks. Project developers submitted applications requesting a certain number of certificates in exchange for implementing energy-saving measures, and ERO ranked the bids using a specific performance metric known as the omega coefficient (ω). The omega coefficient was calculated as the ratio of a project's average annual energy savings, measured over its expected lifetime, to the number of white certificates requested. It served as a proxy for cost-effectiveness, with higher ω values indicating more energy savings delivered per certificate. To determine which projects would be approved, ERO applied an acceptance range defined by a lower and upper threshold. The lower bound was calculated by multiplying the average ω of all bids by a factor t, referred to as the flexibility coefficient, which typically ranged between 0.3 and 0.5 depending on the auction. The upper threshold corresponded to the highest ω submitted in the round. Only projects with ω values within this range were awarded certificates, which meant that both inefficient and disproportionately efficient bids could be excluded. Although the system was designed to reward technically sound and cost-effective projects, it gradually became susceptible to strategic behaviour. Applicants began to understate their expected energy savings in order to increase the number of certificates requested, thereby lowering their ω value and enhancing their chances of selection. By the fifth auction, the average ω in the end-user category had fallen to 0.36, indicating that 2.77 certificates were issued for each unit of annual savings. This erosion in cost-effectiveness, combined with administrative complexity and limited project verification, ultimately led to the abandonment of the auction-based and ω-dependent mechanism in the second period (Rosenow et al., 2020).

In 2016, as the scheme entered its second obligation period (2016-2020), Poland implemented a significant redesign of its white certificate scheme through the adoption of the second Energy Efficiency Act. While the initial phase of the scheme relied on a competitive auction mechanism to allocate certificates, the reformed system introduced an open application model. This transition aimed to streamline administrative procedures and improve accessibility for project developers, particularly by reducing entry barriers and allowing for continuous, rather than periodic, submission of energy-saving proposals. The second period retained the annual obligation level of 1.5% of energy sales revenue and penalty mechanism. Another key modification was the restriction of buy-out compliance: whereas the first phase allowed more generous use of this option, the second phase gradually reduced its scope, from 30% of the obligation in 2016, to 20% in 2017, and just 10% in 2018. Simultaneously, the buy-out price was raised by 50% in 2017 reaching approximately €350 per toe and indexed for annual increases of 5% thereafter. This escalation was intended to reinforce the incentive to pursue actual energy-saving investments rather than opting for financial compliance. Moreover, starting from 2019, the use of the buy-out option has been restricted and is now permitted only in cases where white certificates are unavailable on the market. Another important reform introduced in the second phase of Poland’s white certificate scheme was the restriction of eligibility primarily to planned energy efficiency projects, rather than those that had already been implemented. This change was intended to enhance the scheme’s additionality by ensuring that only new, policy-induced savings would be supported. The reform sought to minimize the risk of free-ridership and improve the credibility of certified savings. However, exemptions were granted for large energy consumers with annual consumption exceeding 100 GWh, and a transition period lasting until the end of 2017 allowed certain historic projects to still apply. In addition, the metric for evaluating energy savings was changed from primary to final energy, effectively narrowing the eligible scope of interventions and excluding certain renewable energy technologies. These design adjustments aimed to align the scheme more closely with end-use efficiency goals and EU-level definitions of energy savings. Furthermore, the second period introduced a stronger focus on standardization and audit requirements, as only projects with clearly defined energy savings methodologies and supported by pre-implementation energy audits were considered eligible. In parallel, regulatory oversight was significantly tightened: while small-scale projects delivering up to 100 toe of annual savings had previously not been subject to any systematic checks, they now became explicitly included in the compliance framework through random inspections conducted by ERO. Additionally, a savings banking mechanism was introduced, allowing surplus energy savings from approved projects to be carried forward and used toward fulfilling future obligations. Another important addition was the allowance of certain energy efficiency measures implemented within industries covered by the EU ETS (ENSMOV, 2020; Rosenow et al., 2020).

By the end of 2019, Poland's white certificate scheme had approved a total of 4,620 energy efficiency projects. During the first phase, certificates were awarded through competitive auctions, but many approved projects were never implemented, and a substantial number of certificates remained unused. In the second phase, the transition to an open application model increased the number of submissions, yet the system still struggled to meet its annual targets. Between 2014 and 2017, none of the yearly energy savings goals were achieved. For the 2018-2020 period, compliance with annual targets was considered possible if delayed project approvals were finalized, although the cumulative savings target remained far out of reach, with an estimated gap of 77% for the 2014–2020 compliance window under Poland's obligations pursuant to Article 7 of the EU EED. In terms of project types, most final energy savings originated from building insulation (34%), and industrial processes (33%), followed by heating system upgrades (17%), lighting improvements (9%), and ventilation or air conditioning measures (5%), with the remaining 2% falling into miscellaneous categories. Several factors contributed to the scheme's underperformance, including the limited realization of early projects, the omega-based auction model leading to the over-allocation of certificates, and persistent administrative complexity that discouraged participation. These issues underscore the gap between policy ambition and practical implementation, highlighting the need for a more streamlined and transparent framework (ENSMOV, 2020; Rosenow et al., 2020).

As of 2020, the Polish white certificate market featured three distinct categories of certificates, each associated with different levels of market value due to their varying validity periods. The first category included certificates issued under the old auction-based scheme, which remained valid only until the end of 2021. The second group comprised certificates from the transition phase of the scheme, which were valid solely in the year they were issued. Finally, certificates issued under the new open-application model had at that time no expiration date and could be used flexibly across obligation years. Because of these differences, certificate prices varied significantly across the three groups, with newer, long-validity certificates commanding higher prices due to their greater usability and strategic value (ENSMOV, 2020).

For the 2021–2030 compliance period under the EU EED, Poland has a cumulative energy savings target of 30,635 ktoe. According to its National Energy and Climate Plan (NECP), the country expects to achieve a total of 46,775 ktoe in cumulative savings, with approximately 24,500 ktoe delivered through the white certificate scheme and the remaining 22,275 ktoe through alternative measures. This policy shift reflects a recognition that the scheme alone is insufficient to meet long-term savings targets, necessitating a diversified approach alongside market-based mechanisms (ENSMOV, 2020; ENSMOVPlus, 2020)

Over the past decade, Poland's white certificate scheme has undergone significant transformation in its design, administration, and performance. Initially built around competitive auctions and cost-effectiveness metrics, the mechanism gradually evolved toward a more accessible, open application framework that prioritized administrative simplification and standardised evaluation. Despite these efforts, the scheme faced persistent implementation challenges, including unrealized savings, regulatory complexity, and limited market liquidity. As of 2020, Poland has acknowledged the limits of relying solely on the white certificate model and has adopted a more diversified strategy for meeting its energy savings obligations. The Polish experience provides a rich case of institutional learning, policy adjustment, and evolving approaches to energy efficiency governance within the EU framework.

7.3 Discussion and Insights for Türkiye

EEOS is a dynamic framework that integrate various flexibility options and market-based features. These design elements, including buy-out provisions, banking, borrowing, inter-party saving trading, and white certificates, serve to easy compliance, enhance cost-effectiveness, administrative feasibility, and long-term sustainability. However, the structure, scope, and effectiveness of these instruments vary significantly across countries, shaped by distinct policy priorities, institutional capacity, and market maturity. The European experience has shown that finding the optimal combination of flexibility mechanisms and market components is both technically complex and politically sensitive. A misalignment between design choices and national context can lead to implementation gaps, inefficient outcomes, and erosion of stakeholder trust. Therefore, for Türkiye, the challenge lies not in replicating existing models but in identifying a tailored configuration that balances ambition with practicality, and innovation with institutional readiness.

Buy-out mechanisms are among the most widely adopted flexibility tools in EEOS, offering obligated parties a non-physical route to compliance through financial contributions. Their core purpose is to provide administrative ease and short-term flexibility, particularly in contexts where direct savings delivery may be constrained due to market immaturity, high marginal costs, or capacity gaps. However, international experience has demonstrated that if left unchecked, buy-out options can undermine the core objective of EEOS by diverting attention from real, measurable energy savings. For this reason, successful schemes have integrated buy-out mechanisms not as substitutes but as carefully bounded compliance tools, reinforced by transparent rules, pricing strategies, and robust oversight. International experience provides useful insights into how such mechanisms can be effectively designed and controlled. For example, Ireland's buy-out mechanism is carefully structured to align with the broader EEOS design, which includes sector-specific sub-targets. To use the buy-out option, applicants must indicate the relevant sub-target. They must also pass an eligibility screening, which considers their historical performance in the scheme, including any prior underachievement or excessive use of buy-out option. The mechanism is subject to a usage cap of 30% and features differentiated buy-out prices across sectors (higher rates for energy poverty targets) ensuring that it remains a controlled flexibility tool that supports, rather than undermines, the delivery of actual savings. Other countries have taken different but instructive approaches. Slovenia, Austria, and Latvia offer buy-out options, but also impose serious consequences for late or inadequate compliance. In Slovenia, unpaid contributions accrue interest and are legally enforceable, reinforcing the mechanism's status as a compliance tool rather than a soft alternative. Latvia combines flexibility with enforcement: if obligated parties fall short of meeting 80% of their target, the buy-out becomes mandatory and is levied at 1.5 times the value of the shortfall. This dual structure provides early-stage flexibility while applying pressure on persistent underperformance. In contrast, Poland's early experience highlights the risks of over-reliance on buy-out. In the initial years of its scheme, a relatively generous buy-out ceiling weakened incentives for project implementation and led to a mismatch between expected and actual savings delivery. Recognizing these drawbacks, Poland later restricted the use of the buy-out to cases where white certificates are unavailable on the market, turning it into a conditional, last-resort option. These examples emphasise that while buy-out mechanisms can play a useful role in enabling compliance flexibility, their design must avoid becoming a substitute for physical savings. They are most effective when used as tightly controlled, transparently governed tools that support administrative feasibility without compromising the scheme's integrity.

In the case of Türkiye, introducing a limited and transitional buy-out option could be useful in the early years of the EEOS, especially while the delivery ecosystem and technical capacity are still developing. However, to maintain policy credibility, the mechanism should be strictly capped, priced above the cost of average physical savings, and activated only under well-defined conditions. All revenues should be allocated to a dedicated, ring-fenced fund used exclusively for verified efficiency actions. Finally, strong eligibility rules, transparent governance, and consistent oversight will be essential to prevent misuse. The Irish model, with its sector-sensitive pricing and rigorous administrative process, offers a valuable reference.

Temporal flexibility mechanisms, especially banking, have been shown to support investment continuity and encourage early action. Allowing obligated parties to carry forward surplus savings within a single obligation period, subject to volume caps and time limits, could improve planning efficiency without undermining accountability. However, despite its advantages, banking is not without potential drawbacks. If not carefully designed and regulated, banking can lead to the stockpiling of savings, enabling obligated parties to meet future targets without delivering new savings. This can cause artificial slowdowns in project activity, reduce market demand for efficiency services, and hinder the development of stable delivery pipelines. Unlike banking, borrowing mechanisms are not widely used and carry significant risks, including delayed delivery, weakened compliance signals, and reduced scheme credibility. If borrowing is ever considered, it should be strictly limited (e.g., capped at a small percentage and permitted only in exceptional circumstances) and paired with strong oversight. For Türkiye, while allowing a limited degree of banking may support early investment and help stabilize the scheme in its initial years, enabling planning beyond the current obligation period can strain the system and increase the administrative burden. Instead of permitting the banking of surplus savings, it may be more effective to design alternative options that provide benefits to obligated parties in a more structured and time-bound manner.

In light of international experience, inter-party saving trading is not widely used as a central compliance mechanism, but rather as a limited flexibility option in several EEOS. Countries such as Ireland and the United Kingdom allow bilateral exchanges between obligated parties under clearly defined administrative rules, while Austria and Luxembourg permit savings transfers through civil contracts or subcontracted arrangements. However, trading volumes tend to remain low, partly due to the absence of price transparency and the preference of obligated parties to retain control over their own delivery. Ireland's approach offers a well-structured example of how trading can be allowed without jeopardizing the scheme's integrity. In the Irish scheme, exchanges of energy savings are only permitted between obligated parties and must occur within the same sectoral sub-target. This design feature prevents cross-sectoral leakage and ensures that each sector's specific policy objectives remain intact. All exchanges require formal approval, and the original owner retains responsibility for the quality of the associated savings, further reinforcing accountability. International experiences also indicate that while inter-party trading can offer some operational flexibility, it rarely evolves into a fully functioning market and often depends on strong administrative oversight and trust-based relationships between actors. If Türkiye were to explore similar mechanisms in the future, these patterns offer important insights into both the opportunities and the structural limitations of saving trading within an EEOS framework. On one hand, allowing limited exchanges between obligated parties could help address asymmetries in delivery capacity, improve short-term compliance flexibility, and reduce transaction costs for smaller suppliers. On the other hand, international cases highlight that without robust oversight, transparent reporting, and consistent verification standards, such mechanisms may lead to low market engagement, uneven participation, and potential coordination challenges.

It is essential to recognize that flexibility mechanisms must not only be individually well-designed and justified, but also strategically integrated into the broader EEOS architecture to ensure coherence, avoid negative interactions, and uphold the scheme's integrity. While each flexibility mechanism offers specific advantages, international experience underscores that their simultaneous application requires careful calibration. Not all mechanisms are complementary, and certain combinations may weaken scheme or generate unintended trade-offs. For example, if generous buy-out options are combined with unrestricted banking, obligated parties may opt to delay actual energy-saving investments and rely on financial compliance or surplus from previous years, thereby undermining the objective of real-time delivery. Similarly, allowing borrowing alongside inter-party trading can result in complex compliance tracking, create enforcement loopholes, and blur accountability, especially in settings with limited regulatory capacity. Furthermore, if banking and saving trading are allowed without limits, obligated parties may stockpile savings and trade them strategically, which could disrupt market balance. Pairing borrowing with a buy-out option may further reduce the motivation to invest in actual efficiency measures, as parties could rely on future savings or financial payments instead of taking action immediately. When multiple flexibilities overlap, such as banking, borrowing, and trading, it becomes harder to track who is truly responsible for delivering savings, which can create enforcement and credibility problems. These interactions show that flexibility mechanisms should not only work well individually but also fit together in a way that supports the core goals of the EEOS.

The primary objective of incorporating flexibility options within an EEOS is to provide obligated parties with a manageable degree of compliance adaptability that helps maintain their engagement and motivation in the system. However, if this flexibility becomes too permissive, it may lead to strategic manipulation, weaken enforcement signals, and, most critically, slow down or even stop the implementation of energy efficiency actions. This is the most undesirable outcome, as it directly compromises the core purpose of the scheme. Ultimately, the successful integration of flexibility options in Türkiye's EEOS will depend not only on policy design but also on institutional readiness, regulatory clarity, and adaptive oversight. Early-stage flexibility should focus on reducing delivery barriers and market entry risks, while long-term credibility must be maintained through stringent rules, transparent processes, and performance-based adjustment.

Among all design elements of EEOS, white certificates stand out as the component that most fully embodies its market-based character. Far beyond a simple reporting or compliance mechanism, a functioning white certificate scheme requires the construction of a dedicated marketplace for verified energy savings, supported by a strong regulatory and technical framework, clear trading rules, standardised methodologies, robust monitoring and M&V mechanism. White certificates are among the most sophisticated and demanding instruments. Their successful implementation depends not only on technical accuracy but also on high institutional capacity, administrative consistency, and the active participation of both public and private stakeholders. In practice, they are administratively complex, data-intensive, and highly sensitive to policy misalignment. Despite these challenges, when well-executed, white certificate systems can unlock large-scale investment, incentivize innovation, and ensure energy savings are achieved in a cost-effective and transparent manner.

The successful implementation of a white certificate scheme requires not only technical precision, but also highly coordinated administrative and institutional architecture. Unlike basic EEOS structures, white certificate schemes demand the establishment of multiple, functionally distinct institutions working in harmony. A competent regulatory authority must define and enforce the rules, while a separate technical body is often tasked with developing standardised methodologies, validating energy savings, and overseeing M&V protocols. In addition, an independent market operator is typically responsible for managing certificate registries and enabling transparent trading processes. The coordination between these entities is not merely procedural, it is foundational to the credibility and functionality of the system. Failure to clearly define institutional roles, ensure timely communication, or maintain consistent procedures can lead to administrative bottlenecks, market instability, and erosion of trust among participants. As seen in countries like Italy and France, building and maintaining such an integrated governance structure is a challenge in its own right and one that must not be underestimated in any future adaptation.

Despite requiring robust technical and institutional design, white certificate schemes face clear limitations in terms of how much complexity they can accommodate. While some levels of sophistication are necessary to ensure additionality, accuracy, and accountability, excessive complexity has proven to undermine functionality. For instance, in Italy, the use of the tau coefficient initially aimed to promote durable, capital-intensive projects. However, the calculation involved discounting, lifetime assumptions, and project categorization rules that became difficult to navigate for both applicants and administrators. This not only increased the administrative burden but also created uncertainty and disputes, ultimately leading to its removal in the 2021 reform. Similarly, in Poland's early white certificate scheme, the use of the omega coefficient introduced a layer of artificial complexity. Rather than enhancing efficiency, it led to strategic underreporting of savings, distorted market outcomes, and damaged the credibility of the scheme. These cases show that while advanced mechanisms may seem theoretically appealing, they can backfire when not matched by sufficient administrative capacity, data availability, and market maturity. Therefore, white certificate schemes need to strike a fine balance: complex enough to ensure integrity, but simple enough to be usable, predictable, and transparent in practice.

One of the core challenges in white certificate schemes is the establishment of robust and transparent methodologies for calculating energy savings. Defining credible baselines, conducting ex-ante assessments, and validating outcomes through ex-post verification are essential steps to ensure the integrity and additionality of reported savings. However, these processes are technically demanding and highly sensitive to methodological inconsistencies. For this reason, successful schemes place great emphasis on developing detailed guidelines, standardised action sheets, and eligibility criteria to reduce ambiguity and streamline implementation. Yet even the most refined methodologies are only as good as the data and institutions that support them. A reliable white certificate scheme requires not only a technically competent agency capable of developing and maintaining such methodologies, but also a comprehensive and high-quality data infrastructure to underpin baseline setting, monitoring, and evaluation. Without a central technical body and a well-curated database, schemes may struggle with inconsistent rulings, low stakeholder confidence, and administrative delays. This highlights the critical importance of investing early in both technical capacity and data systems as foundational pillars of a functioning white certificate mechanism.

Another key feature observed in mature white certificate schemes, particularly in Italy, is the active promotion of ESCOs and other third-party actors as eligible participants.

By allowing non-obligated entities to generate tradable certificates through accredited energy efficiency projects, the scheme extends beyond the compliance needs of obligated parties and becomes a broader market instrument. In Italy, the inclusion of ESCOs was not just a technical allowance but a deliberate policy decision aimed at stimulating the energy services market. This approach significantly increased project diversity, brought in private capital, and fostered innovation in energy-saving solutions across sectors. It also helped to overcome capacity limitations among obligated parties by enabling a wider ecosystem of professional actors to contribute to target delivery. The Italian case demonstrates that when properly regulated and supported, third-party participation can amplify the reach and impact of white certificate schemes, while simultaneously strengthening the national energy efficiency services industry.

While the inclusion of third-party actors, such as ESCOs, local authorities, and eligible companies, has broadened participation and delivery capacity within white certificate schemes, the actual functioning of the market component remains uneven. Even in long-standing schemes like those in Italy and France, the liquidity of the spot markets has remained relatively low. Instead of vibrant, transparent exchanges, most certificate transactions continue to occur through bilateral agreements (negotiated contracts between parties) and often shaped by pre-existing business relationships. This reliance on trading structures raises important concerns about price transparency, market efficiency, and broader accessibility, especially for new entrants or smaller actors. The persistence of low liquidity, despite two decades of implementation, suggests that the creation of a truly competitive and dynamic white certificate market is more difficult than initially envisioned. It also raises questions about whether the benefits of tradeable savings (such as cost optimization and market-based delivery) can be fully realized without stronger institutional support, centralized trading platforms, and targeted measures to enhance market participation.

For Türkiye to implement a functioning and credible white certificate scheme, establishing a solid institutional and administrative foundation is not optional; it is an essential first step. Unlike more centralized or straightforward policy instruments, white certificate schemes require a multi-actor governance structure built on strong coordination, clear procedures, and technical capacity. International experience has shown that without this foundation, even well-designed policy frameworks can struggle during implementation because of administrative delays, inconsistent decisions, and weakening stakeholder trust. The governance of a white certificate scheme needs to be anchored in three key functions: a regulatory body that sets targets and ensures policy coherence, a technical institution that develops standardised methodologies and verifies savings, and a neutral market platform that manages certificate issuance and trading in a transparent manner. These roles must be clearly defined and distributed across competent institutions. In Türkiye, the MENR may serve as the central policy authority, as also highlighted in the first and second NEEAP. However, MENR's leadership must be supported by a technically capable institution, such as universities, The Scientific and Technological Research Council of Türkiye (TÜBİTAK), or a newly established institution or agency, with the mandate and capacity to manage data systems, develop methodologies, and oversee monitoring and verification processes. The registry and trading functions could be housed within an existing market platform like Energy Exchange Istanbul, Borsa Istanbul (the official exchange institution of Türkiye) or established under a new independent entity designed specifically for white certificate operations. These institutions must work in close coordination, with seamless communication and data sharing to avoid procedural inconsistencies and maintain scheme reliability. Without such coherence, administrative confusion and implementation weakness may quickly emerge, threatening the overall credibility of the scheme. As indicated in the second NEEAP, the introduction of an EEOS is expected by 2027 with the pilot implementation of white certificates. Although the timeline is tight, the remaining period provides a valuable window to prepare the necessary governance and technical systems. Making the right institutional investments now will determine not only the scheme's initial success, but also its long-term sustainability and policy credibility.

A functioning white certificate scheme depends heavily on the existence of clear, credible, and standardised methodologies for calculating energy savings. These methodologies not only enable consistent project appraisal and certification, but also form the basis for transparency, investor confidence, and long-term scheme integrity. For Türkiye, establishing such methodologies will require early prioritization of action standardization. The development of predefined action sheets (specifying eligible measures, baseline conditions, calculation methods, etc.) can significantly streamline implementation, reduce administrative burden, and ensure comparability across projects. International experience shows that without such tools, schemes tend to face delays, inconsistent savings estimations, and weakened stakeholder confidence. Equally important is the formal adoption of the additionality principle, which ensures that certified energy savings go beyond what would have occurred under normal market conditions and exceed existing regulatory requirements. Although additionality is mandatory in EU, it has not yet been formally adopted in Türkiye's regulatory framework. The lack of a legally binding definition may undermine the credibility of future savings claims. As a foundational principle in all white certificate scheme, integrating additionality into Türkiye's upcoming scheme framework will be critical for maintaining environmental integrity and avoiding double-counting.

The success of a white certificate scheme relies not only on the performance of obligated suppliers but also on the active participation of a diverse range of third-party actors. International experience shows that expanding the scope of eligible participants can significantly enhance delivery capacity, foster innovation, and improve cost-efficiency. A wide array of entities including ESCOs, municipalities, local authorities, companies with energy manager or ISO 50001 certificates, universities, commercial buildings, energy companies not subject to direct obligations and housing cooperatives, can play critical roles in scaling up energy efficiency actions, especially in sectors that are harder to reach. These actors bring a combination of technical expertise, institutional experience, and local engagement that can strengthen the overall implementation framework. Their participation would not only reduce the compliance burden on obligated parties but also promote a more competitive, decentralized, and resilient delivery ecosystem. To enable this, Türkiye will need an inclusive approach and to develop a transparent accreditation system, define clear participation criteria, and ensure that all qualified actors have access to the necessary infrastructure for certificate generation and trading.

While the establishment of a white certificate scheme in Türkiye will demand substantial institutional coordination, regulatory precision, and technical infrastructure, the country is not starting from scratch. Türkiye already has a growing and increasingly professionalized energy services market, including accredited ESCOs, certified energy managers, M&V experts. In parallel, Türkiye possesses strong national exchange institutions capable of supporting market-based instruments. In addition, Türkiye has accumulated valuable experience through existing energy efficiency support mechanisms such as the Voluntary Agreements and Efficiency

Enhancement Projects implemented under national efficiency programs. This evolving ecosystem offers a strong foundation for the gradual development of a robust white certificate scheme. Rather than viewing the scheme as a purely administrative challenge, Türkiye can seize this opportunity to strengthen its energy services market, stimulate private investment, and embed long-term efficiency practices across the economy. If designed with clarity, inclusiveness, and institutional foresight, the white certificate scheme can serve not only as a compliance tool, but as a catalyst for broader market transformation.

8. POLICY IMPLICATIONS

In this chapter, the interactions between EEOS and other policy mechanisms are examined with a particular focus on European experiences. Drawing on international literature and implementation practices, the chapter explores how EEOS has been integrated into broader policy mixes and what lessons can be drawn from these cases. Building on these insights, the chapter then turns to Türkiye, analysing how a future EEOS could align with the country's existing energy efficiency instruments and strategic documents, including the Energy Efficiency Strategy 2030 and the second NEEAP.

8.1 Interaction of EEOS with Different Energy Efficiency Policy Mechanisms

While EEOS or white certificate schemes alone can achieve significant savings, they are commonly implemented alongside other energy efficiency-promoting policies. In Europe, they have often been applied in parallel with financial and tax-based incentives, energy efficiency auctions, voluntary agreements, building standards and regulations, energy service market, and carbon pricing mechanisms.

Policy interactions arise when multiple instruments target the same objective simultaneously. Properly designed policy mixes can create complementary effects (synergy), where instruments reinforce each other and achieve greater energy savings than individually. In contrast, neutral interactions produce additive effects without synergy, while conflicting or overlapping interactions, typically involving support for the same action, may result in double incentivization without additional savings, thereby reducing overall effectiveness. Therefore, understanding how EEOS interacts with other instruments is critical (Boonekamp, 2006; Rosenow et al., 2016). This section explores these interactions, drawing on European experiences to assess complementarity, neutrality or conflict, and to identify how EEOS can be strategically aligned with other policies to maximise impact and avoid inefficiencies.

8.1.1 Financial and tax-based incentives

Direct incentives, grants, and tax-based incentives enhance the financial viability of energy efficiency investments. EEOS or white certificates schemes similarly functions as a financial incentive from the end-user's perspective. For instance, an obligated energy company may provide discounted insulation or energy-efficient devices to end-users to meet its obligations. When the same energy-saving measure is supported simultaneously by both an EEOS and a grant or tax reduction or rebate, the incremental energy savings achieved tend to be lower than the combined effect of each policy acting independently. This is because households or businesses receive overlapping financial benefits from two sources for a single action, leading to double payments without corresponding additional savings. In this case, only one saving is realised, while the financial incentives are duplicated. Joint studies by the European Commission emphasize that since EEOS targets are typically fixed, additional incentives such as grants, or tax-based incentives can only generate extra energy savings if the EEOS targets themselves are raised accordingly. Otherwise, these additional incentives only reduce compliance costs for obligated parties, without delivering further national-level savings. Therefore, the coordination of EEOS with other financial instruments is essential to prevent inefficiencies and double counting, and to ensure that public resources contribute to genuine energy savings (Bertoldi and Rezessy, 2006; Rosenow et al., 2016 & 2017).

The French white certificate scheme offers a valuable example of coordinated financial incentives. In France, the scheme has significantly boosted energy efficiency improvements in the residential sector by promoting high-efficiency boilers, heat pumps, insulation, and energy-efficient windows. These technologies were also simultaneously incentivized through income tax credits provided by the government. This strategic alignment, commonly referred to in the literature as piggybacking, enhanced the attractiveness and uptake of residential renovations. It was particularly effective in the French context, where regulated residential energy prices restricted energy suppliers from passing compliance costs entirely onto end-users, thereby increasing the importance of complementary public funding. However, the application of multiple instruments to the same measure raised attribution issues. To address this, France developed specific calculation and reporting rules to ensure that each energy-saving action is attributed exclusively to one policy instrument, thus preventing double counting (Bertoldi, 2011).

In contrast, the Italian experience illustrates the challenges of poor policy integration. Italy implemented a diverse mix of energy efficiency support mechanisms, including tax deduction schemes such as Ecobonus and Superbonus, offering tax credits of up to 110%, and the centrally administered, budget-funded Conto Termico programme. These instruments targeted similar technologies and sectors as the white certificate scheme, but operated independently, with little integration in terms of eligible measures, documentation standards, or savings baselines. This lack of harmonisation led to overlapping eligibility rules, fragmented implementation channels, and inconsistent accounting methodologies, discouraging actors from combining support mechanisms. In many cases, simpler and more predictable tools such as Ecobonus or Conto Termico were preferred by households and businesses, leading to underutilisation of the white certificate scheme. Moreover, tax-based incentives were often directed toward capital-intensive upgrades, such as insulation and heating systems, while the white certificate scheme remained limited to smaller, short-payback measures. This segmentation reduced direct overlap but also limited the potential scope and strategic relevance of the white certificate scheme in the residential sector. Although Italian authorities have attempted to recalibrate the scheme by focusing it on under-supported segments, coordination failures and administrative complexity have persisted, further marginalising the scheme (Bertoldi, 2011; Di Santo et al., 2024).

Both the French and Italian experiences show the importance of a harmonised, transparent, and coordinated policy architecture. In order to enhance complementarity between EEOS and financial or tax-based incentives, policymakers should aim to strategically differentiate the scope, target groups, and eligible technologies under each instrument. EEOS targets must be aligned with the level and scale of additional subsidies introduced to ensure that overlapping instruments contribute to genuine incremental savings, rather than simply shifting costs or responsibilities between actors. Moreover, a centralised, robust tracking and reporting system is essential. It supports transparency, methodological consistency, prevents double counting, and enables accurate attribution of savings, thereby demonstrating the benefits of policy coordination in a multi-instrument environment. In parallel to robust monitoring, enforcing the principle of additionality is critical; energy savings should only be counted if they result directly from policy-driven actions beyond what would have occurred otherwise. Such coordination ensures transparency and accountability, enhancing the overall coherence of energy efficiency policies. Ultimately, strategic alignment between EEOS and complementary financial support mechanisms is vital for scaling up energy efficiency investments, maximising their impact, and effectively achieving long-term climate and energy objectives.

8.1.2 Energy efficiency auctions

Energy efficiency auctions are competitive market-based mechanisms designed to allocate public funding to the most cost-effective savings projects. In this model, a public authority sets aside a fixed budget for energy efficiency improvements, and project developers compete by submitting bids for support. Projects offering the highest savings at the lowest cost are selected. Unlike EEOS, which imposes mandatory savings obligations on energy companies, auctions are voluntary in nature and invite participation from various market actors. In recent years, energy efficiency auctions have gained prominence as market-based instruments across Europe. Countries such as Germany and Austria have implemented auction programmes either as alternatives to or in combination with EEOS. Moreover, the EU's "energy efficiency first" principle and state aid rules increasingly encourage the use of competitive allocation mechanisms for public funds. While auctions and EEOS may appear to be alternative approaches, they can be complementary if carefully designed and well-coordinated. The key to effective interaction lies in avoiding double counting and exploiting the comparative strengths of each instrument. EEOS is particularly effective at mobilising widespread, small-scale savings actions, such as insulation in households or appliance replacements, especially when implemented through obligated energy companies. By contrast, auctions are more suitable for large-scale, well-defined projects where competition can drive down costs, such as industrial waste heat recovery or public building retrofits. When applied in parallel, EEOS can cover broad, decentralised actions while auctions can channel funding into fewer but higher-impact projects, enabling a comprehensive mobilisation of savings across different segments of the economy. Another important distinction lies in the source of funding. Under EEOS, the cost of energy savings is typically borne by obligated parties and ultimately passed on to consumers via energy bills. Auction-based schemes, on the other hand, are usually funded directly from public budgets. In some cases, EEOS programmes may include a buy-out option, where obligated parties can fulfil their targets by paying into a fund instead of undertaking direct measures. This fund can then be used to finance efficiency projects via auction mechanisms. Countries such as Latvia and Poland have adopted such hybrid models. However, as discussed in the seventh chapter, these arrangements require careful balance: if the buy-out is too easy, obligated parties may prefer paying the fee rather than implementing projects; if it is too strict, the intended flexibility is undermined. Auctions also have the potential to drive innovation and cost-efficiency through competition. While EEOS offers long-term stability and planning certainty, auctions encourage project developers to innovate and optimise performance. In Germany's pilot auctions, industrial actors proposed projects at lower-than-expected costs per kWh saved, allowing the government to procure more savings within the same budget. These results shows that auctions could be integrated into future EEOS frameworks, especially for large-scale or hard-to-reach sectors (Anatolitis & Schlomann, 2022; Rosenow et al., 2019).

Italy's experience offers important considerations regarding the potential integration of auctions into an existing white certificate scheme. In 2021, Italy introduced an auction mechanism not as an alternative, but as a complementary tool designed to address structural inefficiencies in the white certificate market, particularly price volatility and limited liquidity. The mechanism aimed to mobilise projects that were challenging to implement under the white certificate framework, especially those requiring stronger financial incentives due to their innovation level, complexity, or positive externalities. Participation in auctions was intended to be open to entities also engaging with the white certificate scheme, ensuring that involvement in one instrument would not exclude eligibility under the other. Italian regulatory discussions acknowledged two competing perspectives: one favouring clear institutional separation between auctions and the certificate market, and another supporting integration by allowing energy savings from auction-funded projects to contribute to market liquidity. A proposed compromise involved awarding certificates to successful auction participants, with their release into the market conditioned on supply–demand dynamics, thus establishing a stabilisation mechanism. The broader objective was to align financial incentives more closely with market needs, improve price signals, and reduce uncertainty. Italy's case illustrates that auctions and white certificate schemes can be complementary under certain conditions. Instead of assuming inherent synergy, policymakers must carefully define project eligibility, prevent savings overlaps, and ensure additionality. If properly coordinated, auctions can reinforce and stabilise white certificate schemes; if poorly aligned, they risk introducing fragmentation or undermining overall policy coherence (Di Foggia et al., 2022).

In summary, although EEOS and energy efficiency auctions rely on different policy logics, one obligation-based, the other competition-based, they are not mutually exclusive. When appropriately designed, they can reinforce each other and create synergy. The critical issue is to clearly define the scope, roles, and savings attribution rules of each instrument.

8.1.3 Voluntary agreements

Voluntary agreements are non-binding commitments between governments and private actors, to undertake specific energy efficiency actions. Like energy efficiency auctions, voluntary agreements operate on a voluntary basis, relying on reputational incentives, soft enforcement, and negotiated targets rather than regulatory obligations. In both cases, success depends on well-designed frameworks, transparency, and robust monitoring systems. However, unlike auctions, voluntary agreements often lack competitive allocation or performance-based funding, which can limit their effectiveness unless complemented by financial or technical support. The interaction between EEOS and voluntary agreements is generally neutral. Empirical studies suggest that they rarely create direct synergies or conflicts, as they tend to operate in parallel policy spaces. For example, while EEOS mandates energy companies to deliver verified savings, voluntary agreements primarily aim to engage industries that are either outside the scope of EEOS or not yet ready for formal regulation. Finland offers a valuable example: it has long used sectoral voluntary agreements supported by monitoring and technical assistance to promote industrial efficiency, despite not having an EEOS in place. If a country introduces both instruments, it would be essential to ensure clear separation of roles, transparent tracking, and proper target adjustment to prevent overlap or double counting (Bertoldi et al., 2010; Boonekamp, 2006; Rosenow, 2016 & 2017).

Overall, while voluntary agreements can support preparatory or complementary roles, especially in sectors with low regulatory readiness, their coexistence with EEOS requires careful coordination, similar to the integration logic applied in auction-based mechanisms.

8.1.4 Building standards and regulations

EEOS often target improvements in the building sector which is the same domain regulated by building energy performance standards and this creates potential overlap in policy coverage. A foremost risk is double counting of energy savings: the same efficiency gain could be claimed under both the obligation scheme and the building standard, or credited multiple times if policies are not carefully coordinated. The EU's policy framework explicitly guards against this. The EU EED requires that EEOS must be additional to those achieved by other mandatory EU laws. In other words, savings stemming from compliance with Union-level requirements (e.g. minimum building codes or product standards) cannot be counted toward an EEOS target. This principle ensures that obligated savings represent genuine new improvements, not simply the effect of pre-existing regulations. If poorly coordinated, EEOS mechanisms may end up subsidising actions that are already legally required under building codes, leading to inefficient use of resources and negligible additional energy savings. Therefore, in most EU countries, eligible savings under EEOS must go beyond existing regulatory requirements. For instance, if national regulations already mandate thermal insulation in all new buildings, energy suppliers cannot claim savings under EEOS by stating they supported insulation in newly constructed homes. The central principle in this interaction is that financial incentives must target performance levels above the regulatory baseline. If mandatory standards and incentives are applied simultaneously to achieve the same target, the financial support largely ends up subsidising compliance with existing law, with minimal net gain, an effect known as diminishing impact. A concrete example is Italy's early support for replacing old refrigerators with A+ rated appliances under its scheme. Once the EU Ecodesign regulation made high-efficiency appliances the market norm, the additional impact of these projects was significantly reduced, prompting a shift in incentive design towards promoting technologies that exceeded regulatory requirements (Bertoldi, 2011; Bertoldi and Rezessy, 2006; Broc et al., 2024; Rosenow et al., 2017).

Despite the risk of overlap, EEOS and building standards can also complement each other, particularly through sequencing and performance differentiation. A sequencing approach involves using incentives prior to regulation to accelerate market readiness and increase political acceptability. For example, in the early 2000s, the UK offered insulation subsidies under its supplier obligation scheme before tightening insulation standards for new buildings. This approach rewarded early adopters, eased the regulatory transition, and led to broader market transformation. EU policy documents have similarly noted that financial incentives can be used to support early compliance ahead of regulatory deadlines. A second form of complementarity arises when regulations define the minimum legal performance, and EEOS incentivises higher performance. In France, for example, white certificates were awarded to developers who exceeded the mandatory U-values for insulation in new buildings, creating a layered incentive structure. The regulation established the floor, while EEOS rewarded voluntary overperformance, avoiding policy conflict while driving enhanced outcomes. Furthermore, building regulations often apply only to major renovations or new constructions, and are sometimes poorly enforced in the existing building stock. EEOS can fill this gap by incentivising voluntary improvements in older buildings not subject to mandatory upgrades. Denmark, for example, has long used its scheme to support insulation and boiler replacements in existing buildings while gradually tightening building codes for new constructions. This dual-track approach enabled Denmark to reduce energy use both in new and existing buildings simultaneously (Boonekamp, 2006; Broc et al., 2011; Surmeli-Anac et al., 2019).

In conclusion, the effective interaction between EEOS and building regulations depends on clear boundaries and defined roles. EEOS should not be used to finance compliance with existing legal requirements. Instead, it should target areas outside the scope of regulation or promote performance beyond the minimum standard.

8.1.5 Energy service market

White certificate schemes present both opportunities and challenges for energy service market. A well-designed EEOS can act as a catalyst for the energy service market by creating new revenue streams tied to energy savings, thereby stimulating private investment in efficiency projects. European experiences illustrate differing approaches to integrating ESCOs into EEOS frameworks.

Italy stands out as a prominent example where the white certificate scheme actively relied on ESCOs. While energy companies were legally obligated to achieve savings, they frequently outsourced the implementation of savings measures to the market via ESCOs. Also, ESCOs can monetise their projects by selling certificates corresponding to verified savings. This created a vibrant marketplace, allowing independent ESCOs to scale up thousands of projects, while enabling obligated parties to meet their targets. As a result, the Italian ESCO market expanded rapidly, with specialising in niche efficiency services (Bertoldi, 2011; Di Santo et al., 2011 & 2016).

France adopted a different model. Although trading of certificates was possible, obligated energy companies in practice preferred to manage savings projects in-house or through tightly controlled subcontracting networks. Obligated parties partnered with equipment manufacturers and contractors to offer standardised packages to customers, effectively acting as ESCOs themselves. Instead of providing cash rebates, suppliers often delivered discounted product campaigns through affiliated installers. Due to regulated energy prices in the residential sector, suppliers were unable to pass EEOS costs onto consumers sufficiently, which incentivised them to seek cost-effective delivery models. Over time, this led to a service delivery ecosystem dominated by energy suppliers rather than independent ESCOs. The United Kingdom presents yet another variant. The scheme does not involve white certificate trading; each obligated energy company is responsible for meeting its own target. Over the years, large, obligated energy companies developed their own networks of certified contractors to deliver upgrades like insulation or heating system replacements. While some local nonprofit organisations and ESCO-like entities participated in project implementation, the UK model generally evolved toward vertically integrated delivery by obligated energy companies themselves (Bertoldi, 2011).

Overall, these varied approaches underline that the role of ESCOs within EEOS frameworks is shaped not only by policy design but also by regulatory environments, market structures, and the degree of flexibility allowed in implementation. Whether through open certificate markets, subcontracting models, or vertically integrated delivery systems, the effectiveness of ESCO participation depends on clear rules for savings attribution, accessible financing mechanisms, and a stable policy landscape that supports long-term engagement.

8.1.6 Carbon pricing mechanisms

Carbon pricing has become a cornerstone of climate policy across the globe, providing market-based tools to internalise the environmental costs of GHG emissions. The two primary instruments in this domain are carbon taxes and ETS. While differing in structure and policy logic, both mechanisms aim to influence the behaviour of emitters by attaching a financial cost to carbon emissions, thereby encouraging more sustainable energy use and cleaner technologies.

A carbon tax imposes a direct levy on the carbon content of fossil fuels or, more broadly, on GHG emissions. It sends a clear and stable price signal to the market, incentivising emission reductions across all sectors. One of the earliest implementations was in Finland (1990), followed by Sweden, Norway, and Denmark in the early 1990s. These systems demonstrated that carbon taxes could coexist with economic growth while effectively reducing emissions, particularly when tax revenues were recycled into the economy or used to lower other distortionary taxes. In the context of the EU, although carbon taxation is not yet harmonised across Member States, it is recognised as an important complementary measure. The recasted EU EED explicitly acknowledges carbon pricing as part of the broader energy efficiency and climate action framework. Article 3 of the recasted EED refers to carbon pricing, including carbon taxation, as a tool that can help reduce final energy consumption by increasing the cost of fossil fuel-based energy, thus encouraging energy efficiency improvements (European Parliament, 2023; World Bank and PMR, 2017).

The ETS, also known as cap-and-trade, sets an overall limit (cap) on GHG emissions and allows regulated entities to buy and sell emission allowances. The most prominent example is the EU ETS, launched in 2005, which covers over 40% of the EU's total emissions, including power generation, industry, and aviation sectors. It is structured in trading phases, with increasingly stringent caps and reduced free allocations over time. The EU ETS has been credited with supporting significant emissions reductions while preserving industrial competitiveness through flexible compliance mechanisms. The EU ETS is currently undergoing substantial reform under the "Fit for 55" package, aiming to align with the EU's target of reducing net GHG emissions by at least 55% by 2030. As part of this reform, a new ETS (ETS2) covering buildings and road transport will be introduced, thereby broadening the reach of market-based decarbonisation (Broc et al., 2024; European Commission, 2025).

In general, carbon taxes are compatible with EEOS and other energy efficiency programmes. Carbon taxes increase the marginal cost of energy consumption, thereby enhancing the attractiveness of financial incentives and regulatory measures designed to reduce energy demand. By internalising the external costs of GHG emissions, carbon tax strengthens the economic rationale for adopting energy-saving technologies and behavioural changes. As such, it creates a reinforcing environment in which EEOS can operate more effectively, encouraging obligated parties and end-users to invest in cost-effective energy efficiency measures (Rosenow et al., 2016).

Integrating the EU ETS with an EEOS introduces more complex challenges compared to carbon taxation. Carbon taxes typically offer a stable and predictable price signal, which supports long-term investment planning. In contrast, the carbon price under the EU ETS is set by the market and can fluctuate significantly. This uncertainty makes it difficult for investors to commit to energy efficiency measures that require stable payback periods, especially in sectors sensitive to energy prices. In addition, according to Commission Recommendation EU/2024/1590, energy savings in sectors covered by the EU ETS can only count towards EEOS targets if they are additional. In other words, if savings occur solely because of increased energy costs due to the carbon price signal, they do not meet the materiality[9] requirement and are therefore not eligible. The logic is that such savings would have happened anyway due to market forces, not because of deliberate policy-driven actions. The rules become even stricter in the case of installations receiving free allocation of emission allowances under the ETS. In such cases, energy efficiency actions taken only to comply with the conditions for maintaining free allowances (e.g. conducting energy audits or implementing recommendations with short payback periods) are considered compliance-driven and do not qualify as additional savings under EEOS. For Member States that wish to include EU ETS-covered sectors in their EEOS, this creates a narrow window for recognising eligible savings. Unless there are clearly defined and independently monitored policy instruments, most savings in these sectors will not meet EEOS

[9] Materiality refers to the requirement that the obligated, participating, or entrusted party under an EEOS must have made a meaningful and demonstrable contribution to the implementation of an energy-saving measure. It ensures that the energy savings counted toward national targets are not the result of actions that would have occurred anyway, but are instead directly influenced or triggered by the policy intervention. If the party's involvement had only a minimal or symbolic effect, the savings are not considered material and should not be credited under the scheme.

criteria. Furthermore, with the expansion of ETS to cover buildings and transport (ETS2), there is a risk that the carbon price signal might be seen as sufficient to drive energy efficiency improvements. This perception could reduce the momentum for introducing complementary policy instruments. However, the recasted EU EED clearly states that eligible savings under EEOS must result from intentional and verifiable actions by obligated or participating parties, not from price-driven behavioural changes alone (European Commission, 2024a).

Therefore, careful policy design must ensure that any interaction with carbon pricing mechanisms preserves the additionality, materiality, and traceability of savings. This calls for robust monitoring frameworks and clear methodological boundaries to ensure that EEOS operates as a distinct and complementary instrument to ETS, rather than being rendered redundant by it.

8.2 Insights for the Future Role of EEOS in Energy Efficiency Policy Mix of Türkiye

Since the enactment of the Energy Efficiency Law in 2007, Türkiye has steadily advanced its energy efficiency policy framework in alignment with the EU. This legislation provided the foundation for a comprehensive institutional and regulatory structure, enabling the development of both strategic vision and practical implementation tools. Following the 2007 law, a wide range of regulations were adopted, including the Regulation on Energy Performance in Buildings, the Thermal Insulation Regulation, and the Regulation on Improving Energy Efficiency in Transport, all introduced in 2008. These were later complemented by the Regulation on the Environmentally Conscious Design of Energy-Related Products (2010), aligning Türkiye’s product standards with EU eco-design directives. Türkiye’s regulatory infrastructure has continued to evolve. The Energy Efficiency Inspection Regulation (2018) reinforced compliance monitoring, while the Regulation on Improving Energy Efficiency in the Use of Energy and Energy Resources (2020) and subsequent provisions on energy performance contracting in the public sector (2020–2021) aimed to institutionalise market-based mechanisms. In parallel, capacity-building efforts were undertaken to enhance professional competence, including updates to training and certification standards. This evolving policy and regulatory ecosystem have been operationalised through a range of incentive-based support mechanisms designed to stimulate energy efficiency investments, modernise outdated infrastructure, and encourage behavioural and technological change, particularly in the industrial and commercial sectors. These programmes are coordinated primarily by the MENR under the framework of Energy Efficiency Law and were significantly strengthened through legislative reforms adopted in 2024 (MENR, 2025a).

Among these instruments, three major support programmes stand out in terms of their financial capacity and strategic relevance. The Efficiency Improvement Project (VAP) Support Programme, operational since 2009, has served as a cornerstone of Türkiye's industrial energy efficiency strategy. Currently, it provides direct investment grants for eligible projects across all sectors. Covering up to 30% of total investment costs, capped at 15 million TL per project, VAP targets high-impact measures such as process optimisation, replacement of inefficient equipment, waste heat recovery, cogeneration, and renewable-based thermal systems. The Energy and Carbon Reduction (EKA) Incentive Programme, introduced in 2024 as a successor to the former Voluntary Agreements scheme, promotes performance-based savings by supporting entities that achieve measurable reductions in energy intensity, carbon intensity, or specific energy consumption. The scheme offers reimbursement of up to 30% of the energy expenditure in the reference year, capped at 10 million TL, and accommodates single or multiple projects per application. Its design reflects a shift toward verifiable, outcome-oriented support mechanisms in line with Türkiye's decarbonisation agenda. In addition, to encourage large-scale industrial efficiency investments, Türkiye offers Fifth Region Investment Incentives to manufacturing facilities achieving at least 15% energy savings and consuming a minimum of 500 toe annually. Regardless of actual geographic location, eligible projects can benefit from a suite of fiscal advantages, including VAT exemption, customs duty exemption, corporate tax reductions, social security premium support, interest subsidies, and land allocation. These incentives are coordinated by the Ministry of Industry and Technology, based on technical validation from MENR (MENR, 2025b).

Complementing these support schemes, Türkiye's energy services market plays an increasingly important role in delivering energy savings. Since 2007, the national policy framework has included provisions for ESCOs and EPCs, encouraging private-sector engagement in efficiency projects. Today, the sector is primarily shaped by Energy Efficiency Consultancy (EVD) companies, which are certified by MENR to conduct audits, prepare project proposals, and assist in implementation. As of 2025, there are 67 active EVDs nationwide. While most have not yet transitioned into fully integrated ESCOs capable of offering guaranteed savings and project financing, their technical expertise continues to expand. While challenges such as limited access to finance, unfamiliarity with EPC, and uneven demand persist, the sector is steadily evolving into a more professional and structured ecosystem. With sustained institutional support and clearer EPC frameworks, EVD companies hold considerable potential to evolve into scalable ESCOs capable of playing a pivotal role in Türkiye's energy transition (Acuner et al., 2021; Akkoç et al., 2023; MENR, 2025c; Öncü et al., 2024).

Türkiye has also strengthened its institutional capacity for monitoring and evaluation. Under the Energy Efficiency Law, a mandatory energy consumption reporting framework has been established for large energy consumers, including industrial enterprises consuming over 1,000 toe annually, public buildings with more than 250 toe consumption or 10,000 m² of floor space, commercial and service sector buildings exceeding 500 toe or 20,000 m², electricity generation facilities with an installed capacity of at least 100 MW, and organised industrial zones with a minimum of 50 active facilities. These entities are required to submit regular energy consumption declarations to the MENR through designated sectoral communication channels. To support benchmarking and strategic planning, the Directorate of Energy Efficiency and Environment (EVÇED) under MENR has developed comparative sectoral reports across energy-intensive industries such as iron and steel, cement, textile, and glass. These benchmarking studies aim to expand into other manufacturing sectors such as ceramics and paper. They enable detailed process-level energy performance analysis and facilitate the development of sector-specific energy intensity indicators. The results support international comparisons, allowing for better insight into economic structure, consumption patterns, and technological efficiency levels. Additionally, benchmarking empowers enterprises by providing reference points to evaluate their own performance, identify improvement areas, and set realistic efficiency targets. It also supports more informed investment planning by helping to optimise energy costs per unit of production and serves as a strategic tool for energy management and policy monitoring (MENR, 2025d).

Moreover, capacity building through certified training programmes has become an essential for Türkiye's energy efficiency policy infrastructure. In accordance with the Energy Efficiency Law and its implementing regulation on the efficient use of energy resources, training programmes are organised to certify energy managers in public institutions, industrial enterprises, organised industrial zones, electricity power plants, and large buildings. Energy managers are officially designated professionals responsible for overseeing the implementation of energy management activities on behalf of the organisation. Furthermore, to strengthen project development capacity in buildings and industry, specialised audit and project design training is provided primarily to engineers working in EVD companies. For the verification of savings achieved through energy efficiency measures, a certification programme for M&V Experts has been introduced. These experts are trained in internationally recognised protocols such as IPMVP, as well as national standards like TS ISO 50006 and TS ISO 50015, equipping them to plan, measure, analyse, and report energy savings with precision (MENR, 2025d).

Most recently, in 2024, Türkiye adopted a forward-looking document, the Energy Efficiency 2030 Strategy and the Second NEEAP, which introduced updated sectoral targets, implementation priorities, and governance mechanisms to reinforce the country's long-term energy transition goals (MENR, 2024).

Building on this policy landscape, the potential future role EEOS within Türkiye's evolving energy efficiency policy mix is analysed in the following sub-sections. Drawing on the current regulatory and institutional architecture, as well as the strategic priorities and actions outlined in the Energy Efficiency 2030 Strategy and the Second NEEAP, the discussion explores the prospective function of EEOS across key sectors.

8.2.1 Cross-cutting areas

The cross-cutting actions outlined in the second NEEAP is not only include the implementation of an EEOS action but also encompass several actions that are directly relevant to constructing and strengthening the institutional and technical infrastructure required for EEOS.

Both Y1 (Establishing Energy Management Systems and Increasing Their Effectiveness) and Y5 (Development of the Energy Efficiency Portal in Line with Net Zero Goals) directly contribute to the foundational infrastructure required for the implementation and effective operation of an EEOS in Türkiye. One of the most critical prerequisites for EEOS is the existence of monitoring framework, including reliable baseline data to assess energy savings. Action Y1 plays a key role in this regard by reinforcing the implementation of already-mandated requirements, including the appointment of certified energy managers and the installation of ISO 50001 energy management systems in buildings, industrial enterprises, and power plants. The action focuses on ensuring that these obligations are fulfilled through systematic monitoring, audits, and inspections. By doing so, it aims to strengthen the reliability and completeness of energy consumption data, which is essential for establishing credible baselines and accurately verifying savings within an EEOS framework. Meanwhile, Y5 enhances the Energy Efficiency Portal (ENVER) to support benchmarking, reporting, and data dissemination aligned with sectoral net-zero targets. The development of sector-specific indicators and the expansion of benchmarking capabilities under this action will facilitate the tracking of energy efficiency improvements and support comparative performance assessments. These functionalities are essential for an EEOS, which depends on reliable sectoral baselines and comparative data to determine eligible savings, define cost-effective measures, and manage savings attribution.

Actions Y2 (Improving Energy Efficiency Financing Opportunities) and Y3 (Improving the Energy Efficiency Investment Environment) of the second NEEAP create an enabling financial and regulatory environment that could strongly support the implementation of an EEOS in Türkiye. Y2 focuses on improving financing mechanisms for energy efficiency, and it can directly support the financial infrastructure needed for EEOS implementation, particularly for managing penalty or buy-out (if established) payments. Y3, on the other hand, enhances the investment environment by proposing performance guarantees, insurance structures, and regulatory adjustments for ESCOs operating under EPCs. These steps would reduce risks and strengthen the delivery capacity of market actors, thereby contributing to the development of a more prepared and resilient market environment for EEOS implementation.

Action Y6 directly supports the implementation of EEOS by promoting societal awareness, behavioural change, and technical capacity-building, all of which are essential for achieving widespread end-user participation and acceptance. Action Y10

(Strengthening R&D Activities to Increase Energy Efficiency) enhances the technological backbone of Türkiye’s energy efficiency agenda and holds strong relevance for EEOS by fostering innovation in key areas such as energy monitoring, savings verification, and sector-specific applications. Furthermore, promoting high-efficiency technologies through R&D ensures a richer portfolio of eligible measures for obligated parties, facilitating deeper and more diversified savings outcomes.

Action Y4 (Supporting Energy Efficiency Projects with Energy Efficiency Competitions) introduces a competition-based funding mechanism similar to energy efficiency auctions. Its coexistence with an EEOS requires clear differentiation in objectives and scope. While EEOS relies on obligated parties to deliver predefined savings, competitions under Y4 are designed to promote green innovation and support high-impact projects through budget allocations. To avoid overlap or double incentivization, careful coordination is needed, ensuring that projects supported through competitions are not simultaneously used for EEOS compliance. When well-aligned, Y4 can complement EEOS by targeting strategic sectors or technologies that fall outside the scheme’s core focus.

8.2.2 Building and services

The building (including residential buildings) and services sector represents one of the most critical areas for Türkiye’s energy efficiency policies due to its high energy savings potential and wide end-user diversity. Within the second NEEAP, this sector features several actions that both support the potential implementation of an EEOS and carry a risk of overlapping objectives or target groups. Therefore, careful policy coordination and scope definition will be essential to ensure complementarity and avoid duplication.

Actions B1 (Increasing the Implementation Capacity of Energy Efficient Materials and Technologies Used in the Construction Sector), B2 (Conducting Detailed Analysis Studies on Energy Efficiency Potential in Buildings), and B11 (Improving Technical Capacity on Energy Efficiency Applications in Buildings) collectively provide critical institutional and technical support for a future EEOS in Türkiye. Action B1 aims to increase awareness and guidance on energy-efficient construction materials and technologies, contributing to the development of market standards and practices that can be aligned with EEOS measures. Action B2 supports the identification of energy efficiency potential through typology-specific audits and comparison studies, an essential foundation for EEOS baseline-setting and target allocation. Meanwhile, Action B11 strengthens the technical capacity of stakeholders by integrating energy efficiency into academic curricula and providing training materials for professionals, thereby cultivating a skilled workforce capable of implementing and verifying EEOS-related actions. Taken together, these actions enhance the readiness of both the market and technical infrastructure for EEOS deployment.

Actions B5 (Rehabilitation of Existing Buildings and Improving Energy Efficiency) and B10 (Establishing Financial Incentives for the Renovation of Existing Buildings) include a wide array of financial and technical support measures, such as building retrofitting incentives through the VAP scheme, competitions, improvement of existing insulation loan, and specific fiscal incentives for efficient technologies. While these mechanisms are critical for scaling energy efficiency in the building sector, their potential overlap with an EEOS framework necessitates clear policy boundaries. To avoid double counting of savings and ensure additionality, a robust monitoring infrastructure must be established to coordinate support schemes distinctly.

Action B8, which focuses on updating minimum energy performance criteria for new buildings, presents a valuable opportunity for strategic alignment with a future EEOS. To ensure the additionality of savings under EEOS, obligated parties must deliver energy efficiency improvements that go beyond the mandatory baseline established by regulations. In this context, the revised standards introduced through B8 could serve as a policy floor, while EEOS can be designed to incentivize higher-than-required performance levels. Moreover, prior to the enforcement of new building codes, EEOS could target these enhanced criteria as voluntary goals, rewarding early compliance and helping to accelerate market transformation. This sequencing approach not only enhances the ambition level of new constructions but also ensures that EEOS contributes to broader market transformation without duplicating the effects of minimum standards.

8.2.3 Industry

The industrial sector stands out as a prime candidate for inclusion in a future EEOS in Türkiye due to its high energy savings potential and relatively mature monitoring infrastructure. However, it is also the most heavily supported sector to date through a range of public schemes such as the VAPs, the EKA programme (former voluntary agreements), and Fifth Region Investment Incentives. These long-standing support mechanisms have built a solid foundation for implementation but also raise critical considerations for EEOS design, particularly regarding additionality, avoidance of double counting, and the integration of existing incentives. The second NEEAP further expands this support landscape with several actions specifically targeting industrial efficiency, notably Actions S1 (Dissemination of Cogeneration Systems in Large Industrial Facilities Using Heat), S2 (Providing Support to Increase the Number and Diversity of Innovative Energy Efficiency Projects in Industry), and S6 (Supporting the Reduction of Carbon Intensity and Specific Energy Consumption in Industry). Action S1 promotes the deployment of cogeneration systems in large industrial facilities, focusing on waste heat recovery, a measure that aligns well with EEOS objectives but would require careful coordination to avoid overlaps. Action S2 aims to enhance both the number and diversity of energy efficiency projects in industry by modernising VAP support criteria and increasing financial backing, which could indirectly support the market readiness for EEOS. Importantly, Action S6 reforms the Voluntary Agreements by reorienting them around carbon intensity and specific energy consumption targets, effectively transforming them into the EKA programme. As EEOS is introduced, it will be essential to define its obligations in clear distinction from these evolving programmes, ensuring that verified savings represent genuinely additional reductions beyond what is already incentivised. In this context, EEOS could serve to capture residual efficiency potential and drive market-wide performance improvements through its obligation-based, market-driven structure.

Actions S3 (Dissemination of Energy Efficiency Applications for a Low-Carbon, Green and Digital Transformation in the Industry Sector) and S4 (Implementation of Energy Efficiency Performance Standards and Environmentally Friendly Design, Production, Labelling System in Products and Devices) present valuable opportunities for aligning EEOS targets with upcoming regulatory developments. S3 introduces minimum energy performance standards for prioritized machinery and equipment, while S4 aims to harmonize design and labelling requirements with EU standards. If these standards are implemented in the near future, EEOS could play a complementary role by incentivising early compliance before enforcement begins. This approach would help familiarise market actors with new requirements, drive early market uptake, and ensure that EEOS delivers additional savings beyond regulatory baselines. Such sequencing also supports smoother regulatory transitions and maximises policy impact through coordinated timing.

Actions S5 (Mapping Energy Saving Potential in Industry), S8 (Strengthening Capacity Building and Sharing Activities for the Dissemination of Successful Energy Efficiency Practices in the Industry Sector), and S10 (Dissemination of Energy Consumption Monitoring Systems in Industry) support the technical groundwork necessary for an effective EEOS implementation in the industrial sector. Action S5 focuses on expanding sectoral benchmarking studies and updating the energy saving potential map through compulsory surveys, which can provide a data-driven foundation for setting realistic yet ambitious EEOS targets. Action S8 enhances capacity building by promoting peer learning, standardising audit reporting formats, and scaling up training in energy management and M&V, critical components for establishing robust monitoring, reporting and verification systems under an EEOS. Complementing these efforts, Action S10 promotes the widespread adoption of energy consumption monitoring systems and encourages domestic production of related technologies. Together, these actions create the informational, institutional, and technological capacities required to support a credible and performance-based EEOS in the industrial sector.

8.2.4 Energy

Under the Energy sector chapter of the second NEEAP, several actions contribute directly to the development of the technical infrastructure needed for a robust EEOS. Specifically, Actions E3 (Encouraging Energy Efficiency through Billing Information and Tariffs) and E4 (Dissemination of Smart Meters) focus on enhancing consumption transparency and real-time monitoring capabilities. E3 supports the gradual inclusion of detailed billing and consumption information for end-users, which can inform and motivate behavioural change while also creating a basis for more accurate baseline estimations, an essential component for verifying savings under an EEOS. Meanwhile, E4 promotes the deployment of smart meters, particularly among large consumers. The increased granularity and frequency of data provided by smart meters will significantly improve the M&V processes required in performance-based schemes like EEOS, enabling more precise impact assessment and reducing uncertainty in savings calculations. Together, these actions lay foundational elements for an EEOS by expanding access to consumption data, strengthening end-user feedback loops, and building trust in the scheme's accountability.

8.2.5 Transportation

In the transportation sector, U1 (Developing Effective Incentive Mechanisms for Increasing Energy Efficiency in the Transportation Sector) introduces financial and fiscal incentives aimed at accelerating the transition to energy-efficient vehicles. While these measures are valuable, any future EEOS targeting the transport sector must be carefully designed to avoid overlapping with U1 incentives, particularly in terms of additionality and double counting of savings. On the other hand, U2 (Establishing Effective Monitoring Systems by Digitizing Transportation Sector Data) plays a complementary role by laying the groundwork for an effective monitoring and verification system. Its planned data infrastructure, including vehicle-level fuel consumption and emissions records, can significantly support the design and implementation of a transport-focused EEOS by enabling performance tracking, impact assessment, and compliance verification.

8.2.6 Agriculture

In the agriculture sector, Actions T1 (Encouraging the Renewal of Tractors and Combine Harvesters with Energy Efficient Products), T2 (Improving Energy Efficiency in Agricultural Irrigation), and T3 (Supporting Energy Efficiency Projects in the Agriculture Sector) already include substantial financial and technical support mechanisms for energy efficiency improvements, ranging from equipment renewal to irrigation modernization and greenhouse upgrades. While these efforts are highly valuable in enhancing sectoral efficiency, the potential introduction of an EEOS must be designed to avoid overlaps with these schemes. In particular, EEOS savings must be clearly additional to those achieved through T1–T3 incentives, and the same measures should not be double-counted under both frameworks. A robust monitoring and verification infrastructure is essential to track interventions, prevent duplications, and ensure that EEOS drives new and complementary actions rather than substituting existing policy tools.

8.2.7 General assessment

The analysis of Türkiye's existing policy framework reveals a complex yet promising environment for the potential implementation of an EEOS. The current policy landscape encompasses a wide range of measures that both facilitate and intersect with EEOS objectives across all major sectors. On the enabling side, existing institutional and technical capacities, together with targeted actions under the Second NEEAP such as the development of monitoring systems, capacity-building initiatives, and data-driven benchmarking, directly contribute to the foundational infrastructure required for an effective EEOS. These elements are essential for establishing credible baselines, verifying energy savings, and ensuring transparency and accountability. They form the core pillars of any well-functioning obligation scheme.

However, the widespread presence of grant-based and incentive-driven programmes raises valid concerns about additionality and policy overlap. To ensure that an EEOS delivers truly new energy savings, it must be clearly distinguished from existing support mechanisms through robust monitoring, reporting, and verification systems. This is essential not only to avoid double counting but also to prevent conflicting incentives that may reduce the effectiveness of either policy tool.

At the same time, the review highlights important opportunities for strategic sequencing and policy alignment. Planned regulatory measures, such as those introducing new minimum performance standards for buildings or industrial equipment, can be aligned with EEOS to incentivise early compliance and prepare the market for forthcoming requirements. International experience shows that such coordination can enhance cost-effectiveness, increase political and market acceptance, and minimise disruption during regulatory transitions. If implemented before upcoming grant or subsidy programmes, an EEOS can act as an early support mechanism. It can encourage investment and behavioural change even before formal incentives are in place. In this way, EEOS may temporarily take on the role of planned support schemes and help accelerate their impact. This highlights the importance of integrated planning. EEOS should not be seen as a stand-alone policy, but rather as a flexible and complementary tool within the broader energy efficiency strategy.

Looking ahead, the potential introduction of a domestic ETS and the draft Climate Law in Türkiye add both complexity and opportunity to the country's energy and climate policy landscape. As carbon pricing becomes part of the national policy mix, the relationship between EEOS and ETS must be carefully designed to avoid overlaps, particularly in terms of how energy savings are counted. A key lesson from the EU is that energy savings triggered only by rising energy prices under the ETS are not eligible under EEOS. Only savings that result from planned, policy-driven actions can be counted as additional. Therefore, robust coordination and methodological clarity will be essential to ensure that each instrument maintains its integrity and contributes meaningfully to Türkiye's decarbonisation objectives.

In this context, Türkiye's evolving energy efficiency governance framework provides a solid foundation for piloting and gradually scaling an EEOS. However, the success of such a scheme will depend on several critical conditions. These include coherent policy design, strong institutional coordination, and active stakeholder engagement. The implementation strategy must rest on clear eligibility rules, robust monitoring and verification protocols, and close alignment with existing and planned support instruments. If these elements are successfully addressed, an EEOS can go beyond delivering additional energy savings. It can act as a strategic enabler, helping to deepen energy efficiency markets, leverage private capital, and accelerate Türkiye's transition toward its energy and climate objectives.

Although the first NEEAP fell short of implementing an EEOS, it is too early to reach the same conclusion for the second. A careful examination of the current action plan reveals that EEOS holds significant potential within Türkiye's revised energy efficiency strategy. If the complementary actions, particularly those aimed at strengthening institutional capacity, enhancing technical infrastructure, and improving market readiness, are fully implemented, the emergence of an EEOS becomes a natural outcome. In this context, the preparatory steps for establishing an EEOS and the institutional and technical capacity-building efforts outlined in the action plan are mutually reinforcing processes. At the same time, an EEOS can incorporate and operationalise many of the energy efficiency measures that are still in the planning phase, thereby easing the overall implementation burden of the action plan. In doing so, EEOS could serve as a structured, performance-based policy instrument to help Türkiye not only meet but potentially exceed its national energy efficiency targets.

9. OVERALL INSIGHTS AND POLICY RECOMMENDATIONS

This chapter brings together the analytical findings and sectoral insights presented throughout the thesis to provide an integrated perspective on the potential implementation of an EEOS in Türkiye. Building on the assessments of international experiences, cost-benefit analysis, sector-specific opportunities and risks, and policy alignment challenges, the chapter offers a strategic synthesis of lessons learned. It presents a set of forward-looking policy recommendations aimed at ensuring that a future EEOS in Türkiye is both effective and context appropriate. These recommendations are organised under thematic sub-headings to reflect the multidimensional nature of EEOS design and implementation. The goal is to support policymakers in developing a coherent, equitable, and well-functioning EEOS that can contribute meaningfully to Türkiye's energy efficiency and climate goals.

9.1 Strengthening Institutional and Technical Capacity

The successful implementation of an EEOS in Türkiye hinges on the establishment of a coherent and well-coordinated institutional and technical governance framework. While the MENR is designated as the lead authority in both first and second NEEAPs, effective EEOS implementation cannot rest solely on the shoulders of a single institution. Instead, it requires a multi-layered governance architecture supported by clearly defined roles, operational mandates, and collaborative mechanisms across several institutions.

At the apex, MENR should assume the strategic role of scheme owner, setting the overall policy objectives, determining the total savings obligation, and assigning targets to obligated parties. However, day-to-day operations require the designation of a dedicated managing authority responsible for administering the scheme. This body would oversee the implementation process, monitor compliance, coordinate reporting, and facilitate communication between stakeholders.

In parallel, a specialised technical institution must be established or designated to develop and maintain the methodological infrastructure of the scheme. This entity would be tasked with preparing the list of eligible energy efficiency measures, developing deemed savings algorithms and bottom-up calculation methods, and updating these tools in line with technological developments. Moreover, it must have the capacity to evaluate non-standardised project applications, oversee M&V procedures, and ensure that all reported savings meet the scheme's integrity standards.

As Türkiye explores market-based element, white certificates, within the EEOS framework, the integration of a functioning market platform will also become essential. This platform would need to enable the transparent trading of savings or certificates, supported by a robust registry system and appropriate regulatory oversight.

Critically, the mere existence of these institutions is not sufficient. A well-functioning EEOS requires seamless coordination among all entities involved. Harmonised workflows, shared data systems, and collaborative procedures must be established to avoid administrative fragmentation and ensure policy coherence. Without this institutional harmony, the scheme risks inefficiency, low credibility, and eventual policy fatigue.

In sum, institutional and technical capacity building is not a side requirement but a foundational pillar for EEOS success. Türkiye must invest in creating and empowering capable institutions, supported by clear mandates and sustained inter-institutional coordination, to ensure that the EEOS can function as an effective, additional, transparent, and adaptive policy instrument.

9.2 Ensuring Market Readiness

A well-functioning EEOS not only depends on institutional coordination but also on the readiness of the market to participate in, respond to, and benefit from the scheme. This readiness requires a clear understanding of sectoral energy efficiency potentials, the widespread availability of technical and operational data, and the establishment of minimum requirements for participation. Without sufficient market preparedness, even a well-designed scheme may struggle to deliver results at scale.

One of the essential components of market readiness is the availability of sector-specific benchmarks and reference values. Existing benchmarking studies, particularly in energy-intensive sectors have already provided valuable insights into the current performance levels and savings potential. However, these efforts need to be broadened to cover a wider array of sectors and company sizes, especially within the commercial buildings and small-scale industrial segments. A detailed understanding of baseline energy consumption across diverse market actors is crucial for designing fair and achievable targets under an EEOS.

In Türkiye, energy audits and the designation of energy managers, as well as the requirement to implement ISO 50001 energy management systems, are currently mandatory for industrial enterprises and commercial buildings above certain thresholds. While this regulatory framework provides a foundation, it does not yet encompass the full spectrum of energy consumers. For an EEOS to function inclusively and equitably, energy consumption monitoring and performance tracking must extend beyond large enterprises to also include medium and small-sized actors across all sectors.

There is a need for a comprehensive national energy reporting system that facilitates continuous and standardised data collection across sectors and scales. Such a system would serve multiple purposes: enabling the verification of savings, supporting benchmarking and target-setting processes, and informing future policy adjustments. It would also help build institutional memory by archiving historical data on implemented energy efficiency measures, technologies used and achieved impacts.

Furthermore, expanding the deployment of smart meters and advanced metering infrastructure will be instrumental in increasing the granularity, accuracy, and timeliness of consumption data. Real-time monitoring can strengthen feedback loops, improve demand-side responsiveness, and ultimately enhance the credibility and accountability of EEOS-related savings claims.

In sum, achieving market readiness for EEOS in Türkiye requires a multi-dimensional effort: scaling up benchmarking studies, expanding the scope of energy consumption monitoring, upgrading digital infrastructure, and creating a national reporting platform to track and integrate energy efficiency data. These steps will not only facilitate the technical operation of an EEOS but also ensure that all sectors, regardless of size or maturity, can meaningfully contribute to and benefit from the scheme. Additionally, improving stakeholder awareness and technical literacy, especially among small enterprises, and end-users is essential for meaningful participation. Without clear communication, capacity-building efforts, and sector-specific guidance, many actors may lack the confidence or know-how to engage with the scheme. Therefore, awareness campaigns and tailored training programmes should complement the technical measures outlined above to build a truly inclusive and capable market.

9.3 Policy Coherence and Integration

The successful integration of an EEOS into Türkiye's existing policy framework depends critically on ensuring strong policy coherence and preventing overlap or duplication between instruments. Türkiye already implements a wide range of regulatory tools, financial incentive programmes, strategic documents, and long-standing schemes. While this comprehensive landscape offers many opportunities, it also creates the risk of duplication, inefficiencies, and conflicting signals to market actors unless efforts are well coordinated.

A central design challenge lies in ensuring additionality. This means that the energy savings delivered through EEOS must be new and should not duplicate those already expected under other support schemes. It is essential to draw a clear boundary between EEOS and ongoing programmes. Energy efficiency measures financed by other mechanisms should not be counted again under EEOS unless they deliver higher performance or exceed baseline requirements. This is more than a technical matter. It directly affects the credibility and effectiveness of the scheme. If EEOS is perceived only as a rebranding of existing efforts, it is unlikely to shift behaviours or mobilise substantial private sector participation. To avoid this outcome, Türkiye needs a policy design that is both integrated and strategically phased. In areas where new regulations are planned but not yet enforced such as updated building standards or performance requirements for industrial equipment, EEOS can support early compliance. This would help the market prepare for future rules, reduce resistance, and ensure a smoother transition. A similar approach can be followed for upcoming grant or subsidy schemes. If EEOS is introduced before these programmes become active, it can act as an early support mechanism. Once the formal programs are launched, EEOS rules can be updated to reflect the new policy context and continue to deliver additional outcomes.

Another important dimension of policy coherence involves the temporal alignment of instruments. EEOS design should consider the timing of regulatory updates, funding cycles, and technological developments. By strategically sequencing EEOS with upcoming regulations and incentives, policymakers can minimise market disruption and maximise uptake, turning potential overlaps into synergies.

Coordination across institutions is equally important for policy coherence. While the MENR may be the central authority overseeing EEOS, other ministries play important roles in shaping energy efficiency policies. Without strong coordination, different programmes may conflict, create confusion, or undermine each other’s goals. A shared monitoring system, regular inter-ministerial communication, and consistent eligibility rules can help prevent these problems.

Ultimately, EEOS should be designed as a flexible and responsive policy instrument. It should not stand apart from Türkiye’s broader energy and climate goals. Instead, it should contribute to them by complementing existing policies and adapting to future developments. This includes alignment with the upcoming Climate Law, the design of a domestic carbon pricing mechanism, and the potential implementation of an ETS. Only through strong coordination and sustained policy coherence can Türkiye ensure that EEOS becomes an integral part of its national energy strategy, delivering additional, verifiable, and lasting results.

9.4 Effective Sector Coverage

The EEOS adoption action proposed in the second NEEAP does not explicitly specify the targeted sectors. However, the assignment of obligations to electricity, natural gas, and petroleum distributors and/or suppliers strongly implies a broad sectoral scope, encompassing industrial, commercial, and residential/household consumers. Within this framework, the inclusion of the industrial and commercial building sectors is both expected and justifiable. These sectors are relatively advanced in terms of institutional readiness, monitoring infrastructure, and experience with incentive mechanisms, and have already demonstrated substantial energy savings potential. As Chapter 3 of this thesis shows, an ex-ante cost-benefit analysis indicates clear win-win configurations in these sectors under an EEOS model. Each sector receives investment in proportion to its contribution to scheme targets, yielding balanced outcomes in terms of cost-effectiveness and administrative feasibility. With appropriate policy coherence and alignment, the inclusion of these sectors is not only feasible but also desirable and can be considered a natural starting point for a future EEOS.

In contrast, the household sector presents a more complex challenge. While it accounts for a substantial share of Türkiye’s total final energy consumption and holds significant untapped energy-saving potential, it currently lacks the technical and institutional readiness required for the implementation of a market-based scheme. Imposing an EEOS fee on household end-users raises serious concerns regarding political acceptability and social equity, particularly in the absence of complementary measures to protect vulnerable households. Nevertheless, excluding the household sector from a future EEOS would represent a critical policy gap. As demonstrated in Chapter 6, around 60% of households in Türkiye exhibit at least one inefficiency. This corresponds to approximately 15 million households out of the country’s total housing stock of 25 million. Despite the size of this target group, the sector remains largely untouched by comprehensive national energy efficiency programmes, apart from an outdated insulation loan initiative that lacks scale and impact.

Furthermore, the growing emphasis on energy poverty within the EU, reflected in increasing efforts to integrate social responsibilities into EEOS frameworks, signals a broader policy direction that may soon influence Türkiye’s agenda. Incorporating the household sector into a socially responsive EEOS design could therefore serve not only domestic policy needs but also support alignment with evolving European practices and expectations.

From a policy coherence and additionality perspective, the inclusion of the household sector in a future EEOS can be strongly justified. It would allow the scheme to reach an underserved segment, unlocking new savings and supporting the development of a more inclusive policy framework. Crucially, it also presents a strategic opportunity to integrate social equity into the scheme design. If EEOS is to serve as a mechanism for tackling energy poverty in Türkiye, it is vital that policymakers fully understand the limitations of conventional income- and energy expenditure-based energy poverty definitions, as demonstrated in Chapter 5. These definitions often fail to capture hidden energy poverty, where households under-consume energy due to affordability constraints, and typically overlook the role of dwelling inefficiency. Furthermore, they tend to be insensitive to energy price increases, which could disproportionately affect vulnerable households. The 5% EEOS fee simulations conducted in Chapter 5 show that while the introduction of an EEOS fee does not significantly alter energy poverty rates under conventional definitions, this is primarily due to the insensitivity of these definitions to marginal cost increases. In reality, even a modest additional charge may place a considerable burden on low-income households by reducing their already limited financial flexibility. For some, this could translate into difficult trade-offs between essential needs, such as heating or nutrition, highlighting the need for EEOS designs that account for such hidden forms of vulnerability.

As a mechanism fundamentally aimed at delivering energy savings, EEOS can be leveraged as a strategic tool for addressing energy poverty, when inefficiency is the root cause. By targeting structural inefficiencies in vulnerable households, the scheme has the potential to reduce long-term energy costs and improve living conditions, thereby tackling the underlying drivers of energy poverty in a sustainable manner.

Chapter 6 proposes an inefficiency-, financial vulnerability-, and region-informed energy poverty targeting framework, which reveals a significant intersection between energy inefficiency, financial difficulty, and geographic disparities. This approach provides policymakers with a localized and actionable framework for implementing equitable and effective energy efficiency interventions, ensuring that support is directed where it is most needed and that regional and social equity concerns are properly addressed. According to the proposed targeting framework in chapter 6, among the 15 million inefficient households, approximately 15%, or around 2.25 million, experience serious financial difficulty and are identified as the priority energy-poor group. These households exhibit the most severe inefficiency profiles and require immediate, fully subsidised interventions. Another 30%, roughly 4.5 million households, are categorised as at-risk, facing moderate vulnerability and mixed inefficiency patterns. This group would benefit from targeted, preventive measures designed to avoid a deterioration into full energy poverty. As demonstrated in Chapter 3, modelling results indicate that an EEOS scheme with carefully calibrated upper EEOS fee limits can generate an additional budget without imposing excessive costs on industrial and commercial building end-users. This additional budget could be strategically allocated to support comprehensive energy efficiency interventions for the priority energy-poor group. Once the most vulnerable households have been addressed, the scheme could gradually expand its reach to the at-risk group, providing protective support to prevent further hardship and ensuring a more inclusive and socially responsive implementation of the EEOS.

The remaining 55%, approximately 13.75 million households, referred to as regular households, still face energy inefficiency challenges despite their relatively better financial position. For this segment, general EEOS interventions could be delivered through co-financing arrangements between obligated parties and end-users, such as repayment models based on energy bill savings. These mechanisms can promote cost-effective upgrades while ensuring that households with moderate financial capacity can still participate in the scheme. In parallel, households in this group could also be directed toward complementary public financing options outside the EEOS framework. For example, improved versions of existing insulation loan programmes envisioned in the Second NEEAP can provide additional support, particularly if promoted through targeted awareness and engagement campaigns.

Taken together, these findings highlight the necessity of a socially responsive EEOS that goes beyond a one-size-fits-all approach. A carefully designed scheme can not only deliver measurable energy savings but also address long-standing social disparities in energy access and affordability. The targeting methodology developed in this thesis offers a clear operational path for embedding energy poverty mitigation into the core of Türkiye's future EEOS policy.

To sum up, broad sectoral coverage offers EEOS the flexibility to operate across diverse consumption profiles and unlock a wider range of savings opportunities. However, such extend also demands careful calibration of cost allocation mechanisms. In the case of industrial and commercial building sectors, the findings from Chapter 3 demonstrate that EEOS fees can be passed on to end-users without compromising cost-effectiveness, with the scheme reaching clear win-win configurations. However, this does not imply a uniform impact across all actors. More vulnerable subgroups, such as SMEs, may not manage compliance costs. Moreover, these sectors should not be expected to shoulder the full financial burden of the scheme. While the application of an EEOS fee remains a viable approach, the design can incorporate alternative cost recovery mechanisms for obligated parties to ease the financial pressure on end-users. In doing so, the scheme can maintain economic efficiency while protecting competitiveness and equity within the covered sectors. In the household sector, however, imposing an EEOS fee may not be the most appropriate path. While it is certain that residential energy prices in Türkiye remain subsidised and do not reflect full cost recovery, any additional charges must be approached with caution. Rising prices can incentivise efficiency, but only when households are ready to respond. By proactively addressing existing inefficiencies and alleviating energy poverty before full-cost pricing is introduced, EEOS can play a preparatory role, ensuring that vulnerable households are no longer at risk when energy prices begin to reflect real economic costs. In this way, EEOS not only delivers energy savings, but also supports a just and resilient energy transition in Türkiye.

In designing a cost recovery strategy, it is also important to consider how EEOS-related costs are reflected in end-user tariffs. In some schemes, obligated parties are allowed to adjust their tariffs based on their own implementation costs, while others rely on regulated tariffs overseen by public authorities. Given Türkiye's regulated pricing structure and the critical role of affordability, it is essential that all tariff adjustments related to EEOS implementation remain under the oversight of the EMRA, while preserving the pricing freedom of eligible consumers. This will ensure transparency, protect consumers from disproportionate price increases, and maintain coherence between energy efficiency policy and broader energy pricing objectives.

9.5 Selection of Obligated Parties and Setting the Obligations

The selection of obligated parties is central to the successful implementation of an EEOS. As mentioned in Chapter 2, international practice demonstrates that obligated parties can include a range of actors, such as electricity, natural gas, petroleum, heat suppliers, distributors, retailers, traders depending on the country's energy market structure and institutional capacity. In countries with liberalised markets, energy suppliers are most chosen due to their direct access to consumption data and customer relationships. The selection also depends on historical involvement in energy efficiency efforts and the ability to track and verify energy savings.

In Türkiye, the issue of who should be designated as obligated parties has been addressed in both the first and second NEEAPs, albeit in broad terms. The first NEEAP identified electricity, natural gas, and petroleum energy distribution, supply, or retail companies as the entities to which obligations could be assigned. The second NEEAP adopted similar language, referring to obligations for electricity, gas, and petroleum distribution and/or supply companies. Notably, it also introduced a new element by stating that energy efficiency obligations to be assigned to electricity distribution and/or supply companies would be defined as a quality performance criterion. This framing marks a significant step forward, indicating that energy savings are to be considered not only as compliance targets, but as integral indicators of service quality. The broad definition of obligated parties reflects Türkiye's intention to include a wide range of market actors, aligning with international best practices. However, it also highlights the need for a more refined and context-specific identification process, one that considers market structure, regulatory maturity, data access, and administrative capacity in each energy sub-sector.

In Türkiye, the electricity market stands out as the most viable entry point for an EEOS. The country is divided into 21 private electricity distribution regions, each served by one electricity distribution company and one incumbent supply company. Electricity supply in Türkiye is predominantly carried out by incumbent supply companies, which hold a combined market share of approximately 70%. These companies are in direct contact with end-users and have access to detailed consumption data, making them well-positioned to serve as obligated parties under a potential EEOS. Their business model involves purchasing electricity from the wholesale market and selling it to consumers via regulated tariff or negotiated prices, which creates a natural incentive to reduce end-use demand through efficiency measures. In contrast, electricity distribution companies are responsible for the physical delivery of electricity and the maintenance of distribution infrastructure within their designated regions. Their revenues are typically linked to the volume of electricity transmitted, which may reduce their motivation to implement demand-reduction measures. For this reason, and given their operational role in the system, distribution companies are generally considered less suitable as obligated parties in an EEOS.

Given these conditions, this thesis proposes that incumbent electricity supply companies should be designated as the initial obligated parties under future EEOS. These companies are well-positioned to take on this role due to their customer reach, existing billing infrastructure, and access to consumption data. Chapter 3 demonstrates that allocating obligations to incumbent electricity suppliers allows for cost-effective implementation, especially when combined with flexible compliance options and fair cost-recovery mechanisms. Moreover, several incumbent supply companies in Türkiye have already begun expanding their services. Under "customer solutions" initiatives, some offer energy efficiency advice, while others have established subsidiaries aiming to provide ESCO-level services. This shift toward demand-side energy management strengthens the case for selecting these companies as primary obligated parties. Their growing technical capacity, close customer interface, and market experience position them well to deliver measurable and scalable energy savings.

In the natural gas sector, Türkiye remains heavily import-dependent, with upstream and wholesale segments largely dominated by BOTAŞ, which is responsible for approximately 90% of total gas imports. While the downstream market includes 72 licensed private natural gas distribution companies serving final consumers, these companies typically perform both distribution and retail supply functions, unlike the electricity sector where these activities have been legally separated. Although regulated tariffs are applied to most consumers, especially in the household sector, eligible large consumers can negotiate their gas contracts with distribution companies. While natural gas distribution companies have direct access to end-users and consumption data, their dependence on centrally procured gas and limited room for commercial innovation may reduce their flexibility in delivering efficiency obligations.

Like natural gas, Türkiye remains highly dependent on foreign petroleum supply. Nearly 80% of petroleum imports handled by two privately owned companies holding refinery licenses. This points to a highly concentrated market structure at the import level. In the domestic market, a total of 38 licensed distributors are active, but the top four companies account for approximately 68% of total sales. The top ten firms collectively hold around 90% of the market share. These figures show a significant level of concentration, indicating that the petroleum products market is gradually moving toward an oligopolistic structure. Furthermore, unlike electricity and natural gas companies, petroleum product distributors typically do not maintain a direct or continuous relationship with end-users. There is no metering infrastructure or long-term contractual arrangement linking them to individual consumers. This makes the assignment, delivery, and verification of end-user-level energy savings significantly more challenging. Given these structural limitations, such as high market concentration, lack of end-user interface, and minimal regulatory oversight at the consumption level, standard EEOS design approaches may not be directly transferable. Instead, alternative and creative solutions tailored to the specific dynamics of the petroleum sector will be required to ensure meaningful participation and measurable outcomes.

Compared to the petroleum products market, the natural gas sector offers a more direct and structured interface with end-users, making it a more feasible candidate for inclusion in a future EEOS. Thermal efficiency is just as important as electricity savings in advancing Türkiye's energy efficiency goals, particularly in the household sector where space heating constitutes one of the largest sources of energy consumption. Natural gas is the dominant heating fuel in households. Because of this widespread reliance, improving thermal efficiency is essential for any comprehensive energy efficiency strategy targeting households. In this context, natural gas distribution companies are strong candidates to be included as obligated parties in a future EEOS. Their established infrastructure, customer databases, and billing systems provide the operational capacity needed to deliver or coordinate efficiency upgrades. Including these companies in the obligation structure would also support Türkiye's broader objective of reducing foreign demand and increasing supply security. However, the natural gas market differs from the electricity sector in several important ways. Unlike electricity, where distribution and supply are legally unbundled, natural gas companies in Türkiye typically perform both functions under a vertically integrated model. While this structure does not inherently hinder participation in an EEOS, it may reduce market competition and limit incentives for innovation in delivering energy efficiency services. Furthermore, the natural gas market remains less liberalised, with fewer active suppliers and lower levels of consumer switching compared to electricity. Despite these limitations, the close operational relationship between natural gas distribution companies and end-users, along with their existing infrastructure and data access, positions them as viable actors for obligation assignment. Their involvement, especially in supporting household-level thermal efficiency and addressing energy poverty, should be actively pursued during the design of Türkiye's future EEOS.

In conclusion, starting with incumbent electricity supply companies as the initial obligated parties offers a pragmatic and impactful pathway for launching an EEOS in Türkiye. Their technical infrastructure, and growing engagement in energy efficiency make them strong candidates for early implementation. In parallel, natural gas distribution companies should also be considered for inclusion, particularly in the context of household heating and energy poverty mitigation, given their close relationship with end-users and operational reach. Petroleum distributors, on the other hand, pose distinct challenges due to limited consumer interface and market structure. While their potential role in an EEOS should not be dismissed, it will require further exploration and tailored design solutions. With the appropriate mix of obligated parties, the EEOS can be structured to reflect sector-specific realities, maximise energy savings, and ensure equitable policy outcomes across Türkiye's energy landscape.

In some countries, EEOS rules allow small energy companies to be exempt from obligations if their sales or number of customers are below a certain threshold. The threshold aims to reduce administrative complexity and avoid placing disproportionate burdens on minor players. However, such an approach is not well suited to Türkiye's energy market structure. Both incumbent electricity suppliers and natural gas distribution companies operate under geographically defined licenses, each serving an exclusive region. Exempting a company based on a threshold would remove entire regions from the scheme, undermining national coverage, regional equity, and the policy's overall legitimacy. Instead of applying a uniform threshold that could exclude entire service regions, proportionality can be ensured through the way obligations are allocated. As also foreseen in both first and second NEEAPs, obligations can be distributed among obligated parties in proportion to their market share. This approach allows for full territorial coverage while ensuring that smaller companies are not overburdened, as their targets would be scaled to match their market size.

At the core of any EEOS is the requirement that obligated parties deliver measurable reductions in energy consumption through end-use energy efficiency improvements. A clear and standardised obligation metric should be established to ensure clarity, accountability, and comparability across sectors and energy types. International experience demonstrates that obligation metrics can vary depending on the nature of the energy carrier and the characteristics of the market.

In Türkiye, a differentiated approach based on energy type would be appropriate. For incumbent electricity suppliers, the obligation metric could be expressed in terms of final energy savings, measured in MWh. This unit directly corresponds to what end-users consume and is the standard metric used in most electricity-focused EEOS applications globally. For natural gas distribution companies, a metric based on primary energy savings, measured in standard cubic meters, may be more suitable.

Natural gas, as a primary energy source, differs from electricity, which is a secondary energy source derived from primary sources. Therefore, for natural gas, it is more appropriate to measure savings in terms of primary energy, reflecting reductions in the direct consumption of the fuel itself.

An important and ambiguous point arises from the second NEEAP, which states that "*energy efficiency obligations will be defined for energy companies with an approach compatible with country's climate goals*". While this statement underlines the broader alignment of EEOS with Türkiye's decarbonisation trajectory, it also raises critical questions regarding the intended metrics and interaction with other climate instruments. If compatibility refers to carbon reduction targets, EEOS obligations may focus on GHG emission reduction rather than energy savings. This could lead to prioritising high-emission sectors, potentially enhancing climate impact, but it also brings a clear risk of policy overlap. Türkiye is already preparing to introduce a national ETS and other carbon pricing mechanisms. Without clear methodological separation, there is a danger that energy savings achieved under EEOS could be double counted as emissions reductions under the ETS. This would undermine the integrity and effectiveness of both instruments. Additionally, an emissions-oriented approach may not align with the pilot white certificate scheme, which is specifically designed around energy saving metrics instead of emissions reduction. These considerations emphasize the critical need for precise definitions of climate alignment within EEOS and highlight the importance of establishing synchronized methodologies and verification protocols to ensure the additionality and unique contribution of each policy instrument. For these reasons, policymakers must be especially cautious in defining the metric and scope of EEOS obligations. While climate alignment is undoubtedly important, conflating emissions reduction and energy savings without a clear framework could create confusion and inefficiencies. Energy savings and GHG reductions are related but distinct goals. Each serves a different purpose and requires different monitoring and verification systems. To ensure additionality, credibility, and complementarity with other policies, EEOS must operate with clearly defined objectives and harmonised accounting protocols that prevent overlap and maximise the scheme's contribution to Türkiye's climate and energy efficiency targets.

Once the metric is defined and the total obligation is allocated among the designated companies in proportion to their market shares and all major sectors are included in the scheme, the question of where energy efficiency measures will be implemented becomes a practical design issue. By its very nature, an EEOS incentivises obligated parties to pursue energy savings in areas where measures are most cost-effective. This could unintentionally lead to the neglect of sectors where efficiency improvements are less economically attractive but still strategically important. To ensure a balanced implementation across sectors, the obligation design must encourage diversification of efficiency efforts. One viable approach is to introduce sectoral segmentation within the assigned obligations. Instead of allowing companies to independently determine where to focus their savings efforts, a portion of their targets could be aligned with specific end-use sectors based on national priorities or regional consumption patterns. This would ensure that the scheme does not disproportionately favour the most accessible savings and that all segments of the economy benefit from the programme. In addition, Türkiye’s electricity and natural gas distribution systems are regionally organised. Thus, regional obligation segmentation is also an option. By analysing the sectoral energy consumption mix within each distribution region, tailored obligations can be designed for each company. This would allow the scheme to reflect local realities more accurately and promote equity and inclusiveness. Through such an approach, the EEOS can remain both cost-effective and responsive to diverse efficiency needs across Türkiye’s regions and sectors.

9.6 Obligation Period and Compliance Framework

Once the total energy savings target is determined and distributed among obligated parties, a clear definition of the obligation period and compliance rules becomes essential for the proper functioning of the EEOS. These parameters influence the predictability, feasibility, and enforceability of the scheme. A key design question is whether obligated parties should meet their targets through annual savings goals or multi-year obligation periods. While annual targets offer stronger accountability and allow for regular monitoring, they can also create short-term pressures that discourage deep and long-term efficiency investments. On the other hand, multi-year obligation periods, such as three or four-year cycles commonly used in European schemes, provide more flexibility, enabling obligated parties to plan and execute larger projects with higher upfront costs and longer payback periods. To ensure a balance between predictability and flexibility, Türkiye could adopt a multi-year obligation period with interval annual milestones, allowing both long-term planning and regular performance tracking.

Another critical design element of an EEOS is the method used to calculate and credit energy savings. International evidence indicates that there are two predominant accounting methods: lifetime savings and period-based savings. The lifetime savings approach attributes the total projected energy savings over the entire technical lifetime of a given efficiency measure. For instance, if an insulation upgrade is projected to decrease energy consumption over a 20-year period, the responsible entity may be granted credit for the entire 20-year savings at the time of implementation. This method better reflects the long-term impact and value of deep efficiency measures, offering a strong incentive for investments in durable and high-performing technologies. However, it also introduces higher uncertainty, as it relies on assumptions about the persistence of savings over time, potential changes in user behaviour, and the technical durability of the installed measure. In contrast, the period-based savings method accounts only for the savings achieved during the defined obligation period. This approach provides a more conservative estimate, is less reliant on long-term projections, and is easier to verify on an annual basis. It aligns more closely with the temporal scope of policy cycles and budgetary planning, making it administratively more straightforward.

Given Türkiye's current policy environment and the need to strengthen institutional capacity in measurement, reporting, and verification, a hybrid approach may offer the most pragmatic solution. Under such a framework, lifetime savings could be applied to standardised measures with proven performance profiles and established calculation methodologies. However, instead of automatically crediting the full technical lifetime of a measure—such as 20 years for insulation—the actual credited lifetime should be determined by a designated technical institution. For more complex, non-standard, or pilot projects—where savings are harder to predict and verify, a period-based approach may initially be more appropriate. However, rather than applying a fixed rule, each project's savings duration should be reviewed and approved by a designated technical institution. This institution would assess the measure's expected performance, context, and monitoring needs to determine whether lifetime or period-based crediting is more suitable. Over time, as institutional experience and data improve, the scope of measures eligible for lifetime savings can be broadened in a controlled and evidence-based manner.

Establishing a technically sound, fair, and transparent methodology for crediting savings will be essential to build trust among obligated parties and ensure that the scheme delivers verifiable and impactful results. Moreover, a clearly defined obligation period and crediting duration will provide the necessary predictability for compliance planning, enabling obligated parties to develop effective investment strategies, schedule implementation activities, and coordinate with relevant stakeholders in a timely and cost-efficient manner.

A clear and enforceable compliance framework is essential for the credibility, integrity, and effectiveness of any EEOS. Compliance mechanisms ensure that obligated parties not only commit to their energy savings targets but also deliver them in a verifiable and timely manner. For Türkiye's prospective EEOS, designing a robust compliance system will be critical in fostering trust among market actors, maintaining a level playing field, and preventing underperformance.

At the core of the compliance framework lies a reliable Monitoring, Reporting, and Verification system. Obligated parties must be required to submit regular progress reports, detailing the implemented measures, projected and verified energy savings, and supporting documentation. These submissions should be reviewed by an independent body, preferably a technical institution or regulatory agency with the capacity to evaluate project eligibility and validate savings claims based on standardised protocols.

To reinforce accountability, Türkiye's EEOS should introduce a transparent and enforceable penalty structure for non-compliance. If obligated parties fail to meet their assigned energy savings targets within the obligation period, financial penalties should be enforced. As demonstrated in Chapter 3, modelling results show that the presence of a well-defined penalty mechanism create motivation and significantly improves the rate of achieved energy savings.

Türkiye should also consider offering compliance cost flexibility through the establishment of a well-calibrated buy-out mechanism. This mechanism would allow obligated parties, particularly those facing implementation barriers, to fulfil part of their obligations by paying into a central energy efficiency fund or financing mechanism, rather than undertaking all measures themselves. It could also serve as a safety valve at the end of an obligation period, enabling companies to avoid disproportionate penalties in cases where minor shortfalls remain despite good-faith efforts. To ensure the buy-out mechanism remains a supplementary option rather than a primary compliance path, a cap (e.g., 20 or 30%) should be set to limit the share of an obligated party's target that may be fulfilled through buy-out. This approach balances compliance flexibility with integrity, ensuring that the EEOS remains an action-oriented tool while maintaining room for strategic cost optimisation.

In Chapter 3, study results showed that, in the absence of a buy-out option, the penalty must be set at least equal to the maximum unit cost of current energy efficiency investments to provide sufficient motivation for compliance. However, if a buy-out mechanism is introduced as an alternative compliance pathway, this hierarchy must be carefully preserved. In such a framework, the buy-out price should be set at or near the maximum observed unit cost of energy efficiency investment costs. This ensures that it remains a viable but not overly attractive substitute for direct implementation. To preserve the deterrent function of the penalty, the financial penalty should then be set as a fixed multiple of the buy-out amount.

This tiered pricing structure creates a clear and strategic compliance hierarchy. Directly implementing energy efficiency measures remains the most cost-effective and preferred pathway for obligated parties, ensuring that the primary aim of the EEOS is achieved. The buy-out mechanism serves as a controlled and flexible alternative, offering relief for obligated parties. Finally, the penalty functions as a last-resort measure, carrying a significantly higher financial burden to preserve the integrity and enforceability of the scheme. By establishing this hierarchy, the EEOS can promote tangible action, provide targeted flexibility where needed, and maintain overall credibility. To ensure continued relevance and fairness, both the buy-out price and the penalty level should be periodically reviewed and adjusted in line with developments in the energy efficiency market.

A useful example for designing a fair and targeted buy-out mechanism comes from Ireland, as discussed in Chapter 7. In Ireland's EEOS, obligations are defined separately for different sectors, and if an obligated party chooses to use the buy-out option, they must pay a unit price that is specific to the sector target in question. Importantly, Ireland sets the highest buy-out price for the energy poverty target. This ensures that obligated parties either take action directly or pay a higher amount when opting out, increasing the likelihood that measures aimed at supporting vulnerable households are actually delivered. Türkiye could apply a similar approach. Sector-specific buy-out and penalty rates can help guide obligated parties toward priority areas, such as households facing energy poverty or sectors where energy savings are most needed. This would allow the scheme to remain flexible while still encouraging action where it matters most. Setting higher buy-out and penalty levels in these areas would signal their importance and help ensure that EEOS contributes to broader policy goals, not just cost-effective savings, but also social impact and long-term transformation.

In this context, the presence of both buy-out and penalty mechanisms makes borrowing (carrying forward unmet savings to the next period) unnecessary. International experience shows that borrowing can weaken accountability and complicate monitoring. Given tiered compliance structure, excluding borrowing would help preserve clarity and maintain strong incentives for timely savings delivery.

A well-designed compliance system should also incentivize overperformance. Internationally, this is usually done through banking (carrying surplus savings forward to future periods) or inter-party saving trading (transferring surplus savings between parties). While banking can be beneficial and is permitted in some schemes within defined limits, it introduces administrative complexity by extending obligations beyond the defined compliance period. Moreover, simply postponing surplus savings may not be the most strategic use of those resources, especially when other obligated parties may be underperforming in the same period. For Türkiye, a more effective and manageable approach would be to keep surplus savings within the obligation period in which they are generated and allow their redistribution, under strict rules and with regulatory oversight, among other obligated parties through managed inter-party saving trading. This would preserve the temporal integrity of the scheme, support timely achievement of national energy savings targets, and reduce administrative burden. The managing authority should oversee these transfers to ensure transparency, fairness, and alignment with the strategic objectives of the EEOS. Additionally, introducing saving trading at this stage can help build institutional experience and pave the way for a future white certificate scheme.

Building on the Monitoring, Reporting, and Verification system outlined earlier, the managing authority should also develop complementary transparency tools to support public accountability. Publishing periodic performance summaries for obligated parties would reinforce compliance through reputational incentives and enable external stakeholders to track the scheme's progress. Over time, such visibility will not only improve market confidence but also contribute to the institutional maturity and credibility of Türkiye's EEOS.

9.7 White Certificate Scheme and Market Participation

The successful implementation of a white certificate scheme implies a mature phase in the development of an EEOS. If the recommendations outlined in the previous sections are fulfilled, Türkiye can be considered structurally, institutionally, and technical ready to adopt white certificates. These foundational steps ensure the technical and administrative integrity of the scheme and provide the operational reliability and market confidence.

To ensure the scheme's success, it is essential to build a clear and inclusive institutional architecture. The roles of the central regulator, the technical authority responsible for methodology development and verification, and the market platform managing certificate issuance and trading must be well defined. Close coordination between these bodies will be crucial to avoid procedural inconsistencies and build stakeholder trust. In parallel, Türkiye should prioritize the development of standardised action sheets that define eligible measures, baseline conditions, calculation formulas, and reporting requirements. These tools will facilitate the consistent appraisal of projects, reduce administrative delays, and support transparency in implementation. Equally important is ensuring that entities requesting white certificates are equipped to submit detailed and verifiable documentation. Applicants must be capable of preparing comprehensive reports that include long-term measurement plans, performance tracking mechanisms, and clear evidence demonstrating that the claimed savings have been realized. This level of documentation is essential for maintaining the integrity of the trading system. To avoid administrative confusion or disputes, all guidelines, reporting templates, and methodological rules should be communicated in a clear, accessible, and user-friendly manner. Ensuring procedural clarity at this stage will reduce the likelihood of inconsistent interpretations, foster confidence among market participants, and enable smoother implementation. Ultimately, the credibility and effectiveness of the white certificate scheme will depend on how well the reporting and verification processes are structured and understood by all involved stakeholders.

Encouraging the participation of third-party actors is also vital to the success of Türkiye's white certificate scheme. Without broad stakeholder engagement, the mechanism cannot function effectively. For this reason, a wide and inclusive list of eligible participants should be established from the outset. This should include energy EVDs, all industrial enterprises, commercial buildings, residential complexes, universities, and other institutions capable of delivering measurable energy savings. Once the principle of additionality is ensured, the nature or ownership of the entity should not pose a barrier to participation. Naturally, organizations that already employ certified energy managers or operate under ISO 50001 standards will have a comparative advantage in demonstrating compliance. As suggested in the market readiness section, extending these capacity requirements to entities below existing thresholds would enhance preparedness and support wider engagement. Furthermore, all energy companies that are not designated as obligated parties under the EEOS should be allowed to participate on a voluntary basis. Opening the door to such actors would expand the delivery ecosystem, increase liquidity in the certificate market, and promote a more competitive, innovative, and resilient energy efficiency landscape.

Ensuring fair and transparent price formation in the white certificate market will be equally critical. The designated market platform operator, responsible for managing both spot market transactions and bilateral agreements, will play a central role in this process. Beyond facilitating certificate trading, this institution must work in close coordination with the technical institution and managing authority to maintain market integrity. One of its responsibilities will be to detect and prevent trading behaviours that could threaten the credibility of the scheme, for example, large-scale certificate hoarding or attempts to manipulate supply. While strategic actions are part of any market, it is essential to carefully examine measures that could endanger the scheme's integrity. With strong oversight and clear communication, the platform operator can help maintain trust and keep the market running efficiently. Maintaining a stable and transparent pricing environment is not only critical for compliance, but also for attracting private investment. White certificates must be perceived as credible and bankable assets to unlock sustained market interest and financing for efficiency projects.

A key design feature of Italy's white certificate scheme is the close link between verified savings and compliance timelines. Each certificate is tied to the specific year in which the savings verified and can only be used to meet obligations for that compliance year. This "use-by" structure ensures that energy savings are recent, verifiable, and temporally aligned with annual targets. Certificates that are not submitted by the deadline are cancelled and cannot be used in future years. This approach not only reinforces the integrity of the scheme but also helps prevent strategic overstocking and speculative behaviour. Türkiye can adopt a similar principle while adapting it to its multi-year obligation cycles. For instance, certificates generated within a three-year compliance period could be valid for use within that period only. This would maintain flexibility while still ensuring timely delivery of savings. In addition, for measures that produce ongoing savings over several years, additional certificates could be issued if savings continue to be verified annually, in line with the methodology approved by the technical institution. This structure would strike a balance between flexibility, traceability, and market discipline.

Finally, it is important to view the white certificate scheme not merely as a compliance mechanism, but as a strategic policy tool capable of shaping the future direction of Türkiye's energy transition. If designed and implemented with institutional foresight and market sensitivity, the scheme can channel private investment into high-impact measures, foster innovation in energy services, and promote deeper integration of efficiency into long-term decarbonization efforts. By creating a structured and transparent marketplace for energy savings, it will not only improve compliance outcomes, but also stimulate the growth of a more dynamic, competitive, and professionalized energy services sector. In this way, white certificates can evolve from being a technical instrument into a broader catalyst, supporting systemic change, expanding delivery capacity, and embedding efficiency as a central pillar of Türkiye's energy and climate policy.

10. CONCLUSION

This Ph.D. thesis provides a data-driven and evidence-based analysis of the EEOS, a policy mechanism that has long been planned but not yet implemented in Türkiye. By addressing the multidimensional nature of EEOS from conceptual, economic, and social perspectives, the study aims to contribute to the effective, equitable, and sustainable design of the scheme in the context of Türkiye. Drawing on lessons from international experience, empirical data analyses, and sector-specific policy recommendations, the thesis offers a comprehensive framework to support both policymakers and sector stakeholders. It also seeks to make an original contribution to the academic literature. Ultimately, this research is intended to serve as a concrete foundation for Türkiye to achieve its energy efficiency targets and successfully institutionalize the EEOS.

One of the central insights of this thesis is the importance of prior groundwork. A well-functioning EEOS cannot emerge overnight. It requires investment in technical capacity, data systems, institutional clarity, and stakeholder engagement. However, the absence of perfect conditions should not be a reason for delay. Countries that now operate advanced schemes did not begin with flawless systems. Rather, they built them incrementally, through learning, iteration, and adjustment.

Türkiye does not need a complex or overly ambitious starting point. Instead, it can embrace the principle of "Keep It Simple" in the initial phase: start with clear savings targets, well-defined rules, and a compliance framework that is transparent, enforceable, and flexible enough to accommodate different levels of readiness. The introduction of a balanced compliance package can allow the scheme to function pragmatically while still upholding accountability.

Moreover, the fear of market resistance or administrative burden should not discourage action. As this Ph.D thesis has demonstrated, the foundational elements already exist. A strategic effort to unify and mobilize these elements into a cohesive system is needed. By doing so, Türkiye can gradually transform EEOS from a policy concept into an operational leader of its national goals.

In conclusion, the pathway to an effective EEOS does not require perfection at the beginning, but it does require clarity of purpose, decisiveness in action, and persistence in building institutional capacity. With thoughtful design and steady implementation, Türkiye can not only catch up with leading EEOS examples but also tailor its own version, one that is well-suited to national priorities, responsive to social needs, and aligned with the energy transition.

While this Ph.D. thesis offers a comprehensive exploration of the potential design and implementation of an EEOS in Türkiye, several limitations should be acknowledged. First, although the analyses are grounded in official datasets and internationally recognized methodologies, the modelling results inevitably rely on certain assumptions regarding policy parameters, market behaviour, and institutional responses. These assumptions, while necessary for scenario-building, may not fully capture the complexity and variability of real-world implementation. Additionally, some of the proposed targeting strategies, particularly in the household sector, are based on proxy indicators due to limited data availability. In practice, achieving effective targeting of energy-poor households would require obligated parties to collect more granular data from their actual end-user households. This would allow for better alignment with the eligibility framework proposed in the thesis and help ensure that interventions reach those most in need. Second, while the thesis draws on extensive international experiences, it does not cover all existing EEOS models in full operational detail. Instead, it focuses on selected best practices that are most relevant to Türkiye's context. There may be further insights to be gained by expanding the comparative analysis to include additional countries.

Looking forward, future research could address these limitations by incorporating more granular and disaggregated data, once available, and by validating the proposed models through pilot studies or real-world implementations. In particular, the effectiveness of the proposed targeting framework in the household sector could be tested through partnerships with potential obligated parties willing to collect end-user-level data. Further research could also explore behavioural responses to EEOS incentives across different income groups and consumption patterns, shedding light on the social dynamics that influence the uptake and effectiveness of energy efficiency interventions.

Additionally, more refined and dynamic cost-benefit analyses can be developed by incorporating evolving market conditions, more diverse technology cost curves, and differentiated savings trajectories over time. These assessments should also consider various compliance pathways under different flexibility mechanisms and white certificates, to evaluate their economic and administrative feasibility. The role of different market participants, including third-party actors like ESCOs, sector participants, and non-obligated energy companies, should be further explored to understand their capacity and potential to contribute under varying scheme designs.

Moreover, the role of the transportation sector within an EEOS framework remains an underexplored area in both policy and academic literature. Given its significant share in Türkiye’s final energy consumption and rising emissions trajectory, the sector offers considerable, yet untapped efficiency potential. Future research should investigate the feasibility of incorporating transport-related measures into a potential EEOS structure.

Furthermore, as Türkiye prepares to introduce a national carbon pricing mechanism and considers the establishment of an ETS, the potential interaction between EEOS and carbon markets requires deeper investigation. Future studies should assess the risks of double counting, explore methodological harmonisation for monitoring and verification, and identify opportunities for complementary implementation. Such research would not only ensure policy coherence but also enhance the environmental and economic effectiveness of Türkiye’s broader decarbonisation strategy.

Finally, as Türkiye prepares for EEOS implementation, there is a need for continued interdisciplinary research that brings together policy, economics, engineering, and social sciences. Such collaboration will be key to refining the design, anticipating implementation challenges, and ensuring that EEOS contributes to a just, efficient, and transformative energy future for Türkiye.

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APPENDICES

APPENDIX A: Literature Survey Table of EEOS Studies
APPENDIX B: Post-hoc Analysis Results
APPENDIX C: Regional Distribution of Inefficiency Categories and Detailed Eligibility Index Range Distribution

APPENDIX A : Literature Survey Table of EEOS Studies

Table A.1 : Literature Survey of EEOS Studies.

Studies	Publication Year	Purpose	Study Group	Methodology
(Bertoldi et al., 2010)	2010	To provide an assessment and analysis of white certificate programs in the EU up to that point.	Discussion on existing EEOSs	Literature research and discussion.
(Broc et al., 2011)	2011	To illustrate the consistency of energy savings accounting in the French white certificate scheme and the EU Energy Saving Directive (2006) using a concrete case in which an evaluation national system is compared to the supranational framework.	Discussion on existing EEOSs	Literature research, engineering calculations, and discussion.
(Tyler et al., 2011)	2011	To discuss the findings of a 2008 study examining White Certificate schemes as a policy alternative for South Africa.	Proposing possible new EEOSs	Literature research and discussion.
(Bertoldi et al., 2011)	2011	To investigate the use of EEOs in road transport, to debate its imposition on transportation fuel suppliers, to define the eligible technologies, and projects that consider EEOs as a standalone instrument or in conjunction with existing fuel obligations.	Recommending improvements to EEOSs	Literature research and discussion.
(Rosenow, 2012)	2012	To examine the changes and developments of energy savings obligations in the UK.	Discussion on existing EEOSs	Literature research and discussion.
(Norero and Sauma, 2012)	2012	Based on Italian experience, investigate the potential introduction of white certificates in Chile.	Proposing possible new EEOSs	Literature research, cost-benefit analysis, and discussion.
(Giraudet et al., 2012)	2012	To make the costs & benefits analysis of white certificate schemes in the United Kingdom, France, and Italy.	Discussion on existing EEOSs	Cost-benefit analysis.
(Oikonomou et al., 2012)	2012	To find out if white certificates may interact with domestic offset programs.	Interaction analyses of EEOSs with market or different mechanisms	Interaction analysis.
(Oikonomou et al., 2012)	2012	To detect the behavior of an electrical supplier participating in a white certificate program in an oligopolistic market.	Discussion on existing EEOSs	Literature research and discussion.
(Pavan, 2012)	2012	Based on a review of the existing schemes, describe the reason for white certificates and present the primary concerns and challenges in creating and running a white certificates mechanism.	Discussion on existing EEOSs	Literature research and discussion.
(Petrella and Sapio, 2012)	2012	To examine the influence of contracts for differences, retail liberalization, and white certificates on Italian wholesale power pricing.	Discussion on existing EEOSs	SARMAX and EGARCH models.

Table A.1 (continued) : Literature Survey of EEOS Studies.

Studies	Publication Year	Purpose	Study Group	Methodology
(Bertoldi et al., 2013)	2013	To provide theoretically distinct approaches to introducing energy-saving obligations and to examine the benefits and drawbacks of end-user obligations vs supplier obligations.	Discussion on existing EEOSs	Literature research and discussion.
(Rosenow et al., 2013)	2013	To provide an assessment of the stress between lowering carbon emissions and rescue from fuel poverty within EEO, to outline the British Supplier Obligation's fuel poverty provisions, to evaluate its criteria for detecting the fuel poor, to give a critical analysis of the proposed policy changes, and to recommend alternative options to address fuel poverty within future supplier obligations.	Recommending improvements to EEOSs	Literature research and discussion.
(Moser, 2013)	2013	To review measures to alleviate energy poverty and show ineffectiveness, excessive transaction costs, and discordance with the purposes of the obligation system, and briefly outline alternative options to addressing energy poverty.	Recommending improvements to EEOSs	Literature research and discussion.
(Wittmann, 2013)	2013	To propose an alternate way to graphical analysis of White Certificates' interaction with the EU emission trading mechanism.	Interaction analyses of EEOSs with market or different mechanisms	Literature research, Supply-demand analysis, and discussion.
(Schlomann et al., 2013)	2013	To discuss the potential role of innovative market-oriented mechanisms in meeting Germany's energy efficiency targets established by the country's energy framework and the new EED.	Proposing possible new EEOSs	Design analysis and bottom-up simulation models.
(Rosenow & Eyre, 2013)	2013	To examine the likelihood of the Green Deal and the UK's Energy Company Obligations delivering the scale of carbon dioxide reductions projected by the government.	Recommending improvements to EEOSs	Literature research and discussion.
(Bányai and Fodor, 2014)	2014	To discuss the EED and EEOS from an environmental viewpoint.	Discussion on existing EEOSs	Literature research and discussion.
(Düzgün & Kömürgöz, 2014)	2014	To discuss the white certificate system and its applicability in Turkey.	Proposing possible new EEOSs	Literature research and discussion.
(Harmsen et al., 2014)	2014	To assess the feasibility of imposing an EEO in India and to explore design proposals for short and long periods.	Proposing possible new EEOSs	Literature research and stakeholder consultation.
(Wirl, 2015)	2015	To bring focus on the challenges that result from consumer private information.	Recommending improvements to EEOSs	Linear programming.

Table A.1 (continued) : Literature Survey of EEOS Studies.

Studies	**Publication Year**	**Purpose**	**Study Group**	**Methodology**
(Rohde et al., 2015)	2015	To assess EEOs' performance in drawing funds from sources different from the obligated parties, such as private investors and other governmental institutions.	Discussion on existing EEOSs	Literature research and discussion.
(Friedrich and Afshari, 2015)	2015	To assess the EEOs' and tradable white certificates' applicability in the Emirate of Abu Dhabi.	Proposing possible new EEOSs	Basic energy-saving calculations.
(Rosenow et al., 2016b)	2016	To examine how the Member States have applied Article 7 and to outline the implications.	Discussion on existing EEOSs	Literature research and discussion.
(Afshari and Friedrich, 2016)	2016	To assess the feasibility of EEOs and tradable white certificate schemes for the Emirate of Abu Dhabi.	Proposing possible new EEOSs	Basic energy-saving calculations and economic analysis.
(Rosenow et al., 2016a)	2016	To examine the existing policy mix in 14 European Union nations for building efficiency.	Discussion on existing EEOSs	Expert survey.
(Rosenow and Bayer, 2017)	2017	To conduct comparative costs and benefits analysis of EEOs in various nations in Europe.	Discussion on existing EEOSs	Cost-benefit analysis.
(Stede, 2017)	2017	To research and evaluate the features of the Italian white certificate scheme that help in the elimination of numerous obstacles to industrial energy efficiency.	Recommending improvements to EEOSs	Expert survey.
(Moser, 2017)	2017	To question the optimistic results of existing EEOS and investigate the exaggeration of savings.	Discussion on existing EEOSs	Literature research and expert interviews.
(Xylia et al., 2017)	2017	To examine the impact of implementing a Swedish EEOS and what it means for Sweden's energy-intensive businesses.	Proposing possible new EEOSs	Cost-benefit analysis.
(Miu et al., 2018)	2018	To evaluate other strategies proposed to replace the UK's local retrofit program ECO.	Interaction analyses of EEOSs with market or different mechanisms	Stakeholder analysis and economic analysis.
(Amundsen and Bye, 2018)	2018	To investigate the compatibility of green, black, and white certificate mechanisms in the market.	Interaction analyses of EEOSs with market or different mechanisms	The equilibrium solution.
(Locmelis et al., 2019)	2019	To conduct a statistical analysis of the energy expenditure intensity of Latvian manufacturing industries in comparison to other Baltic Sea nations.	Recommending improvements to EEOSs	Descriptive statistics.
(Rosenow et al., 2019)	2019	To analyse the most recent global data for market-based energy efficiency instruments which are EEO and auctions.	Discussion on existing EEOSs	Literature research and discussion.
(Franzò et al., 2019)	2019	To provide a cost and benefit evaluation framework and an economic efficiency analysis of the White Certificates system in Italy.	Recommending improvements to EEOSs	Cost-benefit evaluation framework.
(Fawcett et al., 2019)	2019	To investigate 15 EEOSs in the EU to evaluate EEOSs' role in present and future EU and national policies.	Discussion on existing EEOSs	Literature research and discussion.

Table A.1 (continued) : Literature Survey of EEOS Studies.

Studies	Publication Year	Purpose	Study Group	Methodology
(Rosenow et al., 2020)	2020	To compare the two phases of the Polish EEO based on the 4620 projects delivered.	Recommending improvements to EEOSs	Standard statistical tools.
(Ahmadi et al., 2020)	2020	To create an ESCO risk assessment model that allows market regulators to determine the optimal time for ESCOs to sell their certificates to minimize risk and maximize economic gain.	Recommending improvements to EEOSs	The net present value function and the Monte Carlo method.
(Arsenopoulos et al., 2020)	2020	To provide decision-making tools to assist utilities and energy providers in efficiently identifying energy-poor homes, selecting the most relevant schemes to include in their EEO, developing Energy Poverty Action Plans, and monitoring and evaluating their effectiveness and impact.	Recommending improvements to EEOSs	Decision support tools.
(Giraudet et al., 2020)	2020	To illustrate how energy market competition affects compliance tactics in a liberal market in which obliged parties to comply through subsidized energy efficiency investments made by energy end-users.	Recommending improvements to EEOSs	Hotelling framework.
(Caragliu, 2021)	2021	To present reliable predictions of the implications of the white certificate on a group of Italian glass and paper industries. To distinguish between the direct impact of white certificates on company performance and the indirect mechanisms that cause these consequences.	Recommending improvements to EEOSs	A-spatial proximities.
(Blumberga et al., 2021)	2021	Ex-post policy evaluation of Latvian EEOS, including an assessment of its ability to deliver significant savings in the first phase of the new EEOS.	Recommending improvements to EEOSs	Theory-based policy analysis and the system-dynamic model.
(Quirion, 2021)	2021	To discuss the disappointing situation of tradable instruments (emission trading, energy efficiency certificates, and renewable energy quotas) and find the reasons for this failure.	Interaction analyses of EEOSs with market or different mechanisms	Literature research and discussion.
(Argun et al., 2021)	2021	To contribute adoption of EEOS in Turkey by modelling a system for the 21 local electricity distributors in Turkey.	Proposing possible new EEOSs	Mixed-integer linear programming.
(Cin et al., 2021)	2021	To propose the basic structure of possible Turkish EEOS based on experts' opinions and to make recommendations for policymakers.	Proposing possible new EEOSs	Expert survey and Bayesian Belief Networks.
(Morganti and Garofalo, 2022)	2021	To demonstrate the connections between market forces and regulatory measures in the white certificate scheme of Italy.	Interaction analyses of EEOSs with market or different mechanisms	Standard statistical tools.

Table A.1 (continued) : Literature Survey of EEOS Studies.

Studies	Publication Year	Purpose	Study Group	Methodology
(Ünal et al., 2022)	2022	To calculate the estimated savings for possible Turkish EEOS that electricity distribution companies are obligated to.	Proposing possible new EEOSs	Mixed-integer linear programming.
(Di Foggia et al., 2022)	2022	To give an insight into the role of the white certificate scheme in energy transition, with an emphasis on the Italian case.	Discussion on existing EEOSs	Literature research and discussion.
(Chlond et al., 2023)	2023	To compare the effectiveness of the four kinds of support programs that exist in France.	Interaction analyses of EEOSs with market or different mechanisms	Basic statistical calculations and double-robust inverse probability weighting estimator.

APPENDİX B : Post-hoc Analysis Results

Table B.1 : Post-hoc Analysis Results of Energy Poverty Definitions vs Income Quintiles.

Energy Poverty Definition	Value	Income Quintiles				
		Q1	Q2	Q3	Q4	Q5
10%	Residuals	-3.04	17.11	5.42	-6.11	-13.38
	p values	0.048	0.000	0.000	0.000	0.000
2x Median Share	Residuals	0.19	8.85	2.92	-3.01	-8.95
	p values	1.000	0.000	0.069	0.052	0.000
LIHC	Residuals	54.09	-8.89	-15.07	-15.07	-15.07
	p values	0.000	0.000	0.000	0.000	0.000
No Energy Poverty	Residuals	-32.48	-10.97	4.30	15.52	23.64
	p values	0.000	0.000	0.000	0.000	0.000

Table B.2 : Post-hoc Analysis Results of Energy Poverty Definitions vs Fuel Class Analysis.

Energy Poverty Definition	Value	Fuel Class	
		Conventional	Modern
10%	Residuals	10.48	-10.48
	p values	0.000	0.000
2x Median Share	Residuals	1.37	-1.37
	p values	1.000	1.000
LIHC	Residuals	11.93	-11.93
	p values	0.000	0.000
No Energy Poverty	Residuals	-15.88	15.88
	p values	0.000	0.000

Table B.3 : Post-hoc Analysis Results of Energy Poverty Definitions vs Energy Bill per Square Meter.

Energy Poverty Definition	Value	Energy Bill per Square Meter				
		Lowest	Low	Medium	High	Highest
10%	Residuals	-15.21	-13.23	-11.33	-5.55	45.31
	p values	0.000	0.000	0.000	0.000	0.000
2x Median Share	Residuals	-9.19	-6.69	-2.54	6.37	12.06
	p values	0.000	0.000	0.220	0.000	0.000
LIHC	Residuals	-14.89	-12.92	-0.40	12.95	15.26
	p values	0.000	0.000	1.000	0.000	0.000
No Energy Poverty	Residuals	24.97	21.07	9.69	-7.33	-48.39
	p values	0.000	0.000	0.000	0.000	0.000

Table B.4 : Post-hoc Analysis Results of Energy Poverty Definitions vs Dwelling Age.

Energy Poverty Definition	**Value**	**Dwelling Age**				
		0-10	**10-20**	**20-30**	**30-40**	**40+**
10%	Residuals	-1.71	-2.44	0.15	0.80	3.29
	p values	1.000	0.290	1.000	1.000	0.020
2x Median Share	Residuals	-1.34	-0.15	0.37	0.13	0.95
	p values	1.000	1.000	1.000	1.000	1.000
LIHC	Residuals	-3.19	-4.43	-0.25	0.81	7.18
	p values	0.028	0.000	1.000	1.000	0.000
No Energy Poverty	Residuals	3.93	4.68	-0.12	-1.15	-7.44
	p values	0.002	0.000	1.000	1.000	0.000

APPENDİX C : Regional Distribution of Inefficiency Categories and Detailed Eligibility Index Range Distribution

Table C.1 : SILC dataset NUTS2 codes and Provinces.

NUTS2 Code	Provinces	NUTS2 Code	Provinces
TR10	İstanbul	TR71	Kırıkkale, Aksaray, Niğde, Nevşehir, Kırsehir
TR21	Tekirdag, Edirne, Kırklareli	TR72	Kayseri, Sivas, Yozgat
TR22	Balıkesir, Çanakkale	TR81	Zonguldak, Karabük, Bartın
TR31	İzmir	TR82	Kastamonu, Çankırı, Sinop
TR32	Aydın, Denizli, Muğla	TR83	Samsun, Tokat, Çorum, Amasya
TR33	Manisa, Afyon, Kütahya, Uşak	TR90	Trabzon, Ordu, Giresun, Rize, Artvin, Gümüşhane
TR41	Bursa, Eskişehir, Bilecik	TRA1	Erzurum, Erzincan, Bayburt
TR42	Kocaeli, Sakarya, Düzce, Bolu, Yalova	TRA2	Ağrı, Kars, Iğdır, Ardahan
TR51	Ankara	TRB1	Malatya, Elazığ, Bingöl, Tunceli
TR52	Konya, Karaman	TRB2	Van, Mus, Bitlis, Hakkari
TR61	Antalya, Isparta, Burdur	TRC1	Gaziantep, Adıyaman, Kilis
TR62	Adana, Mersin	TRC2	Şanlıurfa, Diyarbakır
TR63	Hatay, Kahramanmaraş, Osmaniye	TRC3	Mardin, Batman, Şırnak, Siirt

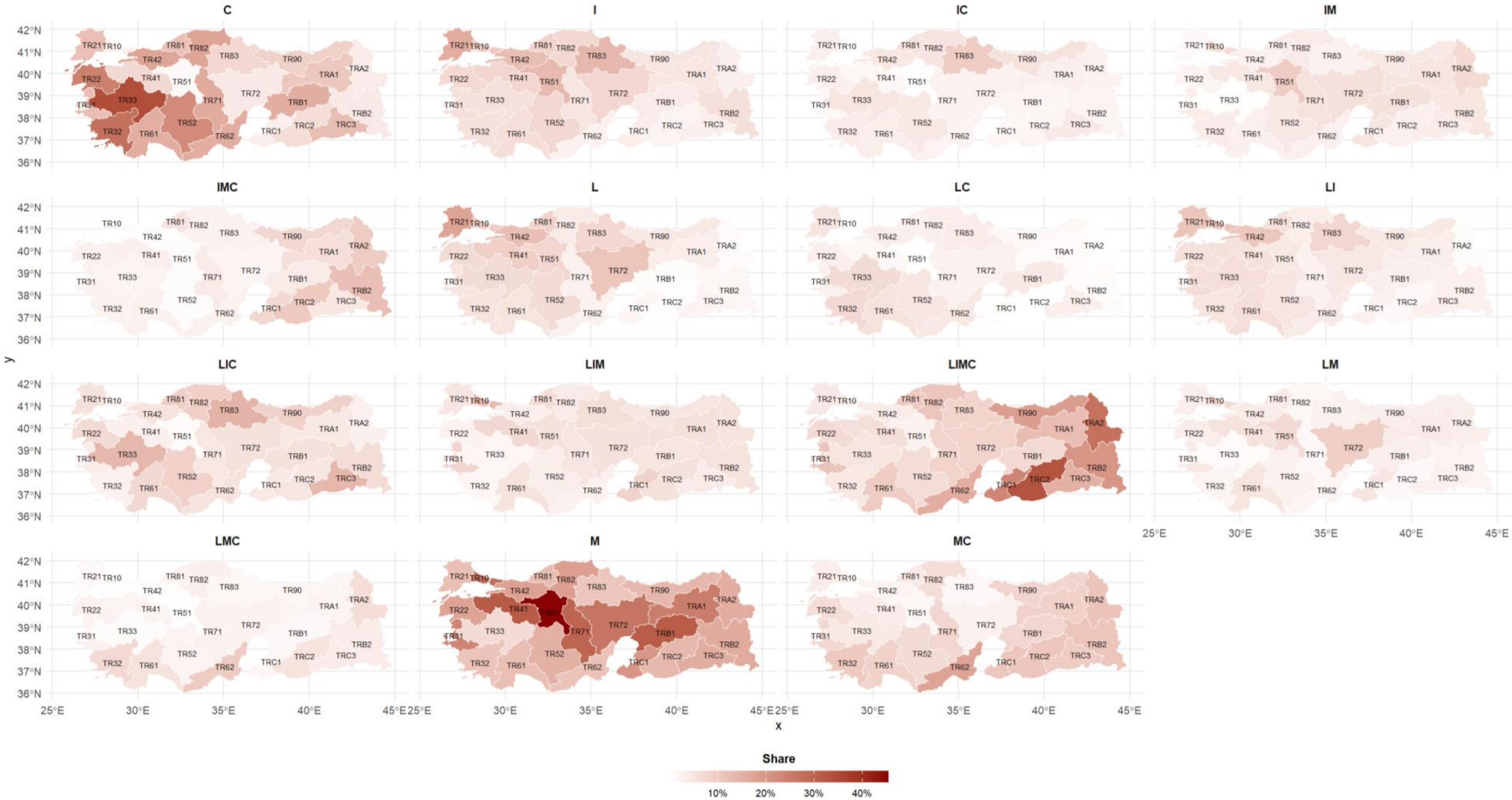

Figure C.1 : Regional Distribution and Share of Inefficiency Categories.

Table C.2 : Priority Energy-Poor Households: Eligibility Index Range by Inefficiency Category and Region.

	C	I	IC	IM	IMC	L	LC	LI	LIC	LIM	LIMC	LM	LMC	M	MC
TR10	0.58–0.59	0.47–0.71	0.53–0.53	0.47–0.86	0.48–0.78	0.48–0.86	0.66–0.66	0.47–0.86	0.52–0.76	0.46–1	0.56–1	0.52–1	0.48–0.72	0.42–1	0.52–0.72
TR21	0.58–0.71	0.58–0.81				0.66–0.71	0.58–0.58	0.56–0.86	0.67–0.91	0.57–1	0.72–1		0.76–0.86	0.48–0.72	0.66–1
TR22	0.59–0.78	0.68–0.86	0.78–0.78	1–1	0.59–0.87	0.59–0.63	0.57–0.57		0.59–0.78		0.68–1	0.58–0.68	0.59–0.66	0.47–0.86	0.58–0.76
TR31	0.59–0.91	0.58–0.58		0.63–1	0.66–1			0.59–0.81	0.87–0.87	0.57–1	0.72–1	0.58–0.86	0.81–1	0.48–1	0.57–1
TR32	0.66–0.66	0.68–0.68	0.72–0.72	0.56–1	0.58–0.71	0.58–0.72	0.58–0.58	0.58–0.76	0.66–0.72	0.86–0.86	0.71–1	0.56–0.72	0.62–0.68	0.47–1	0.56–0.87
TR33	0.57–0.78	0.58–1	0.59–0.67		0.72–1		0.58–0.78	0.57–0.59	0.59–0.66	0.66–0.87	0.76–0.87		0.57–0.57	0.48–0.87	0.57–0.81
TR41	0.56–0.58	0.58–0.58		0.67–1	0.67–1	0.59–0.71		0.56–0.59		0.63–1	0.72–1	0.56–0.87	0.67–0.81	0.47–1	0.58–1
TR42	0.56–0.75	0.67–0.68		0.86–0.86		0.67–0.67	0.58–0.59	0.66–0.86	0.56–0.66	0.63–0.81	0.81–0.86	0.66–0.81	1–1	0.48–1	0.66–0.66
TR51		0.71–0.81		0.57–0.87	0.57–0.57	0.56–0.59		0.57–0.57		0.62–1	0.72–1	0.63–1		0.48–1	0.57–1
TR52	0.57–0.57		0.66–0.91	0.58–0.63	0.87–0.87	0.62–0.62	0.57–0.66		0.66–0.66	0.57–0.57	0.76–0.87		0.91–0.91	0.48–0.89	0.57–0.71
TR61	0.58–0.78	0.56–0.58	0.56–0.76	0.58–0.87	0.58–1	0.58–0.63	0.62–0.68	0.87–0.87	0.62–0.81	0.57–0.87	0.68–1	0.57–0.91	0.57–0.87	0.48–1	0.57–1
TR62	0.68–0.91	0.62–0.62	0.56–0.66	0.62–0.86	0.66–0.78		0.57–0.87	0.57–0.67	0.56–1	0.56–0.87	0.68–1	0.66–0.81	0.56–1	0.48–0.81	0.58–1
TR71	0.87–0.87			0.68–0.68	0.66–0.87				0.66–0.81	0.66–1	0.68–1	0.66–0.66	0.66–0.66	0.48–1	0.57–0.57
TR72		0.57–0.57		0.56–0.81	0.68–0.72	0.57–0.87			0.58–0.78	0.66–1	0.71–1	0.58–0.71	0.56–0.78	0.47–1	0.58–0.89
TR81	0.56–0.71	0.57–0.71	0.71–0.71	0.56–0.75	0.56–1	0.56–0.71		0.58–1	0.57–0.81	0.57–0.86	0.68–1	0.63–0.87	0.68–1	0.46–0.68	0.58–0.71
TR82	0.56–0.62	0.56–0.58		0.57–1			0.58–0.58	0.56–0.56	0.56–0.67	0.59–1	0.68–1		0.81–0.81	0.48–1	0.57–0.81
TR83	0.78–0.78	0.58–0.68	0.58–0.58	0.56–0.87	1–1	0.58–0.68	0.57–0.57	0.87–0.87	0.57–1	0.57–1	0.72–1	0.58–0.67	0.68–1	0.48–0.91	0.66–0.68
TR90	0.59–0.66	0.81–0.81		0.66–0.91	0.57–0.87	0.57–0.71	0.71–0.71		0.59–0.86	0.56–0.87	0.68–1	0.66–1	0.66–0.86	0.48–1	0.58–1
TRA1	0.76–0.76	0.58–0.59	0.66–0.66	0.57–0.68	0.66–1			0.75–0.75	0.57–1	0.57–1	0.68–1	0.67–1	0.66–0.76	0.46–1	0.57–1
TRA2				0.56–0.87	0.57–1					0.58–1	0.68–1	0.57–0.76	0.68–1	0.46–0.81	0.57–1
TRB1		0.62–0.62		0.67–0.67	0.58–0.72				0.71–0.71	0.59–0.59	0.68–0.68	0.58–0.72	0.57–0.57	0.48–0.91	0.68–0.68
TRB2	0.58–0.76	0.66–0.71	0.58–0.58	0.59–0.76	0.57–1	0.57–0.91	0.57–0.57	0.75–0.87	0.66–0.89	0.58–0.91	0.68–1	0.57–0.57	0.66–1	0.46–1	0.57–0.91
TRC1				0.66–0.87	0.66–0.66	0.66–0.66		0.57–0.57		0.66–1	0.71–1	0.66–0.66	0.86–0.86	0.48–1	0.62–0.91
TRC2		0.75–0.75		0.72–1	0.72–1				0.8–0.8	0.72–1	0.81–1	0.72–0.72	1–1	0.56–1	0.71–1
TRC3	0.57–0.76		0.58–0.58	0.58–0.67	0.57–1				0.57–0.81	0.67–1	0.68–1	0.57–1	0.57–0.68	0.48–1	0.57–1

Table C.3 : At-Risk Households: Eligibility Index Range by Inefficiency Category and Region.

	C	**I**	**IC**	**IM**	**IMC**	**L**	**LC**	**LI**	**LIC**	**LIM**	**LIMC**	**LM**	**LMC**	**MC**	**M**
TR10	0.44–0.44	0.38–0.44	0.44–0.44	0.38–0.44	0.38–0.44	0.42–0.44	0.44–0.44	0.42–0.44	0.38–0.44	0.38–0.44	0.29–0.53	0.38–0.44	0.38–0.44	0.38–0.42	
TR21	0.32–0.44	0.28–0.54	0.43–0.54			0.28–0.44	0.43–0.48	0.28–0.54	0.34–0.44	0.29–0.54	0.33–0.66	0.33–0.48	0.44–0.44	0.28–0.38	0.38–0.44
TR22	0.29–0.53	0.34–0.44	0.44–0.44		0.29–0.53	0.34–0.37	0.44–0.48	0.28–0.53	0.28–0.53	0.44–0.54	0.24–0.66	0.33–0.54	0.38–0.53	0.28–0.53	0.38–0.44
TR31	0.29–0.53	0.33–0.44		0.28–0.54	0.34–0.53	0.33–0.47	0.34–0.44	0.29–0.53	0.33–0.54	0.28–0.53	0.24–0.66	0.28–0.54	0.34–0.53	0.29–0.53	0.38–0.44
TR32	0.28–0.53	0.33–0.54	0.34–0.48	0.34–0.54	0.34–0.53	0.33–0.34	0.28–0.53	0.34–0.54	0.33–0.48	0.29–0.53	0.2–0.66	0.34–0.34	0.34–0.53	0.28–0.53	
TR33	0.28–0.54	0.29–0.48	0.29–0.44		0.28–0.53	0.34–0.48	0.38–0.52	0.34–0.53	0.28–0.53	0.38–0.52	0.24–0.66	0.34–0.48	0.53–0.53	0.33–0.53	0.38–0.44
TR41	0.34–0.48	0.28–0.54	0.34–0.44	0.29–0.53	0.29–0.54	0.34–0.48	0.28–0.48	0.28–0.44	0.34–0.47	0.29–0.54	0.2–0.67	0.29–0.54	0.43–0.54	0.29–0.53	0.38–0.44
TR42	0.28–0.53	0.28–0.54	0.44–0.53	0.34–0.34	0.34–0.34	0.29–0.48	0.28–0.54	0.29–0.53	0.29–0.44	0.29–0.53	0.2–0.67	0.29–0.48	0.34–0.44	0.29–0.53	0.38–0.44
TR51		0.29–0.53		0.29–0.54	0.29–0.48	0.28–0.54		0.34–0.53		0.29–0.54	0.28–0.66	0.28–0.54	0.38–0.53	0.34–0.44	0.38–0.44
TR52	0.34–0.53	0.34–0.38	0.32–0.38	0.29–0.44		0.33–0.44	0.34–0.48	0.28–0.38	0.29–0.53	0.33–0.48	0.2–0.66	0.28–0.54	0.29–0.44	0.29–0.53	0.38–0.44
TR61	0.28–0.47	0.34–0.44	0.33–0.44	0.29–0.54	0.29–0.53	0.28–0.48	0.33–0.54	0.34–0.54	0.28–0.48	0.28–0.54	0.2–0.66	0.29–0.53	0.38–0.54	0.28–0.54	0.43–0.44
TR62	0.28–0.53	0.38–0.53	0.33–0.48	0.33–0.55	0.28–0.53	0.34–0.53	0.28–0.48	0.28–0.43	0.28–0.55	0.28–0.54	0.18–0.67	0.44–0.54	0.28–0.53	0.28–0.54	0.38–0.44
TR71	0.29–0.53	0.33–0.48	0.29–0.53	0.33–0.53	0.33–0.55	0.44–0.48	0.48–0.48	0.28–0.52	0.28–0.53	0.28–0.48	0.2–0.66	0.28–0.34	0.33–0.53	0.28–0.53	0.42–0.44
TR72	0.53–0.53	0.29–0.48	0.33–0.48	0.29–0.52	0.28–0.38	0.28–0.53	0.44–0.53	0.43–0.44	0.28–0.44	0.29–0.48	0.18–0.66	0.28–0.53	0.34–0.53	0.33–0.53	0.38–0.44
TR81	0.28–0.47	0.29–0.53	0.34–0.44	0.34–0.44	0.29–0.44	0.28–0.52	0.34–0.42	0.28–0.53	0.28–0.54	0.34–0.54	0.2–0.67	0.34–0.53	0.33–0.38	0.28–0.47	0.38–0.44
TR82	0.28–0.48	0.28–0.48	0.34–0.48	0.34–0.54	0.28–0.54	0.47–0.47		0.43–0.43	0.28–0.53	0.28–0.53	0.22–0.67	0.28–0.53	0.28–0.53	0.33–0.55	0.38–0.44
TR83	0.28–0.48	0.34–0.43	0.28–0.54	0.28–0.48	0.29–0.54	0.34–0.54	0.34–0.44	0.28–0.54	0.33–0.54	0.33–0.53	0.2–0.67	0.28–0.54	0.32–0.53	0.38–0.38	0.38–0.44
TR90	0.29–0.53	0.29–0.44	0.29–0.54	0.29–0.54	0.33–0.54	0.34–0.48	0.29–0.44	0.28–0.42	0.29–0.53	0.29–0.54	0.18–0.67	0.33–0.54	0.34–0.55	0.29–0.54	0.38–0.44
TRA1	0.33–0.48	0.28–0.34	0.28–0.37	0.34–0.54	0.28–0.53	0.34–0.38	0.44–0.44	0.34–0.48	0.29–0.44	0.33–0.53	0.2–0.66	0.28–0.55	0.34–0.54	0.28–0.54	0.38–0.44
TRA2	0.28–0.34	0.28–0.46	0.42–0.46	0.29–0.55	0.28–0.55	0.34–0.52		0.48–0.48	0.28–0.53	0.34–0.55	0.18–0.67	0.34–0.48	0.33–0.53	0.28–0.55	0.41–0.43
TRB1	0.33–0.37		0.34–0.44	0.28–0.48	0.29–0.53	0.34–0.34	0.44–0.44	0.37–0.37	0.38–0.38	0.29–0.54	0.24–0.57	0.34–0.34	0.38–0.44	0.34–0.53	0.38–0.44
TRB2	0.28–0.48	0.28–0.52	0.28–0.53	0.29–0.53	0.28–0.55		0.34–0.53	0.33–0.53	0.28–0.55	0.28–0.54	0.2–0.66	0.34–0.55	0.29–0.55	0.28–0.53	0.38–0.44
TRC1	0.52–0.52	0.28–0.47	0.29–0.52	0.28–0.53	0.29–0.53	0.43–0.52		0.34–0.34	0.33–0.34	0.28–0.48	0.18–0.67	0.28–0.48	0.29–0.46	0.28–0.55	0.38–0.44
TRC2	0.2–0.56	0.22–0.44	0.2–0.58	0.24–0.66	0.24–0.66	0.42–0.42	0.25–0.25	0.22–0.34	0.2–0.57	0.18–0.67	0.09–0.76	0.24–0.57	0.25–0.66	0.18–0.66	0.28–0.55
TRC3	0.28–0.53	0.34–0.44	0.29–0.53	0.28–0.55	0.28–0.53	0.28–0.52	0.38–0.53	0.33–0.48	0.28–0.53	0.29–0.54	0.2–0.67	0.38–0.53	0.28–0.53	0.29–0.55	0.42–0.44

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