

TÜRKİYE EKONOMİSİNDE GÜNCEL DİNAMİKLER:

MAKROEKONOMİ, ENERJİ,
İKLİM VE TÜKETİM

EDİTÖR:

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BİDGE Yayınları

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ÖNSÖZ

Ekonomik yapıların giderek daha karmaşık hâle geldiği günümüzde, küresel ve ulusal ölçekte yaşanan gelişmeler ekonomik karar alma süreçlerini, kamu politikalarını, finansal piyasaları ve toplumsal refahı çok boyutlu biçimde etkilemektedir. Makroekonomik dalgalanmalar, enerji piyasalarındaki dönüşümler, iklim değişikliğinin ekonomik yansımaları, değişen tüketim alışkanlıkları ve finansal sistemde yaşanan gelişmeler, ekonomi biliminin farklı alt disiplinlerinin birlikte değerlendirilmesini zorunlu kılmaktadır. Bu nedenle günümüz ekonomik sorunlarının anlaşılması, yalnızca tek bir bakış açısıyla değil; disiplinler arası yaklaşımlar, güçlü teorik temeller ve gelişmiş ampirik analizlerle mümkün olabilmektedir.

Bu kitap, ekonomi literatüründe güncelliğini koruyan ve politika yapıcılar ile araştırmacılar açısından önem taşıyan konuları bilimsel bir perspektifle ele almayı amaçlamaktadır. Farklı çalışma alanlarına odaklanan araştırmaların ortak paydası, ekonomik süreçlerin dinamik yapısını ortaya koymak, değişen koşullar altında ekonomik aktörlerin davranışlarını analiz etmek ve kamu politikalarının etkinliğine ilişkin bilimsel değerlendirmeler sunmaktır. Bu yönüyle eser, ekonomik olayların birbirinden bağımsız değil; karşılıklı etkileşim içinde şekillenen çok katmanlı bir yapı oluşturduğunu ortaya koymaktadır.

Ekonomik istikrarın sürdürülebilirliği, kaynakların etkin kullanımı, enerji arz güvenliği, fiyat istikrarı, çevresel sürdürülebilirlik, finansal piyasaların işleyişi ve hanehalkı refahı gibi konular, günümüzde yalnızca ulusal ekonomilerin değil, küresel ekonomik sistemin de temel gündem maddeleri arasında yer almaktadır. Bu alanlarda yaşanan gelişmeler, ekonomik politikaların tasarlanmasından yatırım kararlarına, kamu maliyesinden bireysel tüketim davranışlarına kadar geniş bir yelpazede belirleyici rol

oynamaktadır. Dolayısıyla ekonomik deęiřkenler arasındaki iliřkilerin bilimsel yntemlerle incelenmesi, hem akademik literatrn geliřimi hem de kanıta dayalı politika retimi aısından byknm tařımaktadır.

Kitapta yer alan alıřmalar, farklı arařtırma konularını ele almakla birlikte ortak bir bilimsel anlayıřı paylařmaktadır. Bu anlayıř, ekonomik olayların neden-sonu iliřkileri erevesinde deęerlendirilmesini, gncel ekonomik problemlerin teorik yaklařımlar ve ampirik yntemlerle analiz edilmesini ve elde edilen bulguların ekonomik politika tartıřmalarına katkı saęlayacak biimde yorumlanmasını esas almaktadır. Bu kapsamda eser, ekonomi biliminin gncel tartıřmalarına ıřık tutmayı, farklı arařtırma alanları arasında kavramsal bir btnlk oluřturmayı ve gelecekte yapılacak alıřmalara bilimsel bir zemin hazırlamayı hedeflemektedir.

Akademik arařtırmaların temel amacı yalnızca mevcut ekonomik yapıyı aıklamak deęil, aynı zamanda gelecekte karřılařılması muhtemel sorunların anlařılmasına ve zmne katkı sunmaktır. Bu doęrultuda hazırlanan bu kitap, deęiřen ekonomik kořulların kamu kesimi,zel sektr, finansal piyasalar ve hanehalkları zerindeki etkilerini farklı perspektiflerden deęerlendiren alıřmalar aracılıęıyla, ekonomi literatrnezgn katkılar sunmayı amalamaktadır. Kullanılan teorik yaklařımlar ve ampirik yntemler, ekonomik iliřkilerin daha saęlıklı analiz edilmesine olanak saęlayarak hem akademik arařtırmalar hem de uygulayıcılar aısındannemli deęerlendirmeler ortaya koymaktadır.

Bu alıřmanın ortaya ıkmasında emeęi geen tm yazarlar, kendi uzmanlık alanları erevesinde literatrezgn katkılar sunmuřlardır. Gnmz dnyasında, srdrlebilirlik ancak disiplinler arası bir anlayıř ve uzun vadeli stratejik yaklařımlar ile mmkn olabilecektir. Bu kitap, sz konusu gereklilięe mtevacı bir

katkı sunmayı amaçlamaktadır. Kitabın ortaya ıkmasında katkı sunan tüm yazarlarımıza, bilimsel bir titizlikle süreci yürüten ve yayına hazırlık aşamasında emeęi geçen tüm paydaşlara teşekkür eder; iktisat literatürüne ve ilgili tüm okuyuculara faydalı olmasını dilerim.

DO. DR. FUAT LEBE
ADİYAMAN ÜNİVERSİTESİ

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BÖLÜM 1

KAMU ÖZEL İŞBİRLİĞİ PROJELERİNDE MAKROEKONOMİK DALGALANMALARIN KAMU YÜKÜMLÜLÜKLERİNE ETKİSİ

Çağlar ÖZDEMİR¹
Güray KÜÇÜKKOCAOĞLU²

GİRİŞ

Altyapı yatırımları, bir ülkenin sosyal ve ekonomik gelişimini ve bu gelişimin sürdürülebilirliğini sağlayan hizmetlerin bütünü olmakla birlikte ulaşım, iletişim, enerji ve sağlık gibi alanlardaki kolaylaştırıcı etkileriyle yaşam standardını doğrudan yükseltmektedir (Ganelli ve Tervala, 2016). Bu hizmetlerin yokluğu ise üretim süreçlerinde bozulmaları, işsizlik ve toplumsal eşitsizlikleri tetiklemektedir (Hirschman, 1958). Köprü, otoyol, okul ve hastane gibi yatırımlar ayrıca seçmen tercihlerini etkilemekte ve güçlü devlet algısını pekiştirmektedir.

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Bu hizmetler geleneksel olarak kamu bütçesiyle üretilmekteydi. Ancak 20. yüzyılın son çeyreğindeki hızlı nüfus artışı ve teknolojik gelişme maliyetleri büyük ölçüde yükseltmiş, altyapının yalnızca geleneksel yöntemle üretilmesini güçleştirmiştir. Bu yatırımlardan vazgeçmek gerçekçi olmadığından alternatif finansman arayışı rasyonel bir yaklaşım olarak benimsenmiştir. Doğrudan kamu yatırımı ile özelleştirme arasında konumlanan kamu özel işbirliği (KÖİ) projeleri de bu arayışın ürünü olarak ortaya çıkmaktadır. Modelde kamunun bürokratik kolaylaştırma yeteneği özel sektörün finansmana erişimi ve çevik üretim kapasitesiyle birleştirilmektedir ve her proje, devredilen riskler karşılığında özel sektöre tanınan imtiyazları düzenleyen özgün sözleşmelerle kurulmaktadır.

Modelin başarısı büyük ölçüde uygulama esaslarına dayanmaktadır. Şeffaf ve denetlenebilir bir piyasa ile güçlü bir hukuk sistemi ön koşul olmakla birlikte; getiri, risk ve sorumlulukların doğru dağıtıldığı ve sürecin bağımsız kurumlarca denetlendiği durumlarda model kamu yararı sağlayabilmektedir. Tasarım ve uygulamanın hatalı olduğu durumlarda ise uzun vadeli sözleşmelerin barındırdığı öngörülemez riskler kamu maliyesini olumsuz etkileyebilecektir. Nitekim talep ve kur gibi özel sektöre devredilmesi beklenen risklerin çeşitli garantilerle kamu üzerinde kalabileceğine ve uzun sözleşme süresince öngörülemeyen yükümlülükler doğabileceğine dikkat çekilmektedir (Gökten, 2019). Buna karşın model, dünyada ve Türkiye’de proje sayısı ve büyüklüğü bakımından sürekli genişlemekte; projenin sektörüne ve tutarına göre Yap-İşlet-Devret, Yap-Kirala, Yap-İşlet veya İşletme Hakkı Devri gibi biçimlerde kurgulanabilmektedir (Roehrich vd., 2014). Türkiye’de özellikle 2008 krizinin ardından ivme kazanan model ile çok sayıda proje hayata geçirilmiş; hukuksal altyapının ve denetimin yetersiz kaldığı başarısız örneklerde ise zarar gören taraf çoğunlukla kamu olmuştur.

Bu çalışmanın amacı, yaygın biçimde kullanılan KÖİ yapısını yatırımın değer analizi (value for money) yaklaşımıyla kamu ve özel sektör açısından incelemektir. Bu kapsamda varsayımsal bir şehir hastanesi projesi kurgulanmıştır. Projenin sabit ve değişken maliyetleri ile faaliyet dönemi gelir ve giderleri çeyrek dönemler halinde modellenmiş; nakit akış tablosu, gelir tablosu ve bilanço oluşturularak projenin bugünkü değeri hesaplanmıştır. Kamu yükümlülüklerinin Türk Lirası cinsinden ve enflasyona endeksli belirlendiği bu senaryoda, enflasyondaki ani değişimlerin net bugünkü değer, iç getiri oranı ve geri ödeme süresi üzerindeki etkileri analiz edilerek karar alıcılara modelin hangi koşullarda avantajlı olabileceğine ilişkin bir çerçeve sunulması hedeflenmektedir.

LİTERATÜR

Altyapı Yatırımları ve Ekonomik Etkileri

Altyapı, bir ülkenin ekonomik ve sosyal gelişimi ile sürdürülebilirliği için sunulması gereken hizmetlerin bütünüdür; hem büyüme ve istikrara temel oluşturur hem de günlük yaşamı kolaylaştırarak refaha katkı sağlar. Görece soyut bir kavram olduğundan çoğu çalışmada üretime etkisinden ya da hizmet örneklerinden hareketle tanımlanmaktadır. Hirschman (1958) altyapıyı, yokluğunda üretimin gerçekleşemeyeceği temel hizmetler anlamında “sosyal genel sermaye” olarak nitelendirmektedir. Uzlaşılan nokta, altyapının tüm ekonomik faaliyetlerin odağında yer almasıdır.

Altyapının ekonomik etkilerine ilişkin literatürde güçlü ampirik bulgular bulunmaktadır. Aschauer (1989), ABD verileriyle kamu altyapı yatırımındaki %1’lik artışın özel sektör çıktısını yaklaşık %0,24 artırdığını ve kamu sermaye stokunun toplam faktör verimliliğini yükselttiğini ortaya koymuş; Gnade vd. (2017) Güney

Afrika örneğinde altyapının büyüme ve kalkınmayı desteklediğini göstermiştir. Esfahani ve Ramírez (2003) altyapının gayrisafi yurt içi hasılaya katkısının maliyetini aştığını, Agénor (2010) ise yetersiz altyapının gelişmenin önündeki başlıca engellerden olduğunu vurgulamaktadır. Dünya Bankası da altyapı stokunun ikiye katlanmasının hasılayı kayda değer ölçüde artırdığını göstermektedir (World Bank, 2011).

Altyapı gelişmeyi çeşitli kanallardan etkiler. Elektrik altyapısındaki iyileşme, kesinti kaynaklı üretim kayıplarını önleyerek rekabet gücünü artırır ve yatırım çeker (Calderón ve Servén, 2010); temiz su ve sanitasyon hizmetleri ise çalışan sağlığını koruyarak üretkenliği yükseltir, çocuk ölümlerini azaltır ve kat kat sağlık harcaması tasarrufu sağlar (WHO, 2014). Bir hizmetin “temel” sayılması ülkeye ve döneme göre değiştiğinden altyapının etkileri büyük ölçüde bağlamsaldır.

Etkin sunulduğunda altyapı, ticari faaliyetleri hızlandıran ve doğrudan yabancı yatırımı çeken temel unsurlardandır. Palei (2015), yol, liman, su-kanalizasyon ve telekomünikasyon gibi yüksek kamusal taşıyan yatırımların aynı zamanda en yüksek sermaye gereksinimini doğurduğunu ortaya koymaktadır. Bu yatırımların maliyeti son kırk yılda teknolojik gelişme ve nüfus artışıyla yükselmiştir; 1980’de yaklaşık 4,5 milyar olan küresel nüfus 2022’de 8 milyar sınırına dayanmış (Worldometer, 2024) ve 2050’de nüfusun yaklaşık %68’inin kentlerde yaşayacağı öngörülmüştür (Our World in Data, 2024).

Kamu Özel İşbirliği Modeli

Artan nüfusla altyapı ihtiyacı ve maliyeti hızla yükselmiş, hizmetlerin doğrudan kamu bütçesiyle karşılanması güçleşmiştir. Uzun ömürlü ve yüksek sermayeli olan bu yatırımların maliyeti yalnızca ilk inşayı değil yaşam boyu bakım, onarım ve yenilemeyi

de kapsadığından ancak öz kaynak ya da uzun vadeli yabancı kaynakla finanse edilebilir (Gökten, 2019). Öz kaynaktan karşılayabilecek ülke sayısı sınırlı, vergiyle fon yaratmanın da bir sınırı olduğundan; azalan kaynaklar ve yükselen maliyetler kamuyu yatırımdan vazgeçmeye değil alternatif finansman arayışına yöneltmektedir (Parvu ve Voicu-Olteanu, 2009).

Bu çerçevede en etkin yol uzun vadeli yabancı kaynakla finansmandır; bu yapı bilanço içi ya da bilanço dışı kurgulanabilir. Bilanço içinde borçlar finansal tablolara yansır ve şeffaflık sağlarsa da görünen borçlar yeni borçlanmaya tavan işlevi görebilir; bilanço dışında ise yükümlülükler gizlenebildiğinden yüksek kredibilite sağlanabilir, ancak manipülasyon imkanı barındırdığından etkili denetim kritik hale gelir. En yaygın biçim olan yap-işlet-devrette özel sektör proje özelinde bir özel amaçlı kuruluş kurar; finansman dahil yatırım bu kuruluşa aktarılır, yükümlülükler kurucuların değil onun üzerinde doğar ve kamu borçlanma tavanlarından etkilenmez. Spackman'a (2002) göre etkinlik gerekçeleri öne sürülse de asıl amaç çoğu kez makroekonomik kısıtlamaları aşmaktır; belirleyici olan, sürecin şeffaflık ve hesap verilebilirlikle yürütülerek kamu zararının önlenmesidir.

KÖİ'nin standart bir tanımı yoktur; model, kamu ile özel sektör arasında risk ve sorumlulukların paylaşıldığı proje üretim yapılarının tümünü ifade eder. Grimsey ve Lewis (2005) genel geçer bir tanımın mümkün olmadığını, yapının ülkeye, sektöre ve projeye göre değiştiğini belirtmektedir. Saha çalışması yapan kuruluşlar ise modeli, özel sektörün önemli ölçüde risk ve yönetim sorumluluğu taşıdığı ve ücretlendirmenin performansa bağlandığı uzun vadeli sözleşmeler olarak tanımlamaktadır (OECD, 2008; World Bank vd., 2017). Ortak nokta, taraflar arasında işbirliği ile risk ve sorumluluk paylaşımının esas alınmasıdır.

Yeni dönemin özelleştirmesi sayılsa da KÖİ ondan ayrışır: imtiyaz özel sektöre aktarılsa da kamu hem kolaylaştırıcı hem de hizmetin birinci derece alıcısı olduğundan tam bir devir söz konusu değildir. Özelleştirmede devletin varlıkla ilişkisi tümüyle kesilirken KÖİ’de yetki, sorumluluk ve riskler paylaşılır ve kamunun hesap verilebilirlik sorumluluğu sürer (Flinders, 2005). Modele olumlu yaklaşımın temelinde kamu sermayesinin bu ölçekteki projelere yetersizliği ile etkinlik artışıyla daha kaliteli hizmet beklentisi yer alır (Hodge ve Greve, 2007); süreci hızlandıran bir diğer etken 1980’lerde yükselen liberalizasyon politikalarıdır (Çelen ve Bali, 2005).

Bilançoya yansıyan ve borç eşiklerine ulaşan borçlanma kredibilitiyi olumsuz etkileyebilir. KÖİ ise yatırım dönemi yükümlülüklerini bilanço dışında tutup yalnızca operasyonel ödemeleri bütçeye yansıttığından kamuyu borçlanma tavanlarından koruyabilir ve büyük yatırımların bedeli geleceğe yayılabilir; ancak bu özellik, modelin bilanço dışı borçlanma için tercih edilebileceği endişesini de besler. Dolayısıyla başarı, yönetim ve kontrol süreçlerinin bağımsız ve etkin işlemesine bağlıdır; UNECE (2008) bu çerçevede katılımcılık, şeffaflık, hesap verilebilirlik, adalet ve etkinlik gibi yönetim ilkeleri belirlemiştir. Modelin en karakteristik unsuru, yalnızca ilgili proje için kurulan özel amaçlı kuruluştur; bu sayede kredi borçlusu doğrudan bu şirket olur, kurucu firmaların bilançoları korunur ve kamu yalnızca koyduğu sermaye ölçüsünde sorumlu olur (İnan & Aras Hukuk Bürosu, 2017). Pinto’ya (2017) göre bu yapının temel özellikleri borçlunun yalnızca özel amaçlı kuruluş olması, finansörlerin rücu hakkının sınırlı olması ve risklerin onu en iyi yönetecek tarafa tahsisidir.

Model yalnızca etkinlikle değil, avantaj ve dezavantajlarıyla birlikte değerlendirilmelidir. Avantaj tarafında özel sektörün yenilikçiliği, performansla bağlı ödemelerle kaliteli iş motivasyonu

ve bürokratik hantallıktan kaçınma yer alır (Akintoye ve Beck, 2009); 20-30 yıllık projelerde yüksek ilk yatırım özel sektörcce karşılanır ve kamunun ödemeleri uzun vadeye yayılır (PPIAF, 2009). Buna karşılık model, yalnızca finansman yetersizliğini aşmak için yaratıcı muhasebe aracı olarak kullanıldığında maliyetleri ortadan kaldırmaz, bilanço dışına taşır ve ödeme takvimi geldiğinde kamu maliyesinde yıkıcı etkiler doğurabilir; nitekim 2023'te küresel KÖİ yatırım hacmi 85 milyar doları aşmıştır (World Bank, 2024). Türkiye'de model 2010 sonrasında köprü, otoyol, havalimanı ve hastane yatırımlarında yaygınlaşmış (Emek, 2009), 2024 itibarıyla toplam yatırım 100 milyar doları aşmıştır (T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 2024). Sözleşmedeki unsurlara göre Yap-İşlet-Devret, Yap-Kirala-Devret ve İşletme Hakkı Devri gibi adlar alan model risk paylaşımına göre bir bareme oturtulabilir (Zimmermann ve Eber, 2014; Roehrich vd., 2014).

Kamu Özel İşbirliği Projelerinde Risk Yönetimi

KÖİ özünde risk ve getirinin kamu ile özel sektör arasında paylaşımını düzenleyen bir finansman modelidir; çok paydaşlı ve uzun vadeli yapısı nedeniyle çok sayıda risk barındırır. Risk, belirsiz durumların yol açabileceği olumsuz sonuç olarak tanımlanmakta; Pohle ve Girmscheid (2007) ile Wu vd. (2018) riski olasılık ile etkinin çarpımı olarak ifade etmektedir. Ancak riskin salt matematiksel bir modele indirgenmesi sosyal bir olgu için kısıtlayıcı olduğundan ve aynı belirsizlik kimi aktörlerce tehdit kimilerince fırsat görülebildiğinden, risklerin hem sayısal verilerle hem uzman değerlendirmeleriyle bir risk matrisinde ele alınması en sağlıklı yaklaşımdır.

Riskler genellikle dışsal ve içsel olarak ikiye ayrılır; Gatti (2008) ise tamamlama öncesi ve sonrası ayrımı yaparak faiz, kur, enflasyon, politik, yasal ve kredi risklerini safha risklerinin üzerinde bir şemsiye olarak tanımlar. Risklerin belirlenmesinde önceki proje

analizleri, kontrol listeleri ve uzman teknikleri kullanılabilir; ancak bu tekniklerin risklerin birbiri üzerindeki etkisini göz ardı eden yanıltıcı listeler üretebileceği unutulmamalıdır (Iyer ve Sagheer, 2010).

Risk paylaşımında özel sektörün imtiyazlarına paralel olarak riskleri de üstlenmesi beklenir; ancak kamu da risklerden tümüyle kaçınmadığından adil bir paylaşım gerekir. Özel sektör üstlendiği her risk için bedel talep ettiğinden, kamunun kolayca yönetebileceği riskleri devretmesi gereksiz maliyet doğurabilir. Literatürdeki ortak görüş, her riskin onu en iyi yönetebilecek tarafça üstlenilmesidir; ölçüt, riski en iyi kimin önleyebileceği ve önlenemediğinde sonuçlarını kimin yönetebileceğidir (OECD, 2008; Ng ve Loosemore, 2007). Standart bir risk listesi olmadığından riskler projenin yapısı ve coğrafyayla değerlendirilmelidir; Maslova ve Sokolov (2017) en çok atıf alan risklerin politik, finansal, hukuki, operasyonel ve kur riskleri olduğunu, Ameyaw ve Chan (2015) ise riskleri içsel-dışsal sınıflandırıp kritikliğe göre sıraladığını ortaya koymaktadır.

Carbonara vd. (2015) projeyi dört aşamada ele alır: geliştirmede tasarım ve finansal kapanış, inşaatta tamamlanamama veya maliyet aşımı, operasyonda getiri, talep ve tarife, transferde ise hizmet düzeyi riskleri. Bu safhalardan bağımsız olarak yaşam döngüsü boyunca enflasyon, faiz, politik engel, yasal düzenleme ve mücbir sebep riskleri her an doğabilir. Risklerin en erken safhada öngörülüp yönetilmesi esastır; aksi halde kamu ve özel sektörün yanı sıra vergi mükellefleri de ciddi yükümlülüklerle karşılaşabilir. Başlangıçta yaklaşık 2,7 milyar sterlin planlanan maliyeti bitişte 10 milyar sterlini aşan Channel Tunnel projesi (Parvu ve Voicu-Olteanu, 2009), dört katlık sapmayla uzun vadeli sözleşmelerin risk boyutunu açıkça göstermektedir.

Anket alıřmalarında millileřtirme, siyasi sreler ve hkmet istikrarı gibi makro riskler ağırlıkla kamuya; tasarım, inřaat, iřletme ve finansmana eriřim zel sektre; mcbir sebep, mevzuat deėiřikliėi ve taahht eksikliėi ise paylařılması gereken riskler olarak deėerlendirilmiřtir (Li vd., 2001; Li vd., 2005). Dikkat ekici bulgu, enflasyon riskinin ağırlıkla zel sektre atfedilmesine karřın demelerin enflasyona endekslendiėi yapılar da pratikte kamu zerinde kalabilmesidir. Doėru risk paylařımı toplam maliyeti dřrrken etkinliėi artırır (Zou vd., 2008) ve kamunun grevi riskleri kabul edilebilirlik dzeyine gre belirleyip daėıtmaktır (Karim, 2011). Risk ynetimi fizibiliteden bařlayarak proje yařamı boyunca srdrlmeli ve bunun iin kamunun gerekli kurumsal kapasiteye sahip olması gerekir (UNECE, 2008).

Yatırımın Deėer Analizi (Value for Money)

Kamu otoritesinin grevi bir hizmeti her kořulda retmek deėil, bteyi koruyarak en uygun maliyetle ve en yksek kalitede sunmaktır. Kİ yalnızca bte kısıtlarını ařmak ya da poplist saiklerle kullanıldıėında cari dnemde maniplatif bir iyimserlik yaratsa da uzun vadede kamuyu aėır ykmllkler altına sokabilir (Gkten, 2019). Bu nedenle model, tm finansman alternatifleriyle birlikte deėerlendirilip ancak kamu yararı tařıdıėında seilmelidir.

Yatırımın deėer analizi (value for money), geleneksel kamu yatırımı ile Kİ'yi btncl bir fayda-maliyet penceresinden karřılařtırır. Buradaki maliyet yalnızca ilk yatırımı deėil, yařam dngs boyunca bakım, onarım, operasyon ve risk ynetimini de kapsar (Petersen, 2019); deėer ise projenin nicel ve nitel performansıdır. Yntem  “E” zerine oturur: ekonomiklik (kaynak maliyetini dřrme), etkinlik (sabit girdiyle ıktıyı artırma) ve etkililik (beklentiyi karřılayan ıktı) (Jackson, 2012). Asgari bir performans gvence altına alınırken ya aynı maliyete daha yksek

değer ya da daha düşük maliyetle aynı değer sağlanmalıdır (EPEC, 2015).

Analiz, sayısal verilere dayalı nicel ve projenin faydasını esas alan nitel değerlendirmeye dayanır; ikisinin optimizasyonuyla gerçekçi bir fayda-maliyet analizi elde edilir (Kulaksız ve Küçükkocaoğlu, 2019). En çok başvurulanan araçlardan biri kamu kesimi karşılaştırmacıdır: yöntem, projenin geleneksel modelde kamu kaynaklarıyla gerçekleştirilmesi halindeki yaşam döngüsü maliyetlerini referans senaryo olarak alıp özel sektörün sunduğu hizmet ve maliyetle karşılaştırarak modelin tercih edilebilirliğini test eder (OECD, 2008; Grimsey ve Lewis, 2005). Kurumların işlerliği ve şeffaflığı arttıkça en basit yöntemlerden en kapsamlı fayda-maliyet analizine geçiş hızlanır.

Paranın karşılığını sağlamaya yönelik yöntemler en kapsamlıdan en basite doğru; kapsayıcı fayda-maliyet analizi, ihale öncesi ve sonrası kamu kesimi karşılaştırmacı ve rekabetçi ihaleye güvenme biçiminde sıralanır. Kapsayıcı analiz daha çok finansal açıdan güçlü ülkelerce kullanılırken, kaynakları yetersiz ülkelerde projenin bir biçimde gerçekleştirilmesi öncelik kazanabilir (Bovis, 2015). Kamu kesimi karşılaştırmacı genel olarak taban maliyet, risk düzeltmeleri, borçlanma farkları ve vergisel ayarlamalardan oluşur (HM Treasury, 2003). Nicel ölçütlerin yanı sıra nitel ölçütler de gözetilmeli; paranın karşılığı için ihalelerin rekabetçi ortamda yürütülmesi, ekonomik ve risk değerlendirmelerinin doğru yapılması ve tüm alternatiflerin adil ve kapsamlı karşılaştırılması esastır (Kulaksız ve Küçükkocaoğlu, 2019; Grimsey ve Lewis, 2005).

METODOLOJİ

Kamu özel işbirliği, dünyada ve Türkiye’de çok sayıda altyapı yatırımında kullanılan bir model olarak karşımıza

çıkılmaktadır. Türkiye’de özellikle 2010 sonrasında ulaşım, enerji ve sağlık yatırımlarında etkinleşmiştir. Sağlık alanında şehir hastaneleri modelin en görünür örneklerini oluşturmıştır. Adana, Ankara Bilkent, Ankara Etlik, Başakşehir Çam ve Sakura, Bursa, Kayseri, Mersin ve İzmir Bayraklı gibi yüksek kapasiteli pek çok şehir hastanesi bu modelle hayata geçirilmiştir. Bu çalışmanın amacı, KÖİ modeliyle bir şehir hastanesi yapım ve işletme sürecini inceleyerek net bugünkü değer hesabıyla yatırımın değerini analiz etmek ve değişen makroekonomik koşullarda geri ödeme süresinde ortaya çıkacak riskleri görünür kılmaktır.

KÖİ projeleri uzun vadeli sözleşmeler biçiminde ortaya çıktığından ortalama yirmi yıllık bir işletme dönemi esas alınmış ve varsayımsal bir hastane projesi bu çerçevede modellenmiştir. Amaç, değişen piyasa koşullarında projenin taşıdığı riskleri ve sonuçlarını öngörerek karar vericilere veri sağlamaktır. Bu finansman yapısı her ülkede risk barındırmakla birlikte; faiz, kur ve enflasyon gibi parametrelerin uzun vadede öngörülebilirliğinin görece düşük olduğu Türkiye gibi gelişmekte olan ülkeler için çok daha kritiktir.

İnşasına 1 Ocak 2018’de başlanması ve 31 Aralık 2019’da tamamlanması, ardından yirmi yıl özel amaçlı kuruluş uhdesinde faaliyet göstermesi öngörülen bir hastane tasarlanmıştır. Toplam yatırım maliyeti 1 milyar Türk Lirası olup bina yapım işleri, tıbbi ekipman ile mefruşat ve diğer kalemler biçiminde üç kırılda kurgulanmıştır. Finansmanda öz kaynak %20, kredi %80 varsayılmış; yabancı kaynak için iki yılı geri ödemesiz toplam on beş yıllık spot kredi planlanmıştır. Yirmi yıllık işletme dönemi çeyrek dönemlerle modellenmiş ve 1 Ocak 2020-31 Aralık 2039 arasında toplam seksen hak ediş ödemesi öngörülmüştür.

Modelde, Sağlık Bakanlığı’nın KÖİ ile hizmet alımı için yayımladığı tebliğdeki kullanım bedeli eskalasyon formülü esas alınmıştır; formülde kullanım bedeli tüketici fiyat endeksi, yurt içi

retici fiyat endeksi ve dviz alıř kuruna baēlı olarak her dnem yeniden hesaplanmaktadır. Ana belirleyici enflasyon olduēundan geri deme sresi de doērudan enflasyona baēlı deēiřmektedir. alıřmada demelerin Trk Lirası cinsinden ve enflasyona endeksli yapıldıēı senaryo ele alınmıř; kullanım bedeli ilk operasyon yılı iin 180 milyon TL, 10.000 metrekarelik ticari alan kiralama hasılatı ilk yıl iin 20 milyon TL alınarak sonraki dnemlerde eskalasyona tabi tutulmuř, amortisman bina ve diēer duran varlıklar iin yirmi yıl, tıbbi mefruřat iin on yıl ngrlmřtr. Projenin davranıřı iki enflasyon kurgusu altında izlenmiřtir. Olaēan kurguda 2020'ye kadar gerekleřen oranlar, 2024'e kadar Orta Vadeli Plan tahminleri ve 2025-2039 iin Merkez Bankası'nın %5 hedefi; olaēandıřı kurguda ise 2021-2024 arasında gerekleřen yksek enflasyon, ardından yine Orta Vadeli Plan tahminleri ve %5 hedefi kullanılmıřtır. Olaēan enflasyon beklentisinin gerekleřmesi halinde projenin gelir tablosu, nakit akıřı ve bilanosu dengeli seyretmekte; iskonto edilmiř net geri deme sresi ve net bugnk deēer ařaēıdaki tabloda yer aldıēı biimde gerekleřmektedir.

Tablo 1. Olaēan Enflasyon Varsayımlarıyla Elde Edilen Net Bugnk Deēer ve Geri deme Sresi

01.01.2020 itibarıyla Projenin Net Bugnk Deēeri (TL)	266.117.491
01.07.2019 itibarıyla Projenin Net Bugnk Deēeri (TL)	180.806.432
Projenin İ Getiri Oranı (Yıllık)	%19
Projenin İskonto Edilmiř Geri deme Sresi (Yıl)	14

Kaynak: Yazar tarafından oluřturulan finansal modelden elde edilmiřtir.

Ancak sz konusu dnemde Trkiye ekonomisinde yařanan beklenmedik dalgalanma nedeniyle enflasyon beklenenin tesinde artmıř, bu da Merkez Bankası'nın %5 hedefine ulařan

normalizasyonda gecikme getirmiştir. 2021 ve 2022’de ortaya çıkan bu olağandışı durumun enflasyon rakamlarıyla model çalıştırıldığında enflasyona endeksli kullanım bedeli ve hizmet hasılatları hızla yükselmiş; artış operasyonel dönemin hemen başında gerçekleştiğinden ve normalizasyon geciktiğinden etki proje sonuna kadar uzanmıştır. Yeni durumda projenin net bugünkü değeri ve geri ödeme süresi aşağıdaki tabloda yer aldığı biçimde gerçekleşmektedir.

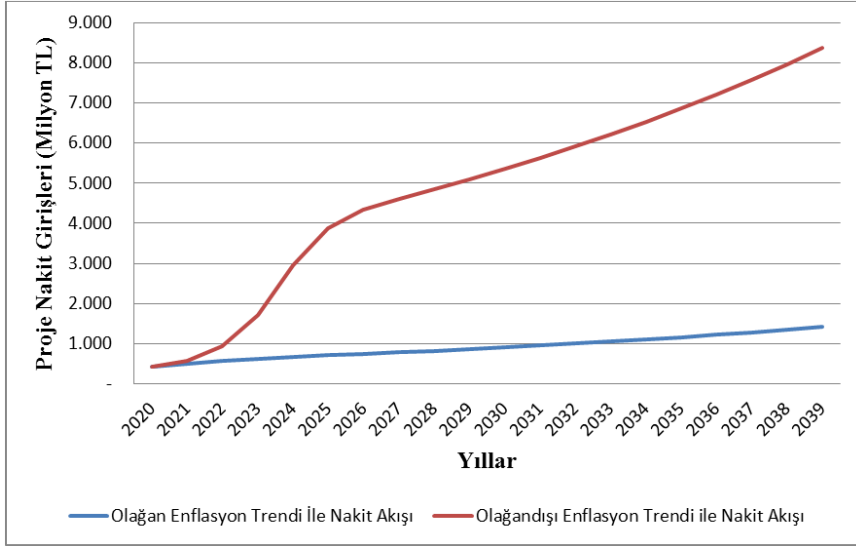
Tablo 2. Olağandışı Enflasyon Varsayımlarıyla Elde Edilen Net Bugünkü Değer ve Geri Ödeme Süresi

01.01.2020 itibarıyla Projenin Net Bugünkü Değeri (TL)	7.891.234.946
01.07.2019 itibarıyla Projenin Net Bugünkü Değeri (TL)	5.361.489.138
Projenin İç Getiri Oranı (Yıllık)	%41
Projenin İskonto Edilmiş Geri Ödeme Süresi (Yıl)	4,5

Kaynak: Yazar tarafından oluşturulan finansal modelden elde edilmiştir.

Görüldüğü gibi, öngörülen enflasyon trendi gerçekleşmiş olsaydı geri ödeme süresi uzun bir döneme yayılacakken, yaşanan dalgalanma sonucunda proje geri dönüşü yaklaşık 4,5 yıla düşmektedir. Bunun temel nedeni kullanım bedellerinin doğrudan enflasyona endeksli olmasıdır. Enflasyonda ani ve sert bir yükselişte enflasyona endeksli kullanım bedelleri üstel biçimde artmakta ve kamunun özel amaçlı kuruluşu yaptığı dönemsel ödemeler hızla yükselmektedir. Aşağıdaki grafikte, beklenen ve olağandışı enflasyon durumlarında projenin kullanım ve hizmet bedellerinden oluşan nakit girişleri karşılaştırmalı gösterilmektedir.

Şekil 1. Olağan ve Olağandışı Enflasyon ile Gerçekleşen Proje Nakit Akışları



Kaynak: Yazar tarafından oluşturulan finansal modelden elde edilmiştir.

Grafikte açıkça görüldüğü üzere, olağan trendde nakit girişleri yıllar içinde ölçülü ve dengeli artarken, olağandışı trendde özellikle 2024 sonrasında üstel bir eğilimle yukarı ayrıışmaktadır. İki eğri arasındaki açıklık, makroekonomik dalgalanmanın enflasyona endeksli yapı üzerinden kamu ödemelerine ne ölçüde yansıdığını somut biçimde ortaya koymaktadır.

SONUÇ

Altyapı yatırımları geleneksel modelde doğrudan kamu eliyle ve kamu bütçesiyle gerçekleştirilmekteydi; ancak artan nüfus ve gelişen teknolojiyle bu yatırımlar çok sayıda ülke için kamunun tek başına üstesinden gelmekte zorlanacağı tutarlara ulaşmıştır. Bu hizmetlerden vazgeçmek pratikte mümkün olmadığından alternatif arayışı öne çıkmış ve özel sektör, kamu özel işbirliği yapısı altında

çeşitli modellerle kamu yatırımlarının finansmanına katkı sağlamıştır.

Model kamu açısından avantajlı görünse de ileriki dönemlere ilişkin gizli bir borç yükü bırakma ihtimalini aynı ölçüde barındırmaktadır. Bu nedenle geleneksel kamu yatırımının doğrudan ve yegane alternatifi olarak görülmemelidir. Risk ve getiri paylaşımına dayanan model uzun vadeli süreçleri planladığından ciddi riskler taşımakta; yalnızca bir bilanço dışı finansman aracı olarak bütçe kısıtlarını aşmak için kullanıldığında kamuya oluşturacağı yükümlülükler tehlikeli boyutlara ulaşabilmektedir. Öte yandan ortalama 20-30 yıllık projelerin tüm yönleriyle öngörülebilir planlanması olası değildir. bu süre boyunca yatırımın değişen talepler ile bölgesel veya küresel, siyasi ya da ekonomik krizlerden etkilenme olasılığı da göz önünde bulundurulmalıdır.

Türkiye’de özellikle 2010 sonrasında hastane, köprü, otoyol ve havalimanı gibi projelerde etkin kullanılan model çok sayıda yatırımın hayata geçmesine vesile olmuş; ancak özellikle 2020 ile birlikte döviz kuru ve enflasyondaki beklenmedik ataklarla ekonomik öngörülebilirlik daralmıştır. Bu durum kamunun döviz ve enflasyona endeksli ileriye dönük yükümlülüklerinin de artışını beraberinde getirmiştir. Bu çalışmada ödemelerin Türk Lirası cinsinden ve enflasyona endeksli yapıldığı bir senaryoyla, enflasyondaki ani değişimin kamu yükümlülükleri üzerindeki etkisi varsayımsal bir hastane modeli üzerinden incelenmiştir.

Olağan ve olağandışı enflasyon koşullarının ürettiği sonuçlar çarpıcı biçimde farklıdır: olağan varsayımda geri ödeme süresi yaklaşık 14 yıl, net bugünkü değer yaklaşık 266 milyon TL ve iç getiri oranı %19 iken; 2021-2022’deki gibi bir enflasyon şokunda geri ödeme süresi 4,5 yıla inmekte, net bugünkü değer yaklaşık 7,9 milyar TL’ye yükselmekte ve iç getiri oranı %41’e kadar artış göstermektedir. Bunun nedeni ise kullanım bedellerinin doğrudan

enflasyona endeksli olmasıdır. Öngörülebilirlik korunduğunda yükümlülükler dengeli dağılırken, ani ve sert bir yükselişte enflasyona endeksli bedeller üstel biçimde artmakta ve proje çok daha kısa sürede kendini geri ödemektedir. Kısalan geri ödeme süresi de kamunun yükümlülüklerinde hızlı bir artışa sebep olabilmekte bu anlamda kamu zararı riskini ortaya çıkarabilmektedir.

Çok sayıda çalışmada takdir toplayan KÖİ modelinin en zayıf yanı da barındırdığı bu risklerden ileri gelmektedir. Siyasi ve ekonomik kırılganlıklar taşıyan gelişmekte olan ülkelerde model çok daha dikkatli ele alınmalıdır. Yatırım kararından önce nitel ve nicel analiz yöntemlerinin, özellikle kamu kesimi karşılaştırmacısının etkin kullanılması ve aciliyet taşımayan projelerin önceliklendirilerek ileride kamu eliyle gerçekleştirilmesi değerlendirilmelidir. Öte yandan kullanım bedelleri ağırlıklı ortalama yöntemi kullanılarak sınırlandırılabilir. Nitekim bu çalışmadaki senaryo özelinde enflasyonun etkisini sınırlamak için kullanım bedelinin endekslenmesinde hareketli ağırlıklı ortalama yöntemi uygulandığında geri ödeme süresi 4,5 yıldan yaklaşık 8 yıla çıkmakta, net bugünkü değer 7,9 milyar TL'den yaklaşık 3,3 milyar TL'ye gerilemektedir. Kullanım bedeline kredi geri ödemelerini aşmayacak bir üst limit konulduğunda ise süre yaklaşık 7,75 yıla, net bugünkü değer yaklaşık 1,5 milyar TL'ye gerilemektedir. Belirli risklerin belirli eşikleri aşması halinde kamu yükümlülüklerine tavan uygulanması ya da risklerin yeniden gözden geçirilmesi de değerlendirilebilir; ancak bunun ek bir sözleşme maddesi olarak ayrı bir risk primi içereceği ve özel sektörece proje başında bir getiri talebiyle karşılanacağı göz ardı edilmemelidir. Sonuç olarak mevcut yapısıyla KÖİ projelerinde makroekonomik riskler kamu üzerinde yükümlülük yaratma eğilimindedir; modelin kamuya fayda sağlaması ve sürdürülebilir bir devlet politikası olarak yürütülebilmesi için sözleşmelere bu tür koruyucu önlemlerin eklenmesi büyük önem taşımaktadır.

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BÖLÜM 2

SHOCK AND VOLATILITY RELATIONSHIP BETWEEN ELECTRICITY INDEX WITH COST INFLATION IN TÜRKİYE: DCC-GARCH MODEL

AYŞEGÜL LADİN SÜMER¹

Introduction

The impact of changes in energy prices on macroeconomic variables has recently been the subject of theoretical and empirical studies due to various price effects caused by wars, technological innovations, and the widespread adoption of renewable energy (Liu et al., 2019; Baumeister et al., 2022; Valmayor et al., 2023). Shocks and fluctuations in energy prices have had a particularly inflationary impact on the overall cost of producing goods and services (Coibion and Gorodnichenko, 2015; Coibion et al., 2018; Hasenzagl et al., 2022). Extensive empirical research has been encouraged to create a favorable economic environment for establishing sustainable cost inflation (Batten et al., 2024).

On the other hand, energy production and distribution are not only important for suppliers, producers, and consumers, but fluctuations in energy markets have also been decisive in investors'

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preferences and decisions in financial terms. The causal relationship between volatility in energy markets and inflation dynamics has become noteworthy (Batten et al, 2024). In this regard, when evaluating the Turkish energy markets, the BIST XELCT index, which includes the shares of electricity companies operating in a wide range of fields, primarily hydroelectric, wind, solar and geothermal power plants, in addition to conventional production methods based on fossil fuels, stands out (Varol et al., 2024). Therefore, potential volatility in the BIST XELCT index represents a risk factor for investors, while it is a cost factor for producers.

Based on the explanations given so far, this study analyzes the relationship between the electricity energy market and cost inflation in Turkey, focusing on shock and volatility effects, using monthly data from 2006, when official inflation targeting began, to the present, with the Dynamic Conditional Correlations (DCC-GARCH) method. In this way, time-varying correlations caused by structural breaks in the period under analysis are identified in the dynamics of macrofinancial variables (Corsetti et al., 2005; Chiang et al., 2007; Cho and Parhizgari, 2008). Furthermore, the answer to the question of whether modeling the shock and volatility relationship between the electricity market and cost inflation will provide meaningful predictions to guide policymakers' decisions will contribute to the limited literature specific to Türkiye. Accordingly, recent empirical studies close to the background of the subject are as follows:

In their study, Lim and Yoo (2013) investigated the effect of changes in energy prices on industrial prices and the general price level in Korea using the input-output method. The estimation results indicate that a 10% increase in electricity prices would have an overall impact of approximately 0.44%, contributing to decision-making processes related to electricity price management. Hunynh (2016) analyzed the overall equilibrium effects of energy price

shocks on the business cycle for America using impulse response functions within the framework of endogenous energy production with convex costs. The study concludes that energy price shocks are influential in the production of energy supply dynamics. In their study, Andini et al. (2019) examined the macroeconomic impacts of renewable electricity generation projects developed due to both environmental concerns and economic reasons. For this purpose, a structural vector autoregression based on macroeconomic and energy data was constructed in the Portuguese sample; it was determined that renewable electricity generation projects positively affect real economic growth in the medium run. Andre et al. (2023) constructed impulse response functions for 21 OECD countries, distinguishing between the short and long run effects and dynamics of rising energy prices on efficiency. Overall, the results show that after an energy price shock, businesses' capacity utilization rates decreased and productivity declined. However, a 5% increase in energy prices reduced efficiency by 0.4% after one year, while a 10% increase in energy prices increased efficiency by 0.9% after four years. Kilian and Zhou (2023) analyzed the impact of shocks in various energy prices, including electricity, on inflation dynamics beyond gasoline prices using the SVAR method for America. It was concluded that changes in energy prices create inflationary pressure on the general price level and core consumer prices. Garzon and Hierro (2024), who believe that changes in wholesale electricity prices are the driving force of inflation in Spain, analyzed the impact of real-time pricing on electricity price shocks and inflation dynamics. According to the impulse response function results, electricity price shocks showed a faster pass-through to inflation after the real-time pricing mechanism and had approximately three times greater interaction compared to the previous period.

Finally, the rest of the study, around its logical framework, is planned as follows: First, the data and methodology based on the

theoretical model are explained. Then, empirical findings and inferences are presented. The study concludes with results and policy recommendations.

Theoretical Model and Data

The energy sector, along with the production of durable and non-durable consumer goods, including its own, provides energy for household consumption. From a production perspective, the use of energy requires consideration of opportunity costs. For example, when the price of energy increases, the cost of producing energy also increases. Based on this, under the assumption that energy is a complement to capital, its cost is indirectly included in the production function by being added to the cost of capital. Accordingly, the production function can be defined as follows (Huynh, 2016: 5):

$$Q_{e,t} = \exp(A_{e,t}) (1 - \alpha_{e,t}) K_{e,t}^{\beta_e} L_{e,t}^{1-\beta_e} \quad (1)$$

Where $Q_{e,t}$; out-put, $K_{e,t}$; sermaye ve $L_{e,t}$; labor.

$$Q_{e,t} = \frac{\vartheta_{e1}}{(1+\vartheta_{e2})} (K_{e,t}^{\beta_e} L_{e,t}^{1-\beta_e})^{1+\vartheta_{e2}} \quad (2)$$

Where ϑ_{e1} and ϑ_{e2} ; represent the lost portion of energy production. $Q_{e,t}$ This functional relationship indicates that as the output of energy production increases, losses may increase due to inefficiencies in the production process. Therefore, a mechanism is created where the energy sector cannot quickly respond to demand shocks faced by the energy market, and energy prices become more volatile.

Based on this model, this article examines the relationship between cost inflation and potential fluctuations in Turkey's electricity market, particularly following shocks. For this purpose, the electricity index ($\ln XELCT$, level) and the domestic producer price index ($\ln DPPI$, 2003=100, level) were used for the period

2006:M01-2025:M10, from the start of the inflation targeting regime to the present. $\ln$; represents the logarithmic transformation of the variables. The data was compiled from the Istanbul Stock Exchange (BIST) and the Central Bank of the Republic of Türkiye (CBRT) - Electronic Data Distribution System (EDS).

Metodoloji

To analyze the time-dependent volatility correlations between different economic variables, the DCC-GARCH Model developed by Engel (2002) is applied in two stages. In the first stage, the univariate GARCH(1,1) model parameters are obtained. In the second stage, DCC model coefficients are obtained for the conditional correlation dynamics of the parameters in question. Accordingly, the DCC-GARCH Model specification is as follows (Engle, 2002: 341-342):

$$H_t = D_t R D_t \quad D_t = \text{diag}\{\sqrt{h_{i,t}}\} \quad (3)$$

Where, a multivariate GARCH estimator is defined based on Bollerslev's (1990) constant conditional correlation (CCC) model. R ; is a correlation matrix containing conditional correlations. This equation is expressed as the unconditional correlation matrix of standardized error terms as follows:

$$E_{t-1}(\varepsilon_t \varepsilon_t') = D_t^{-1} H_t D_t^{-1} = R \quad \varepsilon_t = D_t^{-1} r_t \quad (4)$$

H ; is a GARCH model estimator that includes different variables or exogenous variables in the model, and $H_t = D_t R D_t$ is defined. Based on this, the covariance matrix, which is the geometrically weighted average of the standardized error terms, is as follows:

$$p_{i,j,t} = \frac{\sum_{s=1}^{t-1} \lambda^s \varepsilon_{i,t-s} \varepsilon_{j,t-s}}{\sqrt{(\lambda^s \varepsilon_{i,t-s}^2)(\lambda^s \varepsilon_{j,t-s}^2)}} = [R_t]_{i,j} \quad (5)$$

and

$$q_{i,j,t} = (1 - \lambda)(\varepsilon_{i,t-1}\varepsilon_{j,t-1}) + \lambda(q_{i,j,t-1}), p_{i,j,t} = \frac{q_{i,j,t}}{\sqrt{q_{ii,t}q_{jj,t}}} \quad (6)$$

The GARCH(1,1) model, into which the q 's obtained by rewriting via exponential correction are integrated, is written as follows:

$$q_{i,j,t} = \overline{p_{i,j}} + \alpha(\varepsilon_{i,t-1}\varepsilon_{j,t-1} - \overline{p_{i,j}}) + \beta(q_{i,j,t-1} - \overline{p_{i,j}}) \quad (7)$$

or

$$q_{i,j,t} = \overline{p_{i,j}} \left(\frac{1-\alpha-\beta}{1-\beta} \right) + \alpha \sum_{s=1}^{\infty} \beta^s \varepsilon_{i,t-s} \varepsilon_{j,t-s} \quad (8)$$

Where $\overline{p_{i,j}}$; the unconditional expected value of the cross product is as follows, while the variances and correlation estimators are as follows: $\overline{p_{i,j}} = 1$

$$p_{i,j,t} = \frac{q_{i,j,t}}{\sqrt{q_{ii,t}q_{jj,t}}} \quad (9)$$

$Q_t = [q_{i,j,t}]$; Based on the fact that it is the weighted average of a positive definite and positive semi-definite matrix, the unconditional expectation of the numerator and the expected value of each term in the denominator are equal to one. The matrices of these estimators are as follows:

$$Q_t = (1 - \lambda)(\varepsilon_{t-1}\varepsilon'_{t-1}) + \lambda Q_{t-1} \quad (10)$$

$$Q_t = S(1 - \alpha - \beta) + \alpha(\varepsilon_{t-1}\varepsilon'_{t-1}) + \beta Q_{t-1} \quad (11)$$

Where S ; is an unconditional correlation matrix of coefficients close to zero.

When the unconditional matrices obtained so far are adapted to the sample correlation matrix, the correlation matrix, which includes many generalizations between different variables, can be defined as follows:

$$Q_t = S o(u' - A - B) + A o \varepsilon_{t-1} \varepsilon'_{t-1} + \beta o Q_{t-1} \quad (12)$$

Where ι ; a vector consisting of ones, $\circ$; is the Hadamard product of two matrices of identical size, calculated by multiplying their elements. A , B and $(\iota' - A - B)$ show that if Q is positively semi-determined, then Q will also be positively semi-determined.

Finally, within the framework of the generalizations and models mentioned above, the DCC model can be summarized with the following statistical characteristics:

$$r_t | \zeta_{t-1} \sim N(0, D_t R_t D_t) \quad (13)$$

$$D_t^2 = \text{diag}\{w_i\} + \text{diag}\{\kappa_i\} \circ r_t r_{t-1}' + \text{diag}\{\lambda_i\} \circ D_{t-1}^2 \quad (14)$$

$$\varepsilon_t = D_t^{-1} r_t \quad (15)$$

$$Q_t = S \circ (\iota' - A - B) + A \circ \varepsilon_{t-1} \varepsilon_{t-1}' + \beta \circ Q_{t-1} \quad (16)$$

$$R_t = \text{diag}\{Q_t\}^{-1} Q_t \text{diag}\{Q_t\}^{-1} \quad (17)$$

Equation (13) is interpreted as preventing the assumption of normality and avoiding the half-maximum probability. Equation (16) indicates that a single-variable GARCH process is followed.

Results and Discussion

Before estimating the DCC-GARCH model, the stationarity requirement of the variables was determined using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests (Dickey and Fuller, 1979, Dickey and Fuller, 1981; Phillips and Perron, 1988). According to the unit root test results in Table 1, the $Ln\ XELCT$ and $Ln\ DPPI$ series are stationary in their first differences.

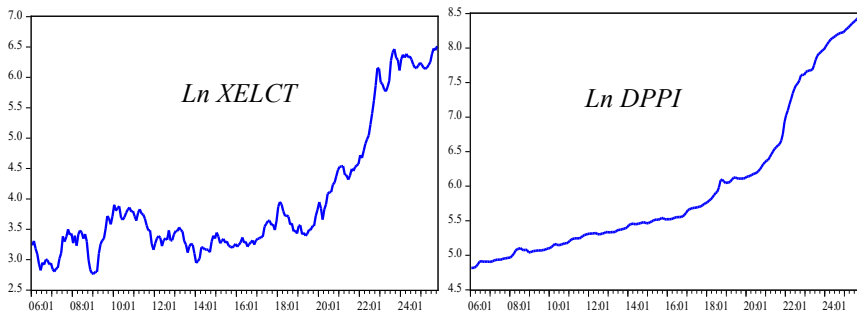
Table 1 Unit Root Tests Results

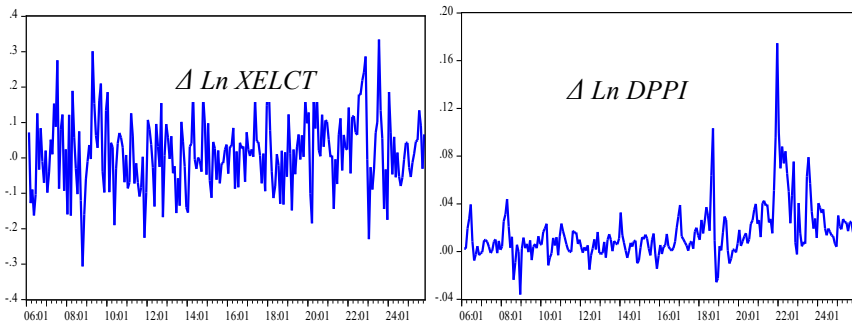
Level	ADF		PP	
	Constant	Trend & Constant	Constant	Trend & Constant
$Ln\ XELCT$	0.568	1.261	0.694	-1.018
$Ln\ DPPI$	2.222	-0.355	3.288	0.074
First Difference	ADF		PP	
	Constant	Trend & Constant	Constant	Trend & Constant
$\Delta Ln\ XELCT$	-12.310***	-12.479***	-12.312***	-4.581***
$\Delta Ln\ DPPI$	-4.663***	-5.462***	-6.362***	-6.966***
Notes: $Ln\ XELCT$; electricity index, $Ln\ DPPI$; domestic producer price index. ***, ** and * denote the stationarity of the series at 1%, 5% and 10% significance levels, respectively. For constant unit root test, -3.457, -2.873, -2.573, -3.506 respectively. -3.997, -3.429, -3.138 for constant and trend unit root testing, respectively. Δ indicates that the first difference of the series is taken.				

Source: Authors own.

Based on the stationarity test results, the trajectories of $Ln\ XELCT$ and $Ln\ DPPI$ are shown in Figure 1. It is observed that the $\Delta Ln\ XELCT$ and $\Delta Ln\ DPPI$ series fluctuate around a specific value.

Figure 1 Plots of Variables





Source: Authors own.

After the stationarity analysis, the DCC-GARCH (1,1) model was estimated to examine the dynamic conditional correlation between *Ln XELCT* and *Ln DPPI*. The results in Table 2 indicate the existence of time-dependent conditional correlations between changes in *Ln XELCT* and *Ln DPPI*. The α and β coefficients, representing the ARCH and GARCH effects respectively, are statistically significant. The significance of the ARCH effect for the *Ln XELCT* and *Ln DPPI* equations indicates that past shocks have an effect on current fluctuations. The significance of the GARCH effect for the *Ln XELCT* and *Ln DPPI* equations indicates that past fluctuations have an effect on current fluctuations. When the α and β coefficients obtained for both equations are compared, it is seen that the fluctuations are driven by long run fluctuations rather than short run shock effects; the finding that $\alpha + \beta < 1$ indicates that the stationarity condition for correlation dynamics is met.

On the other hand, when comparing the *Ln XELCT* and *Ln DPPI* equations in terms of R-squared adjusted for diagnostic test statistics, the *Ln ELCT* equation stands out as having higher explanatory power. Based on this, it can be stated that the *Ln XELCT* equation, which focuses on fluctuations, provides a better fit. According to the results of the Durbin-Watson test statistics used to determine the presence of autocorrelation, the *Ln XELCT* equation, which is closer to the two, stands out; while it can be stated that the

Ln DPPI equation, with its high log probability and small AIC and SC values, explains the data better with fewer parameters.

Table 2 DCC-GARCH(1,1) Model

Variance Equation			
$(Ln XELCT)_\alpha$	$(Ln XELCT)_\beta$	$(Ln DPPI)_\alpha$	$(Ln DPPI)_\beta$
0.113 (0.005)***	0.810 (0.000)***	0.373 (0.000)***	0.609 (0.000)***
Diagnostic Tests			
<i>Ln XECLT</i>		<i>Ln DPPI</i>	
$\overline{R^2}$	0.58	$\overline{R^2}$	0.27
AIC	-1.742	AIC	-5.453
SC	-1.684	SC	-5.395
Log Likelihood	210.434	Log Likelihood	650.201
D.W.	1.569	D.W.	0.513
Notes: <i>Ln XELCT</i> ; electricity index, <i>Ln DPPI</i> ; domestic producer price index, α ; ARCH effect coefficient, β ; GARCH effect coefficient, $\overline{R^2}$; adjusted R-squared, AIC; Akaike information criteria, SC; Schwarz information criteria, D.W.; Durbin-Watson statistics. Probability values are included in parentheses. *** denotes significance level at 1%.			

Source: Authors own.

The results of the DCC model created to determine the existence of a dynamic conditional correlation between *Ln XECLT* and *Ln DPPI* are presented in Table 3.

Table 3 DCC Model

Stability Condition	
Θ_1	Θ_2
0.441 (0.000)***	0.547 (0.000)***
Notes: Θ_1 ; volatility effect of past standardized error terms; Θ_2 ; the lasting effect of shocks on conditional correlations. Probability values are included in parentheses. *** denotes significance level at 1%.	

Source: Authors own.

Where, Θ_1 , representing the volatility effect of past standard error terms, and Θ_2 , representing the shock effect on conditional correlations, are statistically significant. In this context, the finding of $\Theta_1 + \Theta_2 < 1$ indicates that the model is stable and that there is a dynamic relationship between *Ln XELCT* and *Ln DPPI*.

Based on the DCC-GARCH(1,1) model and the DCC model results, a Granger causality test analysis was performed to determine the direction of the causal relationship between *Ln XELCT* and *Ln DPPI* (Granger, 1969); as seen in Table 4, a reciprocal causal relationship was found. However, the causal relationship from *Ln XELCT* to *Ln DPPI* is stronger. In this case, the causal effect of *Ln XELCT* on the dynamic conditional correlation between *Ln DPPI* and *Ln XELCT* is more significant.

Tablo 4 Granger Causality Test Results

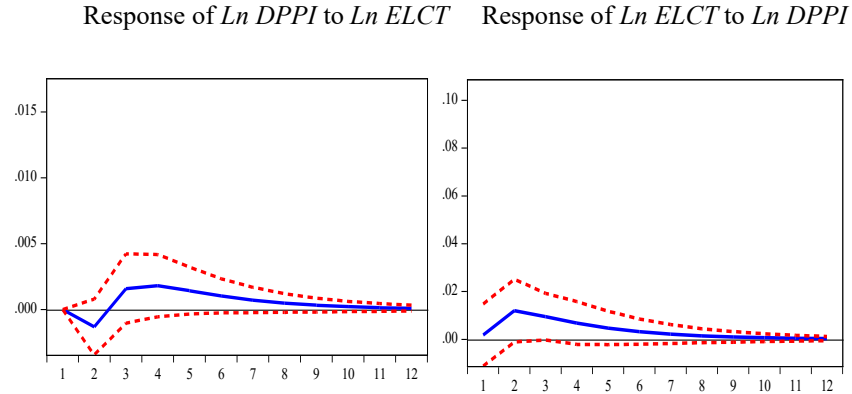
The Direction of Causality	F-Statistics	Possibility
<i>Ln XELCT</i> $\longrightarrow$ <i>Ln DPPI</i>	4.025	0.019**
<i>Ln DPPI</i> $\longrightarrow$ <i>Ln XELCT</i>	2.619	0.075*
Notes: <i>Ln XELCT</i> ; electricity index, <i>Ln DPPI</i> ; domestic producer price index, * and ** denote significance levels at 10% and 5%, respectively.		

Source: Authors own.

In relation to the Granger causality test results, the effects of shocks occurring in the *Ln XELCT* and *Ln DPPI* variables in the DCC-GARCH(1,1) model are shown in Figure 2 with impulse-response functions within the scope of generalized effects theory (Pesaran & Shin, 1998). Accordingly, the *Ln XELCT* shock is positive in the first period. From the first period onwards, *Ln DPPI* responds to the *Ln XELCT* shock by decreasing. From the end of the second period until the end of the fourth period, *Ln DPPI* responds by increasing, and in the long term, it responds by decreasing. On the other hand, the *Ln DPPI* shock is positive in the first period. From the first period until the end of the second period, *Ln XELCT*

responds by increasing, and from the third period onwards, it responds by decreasing in all periods.

Figure 2 Impulse-Response Functions



Note: Confidence intervals (for ± 2 standard errors) are determined using the Monte-Carlo simulation technique.

Source: Authors own.

The obtained empirical findings are consistent with the theoretical model on which the methodology is based. Electricity provides final goods and services both as its own production and as a complement to capital. Sudden upward changes in the electricity market will increase the opportunity cost of electricity production and the cost of capital due to decreased efficiency. In this situation, the perception among producers that upward electricity prices will continue will cause the rapid reactions in the short run to slow down in the long run.

Conclusion and Recommendations

This study empirically investigates the shocks and volatility reflected in producer costs from the electricity energy market in Türkiye. For this purpose, the relationship between the BIST electricity index and the domestic producer price index is examined using variances and covariances developed based on the DCC-GARCH approach for the period 2006:M1-2025:M10.

DCC-GARCH(1,1) and DCC-based equations were used to determine the direction of the causal relationship between variables and the effects of shocks occurring in variables after ensuring diagnostic test statistics and stability conditions. According to the DCC-GARCH (1,1) model and DCC model results, the dynamic correlation parameters are significant and the volatility spillover is from the BIST electricity index to the domestic producer price index. However, the shocks are not persistent. According to the Granger causality test result, the BIST electricity index is more influential in the shock and volatility relationship between the BIST electricity index and the domestic producer price index. The impulse-response function results show that the effects of shocks occurring in the BIST electricity index and the domestic producer price index are effective in the short run but limited in the long run. In summary, the results obtained from the DCC-GARCH(1,1) model are supported by the Granger causality test and impulse-response function results.

The BIST electricity index is a reference point for producers, especially investors, representing companies involved in electricity generation and distribution activities in Turkey's energy sector, which are critically important and have high efficiency potential. The increase in energy demand and the resulting trend towards alternative energy sources such as renewable energy have made the electricity market strategic. Therefore, potential high volatility in the electricity market can be monitored through the BIST electricity index, influencing investment and production decisions. For example, considering the analysis period, global commodity prices rose rapidly due to Covid-19 and problems in energy-rich countries, resulting in increased electricity production costs in the energy market. Consequently, the inflationary effect of electricity prices will weaken the competitiveness of domestic producers in international markets while increasing dependence on energy imports. It is believed that the fundamental measure to be taken here is to

encourage the development and use of alternative energy sources, such as domestic renewable energy, in order to reduce costs in electricity production.

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BÖLÜM 3

HANEHALKI TÜKETİMİNİN DEĞİŞİMİ

FİKRET KARTAL¹

Giriş

Millî gelirin önemli bileşenlerinden biri olan tüketim harcamalarının boyut ve kompozisyonu toplumun refahı ve ülkenin gelişmişliği ile yakından ilişkilidir. Toplam tüketimin ve tüketim kalemlerinin gelirle olan yakın bağı, refah ve gelişmişlik ölçümünde tüketimi belirleyici kılmaktadır. Diğer yandan tüketici davranışları ve tüketim kalemleri, talep üzerinden reel sektörün faaliyet ve yatırım kararlarında belirleyici olabilmektedir.

Başta gelir olmak üzere çok sayıda faktör ve değişkenden etkilenen hanehalkının tüketim harcamalarının kompozisyonundaki değişim, ülkenin makroekonomik görünümü ve istikrarına bağlı olarak şekillenmektedir. Türkiye'nin son dönemde içinden geçmekte olduğu ekonomik kriz ve görece sıkı para politikası özellikle satın alma gücünde kayıplara neden olmuş ve dezenflasyonist süreç talebi baskılamıştır. Gıda fiyatları ile kiralardaki keskin yükseliş harcama kompozisyonuna yön vermiştir. Gelir ve satın alma gücüne olan bağımlılık ve esneklik ile zorunlu harcamalar doğal olarak bu

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kompozisyon deęişiminde kendini göstermektedir. Gelir ve harcama grupları arasında tüketim kalemleri bazında ayrışma mevcuttur.

Hanehalkının tüketim harcamalarının farklı kalemler bazında dağılımını gösterir anket çalışmaları her yıl düzenli olarak gerçekleştirilmektedir. Bu çalışmanın konusu, söz konusu anket verilerine göre 2010-2025 döneminde hanehalkı tüketim harcamalarının gelişimini ve kompozisyonunu gelir ve harcama gruplarına göre analiz etmektir.

Literatür Taraması

Türkiye’de tüketim harcamalarının etkileşimde bulunduğu faktör ve deęişkenleri araştıran çalışma sonuçlarına aşağıda kısaca yer verilmektedir.

TÜİK’in 2014 yılı hanehalkı bütçe anketi verilerini kullanan ve gelir-harcama ilişkisini analiz eden, mal gruplarına ait gelir esneklik deęerlerini tahmin eden çalışmada (Çalmaşur & Kılıç, 2018: 71-72); gelirden en fazla payı %20,1 ile konut, su, elektrik, gaz ve dięer yakıt harcamalarının aldığı, en düşük payın ise %1,9 ile saęlık harcamalarına ait olduęu, yapılan esneklik hesaplamalarında gıda ve alkolsüz içecekler, alkollü içecekler, giyim ve ayakkabı, konut gibi bazı mal ve hizmetlerin zorunlu harcama grubunda, saęlık ve eğitim hizmetleri harcamalarının ise lüks mal grubunda sınıflandırıldığı, haberleşme harcamalarının esneklięi en düşük harcama grubu, eğitim harcamalarının ise gelire en duyarlı harcama kalemi olduęu açıklanmıştır.

Hanehalkı tüketim harcamalarının belirleyicilerine dönük olarak yapılan ve 1980-2015 dönemi verilerini kullanan çalışmada (Erdaş, Erdoğan & Erdoğan, 2017: 323); milli gelir ve tüketim arasındaki ilişkinin pozitif, enflasyon ve tasarruflar ile tüketim arasındaki ilişkinin ise negatif yönlü olduęu belirlenmiştir.

2006-2019 dönemi için hanehalkı tüketim harcamaları ile kamu harcama davranışları arasındaki ilişkiyi araştıran çalışmada (Atgür, 2020: 362-363); hanehalkı tüketimi ve kamu harcama davranışları arasında iki yönlü bir nedensellik ilişkisinin olduğu, maliye politikasına konu araçların hanehalkı tüketim davranışlarını yönlendirmek için kullanılabileceği ifade edilmiştir.

Hanehalkı tüketim harcamalarında tahmin ve öngörü performansına sahip modellerin belirlenmesi amacıyla denetimli makine öğrenmesi yöntemini kullanan ve 2018 yılı hanehalkı bütçe anketi verilerini analiz eden çalışmada (Topal & Çağlayan Akay, 2021: 28-29); harcamaların en temel belirleyicisinin gelir olduğu, hane tipi, asansör, çamaşır makinesi, çocuk oyun alanı, sinema ve kahvehane alışkanlığı, konutta ısınma ve iklimlendirme tercihi, enerji kaynağı, internetten alışveriş ve kredi kartı kullanım alışkanlıkları gibi değişkenlerin de harcama kompozisyonuna tesir ettiği açıklanmıştır.

Hanehalkı tüketim harcamaları üzerinde kamunun sunduğu sosyal transfer harcamalarının etkisini araştıran ve 2019 yılı hanehalkı bütçe istatistiklerini kullanan çalışmada (Çağan, 2023: 547-548); sosyal transfer harcamalarının temel tüketim maddeleri ile eğitim ve sağlık hizmetlerini artırdığı, bu artışın özellikle genç yaşlarda ve eğitim seviyesi yüksek bireylerde daha belirgin olduğu belirtilmiştir.

Hanehalkı tüketimi ve kamunun tüketim harcamalarının tüketim malı ithalatına etkisini araştıran ve 2013-2024 dönemi verilerini kullanan çalışmada (Turna, 2025: 247-248); hanehalkı tüketim harcamalarının tüketim malı ithalatına kısa ve uzun dönemde istatistiksel olarak anlamlı ve pozitif bir etkide bulunduğu, kamu tüketim harcamalarının ise kısa ve uzun dönemde anlamlı bir etkisinin bulunmadığı sonucuna ulaşılmıştır.

Döviz kuru oynaklığının reel tüketim harcamalarına etkilerini 2003-2021 dönemi üzerinden inceleyen çalışmada (Koçak & Karış, 2023: 294); kısa dönemde döviz kuru oynaklığı ve reel tüketim harcaması arasında bir ilişkinin bulunmadığı, uzun dönemde ise kur oynaklığının tüketim harcamalarını negatif etkilediği, bunun ise tüketim kararını etkileyen enflasyon belirsizliğinin kur oynaklığından etkilenmesinden kaynaklanabileceği belirtilmiştir.

Hanehalkı tüketim harcamaları ile tüketici güven endeksi arasındaki bağa odaklanan çalışmada (Yamak, Yamak, & Erkan, 2019: 529-530); kısa ve uzun dönemde tüketim harcamasının en önemli belirleyicisinin gelir olduğu, ikinci önemli belirleyicinin ise tüketici güven endeksi olduğu ve bu endeksin tüketim fonksiyonunda kullanılmasının gerektiği, enflasyonun kısa ve uzun dönemde tüketim harcamalarını ters yönde etkilediği, kısa dönemde etki yaratmayan mevduat faiz oranının uzun dönemde tüketim harcamasını ters yönde etkilediği ifade edilmiştir.

1987-2018 dönemi üzerinden millî gelir ve hanehalkı tüketim harcamaları arasındaki nedensellik ilişkisini araştıran çalışmada (Tütüncü, 2021: 306-307); tüketim harcamalarından kişi başı milli gelire doğru tek yönlü nedenselliğin olduğu, bu nedenle tüketim harcamalarını teşvik ederek ekonomik büyümeyi sağlayacak politikaların politika yapıcılarının gündeminde olması gerektiği belirtilmiştir.

Veri ve Çalışmanın Yöntemi

2010-2025 döneminde hanehalkı tüketim harcamalarının kompozisyonundaki değişimin harcama ve gelir grupları bazında incelenmesi çalışmanın amacını oluşturmaktadır. Türkiye İstatistik Kurumu'nun (TÜİK) her yıl yayımladığı “Hanehalkı Tüketim Harcaması” çalışmasına konu veriler kullanılmıştır. 2008 küresel finansal krizinin etkilerinin ortadan kalktığı 2010 yılı, çalışmanın

başlangıç tarihi olarak ele alınmış ve 2025 yılına kadarki süreç değerlendirilmiştir.

Çalışmamız 2010-2025 verilerini kullanmakla birlikte COVID-19 salgın krizi nedeniyle TÜİK 2020 ve 2021 yıllarında hanehalkı bütçe araştırmasını yapamamıştır; bu nedenle bu yıllara ait veriler bulunmamaktadır.

TÜİK, tüketim harcamalarına ilişkin araştırmalarında hanehalkı bütçe anketlerini kullanmaktadır. *“Bireylerin ve bunların oluşturduğu hanehalkının tüketim harcamalarını, gelir düzeylerini, sosyo-ekonomik kesimler ve bölgelere göre ortaya çıkaran çalışmalar”* olarak bu anketler tanımlamış ve anketlerden elde edilen tüketim harcamalarına konu bilgilerin, *“tüketici fiyat endekslerinde kullanılacak maddelerin seçimi ve temel yıl ağırlıklarının elde edilmesi, hanelerin tüketim kalıplarında zaman içinde meydana gelen değişikliklerin izlenmesi...”* gibi amaç ve analizler için kullanıldığı ifade edilmiştir (TÜİK, 2026a).

Tüketim harcaması ve gelirin kapsamı şu şekilde tanımlanmıştır (TÜİK, 2026a): *“Tüketim harcaması; hanehalklarının anket ayı içinde yaptığı tüketim amaçlı satın alışları, kendi üretiminden tüketimi, çalışan fertlerin hanehalkı tüketimi için işyerinden getirdiği mal ve hizmetler, hanehalkının hediye/yardım etmek amacıyla satın aldıkları ile son üç ay veya son bir yıl içinde satın aldığı otomobil, beyaz eşya, boya-badana, mobilya, bilgisayar, televizyon, özel okul, dersane vb. dayanıklı tüketim mal ve hizmet harcamalarının aylık ortalamasıdır. Gelir kapsamında ise son on iki ayda elde edilen kullanılabilir gelir bilgileri kapsamıştır.”* Kira ödemeyen hanehalkı, izafi kira üzerinden kira harcamasına dâhil edilmiştir.

TÜİK hanehalkını, *“Tek başına yaşayan kişiler ile aralarında akrabalık bağı bulunsun ya da bulunmasın aynı konutta yaşayan, barınma, gıda vb. ihtiyaçlarını ortaklaşa karşılayan, hanehalkı*

hizmet veya yönetimine katılan kişilerden oluşan topluluk” olarak tanımlamaktadır (TÜİK, 2026a).

Yıllık olarak hazırlanan hanehalkı tüketim harcamalarına ilişkin istatistiklerde hanehalkı; gelirine ve harcama tutarlarına göre beş grup (%20’lik dilimler) üzerinden sınıflandırılmaktadır (TÜİK, 2026a). Hanehalkının, gelire göre sıralanmasında, her ay toplanan gelir verileri enflasyonla güncellenerek yıl sonuna çekilmekte, kullanılabilir yıllık gelirler sıralanarak haneler beş eşit parça üzerinden % 20’lik gruplara ayrıştırılmakta, aylık tüketim harcamaları da benzer şekilde beş eşit parçaya bölünmektedir. Harcamalar içinde en yüksek paya sahip olan konut ve kira, gıda ve alkolsüz içecekler ile ulaştırma harcamaları çalışmada daha detaylı olarak sunulmuştur.

Hanehalkı Tüketim Harcamasının Gelişimi

TÜİK, hanehalkı tüketim harcamalarını 14 kaleme sınıflandırmıştır. Aşağıdaki tabloda 2025 verilerine göre toplam harcamalar içinde %2,5 ve üzerinde ağırlığa sahip olan kalemlerin 2010-2025 döneminde ağırlıklarında meydana gelen değişim gösterilmektedir. Salgın krizi nedeniyle 2020 ve 2021 yılına dönük anket çalışmaları yapılmadığı için bu yıllara ait veriler bulunmamaktadır.

Tablo 1 Seçilmiş Tüketim Kalemlerinin Toplam Tüketimden Aldıkları Payların Gelişimi

Tüketim Kalemi	Gıda ve alkolsüz içecekler	Alkollü içecekler, sigara ve tütün	Giyim ve ayakkabı	Konut ve kira	Mobilya, ev aletleri ve ev bakım hizmetleri	Ulaştırma	Haberleşme	Lokanta ve oteller
2010	21,9	4,5	5,1	27,1	6,3	15,1	4,1	5,4
2011	20,7	4,1	5,2	25,8	6,4	17,2	4,0	5,7
2012	19,6	4,2	5,4	25,8	6,7	17,2	3,9	5,8
2013	19,9	4,2	5,3	25,0	6,6	17,4	4,0	5,9
2014	19,7	4,2	5,1	24,8	6,8	17,8	3,7	6,0
2015	20,2	4,2	5,2	26,0	6,1	17,0	3,7	6,4
2016	19,5	4,4	5,2	25,2	6,3	18,2	3,7	6,4
2017	19,7	4,5	5,0	24,7	6,3	18,7	3,4	6,2
2018	20,3	4,0	4,8	23,7	6,5	18,3	3,8	6,5
2019	20,8	4,3	5,0	24,1	6,4	16,5	3,6	6,5
2022	22,9	3,2	4,9	22,4	6,4	21,4	3,8	5,8
2023	20,6	2,8	5,4	23,9	6,5	21,9	3,9	5,9
2024	18,1	2,5	5,1	26,0	5,9	21,6	3,7	6,6
2025	17,3	2,5	4,3	29,3	5,3	20,5	3,6	6,9

Kaynak: TÜİK (2026b) Hanehalkı Tüketim Harcaması verilerinden derlenmiştir.

Konut ve kira harcaması toplam harcamalar içinde daima en büyük ağırlığa sahiptir. 2010 yılında %27,1 olan bu pay 2022 yılında %22,4'e gerilemiş, 2025 yılında ise %29,3 ile incelenen dönemdeki en yüksek düzeye yükselmiştir.

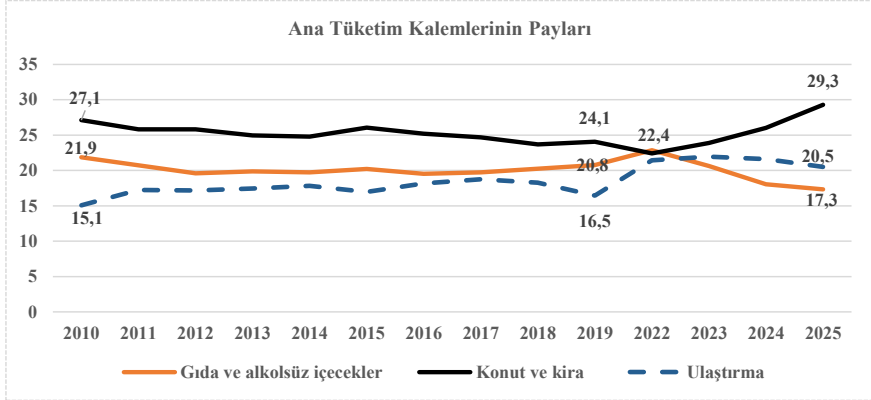
2010 yılında tüketim harcamaları içinde gıda ve alkolsüz içecekler %21,9'luk pay ile ikinci sırada yer alırken 2024 ve 2025 yıllarında bu payda belirgin bir düşüş meydana gelmiştir. 2025 yılında %17,3'lük gıda ve alkolsüz içecekler harcama payı, ulaştırma harcamasının gerisine düşmüştür.

2010 yılında ulaştırma harcaması %15'lik paya sahip iken 2023 yılında %21,9 ile incelenen dönemde en yüksek payına ulaşmış ve 2025 yılında %20,5'lik pay edinmiştir.

İncelenen dönemin tamamına yaygın şekilde genelde lokanta ve hotel harcamasının payının arttığı, 2022'den itibaren alkollü içecekler, sigara ve tütün, 2023 sonrasında giyim ve ayakkabı ile mobilya harcamalarının payının düştüğü görülmektedir.

Harcamalar içinde en yüksek paya sahip olan konut ve kira, gıda ve ulaştırma harcamalarının gelişimi aşağıdaki grafik üzerinden de izlenebilmektedir.

Şekil 1 Ana Tüketim kalemlerinin Gelişimi (2010-2025)



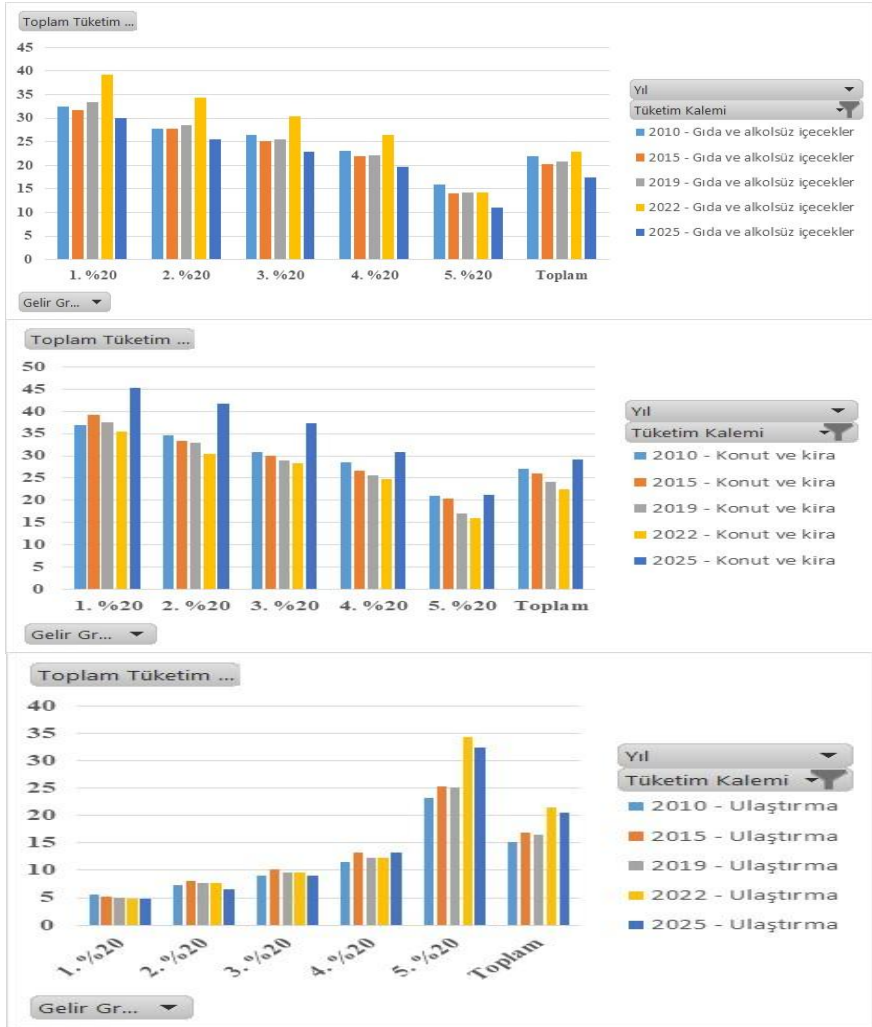
Kaynak: TÜİK (2026b) Hanehalkı Tüketim Harcaması verilerinden derlenmiştir.

Türkiye'nin 2021 sonrasında yaşamaya başladığı mevcut ekonomik krizde toplumun geniş kesiminin satın alma gücü ve reel gelirinin düştüğü, konut satış fiyatları ile kiraların yükseldiği bilinmektedir. Esasında gıda fiyatlarında da keskin bir yükseliş meydana gelmiştir. Yukarıda sunulan veriler, hanehalkının konut ve kira ile ulaştırma harcamalarına daha fazla pay ayırmak zorunda kaldığı ve bu nedenle gıda harcamalarını azalttığı şeklinde yorumlanabilir.

Hanehalkı Tüketim Kalemlerinin Harcamalar İçindeki Dağılımı

TÜİK, oluşturduğu %20'şerlik beş harcama grubu bazında hanehalkını yaptıkları harcama tutarlarına göre sınıflandırmıştır. En az harcayan hane grubu 1. %20'lik grup iken artan harcamalara göre sıralama yapılmakta ve en yüksek harcama grubu 5. %20'lik grup olmaktadır. Harcamalar içinde en yüksek paya sahip olan konut ve kira, gıda ve ulaştırma harcamalarının 2010, 2015, 2019, 2022 ve 2025 yıllarında aldıkları paylar aşağıdaki grafiklerde sunulmaktadır.

Şekil 2 Harcama Gruplarına Göre Tüketim Harcamalarının Dağılımı



Kaynak: TÜİK (2026b) Hanehalkı Tüketim Harcaması verilerinden derlenmiştir.

En düşük harcama grubunu oluşturan 1. %20'lik dilimde 2010 yılında toplam harcamaların %33'ü gıda ve alkolsüz içeceklere ayrılırken bu oran 2022 yılında %39'a yükselmiş ve 2025 yılında %30'a düşmüştür. En düşük harcama grubu 2010 yılında

harcamalarının %37'sini konut ve kiraya ayırırken bu oran 2025 yılında %45'dir. Bu harcama grubu 2010 yılında harcamalarının %5,5'ini ulaştırma kalemine ayırırken bu oran ilk kez 2022 yılında %5'in altına düşmüş ve 2025 yılında da %4,7 düzeyinde gerçekleşmiştir.

En yüksek harcama grubunu oluşturan 5. %20'lik grup 2010 yılında harcamalarının %16'sını gıda ve alkolsüz içecekler kalemine ayırırken sonraki yıllarda bu oran %14 düzeyinde kalmış ve 2025 yılında %11'e gerilemiştir. En yüksek harcama grubu 2010 yılında harcamalarının %21'ini, 2022 yılında %16'sını, 2025 yılında %21'ini konut ve kira kalemine ayırmıştır. Bu grubun ulaştırma kalemine ayırdığı pay ise 2010 yılında %23, 2019 yılında %25 iken keskin bir artışla 2022 yılında 34 düzeyine yükselmiş ve 2025 yılında %32,5 düzeyinde gerçekleşmiştir.

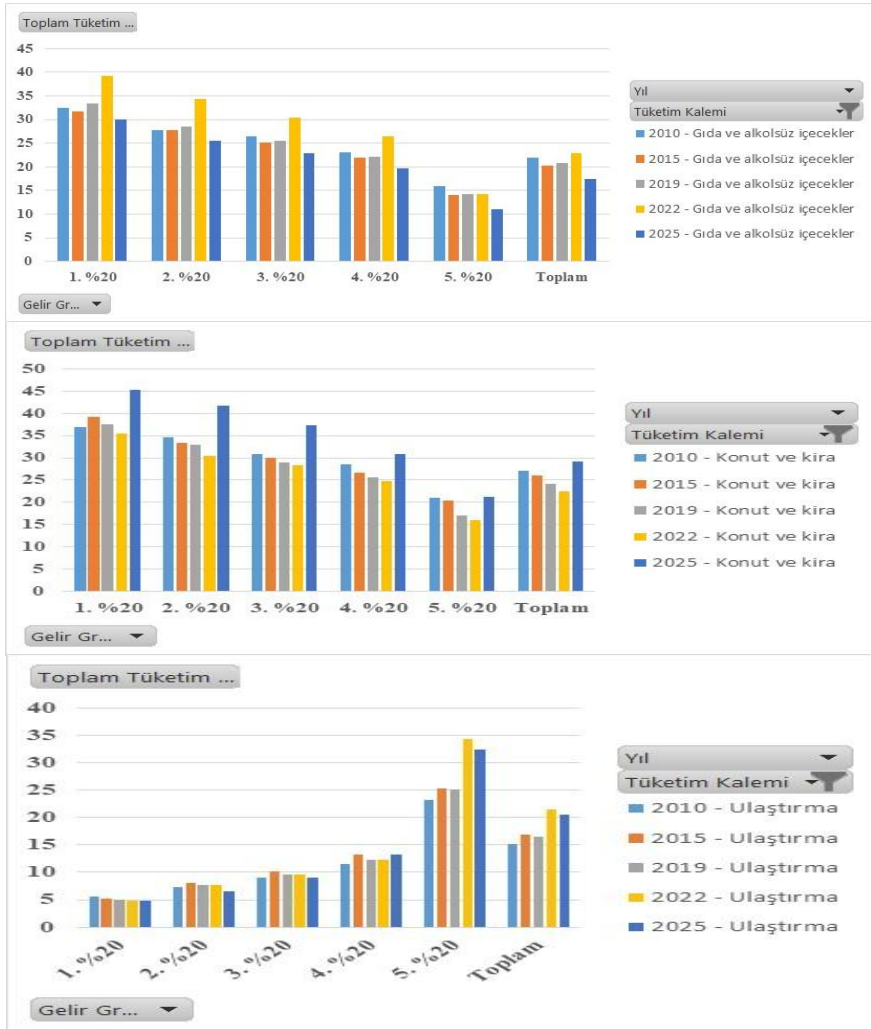
Harcama düzeyi artıkça harcamalar içinde ulaştırma kaleminin aldığı pay belirgin şekilde yükselmekte, konut ve kira kalemi ile gıdanın payı düşmektedir.

En düşük harcama grubunda konut ve kiranın payı incelenen dönemde %37'den %45'e çıkarken, en yüksek harcama grubunda bu oran %21 ile aynı düzeyde kalmıştır.

Hanehalkı Tüketim Kalemlerinin Gelirler İçindeki Dağılımı

TÜİK, oluşturduğu %20'şerlik beş gelir grubu bazında hanehalkı tüketim kalemlerinin harcamalar içindeki dağılımını sunmaktadır. En düşük gelir grubu 1. %20'lik grup iken artan gelire göre sıralama yapılmakta ve en yüksek gelir grubu 5. %20'lik grup olmaktadır. Gelir gruplarının harcamaları içinde en yüksek paya sahip olan konut ve kira, gıda ve ulaştırma harcamalarının 2010, 2015, 2019, 2022 ve 2025 yıllarında aldıkları paylar aşağıdaki grafiklerde sunulmaktadır.

Şekil 3 Gelir Gruplarına Göre Tüketim Harcamalarının Dağılımı



Kaynak: TÜİK (2026b) Hanehalkı Tüketim Harcaması verilerinden derlenmiştir.

En düşük gelir grubunu temsil eden 1. %20'lik dilimde 2010 yılında toplam harcamaların %32'si gıda ve alkolsüz içeceklere ayrılırken bu oran 2022 yılında %36'a yükselmiş ve 2025 yılında %29'a düşmüştür. Bu gelir grubunda konut ve kira harcamalarının toplam harcamalar içindeki payı 2010 yılında %32 iken 2022 yılında

%29'a gerilemiş ve 2025 yılında keskin şekilde %39'a yükselmiştir. Ulaştırma giderleri 2010 yılında %7,5, 2019 yılında %9, 2025 yılında %8,5'lik paya sahiptir.

En yüksek gelir grubunu temsil eden 5. %20'lik grup 2010 yılında harcamalarının %17'sini gıda ve alkolsüz içecekler kalemine ayırırken sonraki yıllarda biraz gerileyen bu oran 2019 yılında %15, 2022 yılında %16,6 iken belirgin bir düşüşle 2025 yılında %12,4 düzeyindedir. Bu gelir grubunda 2010 yılında %24 olan konut ve kira harcama payı 2022 yılına kadar %19'a gerilemiş ve 2025 yılında %26'ya yükselmiştir. Ulaştırma harcamalarının payı ise 2010-2019 döneminde %20 dolayında iken 2022 yılında keskin şekilde %29'a yükselmiş ve 2025 yılında %25'e gerilemiştir.

Harcama düzeyindeki değişime benzer şekilde gelir düzeyi arttıkça ulaşırma kaleminin toplam harcamalardaki payı yükselmekte, gıda ile konut ve kira kaleminin payı ise azalmaktadır.

En düşük gelir grubunda konut ve kira harcamalarının payı incelenen dönemde %32'den %39'a çıkarken en yüksek harcama grubunda bu oran %24'den %26'ya yükselmiştir.

Sonuç

Milli gelir ve üretim faaliyetlerinin en önemli bileşenlerinden olan hanehalkı tüketim harcamaları, sıradan bir istatistiki veri olmayıp ekonominin büyümesi, gelirin paylaşımı ve toplumun refahı hakkında kritik sonuçlara işaret etmektedir. Tüketim harcamaları bir girdi olduğu kadar bir çıktı niteliği de taşımaktadır. Üretici, yatırımcı, sanayici, ithalatçı tüketim harcamaları üzerinden faaliyetlerine yön verdiği gibi politika yapıcılar da tüketime gelişimi ve kompozisyonu üzerinden izlenecek politikalara rota çizmektedir. Enflasyonla mücadelenin, büyümenin, istihdamın belirleyicisi olan tüketim harcamaları, harcanabilir gelirle birlikte çok sayıda faktör ve değişkene bağılı olarak şekillenmektedir.

2010-2025 döneminde hanehalkı tüketim harcamalarının kompozisyonundaki değişimi ele alan bu çalışma, TÜİK'in her yıl yayımladığı "Hanehalkı Tüketim Harcaması" raporuna konu verileri kullanmaktadır. Analizde yer verilen harcama ve gelir grupları, anketlere konu hane harcama ve gelirlerinin % 20'lik beş gruba ayrıştırılması ile oluşturulmaktadır.

Çalışmada, ilk olarak 2025 verilerine göre toplam harcamalar içinde %2,5 ve üzerinde paya sahip olan sekiz harcama kaleminin, 2010-2025 döneminde toplam harcamalar içindeki ağırlıklarında meydana gelen değişim gösterilmiştir. Toplam harcamalar içinde konut ve kira harcama kalemi analiz edilen dönemde her zaman en büyük ağırlığa sahiptir. 2010 yılında %27,1 paya sahip olan konut ve kira kalemi 2025 yılında %29,3'lük pay edinmiştir. 2010 yılında gıda ve alkolsüz içeceklerin %21,9 olan payı 2025 yılında %17,3'e gerilemiş ve ulaştırma harcamasının gerisine düşmüştür. 2010 yılında %15'lik paya sahip olan ulaştırma harcaması kalemi 2025 yılında %20,5'lik pay edinmiştir.

TÜİK'in oluşturduğu beş harcama grubunda en az harcayan hane grubunu oluşturan 1. %20'lik grup, 2010 yılında toplam harcamalarının %33'ünü gıda ve alkolsüz içeceklere ayırırken bu oran 2022 yılında %39'a yükseldikten sonra 2025 yılında %30'a düşmüştür. En düşük harcama grubu 2010 yılında konut ve kira harcama kalemine harcamalarının %37'sini ayırırken, son dönemde konut fiyatları ve kiralarda meydana gelen keskin artış nedeniyle bu oran 2025 yılında %45'e yükselmiştir. Bu harcama grubunun 2010 yılında %5,5'lik pay ayırdığı ulaştırma kalemi 2025 yılında %4,7'lik paya sahiptir.

En yüksek harcama grubunu oluşturan 5. %20'lik grup, 2010 yılında gıda ve alkolsüz içecekler kalemine harcamalarının %16'sını ayırırken bu oran 2025 yılında %11'e gerilemiştir. En yüksek harcama grubu, konut ve kira kalemine 2010 ve 2025 yıllarında

%21’lik pay vermiştir. Bu grubun ulařtırma kalemine 2010 yılında ayırdığı %23’lük pay 2025 yılında %32,5 düzeyine yükselmiştir.

%20’şerlik beş gelir grubu bazında harcamaların kompozisyonuna bakıldığında, en düşük gelir grubunu temsil eden 1. %20’lik dilimde 2010 yılında toplam harcamaların %32’si gıda ve alkolsüz içecekler ayrılırken bu oran 2025 yılında %29’a düşmüştür. Bu gelir grubunda konut ve kira harcamalarının toplam harcamalar içindeki payı 2010 yılında %32 ve 2025 yılında %39’dur. En yüksek gelir grubunu temsil eden 5. %20’lik grup, harcamaları içinde gıda ve alkolsüz içecekler kalemine 2010 yılında %17 ve 2025 yılında %12,4’lik pay ayırmıştır. Bu gelir grubunda 2010 yılında %24 olan konut ve kira harcama payı 2025 yılında %26’dır. Ulařtırma harcamalarının payı 2010-2019 döneminde %20 dolayında iken 2022 yılında %29, 2025 yılında %25’dir.

Bu sonuçlar içinde özellikle en düşük harcama grubunda konut ve kiranın payının incelenen dönemde %37’den %45’e çıkması ve gıda ve alkolsüz içeceklerin payının ise %33’den %30’a düşmesi dikkat çekicidir. En yüksek harcama grubunda ise konut ve kira kaleminin payının %21 düzeyinde kalırken gıda ve alkolsüz içeceklerin payının %16’dan %11’e gerilemesi ve ulařtırma harcamalarının payının %23’den %32,5’a çıkması önemli bir değişime işaret etmektedir.

Harcama düzeyindeki değişime benzer şekilde gelir düzeyi arttıkça ulařtırma kaleminin toplam harcamalardaki payı yükselmekte, gıda ile konut ve kira kaleminin payı ise azalmaktadır.

Yıllar bazında değişim analiz edildiğinde harcama kalemlerinin dağılımı 2022 ve sonrasında belirgin şekilde farklılaşmaktadır. Eylül 2021-Haziran 2023 döneminde izlenen geleneksel olmayan para politikası (negatif reel faiz dönemi) ve Haziran 2023 sonrasında izlenen geleneksel politikalara kademeli dönüş (görece yüksek faiz politikası), harcama kalemlerinde önemli

dalgalanmalara neden olmuştur. Dolayısıyla makroekonomik politikalardaki başarı, dalgalanma veya istikrarsızlık doğrudan gelir düzeyine, satın alma gücüne ve tüketim kalıplarına yansımaktadır.

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BÖLÜM 4

İKLİM DEĞİŞİKLİĞİ VE BORSA PERFORMANSI ÜZERİNE BİR DENEME

MERCAN HATİPOĞLU¹
CANER DİLBER²

Giriş

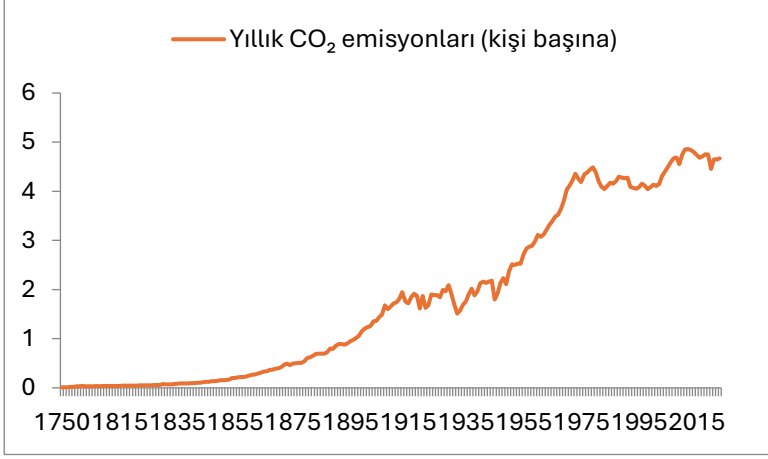
Bilim insanlarına göre 1880’den 2012’ye kadar dünyamızın ortalama sıcaklığı 0,85°C artmış ve bu artışın başlıca nedenleri olarak kömür, petrol, doğal gaz ve ormansızlaşma gösterilmiştir. Tedbir alınmaz ise, 2060 için 4°C ve 2100 yılında 6°C olarak ortalama sıcaklık artışı tahmin edilmektedir. Bu yıkıcı senaryonun gerçekleşmemesi için ortalama sıcaklık artışının en fazla 2°C ile sınırlandırılması gerekmektedir. Karbon bütçesi tanımı ile de sıcaklıklardaki artışın 2°C’nin altında kalması için küresel sera gazı emisyonuna bir sınır konulması amaçlanmıştır (Yeldan vd., 2015). Özellikle COVID-19 pandemisinin ardından son 2 yılda 500’den fazla çevresel, sosyal ve yönetim (ESG) fonu hayata geçirilmiştir (Sreelakshmi & Greeshma, 2023). İklim finansmanı Birleşmiş Milletler İklim Değişikliği Çerçeve Sözleşmesi (UNFCCC) göre “iklim değişikliğiyle mücadelele ilgili gaz azaltımı ve uyum

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önlemlerini desteklemek amacıyla kamu, özel ve alternatif finansman kaynaklarından sağlanan yerel, ulusal veya uluslararası finansman” olarak tanımlanmaktadır. İklim finansmanı, düşük karbonlu bir dünya için, sera gazı seviyelerini azaltmak adına hükümetlerin, şirketlerin ve hane halklarının yapması gereken yatırımlarla ilgili bir konudur. Çünkü enerji, gıda, sigorta ve gayrimenkul sektörüne kadar birçok sektör, küresel ısınmadan, tarımsal üretkenliğe yönelik olumsuz şoklardan veya deniz seviyesinin yükselmesinden olumsuz etkilenmektedir. Hatta şiddetli hava olaylarından giderek daha fazla etkilenen şehirler, temizlik için bile milyonlarca dolar ek bütçeye ihtiyaç duymaktadır. Nitekim, derecelendirme kuruluşları, iklim değişikliğine karşı önlem alan belediye tahvillerinin derecelendirmelerine dahil etmeyi düşünmektedir (Hong vd., 2020). Benzer şekilde, Jin, & Wang, (2025) iklim değişikliği düzenlemelerine maruz kalmanın firmaların borçlanma maliyetlerini yükselttiğine dikkat çekmiştir. Naifar (2023) sonuçları da iklim değişikliğine uyum sağlama kapasitesi zayıf olan ülkelerin, kredi risk primlerinin yükseldiği yönündedir. Kim (2024) yatırımcıların, olası iklim değişikliği kaynaklı riskleri etkili bir şekilde yönetebilecek, çevresel değişikliklere iyi hazırlanmış ve uyum sağlayabilen şirketler beklediğini ifade etmiştir. İklim riskleri, fiziksel riskler ve geçiş riskleri olarak ikiye ayrılmaktadır. İklim değişikliğinin fiziksel riskleri, iklim şartlarının ekonomik faaliyetler üzerindeki doğrudan risklerdir. Örneğin, yükselen deniz seviyelerinin firmaların denize yakın üretim tesislerine zarar verme tehdidi ve buna bağlı olarak gayrimenkul değerlerinin düşmesi, fiziksel bir iklim riski olarak ele alınabilir. Geçiş riskleri ise, düşük karbonlu bir ekonomiye geçişten kaynaklanan, firmaların operasyonları ve iş modelleri üzerindeki çok çeşitli etkileri kapsar (Giglio vd., 2021).

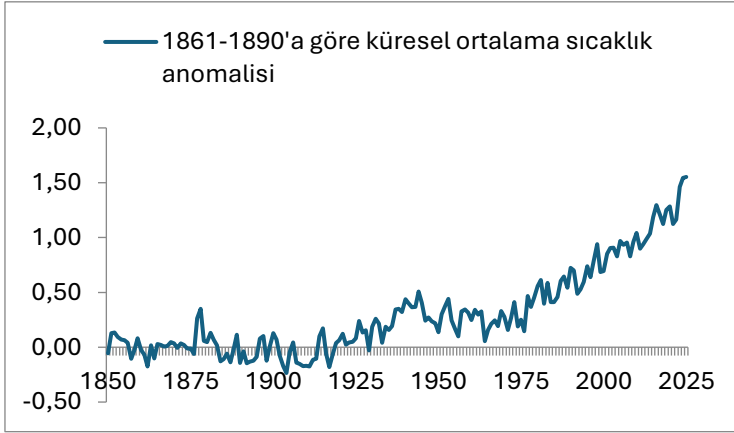
Grafik 1: Yıllık CO₂ emisyonları (kişi başına)



Kaynak: Global Carbon Budget (2024) [OurWorldinData.org/co2-and-greenhouse-gas-emissions](https://www.ourworldindata.org/co2-and-greenhouse-gas-emissions)

Grafiği incelediğimizde dünyada 2023 yılında kişi başına düşen küresel karbondioksit emisyonu ortalama 4,7 metrik ton olarak gerçekleşmiştir. Bir önceki yıla kıyasla hafif bir artışı olsa da, trend 1950 yılından beri doğrusal şekilde artmaktadır. Literatürde firmaların karbonla ilgili politika belirsizliğine maruz kalmaları karbon riski olarak adlandırılmaktadır. Bunun yanında, karbon riski, bir firmanın fosil yakıt bazlı bir ekonomiden daha düşük karbonlu bir ekonomiye geçişte karşı karşıya kaldığı finansal kırılganlığını da ima etmektedir. Bu süreçte firmalar, açıklama maliyetleri, uyum maliyetleri ve düşük karbonlu teknolojilere geçiş için ilave sermaye harcamaları gibi çok çeşitli gider kalemleri ile uğraşmaktadırlar. Ayrıca çevre duyarlılığı kaynaklı kamuoyu baskısı nedeniyle, firmalar yeterli düzenleme yapmazlar ise, yasal cezalara, itibar kayıplarına veya boykotlara katlanmak durumundadırlar (Nguyen vd., 2025).

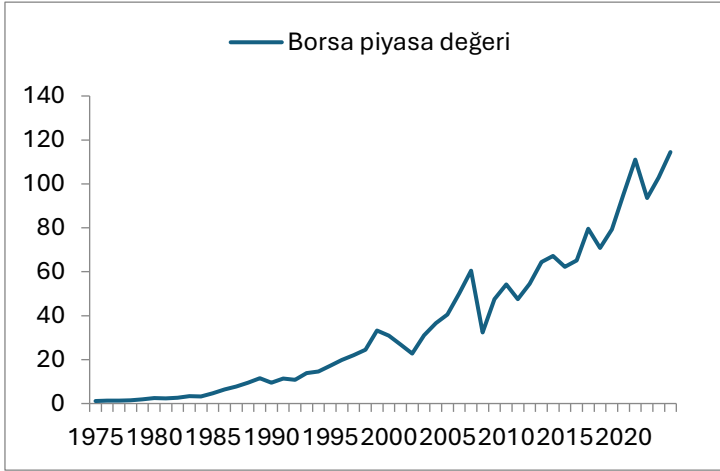
Grafik 2: 1861-1890'a göre küresel ortalama sıcaklık anomalisi



Kaynak: Met Office Hadley Centre - HadCRUT5 (2025) Not: 1861-1890 ortalamasıyla karşılaştırıldığında ortalama kara-deniz yüzey sıcaklığı farkı, santigrat derece cinsinden. <https://ourworldindata.org/co2-and-greenhouse-gas-emissions>

Küresel ısınma grafiğine baktığımızda ise 1930 yıllardan beri ortalama küresel sıcaklıkların 2025 yılına geldiğimizde yaklaşık 1,5°C arttığını görmekteyiz. Anormal derecede yüksek sıcaklıkların ekonomik faaliyetlerin azalmasına yol açması kaçınılmazdır ve aşırı sıcaklıkların tarımı etkilediği de bir sır değildir. Nitekim, Addoum & Ortiz-Bobea (2023) aşırı sıcaklıkların nispeten yaygın olduğunu, ABD endüstrilerinde %40'dan fazla kazançları etkilediğini ve yalnızca tarımla ilgili firmalarla sınırlı kalmadığını kanıtlamıştır.

Grafik 3: Halka açık yerel şirketlerin piyasa değeri (cari ABD doları)



Kaynak:<https://data.worldbank.org/indicator/CM.MKT.LCAP.CD?end=2024&start=2000&view=chart>

Grafik 3' bakıldığında dünya borsalarının ABD doları üzerinden değeri toplamda 1970'li yıllarda 1.3 trilyon dolar iken, 2024 itibariyle söz konusu değer 114 trilyon dolar seviyelerine gelmiştir. Neredeyse sermaye piyasaları 1970-2024 dönemi arası 54 yıllık bir zamanda 90 kat artış göstermiştir. 2000 ve 2008 krizleri dışında değer artışları sürekli artan trend takip etmiştir. Dikkat çeken bir nokta ise, 2000 yılı başı itibariyle, düşüşlerin daha belirgin gerçekleşmesidir. Bu çalışmanın amacı küresel çapta iklim değişikliğinin yine tüm dünya borsalarının toplam piyasa değerine etkisini ölçmektir. Çünkü iklim sistematik bir değişkendir ve dünyanın her bölgesine etkisi vardır. Çalışma bu yönüyle mevcut literatürden ayrılmaktadır. Kitap bölümünün bundan sonraki kısımları, literatür, model ile veri, ampirik bulgular ve sonuç olarak sıralanmaktadır. Çalışmanın teorik çerçevesi, iklim değişikliğinin finansal piyasalar üzerindeki etkisini inceleyen iklim finansmanı literatürüne dayanmaktadır. Ana çerçeveyi iklim değişikliği ve

finansal piyasalar arasındaki bağlantı oluşturmaktadır. Bu kapsamda öne çıkan bağlantı konuları derecelendirme kuruluşlarının iklim riskini tahvil derecelendirmelerine dahil etmesi, iklim düzenlemelerinin firmaların borçlanma maliyetlerini artırması, yatırımcıların iklim risklerini yönetebilen firmalara yönelmesi ve ESG fonlarının yükselişidir.

Literatür

Çetiner (2011) sürdürülebilir kalkınma ve yeşil ekonomi konularının 1969 yılında uluslararası toplumun gündemine girmeye başladığını ve 1971 de Greenpeace örgütünün kurulduğuna dikkat çekmiştir. Karakaya (2016) Kyoto Protokolü ve Paris anlaşmasını değerlendirdiği çalışmasında, %80 üzerinde fosil yakıt kullanan dünya ülkelerinin kömür, doğalgaz ve petrolden vazgeçerek, temiz enerjiye yönelmelerinin zorunluluğundan bahsetmiştir. Ayrıca yazar ülkemiz için yenilenebilir enerji (rüzgar, güneş ve su) üreten firmalara yüksek fiyatla uzun dönemli alım garantisi verilirse, dönüşümün hızlanacağı önerisinde bulunmuştur. Tunahan (2010) araştırmasında, küresel karbon ticaretini analiz etmiş ve fazla karbon salınımı yapan firmaların başka ülkelerde karbon tasarrufu sağlayan projelere finansal destek sağlayarak, oluşan sera gazı fazlalıklarını dengeleyebileceklerini dile getirmiştir. Venturini (2022) yaptığı literatür derlemesinde çeşitli kaynaklardan elde ettiği bilgilere göre; Paris Anlaşması'nda belirlenen 2° ısınma hedefine ulaşmak için 2010'dan 2050'ye kadar petrol rezervlerinin üçte birinin, gaz rezervlerinin yarısının ve kömür rezervlerinin %80'inin yakılmaması gerekmektedir. Çevre sorunlarına kamuoyunun ilgisinin arttığı dönemlerde, karbon riski yüksek borsa endeksleri, düşük performans göstermektedirler. CFA raporuna göre portföy yöneticilerinin %60'ının analizlerinde iklim risklerini dikkate almamaktadır. Yeldan vd., (2015) genel denge analizleri, Türkiye için 1 kg CO₂'yi azaltmanın maliyetinin 7 ila 23 sent (ABD Doları) arasında olacağını kanıtlamıştır. Cavlak (2022) çalışmasında iklim risklerinin faaliyet

raporlarına nasıl yansıtılması gerektiğini örneklendirmiştir. Erdoğan (2022) ülkemizde yeşil araç sigortası, karbon fonu gibi ürünlerin henüz finansal araç olarak kullanılmadığının altını çizmiştir. Jakob vd., (2015) iklim fonlarının gelişmekte olan ülkelere önemli miktarda giriş yaptığını ve bu ülkelerin ekonomilerinde dalgalanmalara yol açtıklarını belirtmişlerdir. Karydas & Xepapadeas (2022) değişen iklim koşullarının, menkul kıymet getiri dağılımlarını daha kalın kuyruklu hale getirerek riski primini artırdığını kanıtlamıştır. Khan vd., (2022) bulguları, yeşil finansın ekolojik ayak izlerini azalttığını ve çevre dostu görüldüğünü göstermektedir. Pham vd.,(2019) genel olarak, Paris İklim Anlaşması'nın kısa vadede hedeflerine ulaştığını, anlaşma duyurularının kirletici endüstrileri risk ve getiri açısından etkilediğini göstermişlerdir. Antoniuk & Leirvik (2024) olay analizi modeliyle, borsa yatırımcılarının iklim değişikliğiyle ilgili yeni bilgilere hızla uyum sağladığını kanıtlamıştır. Doku vd., (2021) daha az nüfusa sahip Afrika ülkelerinin en fazla iklim yardımını aldığını tespit etmiştir. Xu vd.,(2023) yeşil tahvil ihraçlarının ve sektörde yeşil ekonomik büyümenin, tarımın büyüme oranını artırabileceğini doğrulamıştır. Leal vd., (2023) iklim finansmanının çevresel bozulmanın azaltılmasına katkıda bulunduğunu ve bu katkının düşük-orta gelirli ülkelerde daha belirgin olduğunu kanıtlamıştır. Ancak Kalinowski (2024) kredi ve öz sermayeye dayalı özel iklim finansmanının, gelişmekte olan ülkelerin borç yükünü derinleştirerek finans piyasalarını istikrarsızlaştırdığına dikkat çekmiştir. Steckel vd., (2017) İklim finansmanını emisyon fiyatlandırmasına bağlı hale getirmenin, uluslararası iklim iş birliğini istikrara kavuşturacağını iddia etmişlerdir. Aynı zamanda yazarlar, karbon fiyatlandırması, yerel vergi reformlarının finansmanı ve ilgili politika hedeflerine ulaşılması için harcanabilecek ek fonların iklim finansmanı çerçevesinde gerçekleşeceğini dile getirmişlerdir.

Model ile veri

Makalede borsa değişkeni Dünya Bankası web sitesinden temin edilen “*Halka Açık Yerel Şirketlerin ABD Doları Cinsinden Piyasa Değeri*” şeklinde esas alınırken, küresel ısınmayı temsil etmek üzere “*1861-1890'a göre Küresel Ortalama Sıcaklık Anomalisi*” verisi <https://ourworldindata.org/> adresinden alınmıştır. Karbon emisyonları vekil değişkeni olarak ise, “*kişi başına CO₂ emisyonları*” yine <https://ourworldindata.org> adresinden indirilmiştir. Söz konusu verilerin hepsi yıllık frekansta olup analizler 1975-2024 dönemleri kapsamında gerçekleştirilmiştir. Geçmiş iklim değişimlerinin gelecekteki borsa performansı hakkında bilgi içerip içermediğini test etmek amacıyla Ewing & Yanochik (1999) çalışmasına benzer olarak Granger Nedensellik testinden faydalanılmıştır.

Bulgular

Analizlere başlamadan önce serilerin seviye ve durağan (logaritmik birinci fark alınmış) haldeki değerleri tablo 1’de sunulmuştur. Buna göre seviye değerlerinde durağan olmayan seriler, fark alınınca durağan³ hale gelmiştir.

Tablo 1: Serilerin birim kök değerleri

	Seviye	Birinci Fark
Borsa Piyasa Değeri	4.688803	-8.354451***
Küresel Sıcaklık	1.140571	-5.461388***
Küresel Sera Gazı Salınımı	-1.110101	-6.171172***

Not: değerler ADF testi istatistiklerini göstermekte olup, *** %99 önem seviyesini belirtmektedir.

³ Serilerde eşbütünlüşme olmadığı ektaki tabloda ifade edilmiştir. Bundan dolayı nedensellik testi yaparken hata düzeltme vektörü tercih edilmemiştir.

Tablo 2 de yer alan nedensellik testi sonuçlarına göre, küresel sıcaklık anomalilerinin ve sera gazı salınımlarındaki değişimlerin Granger anlamında borsaların piyasa değerlerinde herhangi bir etkiye sahip olduklarını söyleyemeyiz. Çünkü bütün hipotezler yokluk hipotezi olup, olasılık değerleri 0,10 dan büyük olduğu için kabul edilmek zorunda kalınmıştır. Hipotezlerimiz, iklime dair değişikliklerin borsa piyasa değerlerinde değişikliklere yol açmadığını ileri sürmüştür. Şüphesiz bunun tam tersi de geçerli olup, borsa değerlerinden de iklime dair bir nedensellik bulgusuna rastlanmamıştır.

Tablo 2: Granger nedensellik sonuçları

Nedensellik Yönü	Gecikme (1,1)	Gecikme (2,2)
Küresel Sıcaklık → Borsa Piyasa Değeri	(0.006) [0.93]	(0.440) [0.64]
Küresel Sera Gazı Salınımı→ Borsa Piyasa Değeri	(0.862) [0.35]	(0.375) [0.68]
Borsa Piyasa Değeri → Küresel Sıcaklık	(0.000) [0.99]	(0.091) [0.91]
Borsa Piyasa Değeri → Küresel Sera Gazı Salınımı	(1.281) [0.26]	(0.651) [0.52]

Not: Parantez içindeki değerler F istatistiklerini, köşeli parantez içindeki değerler olasılık değerlerini göstermektedir.

Giglio vd., (2021) makalesine göre, iklim riskine maruz kalan menkul kıymetin değeri, olumsuz bir iklim şoku meydana geldiğinde, bu şokun kaynağı ne olursa olsun, düşecektir. Yine, iklim hasarları yüksek olduğunda düşük getiri sağlayan varlıklar için yatırımcılar pozitif risk primi talep etmektedirler. Bugün karbon emisyonlarını 1 ton azaltan bir yatırım ve bu yatırımın bugünkü

değeri, genellikle karbonun sosyal maliyeti olarak adlandırılır. İklim felaketi modellerinde, karbonun sosyal maliyeti nispeten yüksektir, çünkü iklim hasarlarını azaltan yatırımların getirileri, risksiz orandan daha düşük oranlarda iskonto edilmektedir. Yaptığımız nedensellik analizlerine göre dünya borsaları için yukarıda anlatılan mekanizma geçerli değildir. Çünkü ne küresel ısınma, ne de karbon tüketiminden borsa piyasa değerine doğru bir nedensellik ilişkisi tespit edilmiştir. Jena & Chaturvedi (2025) görece ufak ekonomilerde yerel bankalar ve finans kuruluşlarının, uygun kredi koşullarında uzun vadeli borç veremediklerini belirtmişlerdir. Dolayısıyla mevcut elektrik dağıtım ve inşaat şirketlerinin yenilebilir enerji için yeterli fon bulamadıkları ortaya çıkmıştır.

Sonuç

Ne yazık ki, fosil yakıtlar üretim için gereklidir ve ekonomi büyüdükçe emisyonlar artmaktadır. Söz konusu emisyonlar iklim değişikliğine neden olmakta dolayısıyla iklim koşullarındaki bozulma gelecekteki ekonomik faaliyetler üzerinde tehlike arz etmektedir. Finansal piyasalar sürdürülebilir bir ekonomi adına gereken yatırımların yeşil finansman araçları ile sağlanmasını özendirerek iklim değişikliği ile mücadelede destek vermektedir.

Nguyen vd., (2025) Avusturalya firmalar bağlamında, emisyon salan şirketlerin saygın bankalar tarafından finanse edilme olasılığının daha düşük olduğunu ve çevresel risklerin firmaların finansman maliyetlerinde şimdiden ortaya çıkmaya başladığını ifade etmiştir. Sankar vd.,(2024) yatırımcıların karbon riskinin farkında olduklarını ve dünyayı kirleten firmalardan daha yüksek kısa vadede daha yüksek getiri talep ettiklerini göstermişlerdir. Yatırımcı risklerini azaltmak için şirketlerin çok daha hızlı bir oranda karbonsuzlaşmaya gitmesi gerektiği de çalışmada ayrıca vurgulanmıştır. Bu araştırmanın bulguları yukarıda bahsedilen çalışmaların sonuçları ile örtüşmemektedir. Çünkü her iki taraf

arasında herhangi bir nedensellik ilişkisine rastlanmamıştır. Bu kitap bölümünde yöntem olarak Granger nedensellik testi tercih edilmiştir. Bağımlı değişken: Halka Açık Yerel Şirketlerin Piyasa Değer”, bağımsız değişkenler ise: “Küresel Ortalama Sıcaklık Anomalisi” ve “Kişi Başına CO₂ Emisyonları” şeklinde belirlenmiştir. ADF birim kök testleri serilerin seviye halde durağan değil ama birinci farkta durağan hale geldiğini göstermiştir. Granger Nedensellik testi sonuçları;

- Küresel sıcaklık anomalisinden borsa piyasa değerine,
- Sera gazı salınımından borsa piyasa değerine,
- Borsa piyasa değerinden sıcaklık ve emisyonlara doğru herhangi bir nedensellik ilişkisi tespit edilmemiştir.

Tüm olasılık değerleri 0,10’un üzerinde olduğundan yokluk hipotezleri kabul edilmiştir. Buna göre, eğer bozulan çevre şartları, yatırımcıları firmaları cezalandırmaya sevk etseydi ya da halka açık şirketler çevreye duyarlı davrandıkları için ödüllendirilselerdi, iklim ve finans arasında nedensellik ilişkisinin ortaya çıkması, diğer bir anlatımla bir iklime ait bilgilerin, gelişmelerin dünya borsalarında fiyatlanması gerekirdi. Gök & Yeldan (2025) araştırmasının bulguları bize neden her iklim ve finansa piyasalar arasında bir kopukluk olduğuna dair tatmin edici bir cevap verebilir. Çalışmaya göre, küresel bankalar hala daha fosil yakıt üreten şirketlere muazzam miktarda (yaklaşık 2 trilyon dolar) destek sağlamaya devam etmektedir. İkinci olarak, portföy şirketleri raporlarında sürdürülebilirliğe ve yeşil ekonomiye önem atfetmeler bile, portföylerinde hala karbon-yoğun sektörlerde faaliyette bulunan firmaların ağırlıkları yüksektir. Bracking & Leffel (2021) de iklim finansmanının piyasa odaklı karma finansman biçimlerine ve borç temelli finansmana doğru genişlemesinin, gücü piyasa aktörlerine kaydırıldığını ifade etmişlerdir. Dolayısıyla, iklim ve çevre ile alakalı

yatırımcılar farklı düşünmektedir. Bir kısım çevre ve iklimi finansal piyasalarda risk faktörü olarak görmez iken, diğer kısım ESG endekslerine dahil olan firmalara öncelik vermektedir. Bu yüzden de sanki her iki taraf birbirini nötr hale getirmiş gibi bir görüntü karşımıza çıkmaktadır. Bu açıklamalı destekleyen Bhandary vd.,(2021)' de yeşil tahviller için ortaklaşa kabul edilen, uygulanabilir uluslararası standartların eksikliğinin, bu tahvillerin gerçekten yeşil olup olmadığı sorusunu gündeme taşıdığını ifade etmiştir.

O halde denilebilir ki, dünya borsalarının performansı veya büyüklüğü iklime ait değişkenler ile açıklamaktan ziyade, finans literatürünün değişkenleri ile analiz yapmak daha akılcı olacaktır. Nitekim, Phan & To tarafından 2025 yılında yayımlanan çalışmaya göre bir şirketin piyasa değeri; entelektüel sermaye, satış büyümesi, kâr, finansal ve faaliyet kaldıracı ve finansal krizler doğrudan yabancı yatırım, enflasyon ve gayri safi yurtiçi hasıla ile yakından ilişkilidir.

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EK 1: Johansen eş-bütünleşme testi

Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None	0.387033	29.34849	29.79707	0.0563
At most 1	0.103670	6.344621	15.49471	0.6548
At most 2	0.025222	1.200633	3.841466	0.2732

BÖLÜM 5

E-COMMERCE EXPANSION AND PROVINCIAL SECTORAL RECOMPOSITION IN TURKIYE: SHIFT-SHARE TWFE EVIDENCE

Burcu KILINÇ SAVRUL¹

Giriş

E-commerce has become one of the most transformative forces in modern economies, reshaping production, consumption and markets. Business-to-consumer online transactions increased from US\$1.5 trillion in 2014 to US\$2.3 trillion in 2017 and were projected to reach almost US\$4.9 trillion by 2021, while cross-border e-commerce was expected to triple between 2015 and 2020 (Huria, 2019). Digital technologies underpinning this expansion reduce production and transaction costs, support economies of scale, foster innovation and expand export baskets (International Monetary Fund et al., 2023). Digitally delivered services have quadrupled since 2005 and now account for more than half of total services exports (International Monetary Fund et al., 2023). These trends suggest that e-commerce should be understood not only as online

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shopping, but as a broader digital-trade shock with consequences for local economic structure.

The sectoral implications of this shock extend beyond retail. Online orders are smaller and more volatile than conventional wholesale deliveries, requiring flexible last-mile distribution networks and creating a tension between shipment consolidation and rapid individual delivery (Dablanc & Rodrigue, 2024). E-commerce distribution centres require more than three times the logistics space of conventional warehouses because they must accommodate product variety, buffer stock, individual order picking and reverse logistics (Huria, 2019). Scarce urban land has pushed fulfilment centres toward ports and highway junctions, generating logistics sprawl, truck traffic and congestion (Asmussen et al., 2024), while fulfilment-network densification can generate shipping cost savings, as shown by Amazon's expansion in the United States (Houde et al., 2021). E-commerce also interacts with knowledge-intensive services and platform-based industries by enabling remote delivery, SME participation and upgrading toward more sophisticated service activities (Akiwumi, 2022; International Monetary Fund et al., 2023).

Existing empirical evidence shows that e-commerce has important labour-market and distributional effects but leaves a narrower question unresolved. Bauer and Fernández Guerrico (2023) show that e-commerce expansion decreases employment and wages in transportation and warehousing while shifting retail employment from small brick-and-mortar shops to warehouse clubs and supercentres. Houde et al. (2021) document economies of density in Amazon's fulfilment-network expansion, while Chava et al. (2022) find that fulfilment centres reduce local retail employment growth and lower hourly retail wages. These studies identify effects within retail and logistics, but not whether e-commerce changes enterprise composition across a regional economy.

This paper addresses that gap by asking whether e-commerce expansion leads to provincial sectoral recomposition in Türkiye, defined as shifts in the relative prevalence of different enterprise types, rather than only changes in employment or sales. The central research question is whether provinces with stronger pre-2019 exposure to e-commerce-compatible activities experienced greater sectoral recomposition during the national e-commerce surge. Türkiye is relevant because e-commerce expanded rapidly after 2019, following regulatory reforms and widespread adoption of digital payment platforms, while provinces differed in their pre-existing consumer services, logistics capabilities and knowledge-intensive firms. These differences may shape how local economies absorb the national digital-trade shock.

The empirical strategy combines a national e-commerce shock with provincial pre-exposure measures in a shift-share two-way fixed-effects design. The shock is derived from Ministry of Trade data on e-commerce transactions over 2019–2024 and is common across provinces. Pre-exposure is measured using 2015–2018 enterprise shares in e-commerce-compatible sectors, including consumer services, transport-storage, information and communication technologies and professional services. Interacting the national shock with provincial pre-exposure yields a province-specific treatment, following Bartik, or shift-share, designs used in trade and labour studies (Borusyak et al., 2024). The analysis uses provincial enterprise data to examine sectoral shares and aggregate diversification outcomes.

The paper contributes by extending the e-commerce literature from employment, wages and sales toward enterprise-sector recomposition in an emerging-market provincial setting. It shows how a national digital-trade shock interacts with heterogeneous local preconditions, linking digitalisation, regional exposure and structural transformation. The results indicate stronger

provincial diversification and a relative expansion of consumer-facing services in more exposed provinces, while wholesale and retail enterprises do not increase significantly. Transport and storage enterprises decline, consistent with consolidation and economies of scale in logistics. These findings suggest that e-commerce fosters service-channel adjustment and diversification rather than a simple retail boom.

The remainder of this article is organised as follows. Section 2 establishes the theoretical framework and literature review. Section 3 outlines the data and econometric specification, while Section 4 presents the empirical results and robustness checks. Section 5 discusses the underlying mechanisms and study limitations, and Section 6 offers concluding remarks.

Literature Review and Theoretical Background

The following section reviews the literature linking e-commerce, digitalisation and regional economic restructuring, then develops the exposure-based framework used to examine provincial sectoral recomposition in Türkiye.

E-Commerce, Digitalisation and Local Economic Restructuring

E-commerce is both a manifestation and a driver of digitalisation. Digital technologies reduce transaction and production costs, support scale economies, facilitate innovation and expand export baskets (Savrul & Kılıç, 2011). Global B2C and cross-border e-commerce expanded rapidly after 2015, while digitally delivered services quadrupled between 2005 and 2022 and accounted for 54% of global services exports (Huria, 2019; International Monetary Fund et al., 2023). E-commerce is therefore a wider digital-trade shock affecting production, consumption and enterprise structures.

Its organisational effects are visible in retail and logistics. Online orders are smaller, heterogeneous and time-sensitive, requiring a balance between consolidation, rapid delivery and returns (Dablanc & Rodrigue, 2024). Distribution centres require more than triple the logistics space of conventional warehouses. Scarce urban land pushes fulfilment centres toward ports and highways, generating logistics sprawl, truck traffic and congestion (Asmussen et al., 2024). Network densification can reduce shipping costs, but gains are uneven (Houde et al., 2021). Evidence shows reduced transportation and warehousing employment and wages, shifts toward warehouse clubs and supercentres, and lower local retail employment growth and wages (Bauer & Fernández Guerrico, 2023; Chava et al., 2022). E-commerce is not a simple substitute for physical retail; restructuring reflects a format tug-of-war between online retail and warehouse-style formats (Hortaçsu & Syverson, 2015).

E-commerce also restructures services and governance conditions. Digital platforms allow small firms and freelancers to reach wider markets, but benefits depend on infrastructure, skills and regulation (International Monetary Fund et al., 2023). Digitalisation can support structural transformation through infrastructure investment, better regulation and integration of knowledge- and technology-based services into productive sectors (Akiwumi, 2022). Innovation clusters, digital skills and globally connected knowledge-intensive services shape regional diversification and upgrading (Demin et al., 2023; Dinh & El Aynaoui, 2026). E-commerce creates convenience and variety gains that differ by income and county density (Dolfen et al., 2023), while cross-border activity depends on trust, delivery reliability, payment security, customs procedures, consumer protection and data privacy, especially for SMEs (Ahi et al., 2023). Overall, e-commerce densifies logistics, reorganises retail formats, stimulates consumer-facing and knowledge-intensive

services, and deepens regional divides where digital capabilities differ.

Regional Exposure to Common Shocks

The heterogeneous regional effects of national or global shocks are central to economic geography and labour economics. Bartik-style, or shift-share, approaches model regional outcomes as the product of a common shock and region-specific exposure, usually measured through predetermined industry or worker shares. The classic example is the China shock, where U.S. labour markets with higher initial shares of import-competing manufacturing were more adversely affected by rising Chinese imports (Borusyak et al., 2024). Autor et al. (2013) show that exposure to Chinese import competition produced persistent local job losses and wage declines, and Autor et al. (2016) emphasise sluggish adjustment caused by reallocation frictions, capital specificity and limited mobility. The key insight is that regional vulnerability depends on sectoral composition, human capital and institutional structures.

E-commerce represents a comparable common shock for Türkiye. The national expansion of online commerce is driven by broad technological progress, regulatory reforms and consumer preferences that affect all provinces, but provinces differ in their pre-2019 enterprise structures. Some have diversified service sectors, ICT firms and logistics networks; others rely more heavily on traditional retail, agriculture or local services. The shift-share logic implies that the effect of the e-commerce shock depends on initial exposure to e-commerce-compatible sectors. Provinces with higher shares of consumer services, transport-storage, ICT and professional services may be better positioned to attract new enterprise formation, while provinces lacking these capabilities may adjust more slowly or decline. This is consistent with regional-resilience arguments that innovation clusters, digital skills and globally connected services

condition the ability of regions to absorb digital transformations (Demin et al., 2023; Dinh & El Aynaoui, 2026).

Rationale for the Shift-Share TWFE Design

Evaluating sectoral recomposition requires a design that captures a common shock while exploiting cross-provincial variation in exposure. The shift-share framework provides this design by interacting national e-commerce growth with predetermined provincial exposure based on lagged enterprise shares. Borusyak et al. (2024) explain that this identifies the average effect of a shock when the shock is exogenous and exposure shares are predetermined, while requiring attention to correlations between exposure and unobserved confounders. In this study, the national shock is common to all provinces, while pre-exposure uses 2015–2018 enterprise shares in e-commerce-compatible sectors. Their interaction creates a province-specific treatment, while the TWFE model controls for province and year fixed effects.

Recent methodological work motivates caution. Adão et al. (2019) show that regions with similar exposure shares may have correlated residuals, making robust or clustered standard errors understate uncertainty. Goldsmith-Pinkham et al. (2020) emphasise the exogeneity of initial shares and recommend balance tests, pre-trend analysis and diagnostics. de Chaisemartin and D’Haultfœuille (2020) show that TWFE estimates may be difficult to interpret when effects vary across groups or over time. Since the Turkish treatment is continuous and sectoral effects are heterogeneous, the estimates are read as average exposure-based associations rather than structural effects.

Conceptual Framework and Hypothesis Development

The literature suggests five channels linking e-commerce expansion to provincial enterprise recomposition. First, wholesale and retail adjustment occurs because online shopping substitutes for

in-store purchases. U.S. evidence that fulfilment centres reduce retail employment and wages and shift activity toward warehouse clubs and supercentres suggests that Türkiye should not necessarily experience a large increase in retail enterprises despite rising online spending (Bauer & Fernández Guerrero, 2023; Chava et al., 2022). Second, transport-storage restructuring reflects competing forces. E-commerce increases logistics demand, yet economies of density may consolidate distribution networks and reduce the number of small logistics firms, even if large facilities expand (Asmussen et al., 2024; Houde et al., 2021).

Third, consumer-service complementarity arises because time saved from online shopping can increase demand for leisure, dining and personal services. Chava et al. (2022) find that fulfilment-centre openings coincide with restaurant employment gains, and Chun et al. (2023), using more than 30 billion Korean credit-card transactions, show that rising online spending reduced offline retail employment while shifting some employment toward restaurants and personal services, especially in metropolitan areas. Fourth, knowledge- and business-service upgrading follows from digital platforms creating opportunities for ICT, professional services and other knowledge-intensive activities where digital infrastructure and capabilities already exist (Akiwumi, 2022; Dinh & El Aynaoui, 2026). Finally, aggregate diversification captures the possibility that digital platforms lower entry barriers and allow small firms to reach wider markets. However, diversification may remain limited in provinces lacking digital capabilities or facing rigid land and labour markets.

Based on these channels, the study develops five empirical expectations. First, e-commerce exposure is expected to have no large positive effect on wholesale and retail enterprise shares, because online commerce may substitute for in-store activity and centralise retail transactions. Second, its effect on transport and

storage enterprises is expected to be ambiguous, since rising logistics demand may coexist with consolidation among larger providers. Third, e-commerce exposure is expected to increase consumer-facing services through consumption complementarity. Fourth, provinces with stronger pre-existing ICT, professional and business-service bases are expected to experience stronger knowledge- and business-service upgrading. Fifth, e-commerce exposure is expected to be associated with broader aggregate diversification, reflected in lower sectoral concentration and higher entropy.

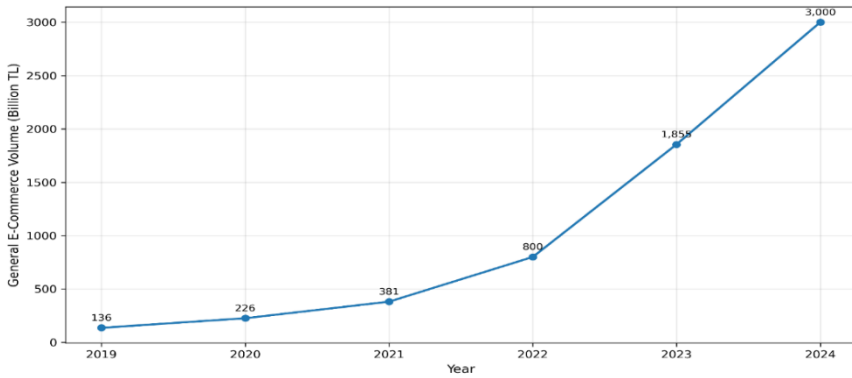
Data and Methodology

This study treats the rapid expansion of e-commerce in Türkiye as a national digital-trade shock and examines whether provinces with a larger pre-2019 share of enterprises in e-commerce-compatible activities experienced stronger sectoral recomposition. The empirical motivation follows evidence that e-commerce growth can alter local labour demand and reshape the composition of retail, logistics and service employment (Bauer & Fernández Guerrero, 2023; Chava et al., 2022). A similar mechanism is relevant for Türkiye, where national e-commerce transactions increased sharply between 2019 and 2024, while provinces differed substantially in their pre-existing enterprise structures and capacity to absorb digital trade opportunities.

The empirical analysis uses a balanced panel of 81 NUTS-3 provinces observed annually from 2019 to 2024. The outcome data are provincial counts of enterprises by NACE Rev. 2 sectors from the Turkish Statistical Institute (TurkStat, 2026) Regional Statistics database. The sample is restricted to 2019–2024 because these are the years for which complete provincial enterprise counts and control variables are available. Four provincial controls are also obtained from the same source: lagged log GDP per capita, lagged population density, lagged share of higher-education graduates and

lagged logistics accessibility, proxied by the log of road and motorway length. A balanced panel check confirms 486 province-year observations, corresponding to 81 provinces observed over six years, with no missing values.

Figure 1. National E-Commerce Expansion in Türkiye, 2019-2024



Note. The figure shows national general e-commerce volume in billion Turkish lira. The 2019-2024 period is used because the provincial enterprise-structure panel ends in 2024. Source: Author's visualization based on national general e-commerce volume data reported in Türkiye'de E-Ticaretin Görünümü Raporu 2025 (Republic of Türkiye Ministry of Trade, 2025).

The national e-commerce data are taken from the Ministry of Trade's Türkiye'de E-Ticaretin Görünümü Raporu 2025, which provides annual time series for general and retail e-commerce volumes (Republic of Türkiye Ministry of Trade, 2025). Figure 1 presents the national general e-commerce volume over 2019–2024 and illustrates the scale of the national digital-trade expansion used to construct the shock variable.

Sector Aggregation and Dependent Variables

The original enterprise data comprise 18 NACE Rev. 2 sectors. To avoid fragmented estimates and improve interpretability, the sectors are aggregated into seven analytically meaningful groups corresponding to the main channels through which e-commerce may affect provincial enterprise structures. As shown in Table 1, these groups are primary and extractive activities; industry and utilities; construction and real estate; wholesale and retail trade; transport and storage; consumer-facing services; and knowledge, business and institutional services. They respectively capture traditional activities with limited direct digital exposure, industrial and infrastructure-related activities, built-environment and property-related activities, direct commercial intermediation, logistics and fulfilment, local consumption and personal services, and digital, professional, institutional and knowledge-intensive services.

Table 1. Aggregation of Enterprise Sectors into Seven Main Sector Groups

Main sector group	Original enterprise sectors included	Analytical interpretation
Primary and extractive activities	Agriculture, forestry and fishing; mining and quarrying	Traditional activities with limited direct digital exposure
Industry and utilities	Manufacturing; electricity, gas, steam and air conditioning supply; water supply, sewerage and waste management	Industrial production and infrastructure-related activities
Construction and real estate	Construction; real estate activities	Built-environment and property-related activities
Wholesale and retail trade	Wholesale and retail trade; repair of motor vehicles and motorcycles	Direct commercial intermediation channel most visibly affected by e-commerce
Transport and storage	Transportation and storage	Logistics, fulfilment and distribution channel

Consumer-facing services	Accommodation and food service activities; arts, entertainment and recreation; other service activities	Local consumption, hospitality, leisure and personal-service activities
Knowledge, business and institutional services	Information and communication; financial and insurance activities; professional, scientific and technical activities; administrative and support service activities; education; human health and social work activities	Digital, professional, institutional and knowledge-intensive service base

Note. The table reports the aggregation of the original 18 NACE Rev. 2 enterprise sectors into seven analytically meaningful sector groups. Sector shares are calculated as the number of enterprises in each group divided by total provincial enterprises. Source: Author's aggregation based on TurkStat provincial enterprise data.

The dependent variables are calculated as the share of enterprises in each aggregated sector group within total provincial enterprises. This construction focuses the analysis on relative sectoral composition rather than absolute enterprise growth. Since the seven sectoral shares sum to one, an increase in one group's share necessarily corresponds to a relative decline in one or more other groups. The aggregation therefore supports the study's central aim of examining provincial sectoral recomposition, while reducing noise from small sectors and avoiding separate, less interpretable models for all 18 original NACE Rev. 2 sectors.

E-Commerce Shock and Provincial Pre-Exposure

The national e-commerce shock captures the common time-varying component of Türkiye's e-commerce expansion. In the baseline specification, the shock is constructed from national general e-commerce volume measured in nominal billion Turkish lira, as reported in the Ministry of Trade's Türkiye'de E-Ticaretin

Görünümü Raporu 2025. Let EComVolume_t denote national general e-commerce volume in nominal billion TL in year t. The baseline shock is defined as the log change in national general e-commerce volume relative to 2019:

$$\text{EComShock}_t = \ln\left(\frac{\text{EComVolume}_t}{\text{EComVolume}_{2019}}\right). \quad (1)$$

This definition normalizes the shock to zero in 2019 and measures proportional growth in the nominal e-commerce market thereafter. In the analysis dataset, the shock rises from 0 in 2019 to approximately 3.09 in 2024, reflecting the sharp increase in reported national e-commerce volume during the sample period. Because the shock is measured in nominal TL, it should be interpreted as capturing the expansion of the observed e-commerce market rather than a purely real-volume shock. For this reason, the empirical analysis also evaluates alternative shock definitions based on retail e-commerce volume and transaction counts, which are less directly affected by price-level changes.

The pre-exposure variable measures the extent to which each province had an enterprise structure compatible with e-commerce before the national shock. Let Enterprises_{ics} denote the number of enterprises in province *i*, sector *c*, and baseline year *s*, and let TotalEnterprises_{is} denote total enterprises in province *i* and year *s*. The baseline share of sector *c* in province *i*, averaged over 2015–2018, is calculated as:

$$z_{ic0} = \frac{1}{4} \sum_{s=2015}^{2018} (\text{Enterprises}_{ics} / (\text{TotalEnterprises}_{is})). \quad (2)$$

Provincial pre-exposure is then defined as the sum of baseline shares in e-commerce-compatible sectors:

$$\text{PreExposure}_i = \sum_{(c \in C)} z_{ic0}, \quad (3)$$

where C denotes the set of e-commerce-compatible activities, including wholesale and retail trade, transport and storage, consumer-facing services, information and communication, professional services and administrative support. This formulation follows the logic of shift-share designs, where predetermined local shares measure differential exposure to a common shock (Borusyak et al., 2022; Goldsmith-Pinkham et al., 2020). In the empirical tables and figures, PreExposure_i is reported as a percentage for readability, although it is conceptually defined as a share.

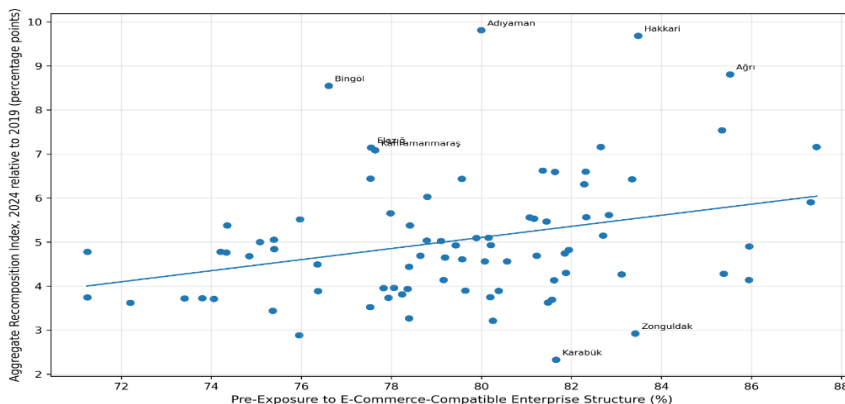
The shift-share treatment variable is constructed by interacting the national e-commerce shock with predetermined provincial pre-exposure:

$$\text{ShiftShare}_{it} = \text{EComShock}_t \times \text{PreExposure}_i. \quad (4)$$

This variable increases over time as national e-commerce expands and takes larger values for provinces that had more e-commerce-compatible enterprise structures before 2019. Because the e-commerce shock is common across provinces, the identifying variation comes from cross-provincial differences in predetermined exposure rather than from province-specific e-commerce shocks. The variable therefore measures the intensity with which the national digital-trade shock is transmitted to each province through its pre-existing enterprise structure.

Figure 2 plots provincial pre-exposure against the aggregate recomposition index between 2019 and 2024. The figure shows how provinces with different initial exposure levels experienced different degrees of sectoral redistribution during the e-commerce expansion, while the fitted line provides a visual summary of the positive association between pre-exposure and aggregate recomposition.

Figure 2. Provincial Pre-Exposure and Aggregate Sectoral Recomposition in Türkiye, 2019-2024



Note. The figure plots the 2015–2018 average provincial share of e-commerce-compatible enterprises against the aggregate recomposition index between 2019 and 2024. The aggregate recomposition index equals one-half of the sum of absolute deviations between 2024 and 2019 sectoral enterprise shares. The fitted line summarizes the association between pre-exposure and recomposition. Selected provinces with relatively high or low recomposition values are labelled. Source: Author’s calculations from the shift-share TWFE model-ready dataset.

Econometric Specification, Identification and Robustness

The choice of a shift-share framework is motivated by identification concerns. A simple comparison of provincial sector shares with contemporary e-commerce intensity would confound the effect of the national shock with persistent differences in provincial economic structure. By interacting a common time-varying shock with predetermined provincial exposure, the shift-share approach exploits cross-provincial variation in sensitivity to the same national shock. This design is consistent with recent methodological work that interprets shift-share regressions as quasi-experimental designs

in which shocks are plausibly exogenous while exposure shares may require careful assessment (Borusyak et al., 2022).

For each aggregated sector k , the following two-way fixed-effects model is estimated:

$$Y_{it}^k = \alpha_i + \lambda_t + \beta_k \text{ ShiftShare}_{it} + \gamma^T X_{(i,t-1)} + \varepsilon_{it}. \quad (5)$$

Here, Y_{it}^k is the share of enterprises in sector k in province i and year t . Province fixed effects, α_i , absorb time-invariant provincial characteristics such as geography and historical development, while year fixed effects, λ_t , absorb national shocks common to all provinces, including macroeconomic conditions and the COVID-19 period. The vector $X_{(i,t-1)}$ includes lagged log GDP per capita, population density, higher-education share and logistics accessibility. Lagging the controls helps mitigate reverse causation. The coefficient of interest, β_k , captures whether provinces with higher pre-2019 exposure experienced different changes in sectoral enterprise shares as national e-commerce expanded.

The identification assumption is that, after conditioning on province and year fixed effects and lagged controls, provinces with higher and lower pre-2019 e-commerce exposure would have followed similar sectoral trajectories in the absence of the national e-commerce expansion. This assumption is analogous to the parallel-trend logic in difference-in-differences designs. It requires that differential exposure is not systematically related to unobserved post-2019 shocks affecting sectoral shares. Given methodological concerns in shift-share designs, the analysis also acknowledges that residuals may be correlated across provinces with similar exposure shares. Adão et al. (2019) show that conventional inference may understate uncertainty when regions with similar sectoral shares have correlated residuals. Borusyak et al. (2022) further show that shock-level approaches can provide valid inference when shocks are

quasi-random, although the short panel used here is not suitable for implementing shock-level inference.

Standard errors are clustered at the provincial level to account for serial correlation and heteroskedasticity. Robustness tests examine alternative definitions of the national shock, including retail e-commerce volume and transaction counts; alternative exposure definitions, including 2018 exposure alone; exclusion of İstanbul, Ankara and İzmir; weighted regressions using total enterprises in 2019; and specifications with NUTS-2 region–year fixed effects. Multicollinearity is assessed through variance inflation factors after centring the shift-share term. Identification validity is further evaluated through baseline balance tests, pre-trend tests using the 2015–2018 period and placebo shift-share tests assigning a pseudo shock before 2019. These checks determine whether the estimated coefficients should be interpreted as credible exposure-based effects or more cautiously as exposure-based associations.

Empirical Results

Before turning to the econometric estimates, this section first presents the descriptive patterns in provincial sectoral recomposition during the 2019–2024 e-commerce expansion period.

Descriptive Evidence on Sectoral Recomposition

Table 2 reports the descriptive statistics for the seven aggregated sectoral enterprise shares, the shift-share components and the control variables over 2019–2024. The descriptive patterns indicate that provincial enterprise structures changed noticeably during the e-commerce boom. Knowledge, business and institutional services increased by 2.07 percentage points, while construction and real estate increased by 1.87 percentage points. By contrast, consumer-facing services, transport and storage, and wholesale and retail trade declined by 2.05, 1.26 and 0.81 percentage points, respectively. These descriptive changes suggest that the average

provincial enterprise structure shifted away from traditional commerce, transport-storage and consumer-facing services, while the relative shares of knowledge, business and institutional services and construction-real estate increased during the sample period.

Table 2. Descriptive Statistics and Sectoral Recomposition, 2019–2024

Variable	Mean	SD	2019 Mean	2024 Mean	Change, 2019–2024
Panel A. Sectoral enterprise shares (%)					
Primary and extractive activities	1.52	0.90	1.46	1.54	0.08
Industry and utilities	10.00	2.22	9.82	9.93	0.11
Construction and real estate	8.60	1.95	7.54	9.40	1.87
Wholesale and retail trade	34.24	3.41	34.23	33.41	-0.81
Transport and storage	14.95	3.26	15.97	14.72	-1.26
Consumer-facing services	21.06	3.64	22.40	20.35	-2.05
Knowledge, business and institutional services	9.62	2.38	8.58	10.65	2.07
Panel B. E-commerce exposure variables					
Pre-exposure to e-commerce-compatible	79.44	3.58	79.44	79.44	0.00

structure (%)					
National e-commerce shock, log change from 2019	1.50	1.11	0.00	3.09	3.09
Panel C. Lagged control variables					
Log GDP per capita	11.11	0.77	10.39	12.30	1.92
Population density	133.66	333.32	130.19	136.00	5.82
Higher education graduate share (%)	15.60	2.95	13.88	16.91	3.03
Logistics accessibility	6.60	0.55	6.59	6.60	0.01

Note. The sample is a balanced panel of 81 NUTS-3 provinces observed from 2019 to 2024. Sectoral variables are expressed as percentages of total provincial enterprises and are based on the seven-sector aggregation described in Table 1. The pre-exposure variable is time-invariant by construction and equals the 2015–2018 average provincial share of e-commerce-compatible enterprises. The national e-commerce shock is measured as the log change in national general e-commerce volume in nominal billion TL relative to 2019. Control variables are lagged by one year. Change is calculated as the 2024 mean minus the 2019 mean. Source: Author’s calculations based on TurkStat provincial enterprise data and Ministry of Trade e-commerce data.

The descriptive evidence also confirms the relevance of the exposure design. The average pre-exposure share of e-commerce-compatible enterprises is 79.4%, showing that a large part of provincial enterprise structures consisted of sectors that could

theoretically complement or compete with e-commerce. At the same time, the pre-exposure measure varies substantially across provinces. Figure 1 shows the sharp increase in national e-commerce volume between 2019 and 2024, while Figure 2 links provincial pre-exposure to the aggregate recomposition index. The scatter plot shows that provinces differed not only in their pre-2019 exposure to e-commerce-compatible enterprise structures, but also in the extent of sectoral redistribution observed by 2024. This variation is central to the empirical strategy because the shift-share variable combines the common national e-commerce shock with province-specific pre-exposure, while the recomposition index provides an aggregate outcome for assessing structural change.

Identification Checks

Table 3 reports three identification checks: baseline balance tests, pre-trend tests and placebo shift-share tests.

Table 3. Identification Checks: Baseline Balance, Pre-Trends and Placebo Tests

Panel A. Baseline balance by pre-exposure group, 2018/2019				
Variable	Low-exposure mean	High-exposure mean	Difference	p-value
Log GDP per capita, 2018	10.546	10.229	-0.317	<0.001
Population density, 2018	189.425	72.390	-117.035	0.104
Higher education graduate share, 2018 (%)	14.730	13.045	-1.684	0.003
Logistics accessibility, 2018	6.732	6.455	-0.276	0.022
Log total enterprises, 2019	10.559	9.548	-1.011	<0.001
Panel B. Pre-trend tests, 2015–2018				
Dependent variable	Pre-exposure × pre-trend		Clustered SE	p-value

Primary and extractive activities share (%)	0.157	0.268	0.560
Industry and utilities share (%)	1.670	0.369	<0.001
Construction and real estate share (%)	0.508	0.578	0.382
Wholesale and retail trade share (%)	-1.516	0.819	0.068
Transport and storage share (%)	-2.227	0.933	0.019
Consumer-facing services share (%)	1.286	0.673	0.060
Knowledge, business and institutional services share (%)	0.122	0.442	0.783
Panel C. Placebo shift-share tests, 2015–2018			
Dependent variable	Placebo shift-share coefficient	Clustered SE	p-value
Primary and extractive activities share (%)	0.249	0.447	0.579
Industry and utilities share (%)	2.767	0.619	<0.001
Construction and real estate share (%)	1.014	0.993	0.311
Wholesale and retail trade share (%)	-2.656	1.369	0.056
Transport and storage share (%)	-3.683	1.564	0.021
Consumer-facing services share (%)	2.057	1.136	0.074
Knowledge, business and institutional services share (%)	0.252	0.733	0.732

Note. Panel A compares provinces below and above the median value of pre-exposure to e-commerce-compatible enterprise structure. The difference is calculated as the high-exposure mean minus the low-exposure mean. Panel B reports pre-trend tests for 2015–2018, where each sectoral enterprise share is regressed on the interaction between pre-exposure and a linear pre-trend. Panel C

reports placebo shift-share tests for 2015–2018 using a pseudo e-commerce shock before the main sample period. Standard errors are clustered at the provincial level. Source: Author’s calculations based on TurkStat provincial enterprise data and Ministry of Trade e-commerce data.

Panel A compares provinces above and below the median level of pre-exposure. High-exposure provinces had significantly lower log GDP per capita, higher-education graduate shares, logistics accessibility and log total enterprises than low-exposure provinces, while the difference in population density was negative but not statistically significant. These results indicate that pre-exposure is correlated with several provincial characteristics and is therefore not randomly distributed. Since the TWFE models include province fixed effects and lagged controls for GDP per capita, population density, higher education and logistics accessibility, these baseline differences mainly justify the controlled specification, but they also require cautious interpretation.

Panel B presents the pre-trend tests for 2015–2018. The interaction between pre-exposure and the linear pre-trend is statistically insignificant for primary and extractive activities, construction and real estate, and knowledge, business and institutional services. This supports the parallel-trend assumption more clearly for these sectors. By contrast, industry and utilities show a positive and statistically significant pre-trend, while transport and storage show a negative and statistically significant pre-trend. Wholesale and retail trade and consumer-facing services display marginal pre-treatment differences. These mixed results imply that the causal interpretation of the shift-share TWFE estimates should be cautious, especially for sectors with significant pre-trends.

Panel C reports placebo shift-share tests for the same pre-treatment period. The placebo coefficients are statistically insignificant for primary and extractive activities, construction and

real estate, and knowledge, business and institutional services. However, placebo effects are statistically significant for industry and utilities and transport and storage, while wholesale and retail trade and consumer-facing services again show marginal placebo patterns. Overall, the identification checks suggest that the results should primarily be interpreted as exposure-based associations, with stronger credibility for sectors where pre-trend and placebo tests do not indicate systematic pre-existing differences.

Main Shift-Share TWFE Estimates

The sector-specific TWFE estimates show that e-commerce exposure is associated with a selective pattern of provincial sectoral recomposition rather than a uniform expansion across all e-commerce-related activities. The estimated interaction between the national e-commerce shock and provincial pre-exposure is positive and statistically significant for industry and utilities, construction and real estate, and consumer-facing services, while it is negative and statistically significant for transport and storage. By contrast, the coefficients for primary and extractive activities, wholesale and retail trade, and knowledge, business and institutional services are statistically insignificant. This pattern indicates that the adjustment associated with e-commerce exposure operates through specific parts of the provincial enterprise structure.

Table 4. Main Shift-Share TWFE Estimates

Regressor	Primary and extractive	Industry and utilities	Construction and real estate	Wholesale and retail	Transport and storage	Consumer-facing services	Knowledge, business and institutional services
E-commerce shock × pre-exposure	0.608 (0.459)	1.803*** (0.579)	2.419** (1.143)	1.582 (1.528)	-12.417*** (1.623)	5.798** (1.138)	0.208 (0.664)

Log GDP per capita, lagged	0.049 (0.142)	-0.434 (0.361)	1.178* (0.665)	-1.111 (0.705)	1.270 (0.956)	-0.907 (0.663)	-0.045 (0.315)
Population density, lagged	0.000 (0.001)	-0.001 (0.004)	-0.008** (0.003)	0.002 (0.005)	0.008 (0.005)	0.001 (0.003)	-0.002 (0.003)
Higher education share, lagged	-0.065 (0.040)	-0.310 (0.190)	-0.316** (0.155)	0.048 (0.196)	0.418 (0.309)	0.144 (0.221)	0.080 (0.108)
Logistics accessibility, lagged	0.346 (0.450)	-0.251 (0.944)	1.348 (2.003)	-1.822 (1.527)	0.870 (2.425)	0.351 (1.867)	-0.842 (1.251)
Province fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	486	486	486	486	486	486	486
Provinces	81	81	81	81	81	81	81
Within R ²	0.078	0.337	0.570	0.413	0.583	0.796	0.898

Note. Dependent variables are sectoral enterprise shares expressed in percentage points. Each column reports a separate two-way fixed-effects regression. Standard errors clustered at the provincial level are reported in parentheses. All models include province and year fixed effects and lagged controls. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Source: Author's calculations based on TurkStat provincial enterprise data and Ministry of Trade e-commerce data.

The positive coefficients for industry and utilities and construction and real estate are 1.803 and 2.419, respectively. These estimates suggest more favourable relative changes in these sectors among provinces with higher pre-2019 exposure. However, the industry and utilities result should be interpreted as an association

rather than a strict causal effect because the pre-trend tests show significant pre-existing differences. The construction and real estate coefficient may reflect a relative shift toward built-environment and property-related activities in more exposed provinces, possibly connected to warehousing, fulfilment facilities and commercial real estate demand, although this channel weakens in some robustness checks.

The strongest positive result appears for consumer-facing services, where the coefficient is 5.798 and statistically significant at the 1% level. This indicates that provinces with higher pre-2019 exposure experienced a more favourable relative trajectory in accommodation, food services, entertainment and other personal services. This result is especially important because the descriptive statistics show that the average consumer-facing service share declined between 2019 and 2024. The TWFE estimate therefore captures a relative exposure-related difference across provinces, not an unconditional national increase in this sector. This finding supports the argument that e-commerce can complement local consumption services rather than simply substitute offline commerce. It is also consistent with evidence that cross-border e-commerce can promote digital technology innovation and producer-service agglomeration (Chen et al., 2024), and with broader evidence that digitalisation supports new service activities and business models (Chen, 2024).

The transport and storage coefficient is negative, large and highly significant, at -12.417. Although e-commerce depends on logistics, this result is more cautiously interpreted as consistent with consolidation and scale effects rather than as evidence that logistics activity itself declined. Finally, the insignificant wholesale and retail coefficient, 1.582, shows that provinces with higher exposure did not experience a statistically distinguishable relative increase in the wholesale-retail enterprise share. The insignificant coefficient for

knowledge, business and institutional services, 0.208, likewise indicates that this sector's descriptive growth is not systematically linked to e-commerce exposure after fixed effects and controls are included.

Robustness of Sector-Specific Results

Table 5 reports robustness checks based on alternative shock definitions, an alternative exposure measure, exclusion of dominant metropolitan provinces, enterprise-weighted regressions and NUTS-2 region-year fixed effects.

Table 5. Robustness of the Shift-Share TWFE Estimates

Specific ation	Primary and extractive	Industry and utilities	Construction and real estate	Whole sale and retail	Transport and storage	Consumer- facing services	Knowledge, business and institutional services
Baseline	0.608 (0.459)	1.803 *** (0.579)	2.419** (1.143)	1.582 (1.528)	- 12.417*** (1.623)	5.798** * (1.138)	0.208 (0.664)
Alternative shock: retail e-commerce volume	0.613 (0.466)	1.899 *** (0.583)	2.500** (1.146)	1.535 (1.535)	- 12.629*** (1.637)	5.815** * (1.153)	0.268 (0.673)
Alternative shock: transaction count	1.396 (0.972)	4.555 *** (1.281)	5.330** (2.389)	2.581 (3.258)	- 27.110*** (3.497)	11.805 *** (2.540)	1.442 (1.543)
Alternative exposure : 2018	0.706 (0.592)	1.497 ** (0.661)	2.804** (1.327)	1.461 (1.807)	- 12.671*** (2.008)	6.087** * (1.259)	0.117 (0.762)

broad exposure							
Excluding Istanbul	0.624 (0.507)	2.043*** (0.633)	2.360* (1.241)	1.307 (1.614)	- 12.424*** (1.730)	5.784** * (1.202)	0.306 (0.717)
Excluding Istanbul, Ankara and İzmir	0.641 (0.562)	1.878*** (0.666)	2.029 (1.311)	1.316 (1.739)	- 12.425*** (1.812)	6.281** * (1.186)	0.280 (0.771)
Weighted by 2019 total enterprises	0.566* (0.287)	1.946*** (0.646)	4.522*** (0.917)	-1.494 (1.609)	- 10.395*** (1.943)	3.593** * (1.237)	1.262** (0.552)
NUTS-2 year fixed effects	1.232 (0.825)	0.135 (0.956)	0.385 (1.870)	-2.391 (2.501)	- 4.509* (2.595)	5.206** * (1.882)	-0.058 (0.900)

Note. Entries report the coefficient on the shift-share treatment variable. Dependent variables are sectoral enterprise shares expressed in percentage points. Standard errors clustered at the provincial level are reported in parentheses. All specifications include province fixed effects and lagged controls. The weighted specification uses 2019 total enterprises as time-invariant province weights. The NUTS-2 specification includes NUTS-2 region-year fixed effects. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Source: Author's calculations based on TurkStat provincial enterprise data and Ministry of Trade e-commerce data.

The robustness evidence shows that the consumer-facing services result is the most stable sector-specific finding. The coefficient remains positive and statistically significant in every specification, ranging from 3.593 in the weighted regression to 11.805 when the national shock is measured by transaction counts. This stability indicates that the positive association between e-

commerce exposure and consumer-facing services does not depend on the baseline shock definition, the baseline exposure measure, the inclusion of major metropolitan provinces, or the weighting scheme. The negative coefficient for transport and storage is broadly consistent across specifications. It remains statistically significant in all robustness models, ranging from -27.110 under the transaction-count shock to -4.509 when NUTS-2 region-year fixed effects are included. Although its magnitude declines after absorbing region-specific annual shocks, the sign and statistical significance remain consistent.

The metropolitan exclusion tests further show that the main pattern is not driven only by İstanbul, Ankara and İzmir. Excluding İstanbul alone produces estimates close to the baseline, while excluding all three dominant metropolitan provinces leaves consumer-facing services positive and highly significant and transport and storage negative and highly significant. The enterprise-weighted specification changes some secondary results, strengthening construction and real estate and making knowledge, business and institutional services positive and significant, but it does not overturn the central consumer-facing services finding. By contrast, when NUTS-2 region-year fixed effects are introduced, the positive coefficients for industry and utilities and construction and real estate disappear, and the transport and storage coefficient weakens to marginal significance. Overall, the robustness checks support a selective main interpretation: e-commerce exposure is most consistently associated with recomposition toward consumer-facing services and with a lower transport-storage enterprise share, whereas the industry and construction results are more fragile.

Aggregate Sectoral Recomposition

Beyond individual sector shares, Table 6 examines whether e-commerce exposure is associated with broader changes in

provincial enterprise structures. It reports three aggregate outcomes: the Herfindahl-Hirschman Index, Shannon entropy, and an aggregate recomposition index, defined as one-half of the sum of absolute deviations between current sectoral shares and each province's 2019 sectoral structure.

Table 6. Aggregate Sectoral Recomposition Outcomes

Regressor	Sectoral concentration, HHI	Sectoral diversification, entropy	Aggregate recomposition index
E-commerce shock $\times$ pre-exposure	-0.0117* (0.0067)	0.0629*** (0.0190)	3.8104*** (1.3134)
Log GDP per capita, lagged	-0.0045 (0.0035)	0.0130 (0.0103)	0.5398 (0.7844)
Population density, lagged	0.0000** (0.0000)	-0.0001** (0.0001)	0.0095** (0.0037)
Higher education graduate share, lagged	0.0001 (0.0007)	-0.0017 (0.0019)	-0.5362* (0.2696)
Logistics accessibility, lagged	-0.0087 (0.0075)	0.0218 (0.0231)	0.0971 (1.9950)
Province fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	486	486	486
Provinces	81	81	81
Within R ²	0.646	0.733	0.877

Note. HHI and entropy are calculated from the seven aggregated sectoral enterprise shares. The aggregate recomposition index equals one-half of the sum of absolute deviations between current sectoral shares and each province's 2019 sectoral structure, expressed in percentage points. Each column reports a separate two-way fixed-effects regression. Standard errors clustered at the provincial level are reported in parentheses. All models include province and year fixed effects. Significance levels: *** $p < 0.01$, **

$p < 0.05$, * $p < 0.10$. Source: Author's calculations based on TurkStat provincial enterprise data and Ministry of Trade e-commerce data.

The shift-share coefficient is negative and weakly significant for HHI, at -0.0117, indicating lower sectoral concentration in provinces with higher pre-2019 exposure. It is positive and highly significant for entropy, at 0.0629, showing greater sectoral diversification, and positive and highly significant for the aggregate recomposition index, at 3.8104, indicating stronger redistribution relative to each province's 2019 structure. These results show that e-commerce exposure is associated not only with sector-specific changes but also with measurable changes in overall provincial enterprise composition. The aggregate findings support the core hypothesis in its broadest form: Türkiye's e-commerce expansion is associated with provincial sectoral recomposition, although sector-specific channels remain uneven. This pattern aligns with evidence that the digital economy can open channels for value addition and structural change (United Nations Conference on Trade and Development, 2019), foster industrial diversification and support service-sector upgrading (Chen, 2024).

Discussion

This section interprets the empirical findings in relation to the research question and the literature on digital trade, structural transformation and regional development. The study treats Türkiye's rapid e-commerce growth as a national digital-trade shock and interacts it with provinces' pre-2019 exposure to e-commerce-compatible activities in a shift-share TWFE framework. The results show selective provincial recomposition: higher-exposure provinces shift relatively toward consumer-facing services and away from small transport-storage enterprises, while retail and professional services do not expand systematically. Aggregate outcomes also indicate lower concentration, higher diversification and stronger

recomposition across provincial enterprise structures, suggesting sector-specific rather than uniform effects overall.

E-Commerce and the Pattern of Provincial Sectoral Recomposition

The central finding is that e-commerce expansion is associated with sectoral recomposition rather than a uniform increase in retail enterprises. In fixed-effects estimates, the interaction between the e-commerce shock and pre-2019 exposure is positively associated with consumer-facing services and negatively associated with transport and storage. The coefficients for wholesale and retail trade and for knowledge, business and institutional services are insignificant, while those for industry and construction are less robust. This pattern supports the argument that digital trade reshapes enterprise structures through adjacent and complementary sectors, not simply through retail expansion.

The aggregate results reinforce this interpretation. Provinces with higher pre-2019 exposure experienced lower sectoral concentration, higher Shannon entropy and larger recomposition indices, indicating that e-commerce exposure is linked to broader diversification in enterprise composition. This pattern aligns with evidence that the digital economy can support industrial structure upgrading and diversification, including findings from Chinese cities that digitalisation promotes industrial structure optimization and generates positive regional spillovers, with human capital acting as a mediating factor (Chen, 2024). In Türkiye, the national e-commerce shock appears to have encouraged more exposed provinces to diversify beyond traditional sectors.

The findings resonate with global evidence on digital trade shocks. Studies of U.S. local labour markets show that fulfilment centres reduce employment and wages in brick-and-mortar retail while increasing warehousing and restaurant jobs (Bauer &

Fernández Guerrico, 2023). Chava et al. (2022) similarly find that fulfilment-network expansion reduces retail income, accelerates small-store exit and increases transport-warehousing and food-service employment. The Turkish evidence extends this discussion from employment to enterprise counts, showing that e-commerce disrupts traditional retail while generating complementary demand for hospitality, entertainment and personal services.

Sectoral Channels: Services, Logistics Restructuring and Retail Non-Expansion

The most robust sectoral result is the positive association between e-commerce exposure and consumer-facing services at the provincial level. Provinces with higher pre-2019 exposure experienced a more favourable relative trajectory in consumer-facing services, with the main coefficient equal to 5.798 percentage points. The effect survives all robustness checks and remains significant with region-year fixed effects, supporting the consumption-complementarity channel. As households shift shopping online, time savings and convenience may increase demand for dining, tourism, entertainment and personal services. This is consistent with evidence that fulfilment centre openings coincide with restaurant employment gains (Chava et al., 2022), and with research showing that cross-border e-commerce can promote digital technology innovation through financing constraint alleviation, digital transformation and producer-service agglomeration (Chen et al., 2024). For policy, the result highlights the importance of helping small service enterprises digitise operations and participate in online platforms.

The negative transport and storage result points to logistics restructuring rather than a declining role for logistics. Contrary to expectations, provinces with greater pre-2019 exposure experienced a significant decline in the transport and storage enterprise share.

This likely reflects consolidation and economies of scale, as increased online transactions may expand large logistics providers while reducing smaller transport firms. Last-mile logistics research supports this interpretation: rapid home delivery encourages facilities closer to dense consumer markets, including dark stores, micro-fulfilment centres and urban distribution hubs (Fried & Goodchild, 2023). These facilities can improve delivery efficiency but may generate congestion, emissions and noise. In Türkiye, large logistics firms may have expanded to meet rising demand, while smaller provincial carriers faced difficulty competing without digital platforms or capital for modernisation. Policies supporting route optimisation, fleet management systems, digital collaboration platforms and intermodal infrastructure could help them remain viable.

The insignificant wholesale and retail effect is also important. E-commerce does not appear to translate into more retail enterprises. Instead, digital platforms may centralise transactions through large online platforms and omnichannel retailers. This result is consistent with U.S. evidence that fulfilment centres reduce retail employment (Chava et al., 2022) and with concerns about market concentration in the digital economy (United Nations Conference on Trade and Development, 2019). Thus, support for small retailers should focus less on automatic expansion and more on access to digital marketplaces, e-commerce technologies, digital literacy and targeted financial support.

Interpretation Boundaries and Policy Implications

Several methodological boundaries qualify the interpretation of the findings. The shift-share TWFE design is appropriate for examining differential exposure to a common national shock, but the pre-trend and placebo tests indicate that some sectors, especially industry and utilities and transport and storage, already followed

different trajectories before 2019. Therefore, the parallel-trend assumption is more credible for consumer-facing services and aggregate diversification than for every sectoral outcome. The short 2019-2024 panel also limits the estimation of long-run effects and restricts the use of richer trend structures. Moreover, the analysis relies on enterprise counts rather than employment, revenue, turnover or productivity. A decline in enterprise numbers may therefore coexist with rising output or employment if activity becomes concentrated among larger firms. Pre-exposure may also capture unobserved provincial characteristics, including digital infrastructure or entrepreneurial culture. Since residuals in shift-share regressions may be correlated across regions with similar sector shares (Adão et al., 2019), the results should be interpreted primarily as exposure-based associations rather than strict causal effects.

The policy implications follow from these boundaries and patterns. E-commerce benefits are more likely to accrue to provinces with pre-existing service-oriented and digital infrastructures. United Nations Conference on Trade and Development (UNCTAD, 2019) warns that digital advances can generate large gains but may also concentrate value without inclusive policies. Türkiye should therefore complement digital trade expansion with policies that improve digital literacy, expand high-speed internet access, simplify digital payment systems and support SMEs in adopting online platforms. As Ahi et al. (2023) note, inclusive e-commerce participation depends on formal institutions and SME adoption. Evidence from cross-border e-commerce pilot zones in China also suggests that digital trade can support enterprise innovation by easing financing constraints and encouraging producer-service agglomeration (Chen et al., 2024). Overall, the findings point to consumer-service expansion, logistics consolidation and broader diversification rather than a simple retail boom. Future research

should use firm-level data, longer panels and outcomes such as employment, revenue and productivity.

Conclusion

This study examined whether the rapid expansion of e-commerce in Türkiye was associated with provincial sectoral recomposition rather than only with changes in retail activity, employment or sales. Its central argument was that e-commerce should be understood as a broader digital-trade shock whose local effects depend on pre-existing enterprise structures. Because provinces entered the digital transition with different combinations of consumer services, logistics activities, knowledge-intensive services and traditional sectors, national e-commerce growth was not expected to produce uniform local outcomes. The study therefore shifted attention from whether e-commerce expanded nationally to how this expansion was absorbed across provincial economies.

The empirical strategy combined a common national e-commerce shock for 2019–2024 with predetermined provincial exposure measured from the 2015–2018 share of enterprises in e-commerce-compatible activities. Their interaction produced a province-specific shift-share treatment variable, estimated in a two-way fixed-effects framework with province and year effects and lagged socioeconomic controls. This design examined differential exposure to the same national shock while accounting for persistent provincial differences and common time shocks. However, identification checks showed that exposure was not randomly distributed and that some sectors displayed pre-treatment differences. Accordingly, the estimates were interpreted cautiously as exposure-based associations, with stronger confidence where pre-trend and placebo evidence were more supportive.

The findings indicate that e-commerce expansion was associated with a selective pattern of sectoral recomposition. The

strongest and most robust sector-specific result concerns consumer-facing services. Provinces with higher pre-2019 exposure experienced a larger relative expansion in accommodation, food services, entertainment and other personal services. This supports the view that e-commerce does not merely substitute for offline commerce. It may complement local consumption services by changing how households allocate time, how services are accessed and how local firms connect with consumers. Its stability makes it the clearest empirical channel.

The transport and storage result points to a different adjustment mechanism. Although logistics is central to e-commerce, the negative association between exposure and the transport-storage enterprise share suggests consolidation rather than simple sectoral expansion. As e-commerce growth increases scale and coordination requirements, larger logistics firms may expand while smaller carriers lose relative importance. A decline in firm numbers does not necessarily imply a decline in logistics activity; it may reflect economies of scale, platform coordination and concentration among larger providers. Because transport and storage showed weaker support in pre-treatment checks, this result should be treated with caution.

The absence of a significant wholesale and retail trade effect is central to the study's contribution. A simple retail-boom interpretation would predict a clear increase in retail enterprises in more exposed provinces, but the results do not support that view. Instead, adjustment appears through adjacent sectors, especially consumer-facing services, and broader changes in provincial enterprise composition. Similarly, although knowledge, business and institutional services increased descriptively, their growth was not systematically linked to e-commerce exposure after fixed effects and controls.

The aggregate recomposition results provide the broadest support for the main hypothesis. Higher exposure was associated with lower sectoral concentration, higher entropy and stronger aggregate recomposition relative to each province's 2019 structure. E-commerce exposure was therefore linked not only to selected sector shares but also to a measurable rebalancing of provincial enterprise structures. The evidence supports a recomposition argument rather than a narrow sectoral expansion argument, with the most robust adjustment occurring in consumer-facing services and evidence of logistics consolidation.

The study contributes by extending the analysis of e-commerce from employment, wages and retail outcomes toward enterprise-sector recomposition in an emerging-market provincial setting. It also demonstrates the usefulness and limits of a shift-share TWFE approach for studying regional exposure to a national digital shock. The results suggest that digital trade policy should not focus only on expanding online transaction volume but should also consider whether provinces can translate digital expansion into diversified enterprise structures. Policies supporting SME digital adoption, service-sector upgrading, digital literacy, logistics governance and fair access to online platforms are therefore important for regional transformation.

Several limitations remain. The analysis is based on enterprise counts rather than firm-level employment, revenue, productivity or transaction data. It covers a short 2019–2024 panel and cannot fully capture long-run adjustment. The exposure measure may also reflect unobserved provincial capabilities. Future research could use longer panels, firm-level data and alternative outcomes to clarify whether the observed recomposition reflects new firm formation, firm exit, consolidation, employment shifts or productivity upgrading. Despite these limitations, the study shows that Türkiye's e-commerce expansion was associated with

meaningful provincial sectoral recomposition and that the local effects of digital trade depend strongly on pre-existing enterprise structures.

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BÖLÜM 6

THE IMPACTS OF INDUSTRIAL DEVELOPMENT, FINANCIAL DEVELOPMENT, ENERGY TRANSITION AND ENERGY CONSUMPTION ON ECONOMIC GROWTH AND ENVIRONMENTAL SUSTAINABILITY: EVIDENCE FROM TÜRKİYE

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Introduction

In the contemporary global economic architecture, the structural tension between sustaining robust macroeconomic growth and preserving environmental quality represents one of the most critical policy trilemmas of the modern era. Historically, the traditional engines of economic expansion—chiefly industrialization and domestic financial deepening—have operated on highly carbon-intensive pathways, accelerating structural ecological degradation through unrestricted primary fossil fuel consumption (Kraft and Kraft, 1978; Grossman and Krueger, 1995). Within the foundational tenets of environmental economics, this growth-degradation nexus is conceptually mapped via the Environmental Kuznets Curve (EKC) hypothesis, which posits that an economy undergoes a scale-driven phase of increasing pollution before reaching an institutional

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and economic maturity threshold that facilitates structural decoupling (Stern, 2004). However, in an increasingly integrated global economy, this baseline income-emission trajectory does not unfold in isolation. International trade openness frequently alters environmental outcomes, igniting highly contested academic debates regarding the Pollution Haven Hypothesis and structural Carbon Leakage, wherein developing market economies inadvertently absorb the carbon footprints of developed nations due to asymmetric environmental regulatory strings (Copeland and Taylor, 2004; Peters and Hertwich, 2008). Concurrently, modern macroeconomic literature has pivoted toward investigating the Green Energy Transition as a non-substitutable mechanism to break this historical carbon-lock-in, evaluating whether the deployment of renewable energy assets can actively sustain industrial productive capacity while systematically mitigating aggregate greenhouse gas emissions (Apergis and Payne, 2010). As an emerging market economy bridging the developed Western supply chains with high-growth regional industrial dynamics, Turkey stands as a compelling empirical laboratory to rigorously isolate the long-run elasticities of industrial scaling and energy usage against ecological thresholds.

To understand the core dynamics driving Türkiye's modern economy, this study establishes a dual econometric specification composed of two distinct but deeply connected macro econometric models, each translated into a specific set of testable expectations. The first empirical framework is structurally designed around an economic growth equation. Here, the extent to which traditional sectors and the ongoing energy transition shape Türkiye's productive capacity is thoroughly investigated. Specifically, it is tested whether industrial development—defined by the manufacturing share of GDP—and financial deepening genuinely act as catalysts for real output, as conventional economic theory suggests. Given the urgent global shift toward green energy, the focus is also directed closely at

energy consumption. The objective is to evaluate whether an expanding renewable energy footprint limits or enhances long-run economic growth, and how heavily Türkiye still relies on primary per capita energy consumption to sustain its economic momentum. Finally, the role of international integration is explored by testing the long-run impact of trade openness on real per capita income.

The second empirical specification shifts the analytical focus to an environmental sustainability equation, evaluating these same macroeconomic drivers through an extended Environmental Kuznets Curve (EKC) framework. The centerpiece of this model is testing the validity of the inverted U-shaped relationship between economic growth and carbon dioxide emissions in Türkiye. The goal is to determine whether Türkiye has reached a point where further income growth naturally begins to reduce environmental damage. Beyond this baseline income-emission path, it is examined whether industrial scaling and financial institutional depth work to accelerate or mitigate pollution.

Crucially, the environmental model incorporates trade openness to provide a baseline macroeconomic proxy that relates to the broader debates on global trade dynamics. Within the literature, trade integration is frequently discussed alongside the 'Pollution Haven' or 'Carbon Leakage' phenomena—where developing nations potentially absorb carbon-heavy manufacturing shares from advanced partners. By examining the behaviour of aggregate trade patterns, this study offers directional clues on whether Türkiye's international trade profile patterns align with carbon expansion or act as a channel for clean, eco-friendly technologies.

Instead of relying on a single output matrix, this study operationalizes a parallel-framework approach as its primary conceptual strength. In a developing economy like Türkiye, macroeconomic expansion and environmental degradation represent distinct but concurrent dimensions of structural transformation. A

policy or structural shift that successfully boosts GDP might simultaneously cause severe environmental damage. Conversely, strict environmental controls could penalize industrial capacity. By evaluating these two distinct econometric vectors side-by-side, this setup identifies potential trade-offs and detects structural 'Win-Win' scenarios where the green energy transition can support economic growth while mitigating environmental degradation.

The foundational motivation of this study lies in providing a clean, dual-perspective empirical assessment of Türkiye's structural parameters. By utilizing parallel macroeconomic specifications (the Environmental Kuznets Curve (EKC) trajectory, the Pollution Haven Hypothesis, structural concerns regarding Carbon Leakage, and the macroeconomic dynamics of the Green Energy Transition), the research framework investigates the long-run and short-run channels through which Industrial Development, Financial Development, and Energy consumption patterns independently dictate national output and environmental quality. Ultimately, this structural decoupling analysis establishes a transparent empirical foundation for executing targeted, macroprudential policy recommendations that secure Türkiye's post-vertex Green Transition without compromising long-term economic momentum.

The remainder of this paper is organized into four consecutive sections. Section 1 reviews the theoretical and empirical literature on the growth-energy-environment nexus to highlight the specific research gaps this study aims to fill. Section 2 introduces the annual dataset spanning from 1965 to 2024, presents the formal mathematical equations for both the Growth and Environmental models, and explains the internal mechanics of the Autoregressive Distributed Lag (ARDL) bounds testing technique used for the estimations. Section 3 provides the detailed empirical results, including the long-run baseline states, the short-run error correction adjustments, and the mathematical derivation of the EKC turning

point. Finally, concludes the paper with a comprehensive synthesis of the core findings and offers practical, macroprudential policy recommendations for Türkiye's sustainable development strategy.

1. Literature Review

The structural interplay between economic expansion, energy utilization, and environmental quality is governed by multifaceted macroeconomic dynamics. To provide a rigorous empirical foundation for the current study, the existing literature is synthesized across four thematic pillars: the industrialization-growth nexus, the income-emission trajectory, the energy transition dilemma, and the environmental implications of international trade.

The Industrialization, Financial Deepening, and Economic Growth Nexus

The relationship among financial deepening, industrialization, and economic growth is a core debate in development economics. Financial development drives real economic performance by mobilizing savings, optimizing resource allocation, and financing technological innovation. By facilitating access to long-term funds required by capital-intensive sectors, financial depth directly accelerates structural transformation and industrialization (Schumpeter, 1934).

Four primary approaches explain this interaction. The supply-leading hypothesis (Schumpeter, 1934) posits that banking credit and financial intermediation drive long-term growth by financing innovative entrepreneurs. This view is supported by cross-country evidence showing that financial development precedes economic expansion (King & Levine, 1993) and that financial liberalization exerts positive long-run effects on investment (McKinnon, 1973; Shaw, 1973; Yakubu et al., 2021). Conversely, the demand-following approach (Robinson, 1952) asserts that financial development merely mirrors real sector expansion, which induces demand for

financial services. Lucas (1988) takes a more skeptical stance, relegating finance to a secondary role in growth mechanics. Adopting a middle ground, Demetriades and Hussein (1996) employ time-series analysis across 16 countries, finding that financial development rarely acts as a leading sector, exhibiting instead highly country-specific bidirectional or reverse causality.

Empirical studies in emerging economies frequently validate a positive, long-run relation between financial indicators and per capita income, with several regional analyses confirming bidirectional Granger causality (Ekanayake, 2021). However, non-linear insights from dynamic panel threshold models reveal that financial deepening stimulates growth only up to a certain inflection point, beyond which the nexus weakens or turns negative (Law & Singh, 2014; Swamy & Dharani, 2019). Conversely, Botev et al. (2019) challenge this "too much finance is bad" thesis, showing that bank credit and stock market capitalization act complementarily to boost growth without an explicit turning point.

In contrast, the financialization literature highlights that certain financial structures—specifically expanding short-term financial profit opportunities—can crowd out real investments. Orhangazi (2008) finds a negative relationship between financialization proxies and real asset accumulation for US non-financial corporations, arguing that rising financial obligations reduce internal funds available for physical expansion. This is mirrored in Europe, where both financial payments and incomes significantly suppress physical capital accumulation (Tori & Onaran, 2018).

Turkey-specific literature presents mixed evidence on the direction and magnitude of the finance-growth nexus. Some analyses find that financial development, driven by credit and market capitalization, positively impacts growth (Demirhan, 2025). In contrast, Tufaner (2022) provides evidence that financial development has a negative long-term impact on growth in Türkiye, arguing that financing

current account deficits with speculative capital inflows can trigger economic contraction and resource misallocation. Yakubu et al. (2021) observe that financial intermediation is highly significant, though primarily driven by short-run dynamics. Other findings reveal that the causality is indicator-sensitive or that growth leads the financial sector (Kar & Pentecost, 2000). Demirhan et al. (2011) establish bidirectional causality with a dominant role for banking, while Soytaş and Küçükkaya (2011) detect no long-run permanent relationship in either direction. Regarding financialization, firm-level data from Turkish manufacturing confirms that rising financial incomes divert corporate focus away from physical production toward interest-bearing financial assets, hindering industrial accumulation (Akkemik & Özen, 2014; Tellalbasi & Kaya, 2013).

Ultimately, the finance-industrialization-growth nexus is non-linear and bidirectional, heavily contingent upon institutional frameworks and market maturity (Demetriades and Hussein, 1996). Aligning financial deepening with macroprudential policies is crucial to safeguard real investments and maximize growth benefits (Law & Singh, 2014; Davis, 2017).

Income-Emission Trajectory and the Validity of the Environmental Kuznets Curve (EKC) Hypothesis

The Environmental Kuznets Curve (EKC) hypothesis posits an inverted-U shaped relationship between economic growth and environmental degradation. First examined empirically by Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992), the framework was conceptualized by Panayotou (1993). The underlying mechanics operate through three channels: the scale effect, where early-stage production increases pollution (Hashmi et al., 2022; Ulucak & Bilgili, 2018); the composition effect, where structural shifts toward services initiate abatement (Sun et al., 2024);

and the technique effect, where cleaner technologies achieve environmental remediation (Acaroğlu et al., 2023; Dinda, 2004).

Empirical support for the EKC is highly sensitive to methodology and indicator selection. Several studies confirm the inverted-U trajectory, showing that growth eventually leads to ecological recovery (Güleç et al., 2026; Hassan et al., 2019; Hashmi et al., 2022; Mrabet & Alsamara, 2017; Özbek & Naimoğlu, 2025). Panel and income-cohort analyses by Destek and Sarkodie (2019) and Ulucak and Bilgili (2018) also substantiate the hypothesis. Conversely, Al-Hajri and Khudari (2026) find that Oman resides on the upward-sloping segment, short of the turning point. Omay et al. (2026) suggested a cyclical, multi-regime structure for the US and UK, while Villanthenkodath et al. (2024) identify metric-dependent trajectories—showing an N-shaped relationship for carbon footprints but an inverted N-shape for ecological footprints—and Caglayan Akay and Kangalli Uyar (2021) reject the hypothesis entirely by accounting for endogeneity.

Evidence for Turkey is similarly divided. The EKC is validated by studies showing that human capital, renewable energy, and financial factors eventually mitigate the ecological footprint (Karahan-Dursun, 2026; Sharif et al., 2020; Bulut, 2020). However, institutional constraints remain critical; Koksall et al. (2020) demonstrate that the shadow economy acts as a significant long-term driver of environmental degradation in Turkey. ARDL bounds testing by Acaroğlu et al. (2023) corroborates this, indicating that renewable diversification offers a structural shield against fossil-induced degradation. On the contrary, Akbostanci et al. (2009) and Ozcan et al. (2018) reject the EKC for Turkey. Disaggregating the footprint, Acar and Asici (2017) reveal that the inverted-U holds solely for production-based footprint, but fails when applied to consumption, import, and export metrics.

The Green Energy Transition vs. Fossil Fuel Consumption Dilemma

Contemporary literature evaluates the environmental and economic consequences of transitioning from primary energy consumption to renewable energy deployment. A specific group of scholars identifies a "Win-Win" paradigm, demonstrating that environmental technological innovations—measured via climate-related patent applications—and renewable energy production actively mitigate ecological damage while functioning as catalysts for long-run growth (Akyol & Mete, 2021; Zeb et al., 2014). Evidence from SAARC economies indicates that while renewable electricity production directly suppresses CO₂ emissions, the resulting economic expansion can trigger dynamic feedback loops where the scale effect of growth leads to a secondary rise in emissions (Zeb et al., 2014).

Robust evidence from European Union economies indicates that a structural transition toward alternative technologies drives down greenhouse gas emissions by generating approximately 50% less environmental pollution per unit of energy consumed compared to fossil fuels (Bölük & Mert, 2014). This mitigating effect is particularly pronounced in emerging contexts, such as the BRICS nations, where the integration of environmental technologies and renewable inputs is vital for fostering green growth and displacing carbon-intensive production structures (Danish & Ulucak, 2020).

In contrast, findings on carbon-intensive energy lock-ins highlight significant developmental constraints. In certain Central and Eastern European (CEE) contexts, a positive association between renewable energy consumption and CO₂ emissions has been paradoxically revealed, suggesting that the initial phases of energy transition—often involving infrastructure modernization and grid construction—may not immediately offset the absolute scale of fossil-fuel-dependent production (Shujah-ur-Rahman et al., 2019).

The literature emphasizes that conventional growth remains heavily energy-dependent in emerging markets, where total primary energy consumption remains the most dominant and highly polluting driver of carbon emissions (Appiah et al., 2021). Furthermore, in low-income country groups, the potential of the energy transition is often stultified unless renewable deployment is accompanied by broad energy efficiency improvements, governance quality, and dedicated infrastructural investments (Appiah et al., 2023; Appiah et al., 2021).

International Trade Openness, Pollution Havens, and Carbon Leakage

The impact of cross-border trade openness on environmental sustainability is marked by a tension between the "Pollution Haven" dynamic and eco-efficiency gains. One line of literature argues that trade integration triggers carbon leakage, particularly when carbon-intensive production relocates from environmentally regulated regions to nations with loose regulations (Aichele & Felbermayr, 2015; Copeland & Taylor, 2004). Empirical evidence for this suggests that binding commitments under the Kyoto Protocol increased committed countries' embodied carbon imports from noncommitted nations by approximately 8%, alongside a 3% rise in the emission intensity of these imports (Aichele & Felbermayr, 2015). Consequently, decarbonization commitments in developed nations may inadvertently shift the environmental burden to trading partners, increasing consumption-based emissions even as production-based emissions decline in the North.

Conversely, another group of empirical studies demonstrates that globalization serves as a channel for cleaner technology transfers and eco-efficiency. Scholars supporting this perspective suggest that global integration facilitates the adoption of international environmental standards and fosters the diffusion of environmentally friendly innovations across emerging markets

through the 'technique effect' (Grossman & Krueger, 1991; Dinda, 2004). This dimension of globalization is highlighted as a potential mechanism to decouple macroeconomic growth from carbon intensity through the integration of green technological spillovers (Danish & Ulucak, 2020). However, the final environmental impact remains inconclusive, as it often depends on the specific regulatory stringency and factor endowments of the trading partners involved (Copeland & Taylor, 2004).

2. Data and Methodology

Data

To rigorously test the Environmental Kuznets Curve (EKC) hypothesis for Türkiye, per capita carbon dioxide emissions ($\ln CO_2$), widely recognized as the gold standard in environmental literature, are employed as the dependent variable to represent environmental degradation. While the World Bank (WDI) database covers a narrower time frame for Türkiye's emission data, this study utilizes the Energy Institute (EI) Statistical Review of World Energy dataset to overcome this data constraint. By doing so, the analysis period is extended to span from 1965 to 2024, which increases the degrees of freedom and reliability of the empirical model due to a larger number of observations, thereby enabling a comprehensive interpretation of the analyses. In alignment with the theoretical essence of the EKC hypothesis, which aims to measure the pure physical burden of economic activities on the environment, the emission series is incorporated into the model not as a total aggregate, but rather as a per capita metric in metric tons, thus isolating it from national demographic dynamics. To facilitate a "Double-Log" elasticity interpretation and to stabilize the variance structure of the series—thereby preventing non-linear specification artifacts—the natural logarithm ($\ln$) of this emission series,

harmonized with the World Bank (WDI) population data, is utilized for the empirical analysis.

The only viable path to testing the validity of the EKC hypothesis for the Türkiye economy is to model the trajectory of real per capita income, which reflects the structural enrichment and development level of the country, rather than using superficial indicators like the economic growth rate (%) that only capture short-term cyclical fluctuations. Accordingly, to fundamentally prevent empirical distortions stemming from nominal price movements and inflation illusion, the 'GDP per capita (constant 2015 US\$)' series—obtained from the World Bank (WDI) dataset and accurately reflecting the actual productive capacity of the country—is selected. To mathematically calculate the turning point of the inverted U-shaped EKC curve, the natural logarithm of real per capita income is computed first ($\ln EG$), and subsequently, the square of this logarithmic series is calculated ($\ln EG^2$) to be included simultaneously in the model specification. This specific ordering is an empirical necessity to maintain the economic elasticity interpretation of the parameters within their proper theoretical boundaries.

As for the most dynamic control variable in extended EKC frameworks, total energy consumption is represented by the Energy Institute (EI) dataset to preserve the continuity of the analysis period back to 1965, given that the World Bank (WDI) database for Türkiye strictly covers the post-1990 era and lacks recent years. To encapsulate the aggregate energy burden, the 'Total Energy Supply per capita (Gigajoules)' metric is utilized, which is fully compliant with United Nations, IEA, and Eurostat accounting frameworks, thus capturing the physical energy flows of the economy in their most refined form. To maintain dimensional consistency with the other macro aggregate volume series in the model, the natural logarithm

(ln ENUSE) of this series—which is already standardized on a per capita basis by the Energy Institute—is directly calculated.

To empirically isolate the net impact of Türkiye's green energy transition and decarbonization initiatives on the environment, total renewable energy consumption, including hydroelectric sources, is integrated into the model specification. A frequent pitfall in the existing literature is the inclusion of the percentage share of renewable energy within total energy (RE_share) as a regressor, which creates a mathematical redundancy on the right-hand side of the equation and introduces a severe risk of Multicollinearity. To ingeniously circumvent this empirical vulnerability and to capture the emission-mitigating capacity of renewable alternatives as a pure volume effect, the 'Renewable Power Total Energy Input (inc hydro)' series extracted from the Energy Institute (EI) database is introduced as an independent actor. The raw data, originally expressed in Exajoules (EJ) to denote massive macroeconomic magnitudes, is first divided by the World Bank total population series to scale it down to a "per capita clean energy consumption" metric. Subsequently, the natural logarithm of these fractional values between 0 and 1 is calculated (ln RE) to establish a stable variance trend and yield elasticity coefficients. The negative logarithmic values resulting from this formulation are fully compatible with the mechanics of time-series econometrics and matrix estimation, playing a stabilizing role against parametric distortions.

The financial system in the Türkiye economy exhibits a structure predominantly reliant on the banking sector. In accordance with this structural reality, the 'Domestic credit to private sector by banks (% of GDP)' variable from the World Bank (WDI) database is incorporated into the model as the empirical proxy for financial development (FD), providing a highly rational framework to analyse how financial expansion and depth affect the environment via funds allocated to the real sector. By quantifying the volume of credit

extended to the private sector by the banking industry, this variable distinctly isolates whether financial widening fosters eco-friendly technologies or instead subsidizes emission-intensive production pathways. Since the variable is already operationalized as a pure ratio scaled to GDP, it is maintained in its raw percentage format without undergoing linear logarithmic transformation, thereby preserving its original economic architecture and bounded distribution within the model matrix.

To control for the structural shifts and global integration inherent in Türkiye's development trajectory, variables representing industrial intensity (ID) and trade openness (TR) are appended to the model. The 'Industry value added (% of GDP)' variable, sourced from the World Bank (WDI) database, represents the industrialization density and subsequent structural pollution potential of the Türkiye economy. Concurrently, the 'Trade (% of GDP)' variable, obtained from the same source, allows for the empirical validation of international trade volumes on environmental quality within the context of the Pollution Haven or the Factor Endowment hypotheses. Much like the financial development metric, both ID and TR indicators are structurally defined as percentage ratios; hence, they are exempted from logarithmic transformations and enter the specification in their level forms. This semi-logarithmic (Semi-Log) design ensures that the coefficients of these variables can be diagnosed in a proper economic vernacular, signifying the percentage change in emissions resulting from a one-percentage-point increase in the respective regressor. Furthermore, applying logarithmic transformations to bounded percentage shares is methodologically flawed, as it artificially distorts the original variance structure and generates mathematical redundancy. Therefore, maintaining these indicators in their level forms preserves the structural integrity of the macro-level distribution while completely eliminating potential specification artifacts.

Ultimately, this methodological architecture, which synthesizes the respective strengths of the World Bank (WDI) and the Energy Institute (EI) databases, provides an unparalleled empirical foundation to execute a continuous analysis for the Türkiye economy over a comprehensive 60-year horizon spanning from 1965 to 2024. Given that a vast majority of contemporary studies are restricted to truncated time frames due to data availability constraints, the extensive data matrix constructed herein allows for the investigation of Türkiye's development and environmental dynamics through the widest historical lens and with the highest level of empirical precision.

Empirical Model

Incorporating this comprehensive and methodologically rigorous 60-year data matrix (from 1965 to 2024) requires the construction of an analytical framework that systematically segregates economic performance from environmental degradation, thereby capturing both the engines of growth and the consequences of structural transformation. To achieve this dual objective, the empirical inquiry is bifurcated into two distinct yet theoretically interconnected equations, allowing for a dual-perspective, parallel assessment of Türkiye's development trajectory.

The Macroeconomic Determinants of National Output (Growth Equation)

The first primary specification treats real per capita income as the ultimate outcome of structural, financial, and resource-based inputs. This model is designed to evaluate how the operational intensity of the energy sector and the structural direction of the energy transition impact Türkiye's productive frontier. The economic growth specification is formulated as follows:

$$\ln EG_t = \beta_0 + \beta_1 ID_t + \beta_2 FD_t + \beta_3 \ln RE_t + \beta_4 \ln ENUSE_t + \beta_5 TR_t + u_t \quad (1)$$

In this equation, real per capita income (lnEG) is modelled against industrialization density (ID), financial deepening (FD), and trade openness (TR). Crucially, the model disentangles energy demands by separating the absolute scale of per capita energy supply (lnENUSE) from the disaggregated volume of renewable energy consumption (lnRE). This allows the analysis to isolate how the "greening" of the energy matrix influences economic growth independently of total fuel utilization, thereby mapping the structural composition effect of the energy transition. While Equation (1) isolates the structural frontier of economic activity, the parameters must be mirrored against their direct environmental costs to capture the complete structural trajectory of the nation. To achieve this, the analytical focus transitions into an expanded Environmental Kuznets Curve (EKC) framework, where the macroeconomic drivers are tested against their aggregate ecological footprint as specified below.

The Environmental Sustainability and Expanded EKC Framework

To contrast these macroeconomic dynamics against their ecological footprints, the second model transitions into a comprehensive environmental sustainability framework. This equation is specifically designed to test the viability of the Environmental Kuznets Curve (EKC) paradigm by evaluating the inverted U-shaped relationship between income and emissions. The ecological benchmark equation is constructed as follows:

$$\ln CO2_t = \gamma_0 + \gamma_1 \ln GE_t + \gamma_2 \ln GE_t^2 + \gamma_3 ID_t + \gamma_4 FD_t + \gamma_5 \ln RE_t + \gamma_6 \ln ENUSE_t + \gamma_7 TR_t + \varepsilon_t \quad (2)$$

The centrepiece of this specification is the inclusion of real per capita income (lnEG) and its quadratic form (lnEG²) to evaluate the scale

and technique effects postulated by the EKC hypothesis. By maintaining the exact same set of structural, financial, and energy-based regressors used in the growth model, this framework ensures analytical consistency. This dual-model setup comprehensively exposes how industrial expansion, financial deepening, openness to trade, and energy source diversification simultaneously drive economic advancement and shape the country's environmental long-term path. However, it must be noted that the sequential nature of the models assumes no feedback effect from environmental degradation to economic growth.

Methods

To test the long-run cointegrating vectors and short-run dynamic adjustments between industrial development, financial deepness, energy infrastructure variables, and the respective targets (economic growth and environmental sustainability), this study utilizes the Autoregressive Distributed Lag (ARDL) bounds testing methodology developed by Pesaran and Shin (1998) and further formalized by Pesaran et al. (2001). Unlike conventional cointegration architectures, such as the Johansen framework, the ARDL bounds testing technique provides distinct methodological advantages that heavily isolate the empirical estimations from structural specifications errors.

First, the ARDL approach does not require all system variables to share a uniform order of integration. The bounds test can be effectively operationalized regardless of whether the underlying time-series regressors are purely integrated at order zero [$I(0)$], purely integrated at order one [$I(1)$], or mutually fractionally cointegrated (Pesaran and Shin, 1998). This eliminates the structural vulnerabilities associated with pre-testing unit roots, although the methodology breaks down if any variable exhibits an explosive order of integration, namely $I(2)$ (Pesaran et al., 2001). Second,

conventional cointegration techniques suffer from severe small-sample biases, leading to unreliable asymptotic inferences when the time span is constrained. The ARDL methodology exhibits superior structural properties and yields robust, unbiased long-run estimates when applied to small or finite sample sizes (Narayan, 2005). Finally, by embedding a flexible lag structure, the ARDL framework simultaneously mitigates endogeneity anomalies and serial correlation bugs by diagnostic modelling of the short-run error dynamics (Pesaran and Shin, 1998).

To evaluate the long-run level relationships and the corresponding short-run adjustments without diagnostic contamination, the unrestricted error correction model (UECM) configurations for the Growth Equation [Equation 3] and the Environmental Sustainability Equation [Equation 4] are estimated independently as follows:

$$\begin{aligned}
\Delta LNEG_t = & \alpha_0 + \sum_{i=1}^p \beta_1 \Delta LNEG_{t-i} + \sum_{i=0}^{q_1} \beta_2 \Delta LNID_{t-i} \\
& + \sum_{i=0}^{q_2} \beta_3 \Delta LNFD_{t-i} + \sum_{i=0}^{q_3} \beta_4 \Delta LNRE_{t-i} \\
& + \sum_{i=0}^{q_4} \beta_5 \Delta LNEUSE_{t-i} \\
& + \sum_{i=0}^{q_5} \beta_6 \Delta LNTR_{t-i} + \lambda_1 LNEG_{t-1} \\
& + \lambda_2 LNID_{t-1} + \lambda_3 LNFD_{t-1} \\
& + \lambda_4 LNRE_{t-1} + \lambda_5 LNEUSE_{t-1} \\
& + \lambda_6 LNTR_{t-1} + \varepsilon_{1t}
\end{aligned} \tag{3}$$

and;

$$\begin{aligned}
\Delta LNC O_{2t} = & \alpha_1 + \sum_{i=1}^m \gamma_1 \Delta LNC O_{2t-i} + \sum_{i=0}^{n_1} \gamma_2 \Delta LNEG_{t-i} \\
& + \sum_{i=0}^{n_2} \gamma_3 \Delta LNEG_{t-i}^2 + \sum_{i=0}^{n_3} \gamma_4 \Delta LNID_{t-i} \\
& + \sum_{i=0}^{n_4} \gamma_5 \Delta LNFD_{t-i} + \sum_{i=0}^{n_5} \gamma_6 \Delta LNRE_{t-i} \quad (4) \\
& + \sum_{i=0}^{n_6} \gamma_7 \Delta LNTR_{t-i} + \theta_1 LNC O_{2t-1} \\
& + \theta_2 LNEG_{t-1} + \theta_3 LNEG_{t-1}^2 \\
& + \theta_4 LNID_{t-1} + \theta_5 LNFD_{t-1} \\
& + \theta_6 LNRE_{t-1} + \theta_7 LNTR_{t-1} + \varepsilon_{2t}
\end{aligned}$$

Where Δ denotes the first-difference operator, α_0 and α_1 represent the structural drift parameters, and ε_{1t} and ε_{2t} are white-noise error terms. The parameters paired with the summation signs (β and γ) evaluate the short-run dynamic impacts, whereas the λ and θ parameters indicate the long-run multipliers of the system.

The empirical diagnostic procedure initiates with the ARDL bounds test for a long-run relationship by applying a joint F-statistic on the lagged level parameters. For the Growth model, the null hypothesis of no structural cointegration ($H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = 0$) is evaluated against the alternative hypothesis (H_1 : at least one $\lambda_i \neq 0$). Similarly, for the Environmental model, the null vector ($H_0: \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6 = \theta_7 = 0$) is tested against the alternative hypothesis. Pesaran et al. (2001) provide two sets of non-standard critical values based on the number of regressors (k). The lower-bound values assume all series are purely I(0), while the upper-bound values assume all series are purely I(1). If the computed F-statistic exceeds the upper bound, the null hypothesis is rejected, providing strong empirical evidence of long-

run equilibrium. If it falls below the lower bound, the null hypothesis cannot be rejected. If it falls between the bounds, the cointegration diagnostic remains inconclusive. Once a stable long-run equilibrium is validated, the short-run structural corrections and transitional convergence dynamics are formalised via an error correction model (ECM), where the significance and negative sign of the lagged error correction term (ECT_{t-1}) confirm structural systemic stability (Pesaran et al., 2001).

3. Empirical Findings and Discussion

This section presents the empirical evaluation of the two macro econometric configurations designated for the Türkiye economy. The analysis is executed sequentially: first, the integration properties of the variables are verified through unit root testing; second, the core economic growth model (Model 1) is estimated via the ARDL bounds testing framework; and third, the environmental degradation profile (Model 2) is operationalized to test the validity of the Environmental Kuznets Curve (EKC) hypothesis.

Unit Root Testing Framework and Integration Profiling

To ensure the operational eligibility of the time-series data within an autoregressive framework, the variables are subjected to stationarity screening. Table 1 documents the outputs of both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root testing protocols.

Table 1. Results of Unit Root and Integration Profiling

Variables	ADF (Level)	ADF (Δ)	PP (Level)	PP (Δ)	Decision
LNEG	0.707 -1.404 5.926	-7.506*** -7.652*** -5.269***	0.902 -1.461 6.159	-7.510*** -7.954*** -5.421***	I(1)
LNEG2	1.092 -1.041 5.998	-7.357*** -7.620*** -5.176***	1.543 -1.082 6.797	-7.357*** -7.924*** -5.332***	I(1)

Variables	ADF (Level)	ADF (Δ)	PP (Level)	PP (Δ)	Decision
LNCO ₂	-2.509 -2.968 2.734	-8.177*** -8.538*** -6.129***	-3.021** -2.917 2.043	-8.177*** -8.594*** -6.348***	I(1)
ID	-2.289 -1.824 0.231	-6.350*** -6.485*** -3.390***	-2.342 -1.932 0.208	-6.295*** -6.412*** -6.339***	I(1)
FD	-2.768* -2.613 -1.941*	-0.768 -0.418 -0.998	-1.249 -1.645 -0.246	-4.422*** -4.371*** -4.458***	I(0)/I(1)
LNRE	-0.415 -2.447 -2.661***	-8.321*** -8.257*** -7.465***	-0.255 -2.445 -3.416***	-8.457*** -8.393*** -7.468***	I(0)/I(1)
LNENUSE	-2.734* -3.192* 5.300	-7.874*** -8.324*** -5.396***	-2.962** -3.194* 4.687	-7.874*** -8.314*** -5.583***	I(1)
TR	-0.632 -4.774*** 1.853	-7.470*** -7.331*** -6.761***	-1.136 -3.596** 1.065	-6.987*** -6.781*** -6.225***	I(0)/I(1)

Notes: Δ indicates the first difference operator. For each variable, the values stacked vertically inside the cells represent the *t*-statistics corresponding to three distinct model specifications, strictly following the sequential order of: (1) With Constant, (2) With Constant & Trend, and (3) None (Without Constant & Trend). ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively, based on MacKinnon (1996) critical values.

The empirical outcomes presented in Table 1 reveal a mixed order of integration. The majority of the variables (*LNEG*, *LNEG*², *LNCO*₂, and *LNENUSE*) are non-stationary in their level forms but become stationary after taking their first differences. Conversely, variables such as *FD*, *LNRE*, and *TR* exhibit stationarity at levels under specific deterministic specifications. Crucially, neither test indicates any variable to be integrated of order two (*I*(2)), satisfying the fundamental prerequisite of the ARDL bounds testing approach. This mixed order of integration invalidates traditional cointegration techniques like the Johansen methodology and justifies the adoption of the ARDL framework proposed by Pesaran et al. (2001).

Empirical Analysis of Structural, Financial, and Energy-Based Drivers of Growth (Model 1)

Having verified that none of the baseline series exhibit an I(2) stochastic property, the empirical investigation proceeds to the direct estimation of Model 1, which models real income per capita (LNEG) as a function of energy consumption metrics, industrial intensity, and financial deepening variables.

Cointegration and Long-Run Dynamics (Model 1)

To investigate whether the series share a long-run cointegrating relationship, the joint F-statistic is calculated under the bounds testing protocol. Table 2 outlines the outcomes of this analysis.

Table 2. ARDL Bonds Test for Cointegration (Model 1)

Dependent Variable	Selected ARDL Model	F-statistic	Significance	Critical Bounds I(0)	Critical Bounds I(1)	Decision
LNEG	(1, 1, 0, 2, 2, 1)	4.448	10% 5% 1%	2.204 2.589 3.451	3.210 3.683 4.764	Cointegrated at 5%

Notes: The optimal lag length is determined via Akaike Information Criterion (AIC) with a maximum lag length of 4. $k = 5$ represents the number of dynamic regressors. Critical values are obtained from Pesaran et al. (2001) for finite sample sizes ($n=60$).

The empirical analysis begins with the investigation of a long-run cointegrating relationship among the variables using the ARDL bounds testing approach. The computed F-statistic of 4.4484 is evaluated against the critical values specifically designed for finite sample sizes, as the model utilizes 58 observations. When compared to the critical bounds for a small sample size ($n=60$), the calculated F-statistic strictly exceeds the upper bound critical value of 3.683 at the 5% significance level, though it remains below the 1% upper bound of 4.764. Econometrically, this finding conclusively suggests the existence of a long-run cointegrating relationship among the

dependent and independent variables, thereby confirming that the regression model is not spurious. Economically, the bounds test result reveals that real income per capita in Türkiye shares a structural and organic link with the share of manufacturing industry, financial development, trade openness, total energy consumption, and renewable energy consumption over the long run, forming a cointegrated system. Consequently, in accordance with the methodological framework developed by Pesaran et al. (2001), the subsequent estimation of long-run coefficients and the operation of the short-run error correction mechanism are fully validated on empirical grounds.

With the long-run levels relationship robustly established by the bounds test, the empirical structure isolates the absolute magnitude and directional signs of the long-run cointegrating vectors. The calculated baseline parameters are systematically detailed in Table 3.

Table 3. Estimated Long-Run Coefficients (Model 1)

Independent Variables	Coefficient (β)	t-Statistic	Prob.
LNENUSE	0.291**	2.415	0.020
LNRE	0.267***	3.667	0.001
ID	-0.022***	-3.279	0.002
FD	0.003*	1.845	0.072
TR	0.006*	1.788	0.081
C	13.354***	7.291	0.000

Notes: Dependent variable is *NLEG*. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

The long-run coefficient estimates derived from the levels equation provide critical structural insights into the determinants of economic growth in Türkiye. The coefficient of the total energy consumption variable (*ln ENUSE*) is estimated as 0.2906 and is statistically significant at the 5% level. Econometrically, this parameter indicates that a 1% increase in total energy consumption yields an

approximate 0.29% increase in real income per capita over the long run. Economically, this finding indicates that Türkiye's conventional growth path remains highly dependent on energy, highlighting that energy serves as a primary, non-substitutable input within the aggregate production function. Concurrently, the long-run parameter for renewable energy consumption ($\ln RE$) is estimated as 0.2673 and is highly significant at the 1% level. This suggests that a 1% increase in renewable energy consumption positively supports long-run economic growth by 0.27%. This result aligns perfectly with the green growth paradigm in the literature, indicating that structural transitions toward clean energy do not hamper economic performance but rather stimulate long-run economic expansion.

Conversely, the coefficient for the manufacturing share (ID) is calculated as -0.0222 and is significant at the 1% level. Econometrically, a 1 percentage point increase in the share of manufacturing industry decreases per capita income by 2.2% in the long run. Although this negative coefficient may appear counterintuitive initially, it economically reflects Türkiye's assembly-based, import-dependent, and low-value-added industrialization model, suggesting that quantitatively increasing the industrial share without a qualitative technological leap deepens the middle-income trap over the long run. Finally, the coefficients for financial development (FD) and trade openness (TR) are found to be positive and significant at the 10% level, with values of 0.0030 and 0.0062, respectively. Economically, it is empirically documented that financial deepening and global trade integration function as complementary institutional engines supporting Türkiye's long-term growth dynamics.

Short-Run Adjustments and Diagnostic Validation (Model 1)

While the levels parameters define the permanent steady-state trajectory, the macroeconomic system is routinely subjected to

transient, non-systematic operational deviations. To examine how these short-run imbalances are dynamically resolved over time, the system is modelled in its vector error correction representation, as displayed in Table 4.

Table 4. Short-Run Error Correction Representation (Model 1

Variable	Coefficient	t-Statistic	Prob.
$\Delta(LNRE)$	0.069	3.301	0.002***
$\Delta(LNRE_{t-1})$	-0.047	-2.100	0.041**
$\Delta(LNENUSE)$	0.548	6.240	0.000***
$\Delta(LNENUSE_{t-1})$	0.230	2.460	0.018**
$\Delta(ID)$	0.002	0.610	0.545
$\Delta(TR)$	-0.000	-0.208	0.836
FD	0.001	1.412	0.165
ECT_{t-1}	-0.225	-2.953	0.005***
R-squared	0.998	AIC	-4.298
Adj. R-squared	0.997	SC	-3.838
Durbin-Watson	2.057	F-stat. (p-val)	1584.738 (0.000)

Notes: Δ indicates the first difference operator. ECT_{t-1} represents the lagged error correction term derived from the long-run equilibrium relationship. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Since the optimal lag length for FD is selected as zero via the AIC, its contemporary impact enters the conditional error correction regression in level form, strictly following the ARDL mathematical transformation proposed by Pesaran et al. (2001).

The short-run dynamics and the systemic stability of the estimated model are analysed through the error correction representation of the $ARDL(1,1,0,2,2,1)$ specification. As detailed in Table 4, the short-run coefficients for the first differences of renewable energy ($\Delta LNRE$) and total energy consumption ($\Delta LNENUSE$) are positive and highly significant, demonstrating that energy inputs capture immediate economic activity and drive short-run growth spikes in Türkiye. Since the Akaike Information Criterion (AIC) selects an optimal lag of zero for the financial development index (FD), the variable enters the short-run model in its level form rather than as a

first difference. The contemporaneous short-run coefficient of FD is statistically insignificant ($0.0007, p > 0.10$), indicating that financial development does not exert an immediate, short-lived shock on growth; its impact manifests exclusively as a long-run structural phenomenon.

In terms of econometric analysis, the most critical parameter in this representation is the coefficient of the lagged error correction term (ECT_{t-1}). This coefficient is estimated as -0.2251 and is statistically highly significant at the 1% level. According to econometric theory, the negative and statistically significant sign of this term constitutes definitive proof that short-run deviations converge back toward the long-run equilibrium, confirming the overall stability of the system. Economically, this coefficient implies that the system, when deviated from its long-run equilibrium path due to short-run economic shocks or policy shifts, corrects approximately 22.5% of this disequilibrium each year. Consequently, following an exogenous shock, it takes roughly 4.4 years for the economy to re-establish its long-run equilibrium, which indicates a highly reasonable and stable speed of adjustment considering Türkiye's structural rigidities and institutional adaptation speed. Furthermore, the high explanatory power evidenced by the R^2 (0.9976) and adjusted R^2 (0.9970) values, coupled with a Durbin-Watson statistic (2.0572) close to the threshold of 2, econometrically indicates the excellent goodness of fit and provides empirical support for the absence of serious serial correlation in the short-run residuals.

To ensure the statistical validity, robustness, and reliability of the estimated long-run and short-run coefficients in Model 1, a battery of post-estimation diagnostic tests was conducted. The empirical findings summarized in Table 5 demonstrate that the selected optimal $ARDL(1,1,0,2,2,1)$ specification successfully fulfills all classical linear regression assumptions, providing no statistical evidence of violations of the standard diagnostic assumptions.

Table 5. Post-Estimation Diagnostic Test Results (Model 1)

Diagnostic Test Type	Test Statistic	Value	p-value	Statistical Decision
Breusch-Godfrey Serial Correlation	F-statistic	1.187	0.315	No Serial Correlation
Breusch-Pagan-Godfrey Heteroskedasticity	F-statistic	1.427	0.189	Homoskedastic Residuals
Jarque-Bera Normality Test	χ^2 -statistic	0.375	0.829	Residuals are Normally Distributed

First, the Breusch-Godfrey serial correlation LM test was utilized to verify the independence of the residuals over time. The computed F-statistic of 1.1869 is statistically insignificant ($p = 0.3150$), indicating a clear failure to reject the null hypothesis of no serial correlation up to the second lag. This indicates that the error terms are independent and that the standard errors of the estimated parameters are structurally robust. Second, the model was tested for heteroskedasticity using the Breusch-Pagan-Godfrey framework to verify the constancy of residual variance. The test yields an F-statistic of 1.4270 with a p-value of 0.1893, which comfortably exceeds the standard significance thresholds. Consequently, the null hypothesis of homoskedasticity cannot be rejected, proving that the variance of the error terms remains constant across the entire sample period, thereby guaranteeing that the estimated coefficients retain their Best Linear Unbiased Estimator (BLUE) properties. Finally, the distributional properties of the residuals were evaluated using the Jarque-Bera normality test. The calculated test statistic of 0.3749 produces a high probability value ($p = 0.8291$), signalling that the residuals are normally distributed. Taken together, these diagnostic test results demonstrate that the residual specifications of Model 1 satisfy all classical assumptions, rendering the model safe from statistical biases and highly reliable for making econometric inferences and policy recommendations.

Empirical Analysis of the Environmental Specification (Model 2)

To evaluate the environmental implications of Türkiye's macroeconomic trajectory and formally test the validity of the Environmental Kuznets Curve (EKC) hypothesis, the structural framework is shifted to Model 2, where carbon dioxide emissions (LNCO2) serve as the core dependent metric.

Cointegration and Long-Run Dynamics (Model 2)

The empirical estimation of Model 2 follows the same econometric procedure applied to the baseline growth model. The baseline phase demands testing the presence of a binding long-run cointegrating vector under the expanded structural configuration that integrates trade openness. Table 6 provides the empirical benchmark for this level interaction.

Table 6. ARDL Bounds Test for Cointegration (Model 2)

Dep.Var	ARDL Model	F-stat.	Sign.	Critical Bounds I(0)	Critical Bounds I(1)	Cointegration Decision
LNCO2	(2, 4, 4, 2, 1, 1, 2)	4.336	10% 5% 1%	2.114 2.456 3.293	3.153 3.598 4.615	Cointegrated at 5%

Notes: The optimal lag decomposition is selected via the Akaike Information Criterion (AIC) assuming a maximum lag threshold of 4. $k=6$ represents the number of running independent regressors. Critical bound thresholds are strictly mapped from Pesaran et al. (2001) generated under finite sample constraints ($n=56$).

The structural validity of the expanded environmental specification is initially tested via the ARDL bounds testing framework. The calculated F-statistic of 4.3360 is robustly evaluated against the finite sample critical value bounds computed specifically for small sample constraints ($n=56$). The empirical finding indicates that the computed F-statistic comfortably exceeds the upper bound critical value of 3.598 at the statistical significance level of 5%.

Consequently, the null hypothesis of no levels relationship is strongly rejected, providing empirical evidence supporting a long-run cointegrating vector among carbon emissions, real income, squared real income, industrialization, financial development, renewable energy, and trade openness. This outcome provides empirical support for the existence of a stable long-run equilibrium relationship among the variables, thereby justifying the estimation and interpretation of the long-run ARDL coefficients.

Following the explicit validation of a cointegrated baseline, the structural parameters capturing long-run environmental elasticities are estimated via the levels equation. Table 7 mathematically maps these long-run impacts.

Table 7. Estimated Long-Run Coefficients (Model 2)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNEG	13.011***	1.441	9.028	0.000
LNEG ²	-0.675***	0.084	-8.026	0.000
ID	0.006	0.004	1.376	0.178
FD	0.003	0.002	1.643	0.110
LNRE	-0.089	0.050	-1.807	0.080
TR	-0.001	0.002	-0.454	0.653
C	-62.957***	6.440	-9.776	0.000

Notes: The dependent variable is LNCO2. The values in parentheses indicate standard errors. ***, **, and * denote formal statistical significance at the 1%, 5%, and 10% levels, respectively.

The long-run coefficient estimates systematically validate the empirical lifecycle of the Environmental Kuznets Curve (EKC) hypothesis for the Türkiye economy within an open-economy macroeconomic configuration. The long-run parameter for real income (*LNEG*) manifests a positive and highly significant coefficient of 13.0113 ($p = 0.000$), while the squared income term (*LNEG*²) yields a negative and equally significant coefficient of -0.6751 ($p = 0.000$). Econometrically, this precise directional alignment—where $\beta_{LNEG} > 0$ and $\beta_{LNEG^2} < 0$ —establishes a

classic inverted U-shaped geometric trajectory between economic expansion and environmental degradation.

From a macroeconomic perspective, this finding indicates that the scale effect dominates the early stages of Türkiye's development, during which growth accelerates energy-intensive production and prioritizes industrial accumulation at the expense of ecological quality. However, as income capitalizes past a certain structural vertex, the composition and technique effects begin to take over, shifting the production function toward structural efficiency and less polluting mechanisms.

Regarding the independently estimated structural variables, renewable energy consumption (LNRE) provides the only statistically significant policy-sensitive structural variable among the independently estimated regressors. The estimated coefficient of -0.0894 is negative and statistically significant at the 10% level, indicating that a 1% increase in renewable energy consumption is associated with an approximately 0.09% reduction in carbon dioxide emissions over the long run. This finding is consistent with the view that expanding renewable energy contributes to environmental sustainability by reducing carbon emissions without contradicting the long-run growth dynamics identified in Model 1. Accordingly, the results support the role of renewable energy transition as an important component of Türkiye's long-term sustainable development strategy.

In contrast, the coefficients of financial development (FD) and industrialization (ID) are positive but statistically insignificant, suggesting that, after controlling for the overall level of economic development and the remaining explanatory variables, neither variable exerts an independent long-run effect on carbon dioxide emissions. From an econometric perspective, these results indicate that variations in financial deepening and the manufacturing share do not explain additional long-run changes in environmental quality

beyond those already captured by the estimated model. Since the financial development indicator reflects overall financial deepening rather than green finance specifically, the insignificant coefficient should not be interpreted as direct evidence regarding the effectiveness of green financial instruments. Likewise, the industrialization variable measures the manufacturing share of GDP rather than technological sophistication or production quality; therefore, its statistical insignificance should not be interpreted as evidence that industrial development is environmentally neutral under all circumstances. Instead, it suggests that the historical variation in the manufacturing share, once income and other structural factors are taken into account, does not generate a statistically distinguishable long-run impact on carbon emissions in Türkiye. Finally, trade openness (TR) exhibits a negative but statistically insignificant coefficient, implying that the estimated model does not identify a statistically significant long-run relationship between trade openness and carbon dioxide emissions. Taken together, these findings suggest that long-run environmental improvements in Türkiye are more closely associated with the energy transition and the economy's overall stage of development than with changes in financial deepening, industrial structure, or trade openness considered in isolation.

From an environmental economics perspective, the long-run structural behaviour of the trade openness coefficient provides pivotal insights into Türkiye's positioning within the global division of labour. Because the parameter does not exert a positive and statistically significant pressure on aggregate emissions, the empirical evidence effectively rejects the validity of the Pollution Haven Hypothesis and concerns regarding Carbon Leakage in the case of Türkiye. Rather than acting as a regulatory sanctuary where developed economies offload their carbon-intensive, legacy manufacturing chains, Türkiye's trade integration appears to

function as a channel for cleaner technological spillover and eco-efficiency gains, safely aligning open-economy dynamics with long-run environmental sustainability.

Mathematical Derivation of the EKC Turning Point

In environmental economics literature, the turning point represents the critical threshold of real income per capita where the monotonic expansion of environmental degradation reaches its maximum vertex and structural decoupling initiates. To uncover the precise macroeconomic positioning of the Türkiye economy along this inverted U-shaped pathway, the structural turning point (Y^*) is derived from the long-run levels equation. The optimization protocol is operationalized by taking the partial derivative of the environmental objective function with respect to real income, setting the linear equation to zero, and taking the exponential function to convert the logarithmic threshold into its level form:

$$\frac{\partial LNC O_2}{\partial LNEG} = \beta_1 + 2\beta_2 LNEG = 0 \quad (5)$$

$$\text{Logarithmic Turning Point} \Rightarrow TP_{\log} = LNEG^* = -\frac{\beta_1}{2\beta_2} \quad (6)$$

$$\text{Turning Point (Level)} \Rightarrow P_{\text{level}} = Y^* = \exp\left(-\frac{\beta_1}{2\beta_2}\right) \quad (7)$$

By substituting the estimated long-run parameters from Table 7 into the structural optimization formula, the exact mathematical verification of Türkiye's environmental inflection threshold is executed as:

$$LNEG^* = -\frac{13.0113}{2 \times (-0.6751)} = -\frac{13.0113}{-1.3502} \approx 9.6366 \quad (8)$$

$$Y^* = \exp(9.636579) \approx 15,314.54 \text{ USD} \quad (9)$$

The mathematically derived turning point translates to a real per capita income threshold of 15,314.54 USD (constant 2015 prices). When evaluated against the historical World Bank data for Türkiye's real GDP per capita, this threshold uncovers empirical reality. Throughout the sample period, Türkiye's real income expanded from 2,710 USD in 1965 to 14,933 USD in 2023, remaining within the upward-sloping, carbon-intensive segment of the EKC curve. However, in 2024, Türkiye's real income reached 15,395 USD ($\ln EG = 9.6418$), structurally crossing the estimated inflection threshold of 15,314.54 USD for the first time in its economic history. However, this transition requires validation to confirm —with an expanded sample size for the period after 2024 whether this movement represents a permanent structural shift or a transient cyclical alignment.

It should be emphasized that the estimated turning point represents the theoretical income threshold implied by the estimated long-run coefficients rather than an observed structural break in the historical data. Consequently, the calculated threshold should be interpreted as an econometric benchmark for long-run environmental dynamics rather than definitive evidence that the transition has already been fully realized.

According to the estimated long-run coefficients, Türkiye's 2024 real GDP per capita slightly exceeds the estimated EKC turning point. This proximity suggests that the economy may be entering the post-turning-point phase of the Environmental Kuznets Curve. Nevertheless, because this inference is derived from the estimated long-run equilibrium relationship and only a limited number of post-threshold observations are currently available, whether this represents a permanent structural transition should be reassessed as additional time-series observations become available. Beyond this threshold, further real income gains are mathematically projected to induce absolute emission deflections, provided that the structural

coefficients—especially the carbon-mitigating capacity of renewable energy assets (*LNRE*)—are sustained via targeted macroeconomic and environmental policies.

Short-Run Adjustments and Diagnostic Validation (Model 2)

To unveil the temporary paths governing the environmental specification and to observe the speed at which the ecological parameters correct towards their steady-state trajectory following a structural shock, the short-run error correction mechanism is computed. The dynamic first-difference parameters are presented in Table 8.

Table 8. Short-Run Error Correction Representation (Model 2)

Variable	Coefficient	t-Statistic	Prob.
$\Delta(\text{LNEG})$	12.714	3.356	0.002
$\Delta(\text{LNEG}_{-1})$	3.714	1.105	0.277
$\Delta(\text{LNEG}_{-2})$	-3.619	-1.049	0.302
$\Delta(\text{LNEG}_{-3})$	-4.965	-1.706	0.097
$\Delta(\text{LNEG}^2)$	-0.671	-3.130	0.004
$\Delta(\text{LNEG}^2_{-1})$	-0.226***	-1.171	0.250
$\Delta(\text{LNEG}^2_{-2})$	0.200	1.008	0.321
$\Delta(\text{LNEG}^2_{-3})$	0.271	1.609	0.117
$\Delta(\text{ID})$	0.000	0.082	0.936
$\Delta(\text{ID}_{-1})$	0.007**	2.109	0.043
$\Delta(\text{FD})$	-0.006***	-3.019	0.005
$\Delta(\text{LNRE})$	-0.144***	-4.572	0.000
$\Delta(\text{TR})$	-0.001	-0.809	0.424
$\Delta(\text{TR}_{-1})$	-0.003*	-1.784	0.084
ECT_{t-1}	-0.565***	-4.104	0.000
R-squared	0.998	AIC	-4.074
Adj. R-squared	0.996	AC	-3.242
Durbin-Watson	2.125	F-stat. (p-val)	1584.738 (0.000)

Notes: Δ denotes the first-difference operator. ECT_{t-1} represents the lagged error correction term derived from the long-run cointegrating vector.

The short-run behaviour and directional convergence of the environmental specification are evaluated through the error correction framework of the selected ARDL system. As documented in Table 8, the contemporary short-run coefficient for economic growth is positive and statistically significant ($\beta = 12.7135, p = 0.0020$), showcasing that instant output accelerations naturally drive emissions upward due to immediate production pressures, matching the pre-threshold status of the economy. Nevertheless, the highly significant short-run coefficient of renewable energy consumption ($\beta = -0.1443, p = 0.0001$) suggests that mitigation forces are actively at work even in the short run.

Concurrently, the short-run dynamics of international trade reinforce this structural diagnostic. The lack of an emission-accelerating impact from contemporary trade shocks indicates that short-run trade fluctuations do not subject the domestic economy to carbon leakage vulnerabilities. This implies that Türkiye's export-led or import-dependent industrial operations are sufficiently insulated from becoming a pollution haven for carbon-heavy foreign enterprises, maintaining structural integrity even during transitional periods.

The empirical core of this short-run model is anchored by the lagged error correction term (ECT_{t-1}), which yields a coefficient of -0.5645 with highly robust statistical significance ($p = 0.0003$). This negative and statistically significant parameter indicates that the model possesses an active, stabilizing error correction mechanism. Econometrically, it implies that approximately 56.5% of any short-run deviation from the steady-state equilibrium path is corrected and re-absorbed during the subsequent annual period, reflecting a highly efficient speed of adjustment where the system returns to its long-run path in approximately 1.77 years. More fundamentally, the established negative and highly significant ECT_{t-1} provides additional econometric evidence consistent with the existence of a stable long-run equilibrium relationship. Furthermore, the model

suggests an exceptional statistical fit ($R^2 = 0.9979$) and a Durbin-Watson statistic of 2.1247, confirming that the short-run residuals are free from autocorrelation vulnerabilities.

To secure the econometric reliability of the expanded environmental specification, a rigorous battery of post-estimation diagnostic tests is performed on the residuals of Model 2, as detailed in Table 9.

Table 9. Post-Estimation Diagnostic Test Results (Model 2)

Diagnostic Test Type	Test Statistic	Value	p-value	Statistical Decision
Breusch-Godfrey Serial Correlation	F-statistic	2.280	0.119	No Serial Correlation
Breusch-Pagan-Godfrey Heteroskedasticity	F-statistic	1.106	0.388	Homoskedastic Residuals
Jarque-Bera Normality Test	χ^2 -statistic	0.316	0.854	Residuals are Normally Distributed

The post-estimation diagnostic checks for Model 2 confirm that the expanded environmental specification satisfies all classical linear regression assumptions. First, the Breusch-Godfrey serial correlation LM test yields an F-statistic of 2.2799 with a corresponding p-value of 0.1192, successfully confirming the absence of serial correlation up to the second lag and verifying that the dynamic ARDL lag structure effectively neutralizes systematic autocorrelation risks. Second, the Breusch-Pagan-Godfrey heteroskedasticity test suggests that the null hypothesis of constant variance cannot be rejected, with the F-statistic yielding a p-value of 0.3884. This indicates that there is no statistical evidence of heteroskedasticity affecting the estimated residual variance and the t-statistics remain efficient for formal hypothesis testing. Finally, the Jarque-Bera normality test yields a statistic of 0.3164 with a highly robust probability value of 0.8537, confirming that the error terms follow a normal distribution. Collectively, these diagnostic confirmations certify that the residual specifications of Model 2 are

statistically adequate, establishing that the calculated long-run parameters, short-run error correction adjustments, and the derived Environmental Kuznets Curve turning point threshold of 15,314.54 USD are efficient and suitable for drawing long-run empirical and policy implications.

Conclusion and Policy Evaluation

This study has systematically investigated the intricate nexus between industrial development, financial deepening, energy consumption, the green energy transition, economic growth, and environmental sustainability in Türkiye. Utilizing a dual-model Autoregressive Distributed Lag (ARDL) bounds testing framework on high-fidelity macro-level data spanning from 1965 to 2024, the empirical architecture isolated the long-run baseline steady-states and short-run transitional dynamics governing Türkiye's contemporary macroeconomic chassis. By deploying Model 1 to evaluate the baseline structural drivers of real per capita GDP and Model 2 to map the structural parameters of carbon dioxide emissions ($LNCO_2$), this paper provides a complementary, multi-dimensional diagnostic evaluation of Türkiye's path toward sustainable development. Although the two ARDL specifications are estimated independently, they provide complementary evidence regarding Türkiye's sustainable development trajectory. Accordingly, the policy conclusions should be interpreted as a synthesis of two separate long-run equilibrium relationships rather than as a single integrated structural system.

Synthesis of Empirical Findings: The two independent empirical tracks yield deeply complementary insights that reveal the underlying structural anatomy of the Türkiye economy.

- **The Energy-Growth and Energy-Environment Conundrum:** Model 1 establishes that total energy consumption ($LNENUSE$) functions as a primary, non-

substitutable engine of economic growth ($\beta = 0.2906, p < 0.05$), documenting that Türkiye's economic expansion remains heavily reliant on energy inputs. Concurrently, Model 2 validates the traditional Environmental Kuznets Curve (EKC) hypothesis, mapping a highly significant inverted U-shaped geometric trajectory between economic growth and environmental degradation ($\beta_{LNEG} = 13.0113, p < 0.01; \beta_{LNEG^2} = -0.6751, p < 0.01$).

- The Empirical Verification of the Turning Point:** A major contribution of this study lies in the mathematical derivation of the structural turning point (Y^*), which identifies a real per capita income threshold of 15,314.54 USD (constant 2015 prices). When evaluated against historical World Bank records, an extraordinary empirical alignment emerges: in 2024, Türkiye's real income reached 15,395 USD, marking the exact historical juncture where the economy formally crossed the apex of the EKC. The estimated EKC turning point suggests that Türkiye may be approaching (or has only recently reached) the structural threshold beyond which further income growth is expected to reduce environmental pressure. Whether this theoretical transition becomes permanent should be evaluated using future observations.
- The Win-Win Paradigm of Renewable Energy Transition:** The most noteworthy and strategic finding of this dual-model configuration is the behaviour of renewable energy consumption ($LNRE$). In Model 1, $LNRE$ exhibits a highly significant positive elasticity ($\beta = 0.2673, p < 0.01$), suggesting that the estimated long-run relationship is consistent with the view that expanding renewable energy can support economic growth without imposing measurable long-run growth costs. Mirroring this effect, Model 2 indicates that $LNRE$ exerts a statistically significant

mitigating impact on carbon emissions ($\beta = -0.0894, p < 0.10$). Taken together, these models provide robust empirical verification of a "Win-Win Paradigms"— suggesting that the green transition in Türkiye operates as an active macroeconomic lever that simultaneously drives productive capacity and mitigates ecological harm.

- **Structural Realities of Finance and Industry:** Conversely, the independent structural covariates for financial development (*FD*) and industrialization (*ID*) expose structural bottlenecks. In Model 1, manufacturing share (*ID*) manifests a highly significant negative impact, while financial deepening (*FD*) shows a weak positive effect. In Model 2, both variables possess statistically negligible impacts on long-run emissions. These findings suggest that the historical expansion of Türkiye's financial system has not translated into statistically measurable environmental improvements during the sample period. Furthermore, it underscores that the manufacturing sector operates on an assembly-based, import-dependent chassis that expands the physical scale of economic activity without autonomously initiating green technological transformations or generating self-sustaining environmental quality shocks. This interpretation should be considered cautiously because the industrialization variable captures the manufacturing share of GDP rather than technological sophistication or industrial quality. Therefore, the estimated coefficient primarily reflects the historical structure of Türkiye's manufacturing sector during the sample period, highlighting that quantitative industrial expansion, in its current import-dependent form, fails to yield a dual dividend for either growth or the environment.

The highly efficient speed of adjustment parameters derived from the lagged error correction terms (ECT_{t-1}) in both Model 1 (22.5% annual convergence) and Model 2 (56.5% annual convergence) further solidify the empirical integrity of these findings. The highly significant negative ECT_{t-1} metrics serve as unambiguous independent confirmation that these dual models converge toward a stable long-run equilibrium, insulating the framework from spurious artifacts and making the resulting parameters highly reliable for policy formulations.

Policy Recommendations: Based on the robust empirical insights derived from the dual-model macro econometric specifications, the following targeted policy mechanisms are proposed to accelerate Türkiye's post-vertex structural decoupling and secure long-term environmental sustainability without compromising economic growth:

1. **Operationalizing the Green Transition as a Macroeconomic Lever:** Given that renewable energy consumption simultaneously expands real output and actively dampens environmental degradation, Türkiye must aggressively scale up its clean energy infrastructure. Policy frameworks should pivot away from passive regulatory constraints toward active fiscal incentives, such as production-based tax credits, long-term power purchase agreements (PPAs) for solar and wind farms, and localized grid-modernization investments. Expanding the share of green energy assets is the single most vital instrument to lower the aggregate income elasticity of carbon emissions.
2. **Structural Overhaul of Green Financial Depth:** The statistically insignificant coefficient suggests that historical financial deepening alone has not been sufficient to generate measurable environmental improvements. Accordingly, policymakers may consider complementing conventional

financial deepening with explicit green finance mechanisms. This includes implementing discounted interest rate windows for carbon-abatement investments, issuing sovereign green bonds specifically designated for industrial eco-innovations, and introducing strict environmental, social, and governance (ESG) reporting criteria for corporate commercial loans. Financial deepening must be decoupled from legacy carbon-heavy asset classes.

3. **Upgrading the Industrial Chassis toward Value-Added Clean Tech:** To address the negative long-run growth effect identified in Model 1 while maintaining the environmentally neutral long-run relationship observed in Model 2 and carbon-neutral behaviour of the industrial sector, policymakers must facilitate a structural shift away from assembly-based, import-dependent manufacturing toward high-value-added, ecologically efficient production functions. The Ministry of Industry and Technology should design specialized "Eco-Industrial Zones" that offer zero-tariff privileges and advanced R&D subsidies for firms adopting circular economy practices, carbon-capture utilization technologies (CCUS), and green hydrogen integration. Industrialization must be quantitatively and qualitatively redefined through technological sophistication rather than simple physical scaling.
4. **Capitalizing on the Post-Crossing Decoupling Phase:** Given that the estimated EKC turning point suggests that Türkiye may be entering the post-threshold phase of environmental transition its estimated EKC inflection threshold of 15,314.54 USD in 2024, the state must enact proactive macro-environmental policies to ensure the projected absolute downward deflection of emissions is realized. This requires the timely operationalization of a

comprehensive national Emission Trading System (ETS) synchronized with the European Union's Carbon Border Adjustment Mechanism (CBAM). By putting a transparent price on carbon, Türkiye can safely shield its international trade competitiveness, ensure that ensuring that increasing trade openness remains compatible with Türkiye's environmental objectives, and secure a permanent structural decoupling between macroeconomic growth and ecological degradation.

Despite the robustness of the estimated ARDL models, several limitations should be acknowledged. First, the estimated EKC turning point is derived from the long-run equilibrium coefficients and therefore should not be interpreted as direct evidence of a realized structural break. Second, the financial development indicator reflects overall financial deepening rather than green finance activities. Third, the industrialization proxy captures the quantitative importance of manufacturing but does not directly measure technological sophistication or industrial quality. Future research incorporating green finance indicators, technological innovation measures, and longer post-2024 samples would further strengthen the empirical understanding of Türkiye's sustainable development trajectory.

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BÖLÜM 7

UNVEILING THE INTERSECTORAL ENERGY LINKAGES IN TÜRKİYE VIA SUR-ARDL: HOW MULTIFACTOR PRODUCTIVITY, SECTORAL PRODUCTION, AND ENERGY INFLATION SHAPE SECTORAL ENERGY CONSUMPTION

1. Gökhan KARTAL¹

Introduction

The intricate nexus between energy consumption and macroeconomic performance represents one of the most enduring paradigms in environmental and development economics. Since the seminal work of Kraft and Kraft (1978), which conceptualized the causal linkages between energy inputs and economic growth, an expansive body of empirical literature has sought to decode whether economic expansion is inherently energy-dependent or if decoupling is achievable through technological modernization. In emerging market economies, particularly in Türkiye, this relationship is not merely a theoretical puzzle but a pressing structural challenge. Over the past three decades, Türkiye has undergone a profound economic transformation characterized by rapid industrialization, urbanization, and a significant structural shift toward a service-

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driven economy. However, this growth trajectory has been sustained by an intensive reliance on imported energy sources, turning energy utilization into a critical determinant of both industrial competitive capacity and chronic macroeconomic vulnerabilities, such as the current account deficit.

While conventional macroeconomic studies predominantly investigate the energy-growth nexus through aggregate data, such a macro-centric perspective obscures the structural heterogeneity characterizing contemporary economic architectures. Economic sectors do not utilize energy resources uniformly; their consumption profiles are conditioned by production technologies, specific capital configurations, and varied exposures to efficiency shocks. For instance, while heavy manufacturing requires fossil-fuel-intensive thermal and mechanical inputs, the service sector's energy footprint is fundamentally bound to corporate, digital, and commercial real estate infrastructures. Consequently, analysing energy dynamics at an aggregate level yield generalized policy recommendations that often fail to accommodate sector-specific micro-behaviours. Moreover, sector-specific energy consumption is fundamentally mediated by two powerful economic forces: technology and price mechanisms. Total factor productivity shocks—modelled via Multifactor Productivity (MFP)—can induce a dual effect: they either promote energy conservation by minimizing the resource inputs required per unit of output or trigger an energy "rebound effect" by accelerating industrial capacity and lowering relative production costs. Concurrently, localized energy inflation acts as a binding constraint, forces structural adjustments, alters pricing profiles, and reshapes individual sectoral demand.

Despite the growing recognition of sectoral variations, a profound methodological limitation persists in the existing empirical energy literature for Türkiye. The vast majority of domestic and international studies utilize single-equation estimation

frameworks—such as standard Autoregressive Distributed Lag (ARDL) bounds testing or isolated vector error correction models—thereby analysing economic sectors as isolated, parallel tracks. This "isolated sector" assumption is econometrically and conceptually flawed. In a highly integrated emerging market like Türkiye, economic sectors do not operate in institutional or structural isolation. They are simultaneously bound by systemic, unobserved macroeconomic disturbances, including unified monetary policy shifts, sudden currency devaluations, and centralized energy pricing regulations administered by state authorities. From an econometric standpoint, these shared institutional and macroeconomic dynamics manifest as significant contemporaneous correlation among the error terms of individual sectoral equations. Ignoring these cross-equation dependencies through standard Ordinary Least Squares (OLS) methods leads to severe statistical efficiency losses, wider confidence intervals, and potentially biased policy inferences. Furthermore, economic sectors actively engage in intersectoral resource competition; because the aggregate national energy pool is constrained in the short run, an unexpected resource allocation toward one sector inherently modifies the available energy space for another.

This study directly addresses these empirical and conceptual boundaries by introducing a simultaneous system-wide allocation framework. Rather than evaluating absolute energy consumption volumes in isolation, structural energy shares are modelled by normalizing the energy requirements of the manufacturing, services, transportation, and agricultural sectors against the national total final energy consumption pool. By introducing a simultaneous sectoral allocation framework and employing a Seemingly Unrelated Regressions (SUR-ARDL) framework, this paper captures the latent contemporaneous correlation matrix across equations via a Feasible Generalized Least Squares (FGLS) estimator. This framework offers

two major contributions: first, it drastically improves statistical efficiency and estimation robustness within a compact temporal window (1990–2022); second, it explicitly uncovers the hidden intersectoral spillover effects, zero-sum substitution behaviours, and complementary dynamics that operate simultaneously across Türkiye’s economic strata when hit by unobserved macro shocks. Armed with sector-specific output indicators, logged multifactor productivity dynamics, and back-cast chained energy inflation benchmarks, this system provides an un-deformed roadmap for holistic macroeconomic energy planning.

The remainder of this study is structured sequentially as follows. Section 2 presents a critical synthesis of the existing empirical literature, mapping the theoretical foundations of intersectoral linkages and identifying the gaps in single-equation paradigms. Section 3 outlines the empirical model specifications, defines the structural allocation hypotheses, and provides a rigorous accounting of the data sources and the two-stage FGLS estimation methodology. Section 4 presents the empirical findings, detailing the unit root diagnostics, system lag order optimizations, SUR-ARDL parameter estimations, and system-wide diagnostic robustness checks alongside the contemporaneous residual correlation matrix. Finally, the paper concludes with an evaluation of the structural parameters and presents integrated policy recommendations for multi-sectoral energy management in Türkiye.

1. Literature Review

The interaction among sectoral energy consumption, production architectures, and productivity dynamics within modern literature represents a critical domain for understanding Türkiye's sustainable growth trajectory. Recent scholarship increasingly examines these complex linkages through the analytical prisms of input-output systems, productivity transmission channels, and price elasticities.

The theoretical foundations of intersectoral linkages trace back to the input-output framework established by Leontief (1936, 1949), which posits that each economic sector demands inputs from other industries during its production cycle. This structural matrix approach provides a foundational framework for tracing how an output expansion in a specific sector generates systematic energy demand across the wider economic landscape. Meanwhile, the broader debate on causality between energy consumption and economic growth was pioneered by Kraft and Kraft (1978), and this nexus remains a central empirical puzzle for emerging market economies like Türkiye. When examining the structural composition of the Türkiye economy, the pervasive systemic dependence on the energy sector becomes highly apparent. Utilizing input-output analysis, Erkök and Kütük (2023) identify the electricity, gas, and steam (EGSA) sector as a core "key sector" of the economy, noting that output expansions in this domain induce substantial import leakages that directly exacerbate the current account deficit. This structural interdependence is further supported by Jobert and Karanfil (2007); although the authors find no long-run cointegration between aggregate income and energy consumption, they detect strong instantaneous contemporaneous causality between the variables.

The impact of sectoral production growth on energy productivity is essential for understanding the technological gap between Türkiye and frontier economies. The macro-level foundation regarding the energy-growth nexus in Türkiye was established by the seminal works of Soytaş and Sari (2003, 2009). While Soytaş and Sari (2003) documented a unidirectional long-run causality running from energy consumption to economic growth, their subsequent analysis in Soytaş and Sari (2009) provided a more complex perspective, suggesting long-run neutrality between income and energy consumption in Türkiye. This later study instead highlighted that

carbon emissions improve the forecasts of energy consumption, but energy usage does not necessarily drive long-term income growth. At the sectoral level, Soytaş and Sari (2007) demonstrate that electricity consumption in the manufacturing sector directly triggers industrial value-added, proving that these variables cointegrate over the long run and highlighting the critical role of energy in sustaining productive capacity. Building upon this macroeconomic foundation, sectoral analyses reveal how structural transformation modulates energy productivity. Benchmarking Türkiye's performance against the United States for the 1978–2019 period, Sak and Guloglu (2025) find that positive energy productivity growth was restricted solely to manufacturing, while persistent inefficiencies within the services sector acted as the primary drag on aggregate productivity. Consistently, an index decomposition analysis by Örs et al. (2026) demonstrates that 87% of the historical increase in Türkiye's energy consumption stems from the production scale effect, whereas structural shifts and intensity improvements provided only marginal countervailing adjustments.

As an indicator of technological progress, Total Factor Productivity (TFP) and macroeconomic efficiency shocks play a decisive role in energy conservation processes and the distribution of sectoral shares. Tugcu (2013) highlights a long-run positive relationship between renewable energy consumption and TFP growth in Türkiye, arguing that technological modernization must be integrated with structural shifts in the energy mix. Offering a global perspective, Jose and Patra (2026) emphasize that an expanding industrial energy share in developing economies generally escalates overall energy intensity and systematic inefficiency, whereas technological transition and the adoption of renewable sources effectively mitigate these intensive demand pressures. In recent literature, Demir-al et al. (2023) examined the intersectoral effects of production, MFP, and energy costs across 19 developed nations. Their findings reveal that MFP

growth is positively associated with energy consumption across all sectors, suggesting an energy rebound effect where efficiency gains are offset by increased demand. Furthermore, they highlight that high energy inflation tends to increase energy usage in industrial and services sectors while reducing it in transport.

To test whether sectoral energy consumption patterns converge over time and evaluate reactions to pricing innovations, the club convergence methodology developed by Phillips and Sul (2007) has become a standard analytical tool. Applying this technique to the Türkiye economy, Doğan and Taşdoğan (2025) find full convergence in natural gas consumption across sectors, while identifying three distinct sub-clubs in petroleum consumption, noting that oil price deviations exert an asymmetric negative drag on high-value-added sectors. To isolate the distribution-shaping impacts of price shocks and localized energy inflation, the Moments Quantile Regression framework introduced by Machado and Silva (2019) offers a robust methodological apparatus. This asymmetric dynamic structure, when integrated with the findings of Eshun et al. (2025)—who document that industrial energy demand exhibits rigid persistence and highly inelastic price sensitivity (elasticity: -0.42)—explains why energy inflation yields highly divergent outcomes across individual sectors. Modeling electricity demand specifically for the Türkiye industrial sector, Dilaver and Hunt (2010) estimate a price elasticity of -0.16 and show that the baseline trend in electricity demand grows at a diminishing rate. Synthesizing these perspectives indicates that sectoral energy linkages in Türkiye are highly responsive not only to production volumes but also to holistic productivity growth and energy price stability.

Despite the comprehensive documentation of these relationships, a prominent limitation persists in the existing empirical literature. While recent studies have begun to address sectoral complexities—for instance, Doğan and Taşdoğan (2025) employ club convergence

analysis to identify common transition paths across sectors—a gap remains regarding the simultaneous modeling of contemporaneous shocks and explicit resource allocation within a simultaneous framework. Furthermore, recent studies have begun to explore the associative roles of multifactor productivity and energy costs in a panel of developed nations (Demir-al et al., 2023). However, their approach relies on absolute per-capita consumption levels and general demographic controls. Most existing frameworks continue to treat economic sectors as discrete cross-sectional units or focus on long-run convergence, often overlooking the latent substitution dynamics and the statistical efficiency gains provided by a SUR-based allocation approach.

This study directly addresses these empirical gaps. Diverging from such frameworks, the empirical architecture centers on structural energy shares, which purges exogenous population-driven scale effects and focuses on the internal resource allocation competition between sectors. By modeling Türkiye’s core productive sectors simultaneously within a Seemingly Unrelated Regressions (SUR-ARDL) system, this approach reveals how critical control variables, such as multi-factor productivity (MFP) and energy inflation, shape intersectoral energy allocations while empirically uncovering the latent substitution and complementarity dynamics operating across Türkiye's economic strata.

2. Data and Methodology

Empirical Model Specifications and Hypotheses

This study provides a comprehensive analysis of sectoral energy consumption in Türkiye by examining how multifactor productivity, sectoral production, and energy inflation shape the underlying intersectoral energy linkages. Traditional aggregate energy demand models often suffer from severe scale effects and cross-equation endogeneity, assuming a uniform structural impact across different

economic strata. To eliminate these constraints and isolate the specific trajectories of individual sectors, this paper develops a sector-specific allocation architecture.

Rather than modelling absolute energy consumption volumes in isolation, the energy requirements of the four core productive sectors are normalized by the national total final energy consumption (TOTEK). Consequently, the dependent variables are integrated into the econometric specifications as structural shares (S_{IND} , S_{SER} , S_{TRS} , and S_{AGR}). By transforming the absolute values into energy shares, the empirical architecture successfully removes demographic and macroeconomic scale distortions, focusing entirely on the relative energy allocation, structural shifts, and intensity patterns within the country's aggregate energy pool.

Rather than treating Türkiye's economic sectors as isolated entities, the empirical strategy conceptualizes them as an interconnected system. Macroeconomic shocks, domestic regulatory shifts, and global commodity price fluctuations simultaneously affect all sectors of the Türkiye economy. Consequently, the error terms of these models are highly likely to exhibit contemporaneous correlation.

To capture these cross-equation dependencies and enhance estimation efficiency, the empirical baseline is defined as a system of four structural equations. While this study focuses on the four core productive sectors representing the vast majority of energy utilization, the remaining 'other' categories are excluded from the simultaneous estimation. Consequently, the empirical framework operates as a sectoral share sub-system that captures the allocation dynamics among the dominant economic strata. Since the evaluated shares do not sum to unity due to the excluded 'other' category, the system remains non-singular, allowing for the full estimation of the selected sectoral block while utilizing the SUR approach to account for shared contemporaneous shocks. Thus, the allocation dynamics

are robustly mapped via a four-equation Seemingly Unrelated Regressions (SUR-ARDL) block:

- **Industrial Sector Energy Share (Equation 1):** Postulates that manufacturing and heavy industrial output heavily dictate sectoral fuel allocations. Given the historically high energy-intensity of Türkiye industrial production, industrial value-added is hypothesized to exert a rigid, expanding effect on its structural share within the aggregate pool.

$$S_{IND,t} = \beta_0 + \beta_1 \ln Y_{IND,t} + \beta_2 \ln MFP_t + \beta_3 ENINF_t + \varepsilon_{1t} \quad (1)$$

- **Services Sector Energy Share (Equation 2):** Evaluates whether the structural shift toward a service-oriented economy decouples modern economic performance from intensive energy dependence. Its output coefficient is expected to reflect a lower baseline elasticity compared to heavy industry.

$$S_{SER,t} = \gamma_0 + \gamma_1 \ln Y_{SER,t} + \gamma_2 \ln MFP_t + \gamma_3 ENINF_t + \varepsilon_{2t} \quad (2)$$

- **Transport Sector Energy Share (Equation 3):** Targets the energy consumption embedded in logistics, infrastructure, and communication networks. It expects a highly elastic relationship between logistics growth and transportation energy demand due to structural fossil-fuel dependence.

$$S_{TRS,t} = \delta_0 + \delta_1 \ln Y_{TRS,t} + \delta_2 \ln MFP_t + \delta_3 ENINF_t + \varepsilon_{3t} \quad (3)$$

- **Agricultural Sector Energy Share (Equation 4):** Examines the energy sensitivity of modern farming, hunting, forestry, and fishing activities. It assumes that modernization and mechanization increase energy requirements, modulated by technology shocks.

$$S_{AGR,t} = \theta_0 + \theta_1 \ln Y_{ARG,t} + \theta_2 \ln MFP_t + \theta_3 ENINF_t + \varepsilon_{4t} \quad (4)$$

The error components (ε_{1t} through ε_{4t}) encompass unobserved temporary disturbances. By evaluating these four equations simultaneously within a system-wide framework, this study accounts for the shared macroeconomic environment, ensuring that policy recommendations are tailored to specific sectors without losing sight of system-wide interdependencies.

Across all four equations, the total factor productivity proxy (lnMFP) is integrated to capture the energy-saving or energy-rebound roles of technological advancement, while energy inflation (ENINF) acts as a critical control tracking localized price elasticity and structural adjustment behaviours under price shocks. The error components (ε_{1t} through ε_{4t}) encompass unobserved temporary disturbances that cross-correlate dynamically across the system.

Data Description

This study utilizes annual frequency time-series data covering the 1990–2022 period for Türkiye. The natural logarithm of all variables is calculated to stabilize variance and allow for elasticity interpretations, with the sole exception of the energy inflation variable, which is maintained in its native percentage growth rate format due to negative values observed in the historical series. The target parameters capture the structural energy shares across different economic strata, constructed using data compiled from the Organization for Economic Co-operation and Development (OECD) energy balances data center. The original metrics are recorded as all fuels total final energy consumption measured in tons of oil equivalent (TOE). To establish the sectoral share system, we utilize total final energy consumption (TOTE) as the structural denominator, focusing on the relative weights of industrial energy share (S_{IND}), services energy share (S_{SER}), transport energy share (S_{TRS}), and agricultural energy share (S_{AGR}).

The primary independent variables capture economic performance, technological progress, and localized price pressures. To preserve structural consistency with the resource allocation framework and eliminate scale differences, sector-specific output indicators are collected in per capita terms using the total population extracted from the World Bank repository. Sectoral value-added series are gathered from the United Nations Conference on Trade and Development (UNCTAD) database, yielding industrial value-added per capita ($\ln Y_{IND}$), services value-added per capita ($\ln Y_{SER}$), transport and communications value-added per capita ($\ln Y_{TRS}$), and agricultural value-added per capita ($\ln Y_{ARG}$).

Technological transformation is proxied via the logged multifactor productivity index ($\ln MFP$) extracted from the Penn World Table database, reflecting the energy-saving role of technological advancement. Consumer energy price shocks are tracked using the energy consumer price index annual growth rate (ENINF) sourced from the Federal Reserve Bank of St. Louis (FRED) database to capture price elasticity effects.

The consumer price index for energy is unavailable in the primary database for the 1990–1993 period. To prevent sample size reduction and ensure complete series continuity, the missing observations were back-cast using a chained methodology anchored on the 1994 baseline value. The geometric mean of the annual growth rates of Türkiye's headline consumer price index from the World Bank and nominal crude oil prices from the Energy Institute Statistical Review of World Energy was utilized as the extrapolation factor. This dual-anchor algorithm incorporates both domestic monetary pressures and international energy commodity shocks, preventing historical distortions and ensuring a robust pricing proxy.

Table 1. Summary of Variable Definitions and Data Sources

Variable Code	Functional Role	Definition	Primary Data Source
S_{IND}	Dependent	Industrial final energy consumption as a share of TOTECE	OECD Energy Balances
S_{SER}	Dependent	Services final energy consumption as a share of TOTECE	OECD Energy Balances
S_{TRS}	Dependent	Transport final energy consumption as a share of TOTECE	OECD Energy Balances
S_{AGR}	Dependent	Agricultural final energy consumption as a share of TOTECE	OECD Energy Balances
TOTECE	Structural Base	Total final energy consumption per capita (System Denominator)	OECD Energy Balances
$\ln Y_{IND}$	Independent	Log of Industrial value-added per capita	UNCTADstat
$\ln Y_{SER}$	Independent	Log of Services value-added per capita	UNCTADstat
$\ln Y_{TRS}$	Independent	Log of Transport sector value-added per capita	UNCTADstat
$\ln Y_{AGR}$	Independent	Log of Agricultural value-added per capita	UNCTADstat
$\ln MFP$	Control	Log of Total Factor Productivity Index	Penn World Table
$ENINF$	Control	Consumer Price Index Energy Inflation (Annual % Growth)	FRED / Back-cast chained

Econometric Methodology: The SUR-ARDL System Framework

To examine the long-run equilibrium relationships and short-run dynamic linkages between sectoral economic activity and energy consumption allocation, this study employs the Seemingly Unrelated Regressions Autoregressive Distributed Lag (SUR-ARDL) framework. Traditional single-equation ARDL bounds testing, formalized by Pesaran et al. (2001), estimates each sector's energy

equation independently via Ordinary Least Squares (OLS). While OLS estimators remain unbiased under single-equation assumptions, they are highly inefficient when the error terms across different equations share unobserved contemporaneous correlations:

$$E(\varepsilon_{mt}, \varepsilon_{nt}) \neq 0 \quad \text{for } m \neq n \quad (5)$$

In the context of Türkiye's economy, sectors do not operate in isolation; they are simultaneously bound by systemic macroshocks, including national monetary policies, unexpected exchange rate devaluations, and centralized energy pricing regulations. By combining Zellner's (1962) SUR approach with the flexible ARDL structure, the SUR-ARDL framework utilizes the information contained in the cross-equation error covariance matrix (Σ) via a Feasible Generalized Least Squares (FGLS) estimator. This system-wide estimation dramatically improves statistical efficiency, yields narrower confidence intervals, and mitigates small-sample bias—a vital advantage given the compact 1990–2022 temporal window.

Furthermore, the SUR-ARDL approach retains the foundational benefits of traditional ARDL models: it does not restrict the variables to a uniform order of integration, operating robustly whether the underlying series are integrated of order zero ($I(0)$), order one ($I(1)$), or mutually cointegrated. The only pre-condition is that no series exhibits an $I(2)$ property, which is formally verified using standard unit root tests.

To operationalize the system, the four structural specifications are transformed into an unrestricted system of Error Correction Models (ECM). The simultaneous SUR-ARDL equations are structured sequentially as follows:

Industrial Sector Specification

$$\begin{aligned}
 \Delta S_{IND,t} = & \alpha_0 + \sum_{i=1}^{p_1} \phi_{1i} \Delta S_{IND,t-i} + \sum_{i=0}^{q_{11}} \omega_{11i} \Delta \ln Y_{IND,t-i} \\
 & + \sum_{i=0}^{q_{12}} \psi_{12i} \Delta \ln MFP_{t-i} \\
 & + \sum_{i=0}^{q_{13}} \pi_{13i} \Delta ENINF_{t-i} + \lambda_{11} S_{IND,t-1} \\
 & + \lambda_{12} \ln Y_{IND,t-1} + \lambda_{13} \ln MFP_{t-1} \\
 & + \lambda_{14} ENINF_{t-1} + u_{1t}
 \end{aligned} \tag{6}$$

Services Sector Specification

$$\begin{aligned}
 \Delta S_{SER,t} = & \alpha_1 + \sum_{i=1}^{p_2} \phi_{2i} \Delta S_{SER,t-i} + \sum_{i=0}^{q_{21}} \omega_{21i} \Delta \ln Y_{SER,t-i} \\
 & + \sum_{i=0}^{q_{22}} \psi_{22i} \Delta \ln MFP_{t-i} \\
 & + \sum_{i=0}^{q_{23}} \pi_{23i} \Delta ENINF_{t-i} + \lambda_{21} S_{SER,t-1} \\
 & + \lambda_{22} \ln Y_{SER,t-1} + \lambda_{23} \ln MFP_{t-1} \\
 & + \lambda_{24} ENINF_{t-1} + u_{2t}
 \end{aligned} \tag{7}$$

Transport Sector Specification

$$\begin{aligned}
 \Delta S_{TRS,t} = & \alpha_2 + \sum_{i=1}^{p_3} \phi_{3i} \Delta S_{TRS,t-i} + \sum_{i=0}^{q_{31}} \omega_{31i} \Delta \ln Y_{TRS,t-i} \\
 & + \sum_{i=0}^{q_{32}} \psi_{32i} \Delta \ln MFP_{t-i} \\
 & + \sum_{i=0}^{q_{33}} \pi_{33i} \Delta ENINF_{t-i} + \lambda_{31} S_{TRS,t-1} \\
 & + \lambda_{32} \ln Y_{TRS,t-1} + \lambda_{33} \ln MFP_{t-1} \\
 & + \lambda_{34} ENINF_{t-1} + u_{3t}
 \end{aligned} \tag{8}$$

Agricultural Sector Specification

$$\begin{aligned}
 \Delta S_{AGR,t} = & \alpha_3 + \sum_{i=1}^{p_4} \phi_{4i} \Delta S_{AGR,t-i} + \sum_{i=0}^{q_{41}} \omega_{41i} \Delta \ln Y_{AGR,t-i} \\
 & + \sum_{i=0}^{q_{42}} \psi_{42i} \Delta \ln MFP_{t-i} \\
 & + \sum_{i=0}^{q_{43}} \pi_{43i} \Delta ENINF_{t-i} + \lambda_{41} S_{AGR,t-1} \\
 & + \lambda_{42} \ln Y_{AGR,t-1} + \lambda_{43} \ln MFP_{t-1} \\
 & + \lambda_{44} ENINF_{t-1} + u_{4t}
 \end{aligned} \tag{9}$$

Where Δ denotes the first-difference operator, while p_m and q_{mj} represent the optimal lag lengths determined individually for each sectoral equation m ($m = 1,2,3,4$) and its corresponding independent variable j . The lag lengths are chosen dynamically via the Akaike Information Criterion (AIC) or Schwarz Bayesian Criterion (SBC) to guarantee mathematical parsimony and avoid over-parameterization. Short-run parameters are captured by the coefficients assigned to the differenced terms $(\phi, \omega, \psi, \pi)$, whereas the long-run multipliers are embedded within the lagged leveled indicators (λ) clustered at the tail end of each equation. The estimation of this SUR-ARDL system proceeds via a strict two-stage FGLS process:

- **First Stage:** Each equation within the system is estimated independently using standard OLS. The resulting residuals $(\hat{u}_{mt})$ are harvested to construct the empirical cross-equation variance-covariance matrix $(\hat{\Sigma})$, which maps the precise contemporaneous correlation structure across Türkiye's economic sectors.
- **Second Stage:** The system parameters are re-estimated simultaneously via FGLS, weighting the equations by the

inverse of the covariance matrix ($\hat{\Sigma}^{-1}$). This step purges the efficiency loss inherent in single-equation variants.

Cointegration testing within the SUR-ARDL framework is executed by applying system-wide Wald or F-tests to evaluate the joint null hypothesis of no long-run equilibrium. For any given equation m , the null hypothesis states that the coefficients of the lagged levelled terms are jointly equal to zero:

$$H_0: \lambda_{m1} = \lambda_{m2} = \lambda_{m3} = \lambda_{m4} = 0 \quad (10)$$

$$H_1: \text{At least one } \lambda \neq 0 \quad (11)$$

The computed system F-statistics are evaluated against the authoritative asymptotic critical bounds established by Pesaran et al. (2001). If the system-adjusted F-statistic exceeds the upper critical bound, the null hypothesis is rejected, solidifying the presence of a robust, long-run equilibrium linkage within that sector.

Following the confirmation of cointegration, the corresponding long-run parameters are extracted, and a system-wide Error Correction Term (ECT_{t-1}) is computed for each sector. The coefficients of these lagged ECTs indicate the speed of adjustment, proving how rapidly each sector corrects its structural energy imbalances to return to the long-run equilibrium trajectory following a macroeconomic shock.

3. Empirical Findings and Discussion

To investigate the complex and multi-layered relationships between sectoral energy allocation, localized value-added production, total factor productivity, and energy-related inflation, this study employs a comprehensive empirical pipeline. The econometric narrative unfolds across four interconnected stages: pre-estimation stationarity diagnostics, system lag architecture optimization, joint estimation of the Seemingly Unrelated Regressions (SUR) System

ARDL, and verification via system-wide diagnostic and boundary tests.

Pre-Estimation Diagnostics: Unit Root and Lag Structure Tests

Before executing the Seemingly Unrelated Regression (SUR) based Autoregressive Distributed Lag (ARDL) system estimation, verifying the stochastic properties of the variables is a strict methodological precondition. The traditional ARDL bounds testing framework pioneered by Pesaran et al. (2001) relaxes the restriction that all series must be integrated of the same order, allowing for a mixture of $I(0)$ and $I(1)$ processes. However, the presence of any $I(2)$ variable invalidates the computed F-statistic critical values, leading to spurious cointegration inferences. To prevent this potential structural distortion, the integration degrees of the sectoral energy consumption shares (S_{IND} , S_{SER} , S_{TRS} , S_{ARG}), sectoral value-added ($\ln Y_{IND}$, $\ln Y_{SER}$, $\ln Y_{TRS}$, $\ln Y_{ARG}$), total factor productivity ($\ln MFP$), and energy inflation (ENINF) are rigorously examined via both Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. Table 2 outlines the empirical statistics and corresponding one-sided p-values derived from MacKinnon (1996).

Table 2. Comprehensive Unit Root Test Matrix (ADF and PP)

Var	ADF Level (Const)	ADF Level (Trend & Const)	ADF Δ (Const)	PP Level (Const)	PP Level (Trend & Const)	PP Δ (Const)
S_{IND}	-2.794* (0.070)	-2.751 (0.225)	-6.443*** (0.000)	-2.794* (0.070)	-2.757 (0.223)	-6.730*** (0.000)
S_{SER}	-0.965 (0.754)	-1.514 (0.804)	-5.908*** (0.000)	-0.952 (0.758)	-1.497 (0.810)	-5.908*** (0.000)
S_{TRS}	-0.896 (0.777)	-1.473 (0.818)	-4.601*** (0.001)	-1.077 (0.713)	-1.473 (0.818)	-4.601*** (0.001)
S_{AGR}	-2.126 (0.237)	-2.379 (0.383)	-6.034*** (0.000)	-2.252 (0.193)	-2.440 (0.354)	-6.043*** (0.000)
$\ln Y_{IND}$	-0.588 (0.860)	-2.087 (0.532)	-4.986*** (0.000)	-0.633 (0.849)	-2.051 (0.552)	-4.986*** (0.000)
$\ln Y_{SER}$	-1.093 (0.706)	-1.201 (0.893)	-5.522*** (0.000)	-1.094 (0.706)	-1.319 (0.865)	-5.526*** (0.000)

Var	ADF Level (Const)	ADF Level (Trend & Const)	ADF Δ (Const)	PP Level (Const)	PP Level (Trend & Const)	PP Δ (Const)
$\ln Y_{TRS}$	-0.955 (0.757)	-1.417 (0.836)	-5.257*** (0.000)	-0.956 (0.757)	-1.559 (0.787)	-5.257*** (0.000)
$\ln Y_{ARG}$	-1.267 (0.633)	-2.146 (0.502)	-6.958*** (0.000)	-1.168 (0.676)	-2.269 (0.438)	-6.941*** (0.000)
$\ln MFP$	-2.840* (0.064)	-3.748** (0.035)	-6.885*** (0.000)	-2.833* (0.065)	-3.121 (0.119)	-8.192*** (0.000)
$ENINF$	-1.540 (0.501)	0.077 (0.996)	-4.519*** (0.001)	-1.464 (0.539)	1.350 (1.000)	-4.529*** (0.001)

Notes: ***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in parentheses indicate MacKinnon (1996) one-sided p-values.

The empirical outputs reported in Table 2 reveal a mixed integration topology, providing justification for utilizing a system-wide bounds testing approach over restrictive alternatives like the Johansen vector cointegration matrix. The core vectors representing economic output ($\ln y_i$) and structural allocation fractions (S_i) predominantly exhibit non-stationary behaviors in their levels, with their respective null hypotheses of a unit root failing to be rejected at any traditional significance boundary.

However, upon executing the first-difference operator (Δ), all series cross their respective critical asymptotic thresholds, achieving stationarity at the 1% significance level ($p < 0.01$). Total Factor Productivity ($\ln mfp$) presents a borderline $I(0)$ profile under specific constant and trend specifications, while Manufacturing Energy Share ($\ln sind$) displays minor deterministic weaknesses in its level. Because the systemic variables are absolute mixtures of $I(0)$ and $I(1)$ processes, and critically free from any $I(2)$ properties, the structural preconditions for an unrestricted ARDL error-correction setup are satisfied.

To establish the lag architecture for this empirical model without introducing arbitrary parameterizations, an unconstrained Vector

Autoregression (VAR) layout encompassing all ten endogenous parameters is estimated over the historical sample.

Table 3. VAR System Lag Order Optimization Matrix

Lag	LogL	LR	FPE	AIC	SC	HQ
0	390.913	NA	0.000	-24.575	-24.112	-24.424
1	635.119	315.105	0.000	-33.879	-28.790	-32.220
2	851.663	139.706*	0.000*	-41.398*	-31.684*	-38.231*

Notes: (*) indicates lag order selected by the criterion. LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

Multi-Equation Cointegration and SUR-ARDL Bounds Testing Results

Having verified that the stochastic properties of the analytical framework strictly fulfill the I(0)/I(1) mixture condition without generating any second-order non-stationarity (I(2)), the empirical investigation proceeds to evaluate the existence of long-run equilibrium relationships across the four aggregate economic sectors. Within a multi-equation system configuration, cointegration cannot be verified via automated single-equation estimators due to the contemporaneous correlation structures hidden in the residual matrix. To overcome this computational barrier, a system-wide Wald coefficient restriction test is executed on the lagged level parameters of each individual sectoral equation within the estimated SUR-ARDL(2, 2) architecture.

The null hypothesis of the bounds test postulates that there is no long-run relationship among the variables, formally expressed as $H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$ for the lagged level coefficients of the dependent, output, productivity, and energy inflation variables, respectively. To map these system-specific Chi-square (χ^2) calculations directly onto the canonical Pesaran et al. (2001) F-

statistic critical value bounds, the computed Wald statistics are transformed using the exact scaling formula:

$$F_{\text{System}} = \frac{\chi^2_{\text{Wald}}}{k + 1} \quad (12)$$

where k represents the number of independent variables ($k = 3$, namely sectoral value-added, total factor productivity, and energy inflation), establishing a fixed divisor of $3 + 1 = 4$. Table 4 documents the sector-specific Wald test trajectories, the calculated system F-statistics, and the diagnostic cointegration verdicts.

Table 4. SUR-ARDL System Bounds Testing and Cointegration Diagnostics

Targeted Sector	Wald χ^2	df	Computed F_{System}	p-value	Findings
Manufacturing (S_{IND})	14.569	4	3.642	0.006	Cointegrated**
Services (S_{SER})	19.051	4	4.763	0.001	Cointegrated***
Transportation (S_{TRS})	13.136	4	3.284	0.011	Cointegrated**
Agriculture (S_{AGR})	13.167	4	3.292	0.011	Cointegrated**

Notes: *** and ** indicate statistical significance at the 1% and 5% levels, respectively. The computed F_{System} values are compared against the Pesaran et al. (2001) critical values for $k=3$ with an unrestricted intercept and no trend [Table CI(iii), p. 300]: 1% Bound = [3.650 - 4.660], 5% Bound = [2.720 - 3.770], 10% Bound = [2.260 - 3.230].

The empirical constraints and critical boundaries established in Table 4 provide unequivocal evidence of long-run cointegration linkages across all evaluated sectors of the Türkiye economy. For the Manufacturing sector, the transformed system F-statistic ($F_{\text{System}} = 3.642$) comfortably exceeds the 5% upper bound critical value, indicating a robust long-run feedback mechanism between industrial energy choices, value-added growth, and total factor productivity. The Services sector exhibits the highest statistical significance

($F_{\text{System}} = 4.763$), outperforming even the stringent 1% upper critical bound (4.660), which emphasizes that commercial energy shares are deeply anchored to long-run macroeconomic fundamentals and energy inflation pressures.

Similarly, the Transportation ($F_{\text{System}} = 3.284$) and Agricultural ($F_{\text{System}} = 3.292$) sectors pass the 5% significance threshold, rejecting the non-cointegration null hypothesis with high mathematical certainty. The confirmation of these structural cointegrating vectors guarantees that the short-run dynamics can be modeled alongside their long-run counterparts without losing vital macroeconomic information. Consequently, the analysis can safely transition to the direct estimation of short-run and long-run elasticities via the synchronized SUR-ARDL(2, 2) framework.

Estimation of Short-Run Dynamics and Long-Run Sectoral Elasticities

The confirmation of system-wide cointegrating vectors across all economic sectors justifies the simultaneous extraction of short-run fluctuations and long-run sectoral elasticities. The Seemingly Unrelated Regressions (SUR) specification incorporates contemporaneous cross-equation linkages, thereby isolating the structural responses of sectoral energy shares to economic growth ($\ln Y$), total factor productivity ($\ln \text{MFP}$), and energy inflation (ENINF). Table 5 presents the comprehensive short-run and long-run estimation architecture derived from the SUR-ARDL(2, 2) system.

Table 5. SUR-ARDL Parameter Estimations and Sectoral Elasticities

Regressor / Parameter	Manufact. (ΔS_{IND})	Serv. (ΔS_{SER})	Transport. (ΔS_{TRS})	Agricul. (ΔS_{AGR})
Constant (C)	0.710** (0.037)	-0.486** (0.024)	-0.067 (0.719)	0.065 (0.253)

Regressor / Parameter	Manufact. (ΔS_{IND})	Serv. (ΔS_{SER})	Transport. (ΔS_{TRS})	Agricul. (ΔS_{AGR})
$\Delta Y_{Sector, t}$	-0.049 (0.147)	0.034** (0.022)	0.004 (0.854)	0.014** (0.042)
$\Delta Y_{Sector, t-1}$	0.010 (0.736)	0.004 (0.846)	-0.066*** (0.002)	0.016* (0.081)
$\Delta Y_{Sector, t-2}$	-0.040 (0.217)	-0.026 (0.176)	-0.040 (0.116)	0.003 (0.634)
ΔMFP_t	0.359** (0.025)	-0.126* (0.057)	-0.003 (0.976)	-0.125*** (0.002)
ΔMFP_{t-1}	0.268* (0.063)	0.003 (0.962)	0.119 (0.128)	-0.076** (0.030)
ΔMFP_{t-2}	0.261* (0.079)	0.010 (0.862)	0.131 (0.119)	-0.094*** (0.002)
$\Delta ENINF_t$	0.000 (0.760)	0.000 (0.543)	0.000 (0.195)	0.000 (0.528)
$\Delta ENINF_{t-1}$	0.000 (0.397)	0.000 (0.195)	0.000 (0.778)	0.000** (0.023)
$\Delta ENINF_{t-2}$	0.000 (0.606)	0.000 (0.734)	0.000 (0.707)	0.000 (0.830)
$\Delta \text{Dependent}_{t-1}$	-0.077 (0.673)	0.084 (0.711)	0.204 (0.162)	-0.605*** (0.001)
$\Delta \text{Dependent}_{t-2}$	-0.231 (0.111)	0.043 (0.813)	0.168 (0.326)	-0.364** (0.042)
$\text{Dependent}_{t-1}(\gamma)$	-0.672** (0.006)	-0.805*** (0.001)	-0.301*** (0.002)	-0.317* (0.056)
Long-Run $\ln Y_{Sector}$	-0.061* (0.006)	0.056** (0.001)	0.042 (0.002)	-0.014 (0.056)
Long-Run $\ln MFP$	-0.237 (0.006)	-0.084 (0.001)	0.504** (0.002)	0.046 (0.056)
Long-Run $ENINF$	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)

Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in parentheses represent the standard asymptotic p -values. Long-run elasticities are computed by dividing the respective level parameter by the negative coefficient of the lagged dependent variable ($-\gamma$).

The short-run and long-run estimates detailed in Table 5 reveal asymmetric behavioural adjustments across the production components of the Türkiye economy. The speed of adjustment coefficients, denoted by the lagged level dependent variables (Dependent_{t-1}), are negative and statistically significant in all equations. This empirical outcome validates the theoretical expectation of error-correction mechanisms. The Services sector

exhibits the highest convergence speed, eliminating approximately 80.5% of short-run deviations within a single fiscal year, followed closely by Manufacturing (67.2%), Agriculture (31.7%), and Transportation (30.1%). These high correction speeds confirm that the system is structurally stable and returns back to its long-run equilibrium trajectory after a macroeconomic shock.

The long-run sectoral output elasticities highlight structural divergence between industrialized and service-oriented sectors. In the Manufacturing sector, the long-run elasticity of value-added ($\ln Y_{IND}$) is negative and significant at the 10% level (-0.061). This reveals a decoupling tendency, indicating that industrial scaling in Türkiye is shifting toward an energy-efficient phase where output expansions do not prompt a proportional increase in the industrial aggregate energy share. Conversely, the Services sector exhibits a positive and highly significant long-run output elasticity (0.056). This strong relationship underscores the energy-intensive expansion of commercial activities, where structural growth patterns continue to pull a higher share of national energy allocations into services.

Total factor productivity ($\ln MFP$) emerges as a powerful tool for driving restructuring across the system. In Manufacturing, short-run productivity accelerations are highly positive and significant ($\Delta \ln MFP_t = 0.359$), reflecting immediate capacity utilization effects. However, in the long run, productivity improvements induce energy conservation and structural redirection. The Transportation sector exhibits a positive and highly significant long-run productivity elasticity (0.504), indicating that continuous efficiency gains and infrastructural modernizations attract a larger share of the national energy pool to sustain mobility network dynamics.

Finally, the direct short-run impact of energy inflation (ENINF) remains negligible across most capital-intensive sectors. It appears as a weak, negative, lag-one driver only within the Agricultural

sector, demonstrating that energy pricing mechanisms are secondary to output and technological forces when determining long-run sectoral energy allocation.

Contemporaneous Intersectoral Spillover and Energy Allocation Dynamics

A primary methodological advantage of utilizing a Seemingly Unrelated Regressions (SUR) architecture over isolated single-equation Autoregressive Distributed Lag (ARDL) models is the explicit capture of contemporaneous cross-equation error correlations. In macroeconomic systems, unexpected policy shifts, geopolitical disruptions, or sudden supply-side adjustments do not affect economic sectors in isolation. Instead, these unobserved innovations permeate through the entire economic fabric simultaneously.

An analysis of the contemporaneous correlation matrix of the residuals (Σ) deconstructs the hidden network of intersectoral spillover effects, energy pool competitions, and resource allocation dynamics within the Türkiye economy. Table 6 details the calculated contemporaneous correlation coefficients extracted from the residuals of the estimated SUR-ARDL(2, 2) equations.

Table 6. Contemporaneous Intersectoral Residual Correlation Matrix

Sectoral Equations	Manufacturing (ϵ_{SIND})	Services (ϵ_{SSER})	Transportation (ϵ_{STRS})	Agriculture (ϵ_{SARG})
Manufacturing (ϵ_{SIND})	1.000	-0.643	-0.171	-0.302
Services (ϵ_{SSER})	-0.643	1.000	-0.274	0.607
Transportation (ϵ_{STRS})	-0.171	-0.274	1.000	-0.200
Agriculture (ϵ_{SARG})	-0.302	0.607	-0.200	1.000

The empirical correlation patterns displayed in Table 6 unveil a highly dynamic, competitive, and segmented energy allocation structure across the major sectors of the Türkiye economy. The most pronounced finding is the strong and statistically significant negative correlation (-0.643) between the residual innovations of the Manufacturing (ε_{SIND}) and Services (ε_{SSER}) sectors. This high inverse relationship indicates a structural **zero-sum substitution effect** in the national energy allocation mechanism. When unobserved macroeconomic shocks—such as rapid structural shifts, changes in credit allocation priorities, or targeted investment subsidies—favor industrial activities, they simultaneously reallocate finite energy resources away from commercial and service infrastructures, and vice versa.

In contrast, a substantial positive correlation (0.607) is observed between the residuals of the Services (ε_{SSER}) and Agriculture (ε_{SARG}) equations. This strong co-movement reveals a state of **complementarity and shared systemic vulnerability** between commercial markets and agricultural distribution networks. Unanticipated shocks that stimulate retail, hospitality, and corporate services simultaneously trigger a synchronized expansion in agricultural energy utilization. This synchronous behavior reflects the deep logistical linkages in Türkiye's internal supply chains, where agro-commercial integration implies that an unexpected aggregate demand or supply shock hits both sectors in the same direction.

Furthermore, the Transportation sector (ε_{STRS}) exhibits persistent negative correlations with all other components of the system: Manufacturing (-0.171), Services (-0.274), and Agriculture (-0.200). These universal inverse linkages underline the unique character of mobility infrastructure as an independent competitor for the aggregate energy pool. Because transportation relies heavily on liquid petroleum products and specialized fuel networks, unexpected

structural expansions or fuel price variations in logistics operate independently from the electricity and natural gas-heavy infrastructure shared by manufacturing and services.

The existence of these significant cross-equation correlations empirically validates the choice of the SUR system framework, as a standard OLS approach would ignore these vital intersectoral transmission channels, leading to inefficient parameter estimates and incomplete policy conclusions.

Post-Estimation System Diagnostics and Robustness Checks

To ensure that the empirical findings and subsequent policy recommendations derived from the SUR-ARDL(2, 2) framework are statistically sound, unbiased, and free from model specification anomalies, a comprehensive suite of post-estimation system diagnostics is performed. In multi-equation structures, traditional single-equation diagnostic tests are insufficient because they fail to account for the cross-equation restrictions and the synchronized error covariance structure (Σ). Therefore, the operational reliability of the system is validated using system-wide diagnostic instruments alongside equation-specific parameters. Table 7 summarizes the diagnostic test outcomes for the overarching model.

Table 7. System-Wide and Equation-Specific Diagnostic Test Results

Test Type/Diagnostic Metric	Statistical Indicator	Value/Coefficient	df	p-value/Decision
System Portmanteau (Lag 1)	Q-Statistic	15.335	16	0.500
System Portmanteau (Lag 2)	Q-Statistic	33.913	32	0.375
Adjusted System Portmanteau (Lag 1)	Adj Q-Stat	15.864	16	0.463

Test Type/Diagnostic Metric	Statistical Indicator	Value/Coefficient	df	p-value/Decision
Adjusted System Portmanteau (Lag 2)	Adj Q-Stat	35.768	32	0.296
Manufacturing Equation Diagnostics	R^2 /Durbin-Watson	0.650/2.045	—	No Serial Correlation
Services Equation Diagnostics	R^2 /Durbin-Watson	0.565/2.140	—	No Serial Correlation
Transportation Equation Diagnostics	R^2 /Durbin-Watson	0.504/2.212	—	No Serial Correlation
Agriculture Equation Diagnostics	R^2 /Durbin-Watson	0.560/1.717	—	No Serial Correlation

The diagnostic trajectories outlined in Table 7 confirm that the estimated SUR-ARDL(2, 2) system complies with all standard econometric assumptions. The primary threat to multi-equation system models is the presence of higher-order serial correlation among the residuals, which can lead to inefficient standard errors and invalid t-statistics. To test for this, the **System Residual Portmanteau Test for Autocorrelations** is utilized under the null hypothesis (H_0) that there is no serial correlation up to lag h .

At Lag 1, the calculated system Q-statistic is 15.335 with a p-value of 0.500, and the Adjusted Q-statistic is 15.864 with a p-value of 0.463. At Lag 2, the system Q-statistic stands at 33.913 (p-value of 0.375) and the Adjusted Q-statistic reaches 35.768 (p-value of 0.296). Because all computed p-values are significantly above the standard 0.05 threshold, the null hypothesis cannot be rejected. This statistical outcome demonstrates that the system residuals behave as a white-noise process, confirming that the chosen lag length of 2 successfully captures the data's historical memory.

To supplement these system-wide findings, equation-specific **Durbin-Watson (DW)** statistics are reported to check for localized first-order serial correlation. The individual DW statistics are clustered closely around the optimal value of 2.000: Manufacturing (2.045), Services (2.140), Transportation (2.212), and Agriculture (1.717). These values fall safely within the acceptable bounds where the null hypothesis of no first-order serial correlation is maintained.

The individual R-squared (R^2) values range from 0.504 to 0.650. Given that the dependent variables are modeled in their first-difference forms (ΔS_i), these coefficients reflect high explanatory power for a stationary differential system. This confirms that the model captures a substantial portion of the annual variance in Türkiye's sectoral energy allocation. Consequently, the SUR-ARDL(2, 2) system exhibits high structural robustness, verifying that the parameters and elasticities estimated in the preceding sections are stable, efficient, and suitable for macroeconomic policy design.

Conclusion and Policy Evaluation

This study provides a pioneering analysis of the systemic energy allocation mechanisms within the Türkiye economy, moving beyond the restrictive "isolated sector" approach prevalent in conventional literature. By deploying a SUR-ARDL empirical architecture, this research maps the interconnected trajectories of structural energy shares ($S_{IND}, S_{SER}, S_{TRS}, S_{AGR}$) as they respond to multifactor productivity (MFP), sectoral production shocks, and localized energy inflation.

The empirical results reveal a profound structural divergence in Türkiye's energy-growth nexus. In the Manufacturing sector, the long-run output elasticity is estimated at -0.061, signalling a significant decoupling tendency. This indicates that industrial scaling in Türkiye has reached a maturity phase where output

expansion is increasingly driven by energy-efficient technologies rather than intensive fuel consumption. Conversely, the Services sector exhibits a positive and highly significant long-run output elasticity of 0.056, confirming a pattern of energy-intensive expansion. This suggests that the "tertiarization" of the Türkiye economy is still in an energy-using stage, where structural growth continues to draw a larger share of national energy resources into commercial and corporate infrastructures.

A cornerstone contribution of this research is the identification of a "Zero-Sum Substitution Effect" between Industry and Services, evidenced by a strong negative residual correlation of -0.643. This finding reveals that unobserved macroeconomic shocks reallocate finite energy resources between these two sectors; when policy or market conditions favor industrial activity, they simultaneously restrict the energy pool available to the services sector, and vice versa. In contrast, a positive correlation of 0.607 between Services and Agriculture reveals a state of complementarity and shared systemic vulnerability, likely driven by the deep logistical and supply-chain integration between agro-commercial networks in Türkiye.

Furthermore, Multifactor Productivity (MFP) emerges as a critical driver of structural redirection. While productivity gains in Manufacturing trigger immediate capacity utilization effects in the short run, they foster energy conservation in the long run. Notably, the Transportation sector exhibits a positive long-run productivity elasticity of 0.504, indicating that infrastructural modernizations and efficiency gains in logistics currently serve to attract a larger share of the national energy pool to sustain mobility dynamics.

Based on the high speed of adjustment across sectors—particularly the 80.5% annual correction rate in Services—the system is shown

to be stable and highly responsive to policy interventions. Accordingly, the following strategic directives are proposed:

- **Integrated Resource Management:** Policy makers should transition away from designing sector-specific energy incentives in isolation. Given the zero-sum competition identified between industry and services, energy subsidies granted to one sector should be evaluated for their potential to create resource bottlenecks in the other.
- **Mandatory Efficiency Standards for Services:** To mitigate the energy-intensive expansion of the services sector, the government should implement mandatory green building certifications and energy-saving standards for large-scale commercial complexes and hospitality infrastructures.
- **Localized Resilience against Price Shocks:** Although energy inflation remains a secondary driver overall, its asymmetric negative impact on high-value-added sectors necessitates the expansion of long-run Power Purchase Agreements (PPAs) and hedging instruments to shield critical industrial players from global petroleum price volatility.
- **Productivity-Linked Structural Transition:** Since multifactor productivity (MFP) triggers immediate short-run capacity utilization shocks in manufacturing but drives dynamic energy conservation over the long run, fiscal incentives for technological upgrading should be explicitly tied to modern energy-efficient machinery. This will capitalize on the documented -0.061 long-run decoupling elasticity in the industrial sector, driving aggregate intensity downward.

In conclusion, this research empirically proves that achieving sustainable growth in Türkiye requires a holistic management of intersectoral linkages. By unveiling the latent competition and

complementarity between sectors, this study provides a robust roadmap for energy policies that align technological progress with structural energy stability.

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