Volume 9
Issue 1
July 2026

InTraders

International Trade Academic Journal

(InTraders Journal)

Publisher
Kürşat ÇAPRAZ

OPEN ACCESS
Free and unrestricted access to research

PEER REVIEWED
Rigorous and transparent peer review process

ACADEMIC JOURNAL
Promoting innovation and excellence in research

e-ISSN: 2667-4408

Open access, peer reviewed academic journal

Publisher

Kürşat ÇAPRAZ

ORCID: https://orcid.org/0000-0001-7133-6052

Address: Kırklareli University, Babaeski Vocational School, Babaeski, Kırklareli/Türkiye

www.intraders.org

intradersorg@gmail.com

WhatsApp+90 539 529 4288

InTraders International Trade Academic Journal

Volume 9, Issue 1

July 2026

Open access, peer reviewed academic journal
e-ISSN: 2667-4408

InTraders Journal

InTraders International Trade Academic Journal is peer reviewed academic journal, open access and accepts "PRINCIPLES OF TRANSPARENCY", follows the practice guidelines prepared by the Publication Ethics Committee (COPE).

About

InTraders, which began publication in 2018, offers open access.

The journal has been published exclusively in English since 2024. Articles published before 2024 may include Turkish content as part of the archive.

InTraders Journal has published all content exclusively in English since 2024.

Authors may use either American English or British English. However, the chosen style must be applied consistently throughout the manuscript. To enhance global readability and academic standardization, the journal strongly recommends using American English.

Submissions containing inconsistent language usage may be returned to authors for revision prior to peer review. Authors are responsible for ensuring linguistic quality. Professional language editing may be required where necessary

InTraders is indexed by TR Dizin for 2024 and 2025.

The journal's main subject is international trade. For 2024 and beyond, it accepts economy-based studies.

Authors must upload the Plagiarism Report (system-created), Author Information File, Copyright Agreement Form, Ethics Committee Permission Document -Declaration of Artificial Intelligence Forms to the system along with their work. The work uploaded to the system must be prepared in accordance with the journal's writing guidelines. Uploads that do not follow the spelling rules will be returned at the pre-check stage. Obtaining necessary permissions from ethics committees or commissions for studies that require ethics committee permission (works that require a survey or scale application, contain interviews and observations, documents, pictures, questionnaires, etc., developed by others and require permission to use), specifying these in the study content or must be submitted in addition. Without these permissions, the publication is returned to the author at the preliminary examination stage.

InTraders runs all its processes through Dergipark.

Broadcast range: July-December

Manuscript language: English (Should not include abstracts in languages other than English.).

InTraders accepts the Open Access Principles outlined in the Budapest Open Access Initiative (BOAI) and, accordingly, provides instant open access to its content, adopting the principle that making scientific publications accessible to researchers will increase the global sharing of knowledge. InTraders has accepted the Budapest Open Access Initiative, which allows readers to read, download, copy, distribute, print, and use the journal's articles for any legal purpose.

*-English studies are accepted for 2024 and later. Studies in English should not include abstracts in languages other than English.Aim

InTraders International Trade Academic Journal aims to publish researchers' scientific studies and create an international platform that supports academic development and increases the number of qualified academic studies.

Aim & Scope

InTraders International Trade Academic Journal publishes scientific studies by researchers; it aims to create an international platform that supports their academic development and increases the number of high-quality academic studies.

InTraders International Trade Academic Journal is peer-reviewed by international referees and an international journal that publishes original scientific research in English, primarily in international trade.

The journal's main subject is international trade. For 2024 and beyond, it accepts economy-based

studies. The journal is available with open access to all researchers. The language, scientific, legal, and ethical responsibilities of the articles published in the journal belong to the authors. Articles published in the journal may be used only when the source is cited.

Price Policy

The fee policy has been updated as of 2026.

Articles submitted to the journal are subjected to the editorial process (scientific evaluation and publication) for a fee. The Editorial Processing Fee is charged regardless of the acceptance/rejection condition of the article. No refund is made for rejected and withdrawn articles. After the articles submitted to the journal are subjected to preliminary review (whether the article is within the scope of the journal, whether it is a research article, and whether it complies with the journal's writing rules), the responsible author will be informed by email to make payment. The editorial process will be initiated after payment is completed.

For Invoice: You need to share your "Your Name/Surname, Citizen Number, Project Number(If it is supported by your project), Address" via intradersorg@gmail.com.

Peer Review Process

InTraders International Trade Academic Journal follows the ethical guidelines of the Committee on Publication Ethics (COPE). All manuscripts undergo a rigorous double-blind peer review.

Double Blind Peer Review Process

1. Editorial Screening

- The assigned editor checks whether the manuscript is within the journal's scope, complete, and properly formatted.
- Incomplete or out-of-scope manuscripts are returned to the author or rejected with a justified reason.

2. Technical and Language Check (Using Grammarly Software)

- Manuscripts are evaluated for language quality, grammar, and bibliography by the Secretariat.
- English manuscripts are checked using Grammarly software.
- A minimum of 95% language accuracy is required.

- Necessary corrections are requested from the author.

3. Plagiarism and Ethics Verification

- Manuscripts must be original, unpublished, and not under consideration elsewhere.
- The maximum allowed similarity rate is 20%.
- Ethics approval is required for studies involving human or animal subjects.

4. Double-Blind Peer Review

- Each manuscript is reviewed by at least two independent referees.
- Reviewers provide one of the following decisions: accept, minor revision, major revision, or reject.
- Detailed evaluation reports are required.
- In case of conflicting reviewer opinions, a third reviewer may be assigned at the editor's discretion.

5. Author Revision (After Peer Review)

- Authors address all reviewer comments and submit a revised manuscript.
- The editor may send the revised manuscript back to reviewers for verification.

6. Re-Review by Referees (Same Reviewers)

- The revised manuscript is re-evaluated by the same reviewers
- Reviewers again provide decisions: accept, minor revision, major revision, or reject.
- Detailed reports are required.
- If reviewer opinions conflict, a third reviewer may be assigned.

7. Re-Review (Iterative Review) Process

- Steps 5 and 6 are repeated as necessary until a final decision (accept or reject) is reached.

8. Final Acceptance

- Upon successful completion of the review process, the editor approves the manuscript for publication.
- A DOI is assigned via Crossref.

9. Proofreading

o The manuscript undergoes final language editing and layout preparation before inclusion in an issue.

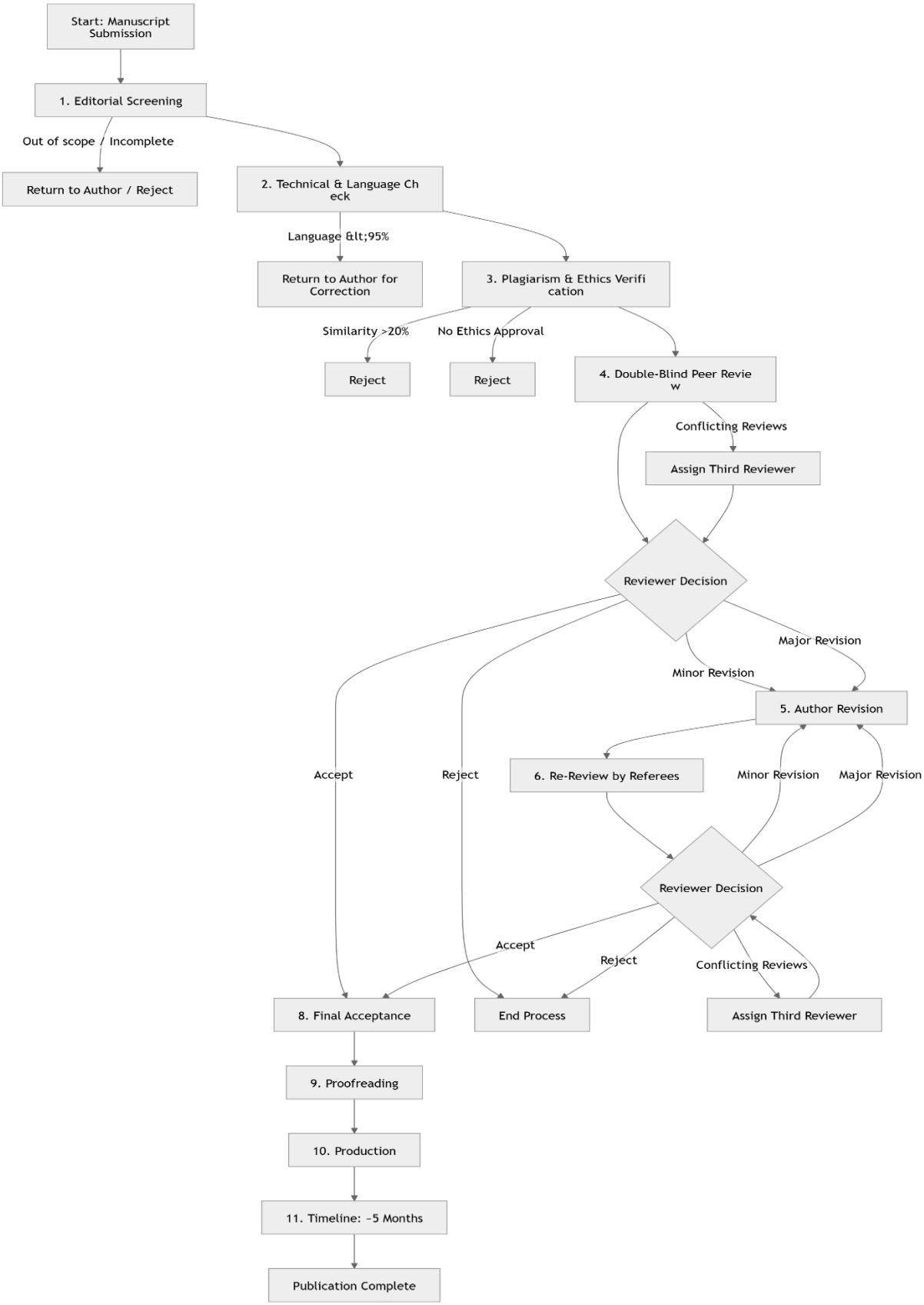
10. Production

o The manuscript undergoes layout preparation before inclusion in the next issue.

11. Timeline

The entire peer review process is designed to be completed within approximately five months.

Double Blind Peer Review Process



Publishing Periods

It is published twice a year. It is published in July and December. If it is deemed necessary, specific numbers / supplements may be issued for specific topics and for expanded notifications qualified by InTraders subject to conventions. Articles may always be accepted by InTraders.

Writing Rules

Preliminary Information

-Research articles should be loaded.

-English studies are accepted for 2024 and later. Studies in English should not include abstracts in languages other than English. InTraders Journal publishes all content exclusively in English.

Authors may use either American English or British English. However, the chosen style must be applied consistently throughout the manuscript. To enhance global readability and academic standardization, the journal strongly recommends using American English.

Submissions containing inconsistent language usage may be returned to authors for revision prior to peer review. Authors are responsible for ensuring linguistic quality. Professional language editing may be required where necessary

After the author (s) have prepared the forms below, they should begin uploading the files.

-Abstract must include: Purpose, Methodology, Findings, Contribution.

-InTraders Journal Article Writing Format

-APA 7 Reference Style Sample File

-Author Information File (Refer to item 4). At the end of the page, it should be stated whether there is a conflict of interest, whether there is an institution from which financial support is received, and the contribution rates of the authors.

-Copyright Agreement Form

-Ethics Committee Permission: In studies that do not require ethics committee permission, the author must upload the signed document stating "InTraders-ethics committee permission " by stating the study title and author information on a form while uploading the article to the system.

-Declaration of Artificial Intelligence (Valid within 2025)

1-The journal does not require authors to cite articles from the journal or any specific publisher. Only English articles are published in InTraders Journal for 2024 and later.

2. The APA 7 system should be used for article citations and source indication. The journal's rules will be followed for other article-writing rules.

3. Articles must be written on A4-sized paper with 1.5 spacing, in Times New Roman font, 12-point font, and not to exceed 25 pages. Submissions made from outside the DergiPark platform are strictly not accepted. Your article must be edited using the Article Writing Template. You can download the Article Writing Template here. (Author information should be excluded from the Article File).

4. Author Information File: The article should not contain any information about the author(s). (The file from the author is used to initiate the 2-blind referee process of the article. Therefore, the information about the author(s) should be specified on a separate Word page and uploaded to the system. The following information should be included on the separate Word page: (i) title of the article; (ii) author(s) name and academic title; (iii) ORCID ID numbers; (iv) address of the institution to which the author(s) is affiliated; (v) keywords and (vi) JEL codes of the study, (vii) e-mail address, (viii) telephone The number should be stated as +. The abstract should be between 150 and 250 words.

5. Tables, figures and graphs should be given titles and numbers. Table titles should be placed above the tables, and titles of figures and graphs should be placed below the relevant figure or graph. References should be written below the tables, figures and graphs. Commas must separate decimal fractions in numbers. The sequence number to be given to the equations should be placed in parentheses at the far right of the page. If the derivation of the equations is not clearly shown in the manuscript, the derivation, including all steps, should be provided on a separate page for the referees' evaluation. Times New Roman type and 11-point font should be used in table and figure titles and in-table text. If the table does not fit, 8-, 9-, or 10-point size may be preferred.

6 Footnotes regarding the references made in the articles should be included at the bottom of the

page.

7. At the end of the text, a list of sources used in the study is given under the heading REFERENCES. This bibliography lists the references used in the study and is arranged alphabetically by the authors' surnames.

Include the complete citation at the end of your paper in a references section. References: line spacing should be set to 0 first, then to 6 pt, single-line spacing; indent setting: "hanging" and "1 cm"; Times New Roman, 12 pt. Use a hanging indent to separate each list item.

8. References to sources should be made in the text, not in footnotes, including page numbers, as shown in the examples below.

9. The page layout of the articles to be added to the system must be made by the author, and by the following values:

Paper Size: A4 Vertical (Landscape pages should not be included in the article)			
Top	Margin:	2.5	cm
Bottom	Margin:	2.5	cm
Left	Margin:	1.0	cm
Right	Margin:	1.0	cm

Font: Times New Roman

Font Size: 12 and bold in the title, 12 in the text, 11 in abstracts and 8 in footnotes. Paragraph Spacing: 6 pt before - 6 pt after, line spacing 1.5 in the text; In abstracts, first 6 pt - then 6 nk, line spacing - Single (The aim is for the abstracts to be easily read by the reader.)

10. There should be no paragraph beginnings (indentations) in the article text, and paragraph breaks should be made clear by leaving spaces (spacing before: 6nk, after: 6nk, line spacing: 1.5 lines).

11. Section Headings: The article can use main, intermediate, and subheadings to ensure an orderly transfer of information; headings will not be numbered. Headings should be leveled according to case sensitivity as specified in the Article Writing Template.

12. Tables and Figures: Tables must have numbers and titles and be located where they should be in the text. Figures must be prepared for color printing. Table numbers and titles should be written centered on the table, and figure numbers and names should be set just below the figure

(See Article Writing Template).

13 Images: They should be included in the text in high-resolution, print-quality scans. When naming pictures, the rules in figures and tables must be followed.

14. Articles that do not comply with InTraders Journal Publication Principles in any respect will not be evaluated.

Privacy Policy

Information such as names, titles and contact addresses shared through the InTraders website will only be used for the purposes set forth by InTraders; for any other purpose or for the use of third parties.

Copyright and Licensing

Ethical Principles and Publication Policy

The journal follows the ethical guidelines of the Committee on Publication Ethics (COPE). The journal does not require authors to cite articles from this journal or from any specific publisher. All references must be relevant to the research topic and selected solely based on academic merit.

1. General Ethical Principles

1. Obtaining the necessary permissions from the ethics committees or commissions for studies that require permission from the Ethics Committee (for studies that require the application of a questionnaire or scale, including interviews and observations; documents, pictures, questionnaires, etc., developed by others and require permission to use), and these should be stated in the article content. or as an addendum. Without these permissions, the publication is returned to the author at the preliminary examination stage. Ethics Committee approval is mandatory for studies sent from Turkey (researchers located within the borders of the Republic

of Turkey). Ethics committee approval is the author's responsibility, given the country's own management and systems.

2. It is essential that the raw data regarding the research in the peer reviews be submitted when requested by the referees. It is obligatory to provide the data after the article's publication when necessary.

3. The authors accept that the contact information (mail, institution, ORCID) specified in their article will be included to be published/published in InTraders. InTraders agrees not to publish the authors' information outside the journal issues and not to share it with third parties for commercial or advertising purposes.

1. A. Ethical Principles for Authors

1. Authors guarantee that their work is original, and when they include ideas, languages, pictures, graphics and tables of other researchers in their work, they must indicate this as a quotation. Quoting without specifying the source is plagiarism.

2. Each author named in the study is equally responsible for the content of the study. It is unacceptable to not include the name of the researcher who contributed to the study or to include his name unjustly, even though he did not contribute.

3. Authors should stick to their research findings. It is out of the question to change the findings, make up findings and results, and conduct research based on them. Situations such as tampering with data and materials, deleting, removing, or skipping the interpretation of difficult data are suspicious.

4. Simultaneous submission of the study to journals is not possible. Authors cannot send their previously published works to the journal.

As of 2020, the TR Index-Journal Evaluation criteria have been updated. The articles related to ethics committee permission for scientific research have been detailed.

The "documents and information requested for studies requiring ethics committee approval" is not expected to be applied to studies submitted in previous years, the evaluation process of which has been completed but has not yet been published, and for which research data before 2020 has been used, although the evaluation process is still ongoing. The process will start in 2020, and

research data will be mandatory for articles starting in 2020. The articles for which the Ethics Committee Permission Document is required are explained below.

EXPLANATION AND INFORMATION on the Ethical Rules Made by TR Index

The articles related to the Code of Ethics, which were included in the previous years' criteria, were detailed with explanations in 2020, and the issue of "includes information about the permission in the article" was added to the criteria, assuming that the permissions were obtained for the studies requiring ethics committee permission in the research field.

QUESTION: Is ethics committee approval required for all articles?

No. The criteria state that it applies to “articles that require the permission of the Ethics Committee.”

Studies that require the approval of the Ethics Committee are as follows:

• All kinds of research conducted with qualitative or quantitative approaches require data collection from the participants using surveys, interviews, focus group work, observation, experiments, and interview techniques.

• The use of humans and animals (including material/data) for experimental or other scientific purposes,

• Clinical studies on humans,

• Research on animals,

• Retrospective studies on the law on the protection of personal data,

Also;

• Indicating that an “informed consent form” was received in case reports,

• Obtaining and specifying permission from the owners for the use of scales, questionnaires, and photographs belonging to others,

• Indication of compliance with copyright regulations for the intellectual and artistic works used

QUESTION: Should a retrospective Ethics Committee Permission be obtained for publications produced from studies and a thesis completed in previous years?

Retrospective ethics committee approval is not required for articles published before 2020, produced from master's/doctoral studies (must be specified in the article), submitted an application for publication to the journal in the previous year, and accepted but not published.

QUESTION: Are there any restrictions on publications made outside universities under these TR Directory rules?

No. Non-university researchers can also apply to the Ethics Committees in their regions.

Also;

In articles to be published in journals, it should be stated in the article whether ethical committee permission and/or legal/special permission is required. If it is necessary to obtain these permissions, it should clearly state from which institution, on what date, and with which decision or number the permission was obtained.

If the study requires the use of human and animal subjects, an international declaration, guide, etc., should be declared appropriate.

1. B. Ethical Principles for Referees

1. The journal does not require authors to cite articles from the journal or any specific publisher.

2. Referees should know that the evaluation process is confidential and should not be shared with third parties.

3. The referees must submit an objective, impartial, scientific, understandable and constructive evaluation report about the study within the specified time.

4. Referee reports will also include an assessment of the scientific nature of the article (the subject covered, the method used, or the appropriate use of the relevant literature). This evaluation must be made about the content, whether positive or negative.

5. When it is understood that the work is plagiarised or has been previously published elsewhere, the referees should notify the editor.

2. Publication Policy

*The journal does not require authors to cite articles from the journal or any specific publisher.

1. InTraders International Trade Journal (InTraders) is an international, peer-reviewed and scientific journal. It is published using the publication principles listed below.

2. InTraders aims to contribute to developing science at the national and international levels by creating a platform for publishing scientific studies.

3.InTraders publishes original scientific research in international trade, economics, business, supply chain management, law, and international relations, presenting congress papers, book reviews, and letters to the editor.

4. InTraders publishes scientific studies in English.

5. InTraders are published twice a year electronically, in the Summer (July) and Autumn (December) terms.

6. InTraders does not accept articles for any issue, but articles can be submitted to the journal anytime.

7. InTraders publishes using the TÜBİTAK ULAKBİM DergiPark system. All transactions related to the article are carried out through the DergiPark system.

8. InTraders publishes at https://dergipark.org.tr/tr/pub/intraders. In addition, it offers all issues in the archive section of its congress pages free of charge to open access. https://www.intraders.org/turkce/

9. The author/authors declare and undertake that the article submitted to InTraders for evaluation for publication has not been published, accepted for publication, or sent to another journal for publication, in Turkey and/or abroad, in Turkish or any other language before.

10. Copyright Holder: The author(s) hold Commercial rights, Patent rights, and intellectual property rights, including copyright, of the author(s) or, if any, of the author(s) employer are reserved. InTraders Journal allows authors to retain the copyright of their papers without restrictions.

11. All legal and scientific responsibilities regarding the content of the articles published in

InTraders belong to the author(s).

12. InTraders does not pay royalties for work.

13. InTraders is free of charge for authors and readers.

14. InTraders published articles can be quoted by showing the source.

15. InTraders permits readers to read, download, copy, distribute, print, and use the articles in the journal for any legal purpose by citing the source.

16. InTraders undertakes not to publish in violation of publication ethics, and all articles submitted to the journal are subject to plagiarism/similarity control by the editor.

17. Whether the article submitted to InTraders is covered by the journal, the editor checks whether it is uploaded to the system correctly and completely, and is prepared properly.

18. InTraders uses a double-blind referee evaluation system. The "positive" opinion of at least two referees is sought for the article's acceptance for publication. If one of the referees gives a "positive" opinion and the other a "negative" opinion, the article is sent to a third referee. The editor completes the referee evaluation process by sending two “positive” referee opinions to the Editorial Board.

19. The Editorial Board decides to publish all articles with two “positive” referee opinions.

20. For articles accepted for publication, the editor sends a “Certificate of Acceptance for Publication” signed by the author upon the author's request.

21. Uses information such as names, titles and e-mail addresses shared on the journal website only for the stated purposes of this journal; It is not used for any other purpose or made available to other people.

22. InTraders accepts the Open Access Principles outlined in the Budapest Open Access Initiative. The journal has accepted the Budapest Open Access Initiative.

23. InTraders is committed to applying publication ethics to the highest standards and following the practice guide prepared by the Committee on Publication Ethics (COPE: Committee on Publication Ethics).

24. Articles in InTraders are archived with the Dergipak system.

Intradersorg@gmail.com address can be used for questions, suggestions and comments.

Archiving Policy & Repository Policy

Archiving Policy

Long-term preservation service(s) where the journal archives and preserves digital content by using LOCKSS through DergiPark.

LOCKSS system has permission to collect, preserve, and serve this open-access Archival Unit.

LOCKSS: DergiPark LOCKSS ARCHIVE

Dergipark Archive Link: https://dergipark.org.tr/en/pub/intraders/archive

Repository Policy

InTraders Journal has a policy allowing authors to deposit a copy of their paper in an institutional or other repository of their choice. InTraders Journal, in accordance with the journal repository policy for each article of the authors published in the journal; Submitted version, Accepted version (Author Accepted Paper), Published version (Record Version).

It allows such versions to be stored in the preferred corporate or other archive without embargo.

Indexes

TRDİZİN (2024,2025)

SOBIAD

EBSCOhost (Contract Date: June 13,2022)

ERIH PLUS (Approved 2024-01-03)

Sherpa Romeo (Approved 2024-02-15)

For questions, suggestions and comments, you may contact intradersorg@gmail.com

Appreciation

I am gratified to have the honor of offering the vote of thanks to all the InTraders Journal Committees and Authors who provided intensive work for the InTraders Journal under the name InTraders Academic Platform.

The journal's main subject is international trade. For 2024 and beyond, it accepts economy-based studies outside international trade and original studies on tourism issues. In the next issue, we look forward to your studies.

I look forward to meeting you all at this new international conference…

Kürşat ÇAPRAZ

Publisher of InTraders Journal

www.intraders.org

Contents

Research Articles

InTraders International Trade Academic Journal

e-ISSN: 2667-4408 **www.intraders.org**

Volume: 9
Issue : 1
Research Article

Received: January 1, 2026
Revision: March 4, 2026
Accepted: April 1, 2026
DOI: https://www.doi.org/10.55065/intraders.1853488

Transport Connectivity and Trade Integration between Türkiye and the Three Seas Initiative: A Gravity Model Perspective

Taner FİLİZ[1]

Abstract

The primary purpose of this study is to empirically examine the main determinants of bilateral trade between Türkiye and the 13 countries within the scope of the Three Seas Initiative (3SI) using a gravity model. Within the methodology of the research, an annual panel dataset covering the 2004-2024 period was utilised to test the impacts of market size and distance-related trade costs via the Augmented Gravity Model. The obtained empirical findings indicate that physical distance is a statistically significant and strong inhibitory factor on trade flows, with a coefficient of -1.251, and further reveal that Türkiye's export performance exhibits a "supply-side" character. Since Türkiye's elasticities of GDP (0.685) and population (2.414) were found to be higher than the market-size effects of the partner countries, it is demonstrated that Türkiye's primary driver of trade is domestic production capacity and economies of scale rather than external demand. As a significant contribution to the literature, this study concludes that active participation in transport infrastructure projects, prioritising digitalisation at border crossings, and reducing "economic distance" through logistics process optimisation are strategic necessities to enhance Türkiye's trade integration with the 3SI geography.

Keywords: *Three Seas Initiative, Türkiye, gravity model, logistics connectivity, foreign trade*

JEL Codes: *F10, F14, R41, C23*

INTRODUCTION

Regional trade initiatives and "connectivity" strategies indicate that international trade is shaped not only by tariffs and regulatory harmonisation but also, to a significant extent, by transport infrastructure and logistics capacity. Free trade agreements, customs unions, and corridor projects are designed to reduce the cost and duration of trade through measures such as expanding port capacity, strengthening rail–road linkages, establishing intermodal terminals, accelerating border-crossing procedures, and broadening the adoption of digital customs practices. From this perspective, geographic distance is treated as fixed; however, "economic distance" can be

There is not a conflict of interest.

[1] Asst. Prof. Dr. Burdur Mehmet Akif Ersoy University. E-Mail:tfiliz@mehmetakif.edu.tr OI: 0000-0002-2888-9695 Contribution rates to the study 100 %.

Cite As: Filiz, T. (2026). Transport connectivity and trade integration between Türkiye and the Three Seas Initiative: A gravity model perspective. *InTraders International Trade Academic Journal, 9*(1), 1–18. https://doi.org/10.55065/intraders.1853488

reduced as countries shorten transit times and lower transport costs, thereby increasing trade volumes. Improvements in infrastructure quality not only reduce unit transport costs but also shorten delivery times and mitigate time uncertainty. As a result, firms' inventory-holding needs, delay risks, and contracting costs are reduced, generating a facilitative effect that expands trade flows. Similarly, as the density of transport networks and service frequency (e.g., sailing frequency and route diversity) increase, market-access costs are lowered, enabling firms to enter more distant markets with reduced risk. This mechanism may be particularly conducive to intermediate-goods trade and to deeper integration into global value chains. Accordingly, the development of regional trade should be considered a multidimensional process that depends not solely on physical distance between countries, but also on infrastructure quality, the efficiency of cross-border procedures, and the reliability of logistics services.

Within such a framework, approaches that simultaneously account for economic size and trade costs are required to explain bilateral trade quantitatively. The gravity-model literature posits that bilateral trade flows are supported, on the one hand, by the market size of partner countries (proxied by indicators such as GDP and population), and, on the other hand, constrained by trade costs (proxied by variables such as distance). In this context, distance may be interpreted not only as geographic separation but also as a core proxy for "economic distance" arising from transport time, logistics reliability, and border-crossing efficiency. For this reason, analysing Türkiye's trade relations with countries covered by the 3SI through the lens of market-size and distance dynamics is important both for identifying the factors that make trade with this region more sensitive and for providing empirical evidence for connectivity-oriented policy debates.

Nevertheless, despite the growing prominence of regional connectivity discussions, no direct empirical study has been identified in the national and international literature accessible to us that addresses Türkiye's trade relations with countries within the 3SI from a Türkiye-centred perspective. Although the gravity-model literature has focused on various regional groupings and country samples, the existing findings have remained limited in generating specific and comparable inferences for the Türkiye–3SI context, as 3SI countries have not been evaluated within a holistic framework. By testing the relative importance of market-size indicators and distance-related trade costs within a single framework, this study aims to fill this gap in the literature on Türkiye–3SI trade and to provide one of the first systematic sets of empirical evidence in this area. Accordingly, the primary objective of the study is to empirically examine the determinants of Türkiye's bilateral trade with 3SI countries within the gravity model framework. The study investigates the direction and magnitude of the effects of variables representing market size (GDP and population) on trade volume, and how distance, as a proxy for trade costs, constrains trade flows.

The remainder of the article is structured as follows. Section 2 provides the study's contextual basis by

summarising the scope of the 3SI, its institutional framework, and its regional connectivity objectives. Section 3 briefly reviews the gravity model and the 3SI-related literature. Section 4 describes the dataset employed in the analysis, defines the variables, and explains the econometric methodology in detail. Section 5 presents the empirical findings and discusses their economic implications. The final section summarises the main results and sets out the study's policy implications and recommendations for future research.

THREE SEA INITIATIVE

The 3SI is a regional initiative launched in 2016 that aims to strengthen trade, infrastructure, energy, and political cooperation among countries in the Adriatic, Baltic, and Black Sea basins. Institutionalised as of 2021 to encompass 12 EU members (Austria, Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia), the initiative was expanded in 2023 with the accession of Greece, thereby increasing the number of members to 13 (Orzelska-Stączek, 2024). The core focus of the initiative is to deepen regional integration through tangible infrastructure projects and investment coordination in transport, energy, and digital connectivity, which are commonly characterised as "low politics" domains (Three Seas Initiative, n.d.). This framework provides the basis for treating 3SI countries as an integrated group, in the present study, since the primary aim is not to emphasise bilateral relations but rather to demonstrate how connectivity capacity within the macro-regional geography described as the "three seas axis" shapes trade costs.

Figure 1 clearly visualises the spatial logic of the Three Seas Initiative. When the Baltic Sea (north), the Adriatic Sea (southwest), and the Black Sea (southeast) are taken as "corner points," the member countries of the initiative form a geographic cohesion across the Central and Eastern European belt located between these three seas. This belt, while connected to Europe's leading economic gravity centres (particularly Western Europe), is considered an area in which east–west infrastructure configurations have historically remained dominant, whereas north–south connections have been relatively more fragmented. Within this framework, the official narrative of the 3SI grounds the scale of the initiative and its "convergence" rationale in concrete indicators: 3SI countries are reported to represent approximately one-third of the EU in terms of land area and to host around 111 million people; however, as of 2018, the average GDP per capita level is reported to be only 78% of the EU average. This suggests that the 3SI geography constitutes a "convergence space" within European integration, characterised by relatively lower development indicators. At the same time, the same source draws attention to the strength of the region's growth dynamics: while the average growth rate in 3SI countries over the 2015–2019 period is reported as 3.5%, the EU average is reported as 2.1%; moreover, IMF forecasts for 2020 project 2.9% growth in the 3SI region, compared to 1.6% for the EU overall (Three Seas Initiative, n.d.). This dual outlook (relatively low per capita income yet high growth potential) explains why the 3SI defines reducing "economic distance" through transport, energy, and digital infrastructure as a strategic priority and frames it as a means to accelerate regional integration.

Figure 1: Countries Participating in the 3SI

Source: Garding & Mix, 2025.

Figure 2 presents the priority transport and energy projects planned within the scope of the 3SI. The map operationalises the initiative's north–south connectivity objective through two main networks: (i) road/rail corridors and (ii) natural-gas transmission linkages. In the transport dimension, the backbone extending from the Baltic to the Adriatic and Black Sea basins is designed according to a "multimodal corridor" logic in which motorway and railway lines are structured to complement one another. From Türkiye's perspective, the most tangible interface with this backbone lies along the Thrace border. Indeed, within the 3SI project inventory, the Alexandroupoli–Pythio (Türkiye border)–Ormenio (Bulgaria border) railway project registered by Greece explicitly articulates an "interoperable" corridor objective by linking the port of Alexandroupoli to the national network and to both the Bulgarian and Turkish borders through components such as line upgrading, electrification, and ETCS. Such projects provide an infrastructural basis that may reduce trade costs for Türkiye's

access to intra-European supply chains by addressing parameters such as delivery time, reliability, and cross-border operational interoperability.

In the energy dimension, Figure 2 renders visible the 3SI's objectives of regional integration and security of supply through pipeline interconnectors and LNG terminals. In this context, Türkiye is integrated into the 3SI energy architecture in an indirect yet strategic manner as a "source and transit" node, particularly through the Southern Gas Corridor, connected via TANAP. TANAP is one of the key links of the Southern Gas Corridor, intended to transport natural gas extracted from the Shah Deniz field in Azerbaijan to Europe via Türkiye (TANAP, n.d.). As emphasised in Vondra's (2018) assessment, lines such as BRUA/the North–South Gas Corridor, which are among the prominent projects of the 3SI, have the potential to be integrated—via Türkiye (through TANAP)—with southern sources in the Black Sea and Caspian regions. Consequently, the transport and energy networks traced in Figure 2 do not remain confined to mere geographic neighbourhoods for Türkiye; instead, they generate a concrete sphere of interaction related to the 3SI's objective of "reducing economic distance" via overland cross-border transport corridors and TANAP-supported energy linkages.

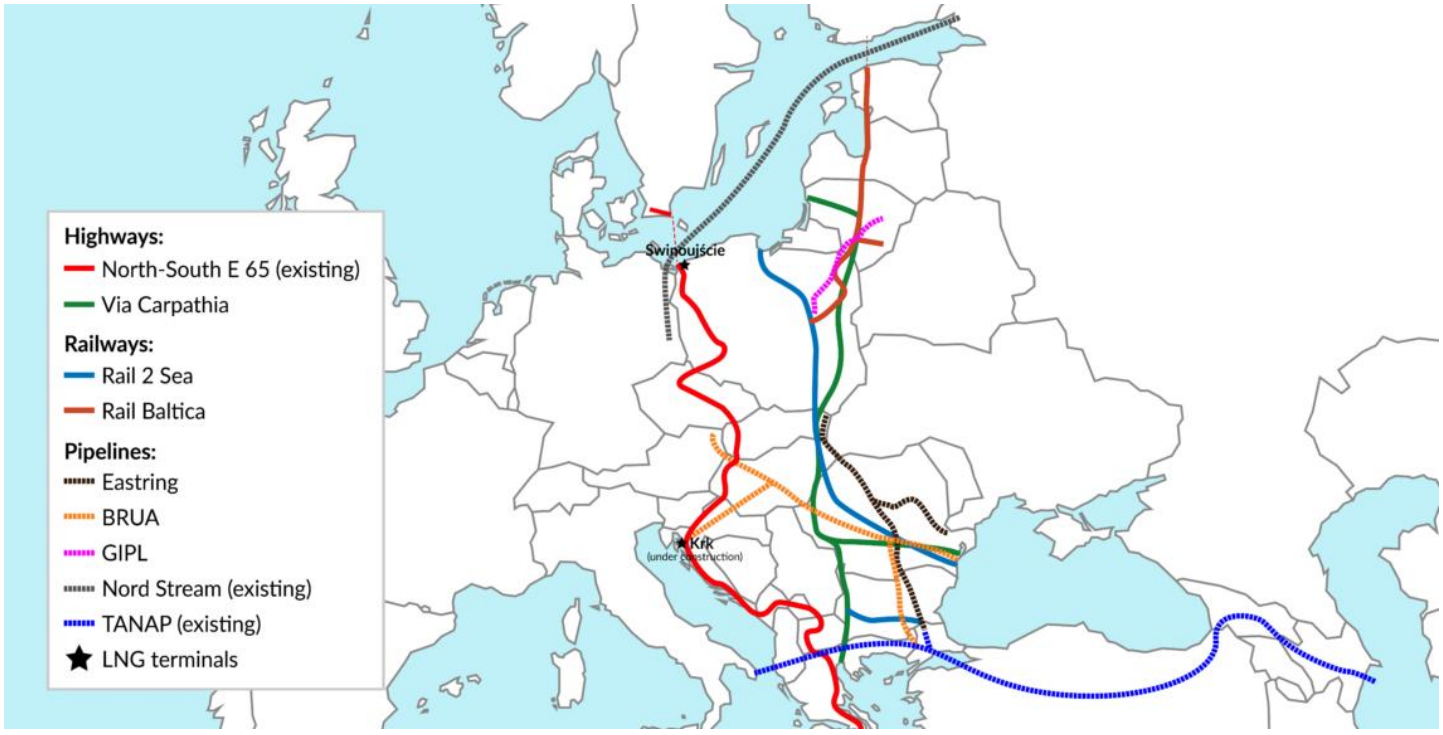


Figure 2: Transportation and Energy Infrastructure Projects Proposed under 3SI
Source: Vondra, 2018.

Türkiye's relationship with the 3SI has acquired an institutional status that extends beyond mere interaction as a "peripheral country" based solely on geographic proximity. According to the announcement of the Republic of Türkiye Ministry of Transport and Infrastructure (2025), Türkiye declared its accession to the initiative as a "strategic partner" at the 10th Summit of the 3SI held in Warsaw, Poland; it was emphasised that this step is aligned with the 3SI's objective of increasing connectivity by addressing transport, energy, and digital

infrastructure deficiencies in Central and Eastern Europe. The Republic of Türkiye Ministry of Foreign Affairs (2025), in its text titled "Türkiye's Connectivity and Multilateral Transport Policy" states that, due to its geographic position, Türkiye considers the development of regional transport corridors as a priority and, within this scope, supports alternative routes for Europe–Asia connectivity through initiatives such as the Middle Corridor and the Development Road.

Figure 3 presents Türkiye's exports to 3SI countries over the 2013–2024 period, country-by-country. Overall, the highest export volumes have been realised with large markets such as Poland and Romania; it is observed that exports to these two countries have accelerated markedly in the post-2020 period and reached their highest levels as of 2024. By contrast, countries such as Bulgaria, Greece, Czechia, and Hungary have been Türkiye's "mid-sized" export markets within the 3SI region. However, fluctuations have been observed over the years; the overall trend has remained upward. In smaller markets (e.g., the Baltic states and certain Central European countries), export levels have remained relatively low; nevertheless, a gradual upward trend has emerged since 2021.

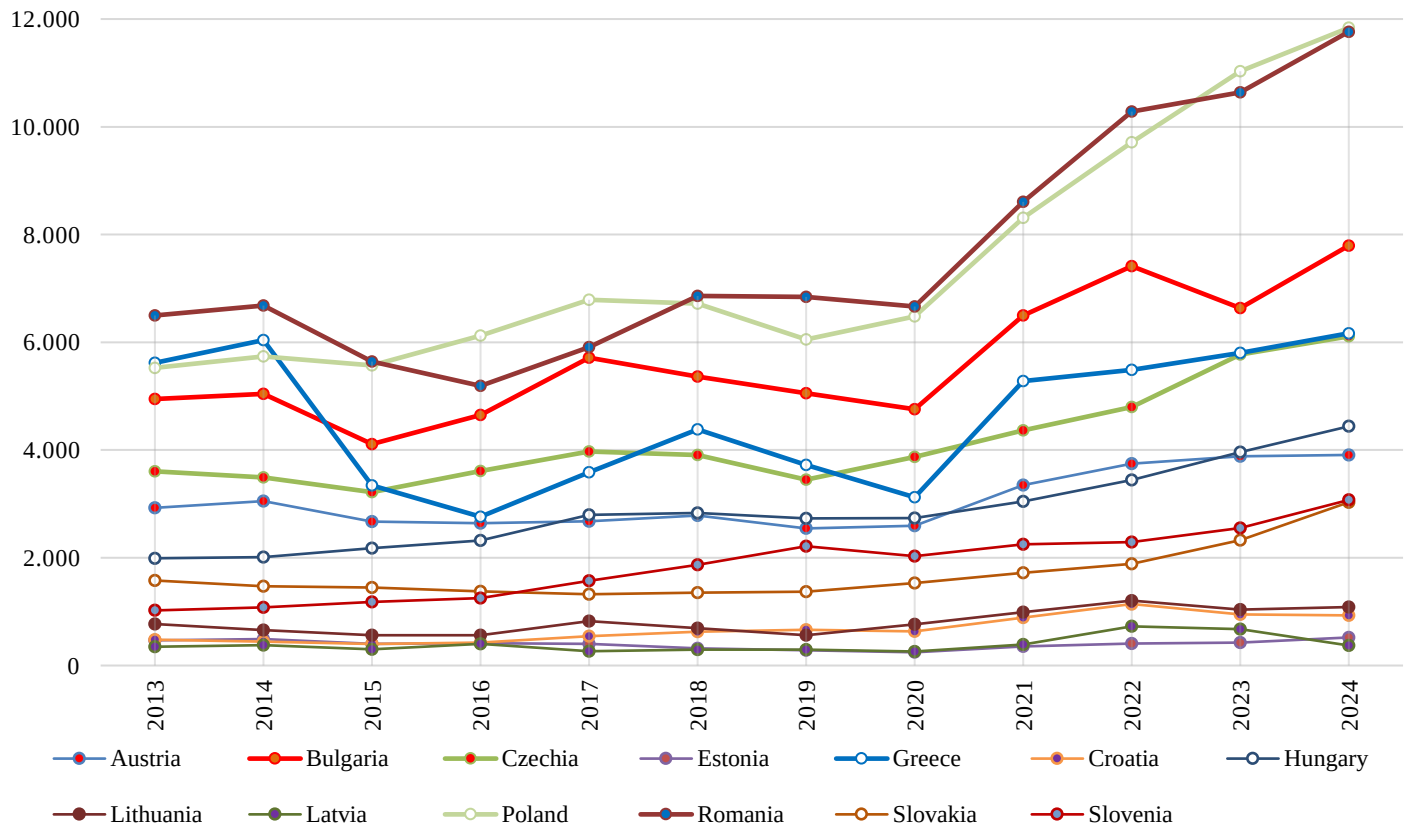


Figure 3: Türkiye's Export Volume to 3SI Countries (*million USD)

Source: UN Comtrade Database, 2025.

LITERATURE REVIEW

The existing literature has predominantly analysed the 3SI through the lens of the evolving global security architecture and shifting regional power balances. Focusing on the historical and institutional evolution of the initiative, Andrea (2024) examined the process through the stages of "conceptualisation" and "political maturation," and demonstrated how the initiative has been transformed into a pragmatic, project-oriented cooperation platform by distancing itself from the geopolitical baggage inherited from the pre–Second World War "Intermarium" idea.

By examining perceptions of the initiative within the European Union and the political turbulence it has generated, Górka (2018) highlighted the scepticism it has engendered in Western European capitals. Although the author highlighted the risk that the initiative could be perceived as a bloc-forming movement that threatens EU unity and deepens the "Multi-Speed Europe" scenario, it was also argued that the project constitutes a valuable instrument for reducing regional development disparities and enabling north–south infrastructure integration. By contrast, Zbińkowski (2019), who focused on the initiative's potential to address structural inequalities within the EU, characterised the project as a necessary step to close the economic gap between "Old" and "New" Europe. According to the author, north–south oriented projects under the 3SI contribute tangibly to EU cohesion by eliminating the "core–periphery" divide.

Addressing the initiative's security character from a Romanian perspective, Dumitrescu (2024) positioned the 3SI as part of Romania's "grand behaviour" in foreign policy and defined the project as a balancing mechanism that strengthens Transatlantic ties against Russia's aggressive posture. Extending the security dimension to the axis of global power competition, Grochmalski et al. (2021) characterised the 3SI as a strategic alternative developed in response to China's increasing influence in the region through the Belt and Road Initiative (BRI) and the "17+1" format. Furthermore, Drăgulin (2025) emphasized that the 3SI has evolved into a vital pillar of the European security and connectivity architecture, particularly in the context of the post-2022 geopolitical shift. The author argues that for countries like Romania, the initiative serves as a strategic instrument to enhance regional resilience and consolidate the North-South transport and energy corridors against emerging threats.

Within this geopolitical equation, Kochis (2021) examined the role of the United States, assessing the initiative as a "strategic investment" for the Washington administration and emphasising that U.S. diplomatic support and financial commitments are vital to its sustainability. Moreover, by scrutinising the effects of the Russia–Ukraine war, Gołębiowska and Lewkowicz (2022) stated that, through the Riga Summit and the "participating partner" status granted to Ukraine, the 3SI has been transformed from a regional development project into a strategic logistics and solidarity platform during periods of crisis.

The initiative's internal dynamics and the hierarchy among member states have also been addressed extensively

in the literature. Using a "Geo-economic Index" (G-Index) they developed, Gębska and Lewandowski (2022) demonstrated empirically that Poland is the group's undisputed leader. Examining this intra-group hierarchy through political perceptions, Lewkowicz (2025) divided members into "trendsetters" and "distanced," finding that Poland and Romania act as active pioneers while other members adopt a more cautious stance. Similarly, Kozera-Kowalska et al. (2021), using taxonomic classification (the Hellwig method), classified 3SI countries according to their economic potential and mathematically confirmed that the region is not a homogeneous bloc but instead composed of "economic anchor" countries and subgroups with differing levels of development. In addition, regarding the global diplomacy dimension of the initiative, Krzymowski (2022a) analysed the relations between the Baltic states and the UAE and highlighted the initiative's capacity to attract funding. At the same time, Sabbaghian and Deep Singh (2022) opened the discussion on the theoretical potential of alternative energy sources, such as Iran under Polish leadership.

A second axis of the literature has focused on the initiative's concrete infrastructure projects. According to Tărînă (2025), the 3SI has the potential to transform the economic model of Central and Eastern Europe by addressing infrastructure, energy, and digital gaps, thereby enhancing the region's competitiveness within the EU. By examining the initiative's project portfolio in the Estonian case, Kusztal (2025) foregrounded the concept of "Smart Connectivity." According to the author, with the 2020 Tallinn Summit, the 3SI agenda evolved beyond merely building physical routes to a hybrid model integrating transport and energy infrastructure with digitalisation. In the context of energy infrastructure, Stonis (2021), who examined the functionality of the North–South Gas Corridor, characterised the Baltic Pipe and LNG investments as the "cornerstone" of the region's energy security and argued that these projects constitute a prerequisite for a competitive market structure. Focusing on the southern (Adriatic) leg of the corridor, Zubovic (2019) emphasised that the Krk LNG terminal in Croatia is a critical entry point that completes the energy line extending from the Baltic to the Adriatic and breaks Central Europe's dependence on Russian gas. Approaching the trade potential of infrastructure investments from a "green economy" perspective, Krzymowski (2022b) argued that these energy networks provide a strategic basis not only for fossil-fuel security but also for trade in renewable energy and hydrogen.

Despite this expanding international literature, Türkiye-centred studies remain relatively limited, and existing works have focused mainly on geopolitical strategy, maritime security, and energy diplomacy.

Approaching the topic from an energy security perspective, Kakışım (2020) defined the 3SI as a geopolitical move that increases U.S. influence in the European energy market, while emphasising that the initiative's primary motivation is to reduce dependence on Russia for energy, the dimension of trade integration with Türkiye was not addressed. From a political science perspective, Hekimler (2021) considered the initiative as a "minilateral cooperation model," noting Poland's search for a balance against Germany and stating that Türkiye should not

remain indifferent to this formation; however, the analysis remained at the political level. Additionally, Güngörmez (2022) evaluated the 3SI as a search for a new geopolitical order in Europe, emphasizing that the initiative's importance has increased following the Russia-Ukraine war and that it aims to reduce energy and infrastructure dependency on Russia while creating a buffer zone. Similarly, Kalkan Küçüksolak (2024), who examined "minilateral" cooperation in maritime security, stated that states have tended to prefer more flexible, results-oriented mechanisms over cumbersome multilateral structures. Although the strategic importance of such arrangements within the maritime security architecture was emphasised, the study focused not on economic data or trade volumes but on the transformation of the security architecture.

Overall, across both international and national literatures, studies have focused on institutional structures, political tensions, energy security, and general security strategies. No study has been found that, taking into account the initiative's logistics infrastructure objectives (Via Carpatia, Rail Baltica, etc.) and Türkiye's "Strategic Partnership" potential with the region, empirically analyses the trade potential between Türkiye and 3SI countries within the framework of the Gravity Model. By treating the 3SI region not as a homogeneous market but, as also emphasised in the literature, as a bloc with differing logistics and economic dynamics, and by modelling Türkiye's export flows through this new perspective, this study aims to fill this gap in the literature.

METHOD

The econometric methodology employed in the empirical analysis of the study, along with the variables incorporated into the model and the data sources used, is detailed below.

Data and Variables

In this study, an annual panel dataset was employed in order to analyse the bilateral trade potential between Türkiye and 13 member countries of the 3SI (Austria, Bulgaria, Czechia, Estonia, Croatia, Latvia, Lithuania, Hungary, Poland, Romania, Slovakia, Slovenia, and Greece). All data utilised in the model were compiled from official databases of international organisations that are publicly available (open-source) and provide online access. The total number of observations included in the analysis is 273 (N=13, T=21). The analysis period spans 21 years, from 2004 to 2024. The definitions, units of measurement, and data sources of the variables employed are summarised in Table 1.

Table 1: Description of Variables and Data Sources

Symbol	Variable	Data Source
$ln(TRD_{ijt})$	Türkiye's (i) exports to 3SI country (j) in year t	UN Comtrade Database (2025)
$ln(GDP_{it})$	Türkiye's gross domestic product in year t	World Bank (2025)
$ln(GDP_{jt})$	Gross domestic product of the 3SI country (j) in year t	World Bank (2025)
$ln(POP_{it})$	Türkiye's total population in year t	World Bank (2025)
$ln(POP_{jt})$	Total population of the 3SI country (j) in year t	World Bank (2025)
$ln(DIST_{ij})$	Population-weighted distance between the two countries	CEPII (2025)

Source: Prepared by the author; data retrieved from UN Comtrade, World Bank, and CEPII databases (Access Date: 2025).

Model Specification

The theoretical framework of this study is based on the Gravity Model developed by Tinbergen (1962), which serves as the fundamental basis of the international trade literature. To linearise the original multiplicative form, a log-linear specification was adopted by taking the natural logarithms of all variables. Furthermore, the model was expanded into an Augmented Gravity Model by incorporating population variables to capture market size effects.

The estimated econometric equation is specified as follows:

$$ln(TRD_{ijt}) = \beta_0 + \beta_1 ln(GDP_{it}) + \beta_2 ln(GDP_{jt}) + \beta_3 ln(POP_{it}) + \beta_4 ln(POP_{jt}) + \beta_5 ln(DIST_{ij}) + \epsilon_{ijt} \quad (1)$$

Where:

i and j: Denote Türkiye (exporter) and the partner country (importer), respectively, while t denotes the time period,

TRD: Represents the bilateral trade volume (Exports),

GDP: Represents the Gross Domestic Product,

POP: Represents the total population of the countries,

$DIST$: Represents the population-weighted distance between the economic centers of the respective countries,

β_0: Is the constant term,

ϵ_{ijt}: Is the error term.

Estimation Method

The estimation of the model parameters was carried out using panel data techniques, given the longitudinal structure of the dataset (N=13, T=21). The choice between Fixed Effects (FE) and Random Effects (RE) estimators was based on the Hausman specification test. The test yielded a p-value of 0.34, indicating no systematic difference between the FE and RE estimators. This finding rules out the necessity of the Fixed Effects specification and supports the use of a pooled specification that retains time-invariant variables, such as geographic distance, which would otherwise be eliminated under FE. Accordingly, the model was estimated via pooled OLS with HC3 robust standard errors. Furthermore, as the bilateral trade flows between Türkiye and the 13 3SI countries are positive throughout the 2004–2024 period, the log-linear transformation does not result in the loss of observations. Although recent gravity literature frequently recommends the PPML estimator—particularly in the presence of zero trade flows and heteroskedasticity—the characteristics of the present dataset allow for the use of the log-linear OLS specification. To enhance robustness, HC3 robust standard errors were used to mitigate potential heteroskedasticity.

RESULTS

This section presents the estimation results of the Augmented Gravity Model, which analyses the determinants of bilateral trade between Türkiye and the 13 member countries of the 3SI over the period 2004-2024.

The estimation results, obtained using the OLS estimator with HC3 robust standard errors, are summarised in Table 2. The model demonstrates a high explanatory power with an R^2 of 0.874, indicating that the independent variables collectively explain approximately 87.4% of the variation in Türkiye's export volume to the region. The F-statistic (352.9) is statistically significant at the 1% level, confirming the model's overall validity.

Table 2: Augmented Gravity Model Estimation Results (Robust Estimation)

Variables	Coefficient	Robust Std. Error (HC3)	t-Statistic	Prob.
Partner GDP	0.424	0.057	7.47	0.000***
Partner Pop	0.388	0.061	6.37	0.000***
Distance	-1.251	0.081	-15.44	0.000***
Türkiye GDP	0.685	0.161	4.24	0.000***
Türkiye Pop	2.414	0.500	4.83	0.000***
Constant	-49.186	6.828	-7.20	0.000***
R^2	0.874	-	-	-
Adj. R^2	0.871	-	-	-
F-Statistic	352.9	-	-	0.000***
Observations	273	-	-	-

*Note: *** denotes statistical significance at the 1% level. Standard errors are heteroscedasticity-consistent (HC3).*

Source: Author's own elaboration.

The empirical findings align with the theoretical expectations of the Gravity Model and provide statistically significant insights into the trade dynamics:

1. Impact of Distance (The Impedance Factor): Consistent with standard gravity theory, geographical distance has a negative and highly significant impact on trade. The coefficient of -1.251 implies that a 1% increase in the distance between Türkiye and a partner country reduces the trade volume by approximately 1.25%. This high elasticity highlights that transportation costs and logistical barriers remain the most significant impediments to trade integration with the 3SI region.
2. Impact of Economic Size (Income Effect): The coefficient for the partner country's GDP is positive (0.424) and statistically significant at the 1% level. This indicates that a 1% increase in the income level of a 3SI member country leads to an approximate 0.42% increase in Türkiye's exports to that country. This confirms that economic growth in the 3SI region creates direct, positive demand for Turkish products.
3. Impact of Market Size (Population): The coefficient for the partner country's population is positive (0.388), suggesting that larger markets in terms of population absorb more Turkish exports.
4. Türkiye's Supply Capacity: The coefficients for Türkiye's GDP (0.685) and population (2.414) are positive and statistically significant. The magnitude of these coefficients, particularly the population elasticity, suggests that Türkiye's domestic production scale and economic growth are crucial "push factors" driving export performance in the region.

During the diagnostic phase, the assumptions regarding the error terms were rigorously tested. The Breusch-Pagan test results, presented in Table 3, indicated the presence of heteroscedasticity in the model. To ensure the reliability of statistical inferences and address this issue, standard errors were corrected using the HC3 (Heteroscedasticity-Consistent) robust covariance matrix estimator, as recommended by Long and Ervin (2000). Additionally, the risk of multicollinearity was assessed using the Variance Inflation Factor (VIF), and no evidence of multicollinearity was observed, as all VIF values were within acceptable limits.

Table 3: Diagnostic Test Results

Diagnostic Test	Test Statistic / Value	Result / Conclusion
Breusch-Pagan Test (LM Stat)	44.56*** (p<0.01)	Heteroscedasticity Detected (Addressed with HC3)
Hausman Test ($\chi 2$)	4.50 (p=0.34)	Fixed Effects Rejected; Pooled OLS Specification Supported
Multicollinearity (VIF)	Mean VIF: 3.52	No Multicollinearity
$\ln(GDP_{partner})$	5.46	Acceptable (< 10)
$\ln(POP_{partner})$	6.17	Acceptable (< 10)
$\ln(GDP_{Turkey})$	2.29	Acceptable (< 10)
$\ln(POP_{Turkey})$	2.27	Acceptable (< 10)
ln(Distance)	1.45	Acceptable (< 10)

*Note: ***indicates significance at the 1% level. VIF values below 10 indicate no severe multicollinearity.*

Source: Author's own elaboration.

DISCUSSION

The empirical findings indicate that geographic distance is a substantial, statistically significant impediment to trade flows (elasticity = -1.25). When results are compared, it is observed that the sensitivity of trade between Türkiye and 3SI countries to distance exceeds global and regional averages. In particular, in a recent study examining the effects of the EU Single Market, Rybacki and Sułkowski (2025) found that the distance elasticity of intra-EU trade ranged between -0.70 and -0.78. The -1.251-coefficient obtained in this study is, in absolute value, markedly higher than the intra-EU average. This difference reflects border-related costs, customs procedures, and logistics frictions that persist because, despite Türkiye's Customs Union membership, full integration into the EU Single Market has not been achieved.

Similarly, in a study comparing China–ASEAN and China–EU trade using a structural gravity model, Tang et al. (2024) confirmed the determining role of geographic proximity and trade complementarity. The authors emphasised that the costs generated by distance can be overcome only through deep economic integration and optimised trade structures. The extent to which distance constrains Türkiye–3SI trade (-1.25), as also implied by Tang et al. (2024), points to logistics networks and structural impediments that have not yet been fully optimised. In addition, while Zhai (2023) noted that physical distance remains a fundamental factor suppressing trade volumes despite regional trade agreements, Wani (2024) demonstrated that, on routes with weak infrastructure connectivity, the trade-impeding effect of distance is far more destructive for developing countries. In this context, the relatively high distance coefficient observed in this study may be explained by Türkiye's structural reliance on road transport for trade with the region. Accordingly, the results indicate that, to increase Türkiye's export potential, priority should be given not only to production capacity but also to logistics infrastructure projects that reduce the cost burden associated with physical distance.

When the economic-size variables are examined, both Türkiye's (elasticity = 0.685) and the partner countries' (elasticity = 0.424) income coefficients are found to be positive and statistically significant. However, Türkiye's GDP coefficient is clearly higher than those of the partner countries (0.69 > 0.42), indicating that, in determining bilateral trade volume, "supply-side" factors play a more dominant role than external demand.

This asymmetric elasticity structure suggests that the primary driver of export performance is not the partner economy's market expansion, but rather the exporting country's domestic production capacity and industrial scale. In other words, growth in the Turkish economy and increases in production strength constitute the central "push factor" driving exports to the 3SI region. This pattern implies that Türkiye's export growth exhibits a structural character that depends more on its own supply potential and competitiveness than on fluctuations in partner countries' income levels.

When the population variables are analysed, Türkiye's population coefficient is found to be remarkably high (elasticity = 2.414). Within the theoretical framework, Bergstrand (1989) noted that a positive coefficient for the exporter's population suggests production advantages rooted in economies of scale. The magnitude of this coefficient indicates that Türkiye's trade potential is significantly driven by its domestic production capacity. Furthermore, as suggested by the literature and the structural characteristics of the Turkish economy, such high elasticity may be interpreted as a reflection of a large labor force and demographically driven production capacity, which provides a supply-side advantage in trade with the 3SI region.

CONCLUSION

This study analysed the bilateral trade potential between Türkiye and 13 member countries of the 3SI, as well as the determinants of this trade, within the framework of an augmented gravity model (Augmented Gravity Model) over the 2004–2024 period. The empirical findings yield three critical conclusions regarding the core dynamics of trade between Türkiye and the 3SI region.

First, physical distance and logistics costs continue to represent the most substantial barriers to trade integration. The relatively high distance elasticity of -1.25 indicates that Türkiye's trade with the region remains highly sensitive to distance. This outcome demonstrates that Türkiye's structural dependence on road transport for trade with 3SI countries, together with non-tariff barriers at border crossings, has substantially increased export costs.

Second, Türkiye's export performance exhibits a "supply-side" character. The effect of Türkiye's economic size (GDP) on exports (0.69) is higher than the income effect of partner countries (0.42). This finding indicates that Türkiye's export expansion to the 3SI market has been driven less by growth in external demand than by increases in Türkiye's domestic production capacity and industrial scale.

Third, the high coefficient on the population variable (2.41) confirms that Türkiye's large population supports

trade not only as a consumption market but also as a decisive production factor that generates economies of scale.

Policy Implications: In light of the study's findings, the following policy steps are recommended in order for the trade potential between Türkiye and the 3SI region to be fully realised:

- Logistics Infrastructure and Rail Integration: The north–south oriented infrastructure projects that constitute the backbone of the 3SI (Via Carpatia and Rail2Sea) should be integrated with Türkiye's east–west Middle Corridor route and the southern-axis Development Road Project. Through such integration, the shortest and most secure route would be formed for 3SI member states, linking ports on the Baltic, Adriatic, and Black Seas to Asia–Pacific (China) and the Persian Gulf (Middle East) markets via Türkiye. In particular, the Development Road Project—envisaged to extend from Iraq through Türkiye to Europe—would render Türkiye an indispensable "bridge country" for 3SI members' access to energy resources and Middle Eastern markets. Accordingly, modernising Türkiye's rail networks and strengthening port connections would not only reduce Türkiye's export costs but also position Türkiye as a strategic transit hub for trade between 3SI countries and Asia and the Middle East. This "win–win" strategy would maximise regional trade volumes by bringing unit transport costs closer to EU levels.
- Modernisation of Border Crossings: To minimise border-related costs stemming from Türkiye's position outside the EU Single Market, digital customs applications and fast-track crossing systems similar to the "Green Lane" should be expanded at western border gates, such as Kapıkule, through bilateral agreements with 3SI countries.
- Production-Oriented Export Strategy: Given the supply-side character of exports, redirecting public incentives away from solely market-research activities and toward industrial investments that directly expand production capacity and deepen technological capabilities would ensure the sustainability of export growth to the region.
- Energy Supply Security and Strategic Partnership: Türkiye's role as an energy corridor (TANAP, etc.) may contribute to the 3SI's energy security. Positioning Türkiye as an "energy hub" in the delivery of Caspian and Middle Eastern energy resources to the 3SI region would deepen not only merchandise trade but also strategic trade in services.
- Institutional Integration and Future Vision: Türkiye's existing "Strategic Partnership" status with the 3SI should not remain limited to a diplomatic framework, but should be deepened through tangible economic projects and operational cooperation.

Although this study has identified the key determinants of trade relations between Türkiye and Three Seas Initiative countries from a macroeconomic perspective, it also opens new avenues for research warranting deeper exploration in the literature. First, given that logistics barriers are not confined solely to physical distance, future

studies could incorporate variables such as the Logistics Performance Index (LPI) or the Liner Shipping Connectivity Index (LSCI), thereby allowing the sources of trade costs to be specified more precisely. In addition, disaggregated analyses conducted by strategic sectors—such as automotive, defence industries, and energy—rather than using aggregate trade data, would play a critical role in identifying the sectors in which the "supply-side" export character detected in this study is more pronounced. Finally, examining the tendency of trade routes to shift from northern corridors toward alternative routes such as the Middle Corridor and the Development Road following geopolitical shocks, including the Russia–Ukraine war, through structural-break time-series models would provide an original contribution to the literature by improving understanding of the region's evolving logistics architecture.

REFERENCES

Andrea, A. A. (2024). An attempt to systematically revisit the process of conceptualization and political maturation of the Three Seas Initiative (3SI). *Analele Universităţii din Oradea. Relaţii Internationale şi Studii Europene (RISE), 16*(16), 17–30. https://doi.org/10.58603/FBCF2749

Bergstrand, J. H. (1989). The generalized gravity equation, monopolistic competition, and the factor-proportions theory in international trade. *The Review of Economics and Statistics*, *71*(1), 143–153. https://doi.org/10.2307/1928061

CEPII. (2025). GeoDist database [Data set]. Centre d'Études Prospectives et d'Informations Internationales. Retrieved November 1, 2025, from http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=6

Drăgulin, A. I. (2025). The Three Seas Initiative: Advantages and challenges for Romania. *Romanian Diplomatic Institute (IDR)*, (78) https://www.idr.ro

Dumitrescu, L. (2024). The Three Seas Initiative and Romania's Grand Behaviour in the Black Sea Area: Change and Continuity. *Central European Journal of International and Security Studies*, *18*(3), 39-60. https://doi.org/10.51870/TPJF6502

Garding, S. E., & Mix, D. E. (2025, March 19). *The Three Seas Initiative* (CRS In Focus No. IF11547). Congressional Research Service. Retrieved November 08, 2025, from https://s3.documentcloud.org/documents/25598319/if115474.pdf

Gębska, M. H., & Lewandowski, P. (2022). Geoeconomic leaders among the Three Seas Initiative countries: Part 2: Research results. *European Research Studies Journal, 25*(1), 113–132.

Gołębiowska, M., & Lewkowicz, Ł. (2022). The Three Seas Initiative after the Riga summit: A new status of cooperation with Ukraine and the support of the United States. *IEŚ Commentaries, 639*(151).

Górka, M. (2018). The Three Seas Initiative as a political challenge for the countries of Central and Eastern Europe. *Politics in Central Europe*, *14*(3), 55–73. https://doi.org/10.2478/pce-2018-0018

Grochmalski, P., Lewandowski, P., & Paszak, P. (2021). Three Seas Project (3SI) and the Belt and Road Initiative (BRI): The Security Dimension. *European Research Studies Journal*, *24*(1), 1230-1239. https://doi.org/10.35808/ersj/2020

Güngörmez, O. (2022). Üç Deniz Girişimi (3SI): Avrupa'da Yeni Bir Jeopolitik Düzen Arayışı Mı? *İktisadi Kalkınma Vakfı*, (256).

Hekimler, O. (2021). Üç Denizler İnisiyatifi: Avrupa bütünleşmesinde minilateral bir işbirliği modeli mi yoksa Polonya'nın denge arayışı mı? *Anadolu Üniversitesi Sosyal Bilimler Dergisi, 21*(3), 725–746. https://doi.org/10.18037/ausbd.1001647

Kakışım, C. (2020). Enerji perspektifiyle Üç Deniz Girişimi. *Ankara Avrupa Çalışmaları Dergisi, 19*(1), 121–151. https://doi.org/10.32450/aacd.770838

Kalkan Küçüksolak, Ö. K. (2024). Deniz güvenliğinde minilateral işbirliği arayışları. *Deniz Araştırmaları ve Mavi Strateji Dergisi, 3*, 71–85.

Kochis, D. (2021). The Three Seas Initiative is a strategic investment that deserves the Biden administration's support. *Heritage Foundation Issue Brief*, (6051). https://www.heritage.org/sites/default/files/2021-02/IB6051.pdf

Kozera-Kowalska, M., Uglis, J., & Lira, J. (2021). A framework to measure the taxonomic of economic anchor: A case study of the Three Seas Initiative countries. *PLoS ONE, 16*(5), e0252292. https://doi.org/10.1371/journal.pone.0252292

Krzymowski, A. (2022a). The Baltic states of the Three Seas Initiative: Estonia, Latvia and Lithuania in creative relations with the United Arab Emirates. *Creativity Studies, 15*(1), 40–57. https://doi.org/10.3846/cs.2022.13867

Krzymowski, A. (2022b). Energy transformation and the UAE green economy: Trade exchange and relations with Three Seas Initiative countries. *Energies, 15*(22), 8410. https://doi.org/10.3390/en15228410

Kusztal, A. (2025). Estonian priority projects in the Three Seas Initiative 2018–2024. *Studia Polityczne, 53*(1), 172–193. https://doi.org/10.35757/STP.2025.53.1.08

Lewkowicz, Ł. (2025). Trendsetting and distance: Perception of the Three Seas Initiative in selected Central European countries. *Przegląd Politologiczny, 3*, 97–112. https://doi.org/10.14746/pp.2025.30.3.7

Long, J. S., & Ervin, L. H. (2000). Using heteroscedasticity consistent standard errors in the linear regression model. *The American Statistician, 54*(3), 217–224. https://doi.org/10.1080/00031305.2000.10474549

Orzelska-Stączek, A. (Ed.). (2024). *The Three Seas Initiative: An original concept of regional cooperation in different approaches* (Three-Seas-Initiative Research Center). Institute of Political Studies of the Polish Academy of Sciences. Retrieved November 03, 2025, from https://3si.politic.edu.pl/wp-content/uploads/2024/09/Three-Seas-Initative-Research-Center.pdf

Republic of Türkiye Ministry of Foreign Affairs. (2025). *Türkiye's connectivity and multilateral transport policy*. Retrieved November 15, 2025, from https://www.mfa.gov.tr/turkiye_nin-cok-tarafli-ulastirma-politikasi.tr.mfa

Republic of Türkiye Ministry of Transport and Infrastructure. (2025). *Türkiye became a strategic partner of the Three Seas Initiative.* Retrieved November 17, 2025, from https://www.uab.gov.tr/haberler/turkiye-uc-deniz-girisimi-nin-stratejik-ortagi-oldu

Rybacki, J., & Sułkowski, D. (2025). The benefits of the EU single market: Evidence from the gravity model. *Central European Economic Journal, 12*(59), 284–294. https://doi.org/10.2478/ceej-2025-0017

Sabbaghian, A., & Deep Singh, R. (2022). Poland and the Three Seas Initiative: Iran's role in the energy security of Central and Eastern Europe. *Journal of Iran and Central Eurasia Studies, 5*(1), 119–135.

Stonis, D. (2021). Diversification of gas supplies as a cornerstone of gas security in the framework of the Three Seas Initiative. *Three Seas Economic Journal, 2*(2), 1–8. https://doi.org/10.30525/2661-5150/2021-2-1

TANAP. (n.d.). *The Trans Anatolian natural gas pipeline project*. Retrieved November 11, 2025, from https://www.tanap.com/en/tanap-project

Tang, C., Rosland, A., Li, J., & Yasmeen, R. (2024). The comparison of bilateral trade between China and ASEAN, China and EU: from the aspect of trade structure, trade complementarity and structural gravity model of trade. *Applied Economics*, *56*(9), 1077–1089. https://doi.org/10.1080/00036846.2023.2174940

Tărînă, A.-R. (2025). The perspectives of the Three Seas Initiative in overcoming the economic disparities in Europe. *Proceedings of the International Conference on Business Excellence*, *19*(1), 477-489. https://doi.org/10.24818/picbe-2025-0039

Three Seas Initiative. (n.d.). *Objectives*. Retrieved November 05, 2025, from https://3seas.eu/about/objectives

Tinbergen, J. (1962). *Shaping the world economy: Suggestions for an international economic policy*. New York: Twentieth Century Fund.

UN Comtrade Database. (2025). UN Comtrade Plus. Retrieved October 30, 2025, from https://comtradeplus.un.org/

Vondra, A. (2018). *Regional integration at the Three Seas summit*. Geopolitical Intelligence Services. Retrieved November 12, 2025, from https://www.gisreportsonline.com/r/three-seas-initiative/

Wani, N. U. H. (2024). Trade potential of Afghanistan with SAARC region and European Union: A gravity model approach. In N. U. H. Wani (Ed.), *Policy solutions for economic growth in a developing country: Perspectives on Afghanistan's trade and development* (pp. 41–57). Emerald Publishing Limited. https://doi.org/10.1108/978-1-83753-430-220241003

World Bank. (2025). *World Development Indicators* [Data set]. Retrieved November 1, 2025, from https://databank.worldbank.org/source/world-development-indicators

Zbińkowski, G. (2019). The Three Seas Initiative and its economic and geopolitical effect on the European Union and Central and Eastern Europe. *Comparative Economic Research. Central and Eastern Europe*, *22*(2), 105–119. https://doi.org/10.2478/cer-2019-0015

Zhai, H. (2023). Evaluation of China-ASEAN trade status and trade potential: An empirical study based on a gravity model. *PLOS ONE*, 18(9), e0290897. https://doi.org/10.1371/journal.pone.0290897

Zubovic, M. (2019). The Three Seas Initiative»: Perspectives of energy sector development within the Croatian foreign policy. *Post-Soviet Issues*, 6(1), 84–91. https://doi.org/10.24975/2313-8920-2019-6-1-84-91

InTraders International Trade Academic Journal

e-ISSN: 2667-4408 **www.intraders.org**

Volume: 9
Issue : 1
Research Article

Received: January 22, 2026
Revision: March 10, 2026
Accepted: April 3, 2026
DOI: https://doi.org/10.55065/intraders.1869708

The Relationship Between Pharmaceutical Expenditure, the Ageing Population and Income in Turkey: A Dynamic Regression Analysis

Ezgi DOĞAN[1]

Abstract

Developments in healthcare technology and improvements in the quality of healthcare services worldwide have increased life expectancy and, consequently, the ageing population. The growing ageing population is exerting pressure on healthcare systems and their financing, threatening their financial sustainability. The ageing population's multiple medication use, chronic disease burden, and frequency of visits to outpatient clinics and emergency departments increase healthcare expenditures and, consequently, pharmaceutical expenditures. This significant increase has been a driving force for the empirical examination of this relationship. This study examines per capita pharmaceutical expenditures, the proportion of the population aged 65 and over, and per capita income. The aim of this study is to determine whether income and the elderly population affect pharmaceutical expenditures and to develop policy recommendations accordingly. To analyse the extent to which pharmaceutical expenditures are affected by the ageing population and income level, a single-equation dynamic regression analysis with a lagged dependent variable was conducted, and Newey–West HAC standard errors were applied to address heteroscedasticity and autocorrelation. The findings obtained in this study, in the short term, the proportion of the ageing population and income level do not have a statistically significant effect on pharmaceutical expenditures; however, in the long term, an increase in the ageing population raises per capita pharmaceutical expenditures. This reveals that the increase in pharmaceutical expenditures is primarily attributable to changes in the demographic structure rather than temporary factors. The study's empirical findings offer implications for health policies. The results highlight the need for policymakers to consider demographic projections when planning health and pharmaceutical budgets.

Keywords: *Health economics, pharmaceutical expenditure, health expenditure, ageing population, income*

JEL Codes: *I10, I12, J14, E21*

INTRODUCTION

In recent years, advances in healthcare technology, improvements in the quality of healthcare services, and developments in medicine have led to increases in life expectancy worldwide, declines in fertility rates, and

There is no conflict of interest.

[1] Dr. Res. Assist., Yüksek İhtisas University, E-Mail: ezgi.dogan@yuksekihtisas.edu.tr, OI 0000-0002-7751-7687 Contribution rates to the study 100 %.

Cite As: Doğan, E. (2026). The relationship between pharmaceutical expenditure, the ageing population and income in Turkey: A dynamic regression analysis. *InTraders International Trade Academic Journal, 9(1)*, 19–32. https://doi.org/10.55065/intraders.1869708

changes in demographic structures. Consequently, the proportion of the ageing population has increased. In Turkey, the proportion of the population aged 65 and over, which was 6.8% in 2008, reached 9.9% in 2022. The increasing prevalence of diseases and chronic illnesses among the ageing population has driven demand for healthcare services, thereby increasing healthcare expenditures (Hayran, 2019, p.71; Beceren et al., 2021, p.5; OECD, 2023; Eryer, 2024, p.193).

Among the reasons for the increase in healthcare expenditure are the growing proportion of the population aged 65 and over and the rising demand for medical and long-term care services. It is stated that the growing ageing population poses a significant burden on healthcare services and social security, and that this situation makes it important to shape future pension and social security policies. In addition, it is thought to negatively affect the sustainability of public finances across countries (Beceren et al., 2021, p.8; Öncebe, 2024, p.109). The ageing population visits outpatient clinics and emergency departments more frequently than the non-elderly population. This means that the ageing population benefits from more healthcare services and that healthcare expenditure increases due to medication use. In this context, studies show that healthcare expenditure for the ageing population is three times higher than for the general population (Lu et al., 2016). In addition to general healthcare expenditures, the ageing population's medication expenditures are also higher than those of the general population, and they often use multiple medications. The prevalence of multiple diseases among the elderly and the associated increase in multiple medication use lead to higher medication and healthcare expenditures (Lu et al., 2016, p.45).

This study aims to analyse, using econometric methods, whether per capita income and the proportion of elderly people in Turkey between 2008 and 2022 affect pharmaceutical expenditure. Within this framework, the study examines the relationships between pharmaceutical expenditure, the proportion of older people, and per capita income, and presents policy recommendations. The empirical part of this study aims to estimate the dynamic adjustment structure and long-term elasticity of pharmaceutical expenditures rather than testing the causal relationship.

Although the relationship between the ageing population and health expenditures is frequently addressed in the literature, studies focusing on the ageing population and pharmaceutical expenditures are rather limited. This study, which aims to analyse the effects of the ageing population ratio and per capita income on pharmaceutical expenditures, is expected to contribute to the literature.

To summarise the study's general outline, it first includes a literature review. Subsequently, the data set is discussed, an econometric analysis is performed, and the findings are presented and interpreted. Finally, the conclusions and policy recommendations are presented.

LITERATURE REVIEW

In the literature, few studies analyse the relationship among pharmaceutical expenditures, the proportion of the ageing population, and income. Studies have predominantly focused on health expenditures and the proportion of the ageing population. Empirical studies specifically analysing pharmaceutical expenditures from an econometric perspective are rather limited in the literature.

The study is distinctive in that it examines pharmaceutical expenditures specifically rather than health expenditures and analyses the effect of the ageing population ratio and per capita income on pharmaceutical expenditures, thereby contributing to the literature.

Getzen (1992) examines whether the increase in per capita health expenditure is due to population ageing or other factors. Analyses conducted using data from 20 countries between 1960 and 1988 show that, at first glance, ageing appears to increase health expenditure. However, this relationship is actually driven by per capita income growth and other factors that change over time. After controlling for income and other variables, no significant relationship is observed between the age structure of the population and total health expenditures. Although ageing determines where health expenditures occur, it does not determine the total level of expenditure. Therefore, it is concluded that the main reason for the increase in health expenditures is health policies and cost management rather than demographic changes.

Zweifel et al. (1999) concluded that the ageing of the population, driven by increases in life expectancy in Switzerland between 1983 and 1992, did not affect per capita health expenditures, as the terminal phase of life is costly regardless of age. It was found that healthcare expenditure is linked to proximity to death (time remaining until death) rather than calendar age. The study indicated that the main reasons for the increase in healthcare expenditure are the structure of the healthcare system, technological developments and inefficiencies in insurance markets, rather than demographic change.

Morgan (2005), in his study, cited the selection of more expensive drugs per treatment process and the increase in the number of concurrent treatments per patient as the main reasons for the increase in pharmaceutical expenditure, and stated that the ageing of the population had no significant effect on expenditure. However, he found that per capita expenditure increased most rapidly among individuals aged 45-64.

Kildemoes et al. (2006) estimated future spending on prescription drugs in Denmark, accounting for the ageing population. The study concluded that population ageing is highly likely to increase spending on prescription drugs.

Morgan (2006) examined demographic profiles related to prescription drug use and drug expenditure in the province of British Columbia between 1996 and 2002. They found that per capita drug expenditure increased by an average of 10.8 per cent annually, with population ageing accounting for 1.0 percentage points of this annual

expenditure increase. The study also found that the remaining annual expenditure increase was attributable to increases in age- and gender-specific drug expenditures.

Palangkaraya and Yong (2009), in their study covering 22 OECD (Organisation for Economic Co-Operation and Development) countries between 1990 and 1996, found that population ageing, when proximity to death is taken into account, is negatively correlated with healthcare expenditure. They suggested that the effects of ageing on health expenditure may have been exaggerated. In contrast, the effects of high end-of-life medical care costs may have been underestimated. Micro-level studies indicate that the primary driver of rising health expenditure in developed countries is proximity to death rather than ageing. However, it has been noted that the macro-level evidence depends on the characteristics of the empirical model used.

In their study, Hermanowski et al. (2015) analysed the relationships between life expectancy and per capita GDP (Gross Domestic Product), and between pharmaceutical and non-pharmaceutical health expenditure in OECD countries. The study used data from 34 OECD countries for the period 1991–2010. The empirical results of the study reveal that there are common long-term trends between life expectancy, economic growth and health expenditure in OECD countries, but that increases in life expectancy cannot be explained by pharmaceutical expenditure alone. The study concludes that long-term increases in life expectancy may be influenced by factors beyond the model, such as technological developments, lifestyle changes, and social determinants.

Tamakoshi and Hamori (2015) examined the cointegration relationships among health expenditures, GDP, and the ageing population ratio across Japan's 47 prefectures using panel cointegration tests. Empirical results indicate a cointegration relationship among the three variables. By estimating the effects of GDP and the ageing population ratio on health expenditures, it was found that the ageing population ratio was positively and significantly associated with health expenditures. As a result of these findings, it was stated that attention should be paid to the ageing society problem in order to control rising health expenditures in Japan.

Lopreite and Mauro (2017) analysed the effects of demographic changes in Italy on health expenditures between 1990 and 2013 using a Bayesian VAR model. The analysis results revealed that health expenditures responded more to the ageing population than to life expectancy and GDP per capita.

Pascual-Saez et al. (2017) examined health expenditures, GDP, and the population aged 65 and over in Spain for the period 2002-2013 using cointegration analysis. The findings revealed cointegration across all of Spain's autonomous regions. The study concluded that the ageing population increases per capita public health expenditure.

Okunade et al. (2018) examined the relationships among total health expenditure, GDP per capita, an ageing population, and technological developments across 34 OECD countries for the period 1980–2014. The panel ARDL approach and Granger causality tests were applied in the research. The study's findings reveal a long-term

relationship among health expenditures, income levels, an ageing population, and technology. Furthermore, it was concluded that technology diffusion through international patent collaborations plays a significant role in long-term health expenditures. The findings reveal that, in the long term, health expenditures are determined by income level, the ageing population ratio, and technological developments; in the short term, the main driving force is income growth.

In their study, Lopreite and Zhu (2020) examined the relationships among the ageing index, life expectancy, economic growth, and healthcare expenditure for the period 1978-2016 in China, which has experienced accelerated economic growth and population ageing over the last 40 years, using a Bayesian VAR model. The study found that the ageing index responds significantly to life expectancy, per capita health expenditure, and per capita GDP.

Konca et al. (2021) analysed per capita health expenditure and the proportion of the ageing population in 36 European countries between 2000 and 2014 using panel least squares regression. The study found that per capita health expenditure and the proportion of the ageing population mutually influence each other. It was stated that an increase in the proportion of the ageing population leads to increased health expenditures, greater utilization of health services, and, consequently, an increase in the proportion of the ageing population.

Eryer (2024) examined the impact of the ageing population on health expenditures for G-7 countries and Turkey between 2000 and 2022 using panel data analysis. The analysis found that, except for the USA, the impact of the ageing population on health expenditures was positive and statistically significant across all countries.

In a study by Öncebe (2024), the relationship between an ageing-dependent population, health expenditures, and domestic debt in Turkey for the period 2000-2023 was analysed using the ARDL model. The study used the domestic debt variable as an indicator of the economic burden. The study's findings reveal that the elderly-dependent population in Turkey during 2000-2023 does not harm domestic debt in the short or long term. However, it was found that higher health expenditures are associated with higher domestic debt.

In the study covering the period 1990-2021, Tıraş and Türkmen (2024) analysed the relationship between per capita pharmaceutical expenditures and per capita GDP variables in the 20 countries with the highest per capita pharmaceutical expenditures using the panel cointegration test. The analysis found that the long-term per capita pharmaceutical expenditure coefficient was not statistically significant across the panel. Increased pharmaceutical spending has been found to boost per capita GDP in the US, Japan, Austria, Australia, the Czech Republic, and Portugal. At the same time, it has decreased per capita GDP in Germany, Canada, Luxembourg, and Ireland. Furthermore, it has been noted that adopting rational drug use would prevent unnecessary pharmaceutical spending and positively contribute to per capita GDP.

DATA SET AND METHODOLOGY

This study examines per capita pharmaceutical expenditure, per capita GDP and the ageing population ratio for Turkey for the period 2008-2022 on an annual basis. The data is compiled from the OECD database. Per capita pharmaceutical expenditure and per capita GDP data are in USD (United States Dollar) and represent real data adjusted for purchasing power parity (PPP). Data abbreviations and sources are presented in the table below.

Table 1: Data Set

Variables	Variable definition	Database
Expenditure	Per capita expenditure on pharmaceuticals (PPP, Constant)	https://data-explorer.oecd.org/
GDP	Per capita GDP (PPP, USD, Constant)	https://data-explorer.oecd.org/
Ageing	Percentage of population aged 65 and over	https://data-explorer.oecd.org/

Source: Created by the author

In this study, the dynamic structure of per capita pharmaceutical expenditures is analysed within a single-equation dynamic regression model that includes a lagged dependent variable. This model is generally referred to in the literature as the ADL (1,0) specification, which is a special case of the Autoregressive Distributed Lag (ADL) approach (Sargan, 1980, p.880; Semykina and Wooldridge, 2013, p.48). The current period's per capita pharmaceutical expenditure is modelled as a function of the previous period's per capita pharmaceutical expenditure and the relevant explanatory variable. This econometric approach aims to reveal factors such as the impact of habits on pharmaceutical consumption and continuity.

In this study, the fact that the series examined have integration degrees such as I(0) and I(1) and that the period range is limited are among the reasons for preferring a single-equation dynamic regression model over multi-equation cointegration methods. This aims to provide more stable coefficient estimates. Newey–West heteroscedasticity- and autocorrelation-consistent (HAC) standard errors were used to ensure robustness against possible autocorrelation and heteroscedasticity in the error terms (Newey & West, 1987). Using the Newey-West HAC estimator in time series, both autocorrelation and heteroscedasticity problems can be solved. This method estimates coefficients and their standard errors, accounting for autocorrelation and heteroscedasticity. This method also adjusts the calculations of standard errors, t-statistics, and p-values for regression coefficients (Kartal, 2024, p.128). This enhances the reliability of statistical inferences. The dynamic multiplier method was used to analyse long-term effects. This allows short-term and long-term effects to be separated. The equation representation of the model is presented below.

$$\ln(\text{Expenditure}_t) = \alpha_0 + \alpha_1 \ln(\text{Expenditure}_{t-1}) + \beta_1 \ln(\text{Ageing}_t) + \varepsilon_t \quad (1)$$

In Equation 1, the natural logarithm of per capita pharmaceutical expenditure is used as the dependent variable. The lagged dependent variable term in the model aims to capture the continuity in pharmaceutical expenditure. The coefficient α_1 represents the effect of past-period pharmaceutical expenditure on current-period expenditure. The ageing population ratio variable shows the effect of demographic structure on pharmaceutical expenditures. The β_1 coefficient expresses the effect of changes in the ageing population ratio on pharmaceutical expenditures

in the short term. Here, ln denotes the natural logarithm, t denotes time, and t-1 denotes a period lag. The error term in the model is denoted by ε_t and represents the effect of other factors not included in the model.

$$\ln(\text{Expenditure}_t) = \alpha_0 + \alpha_1 \ln(\text{Expenditure}_{t-1}) + \beta_2 \ln(\text{GDP}_t) + \varepsilon_t \quad (2)$$

Equation 2 examines the effect of income level on pharmaceutical expenditures, using per capita GDP as the explanatory variable. The lagged dependent variable again represents expenditure continuity and dynamic structure. The β_2 coefficient shows the percentage change in per capita pharmaceutical expenditures in the short term resulting from a 1% increase in per capita income. This coefficient shows the income elasticity of pharmaceutical expenditures. The per capita income variable has been included separately in the model to understand the role of economic factors independently of demographic effects.

$$\ln(\text{Expenditure}_t) = \alpha_0 + \alpha_1 \ln(\text{Expenditure}_{t-1}) + \beta_1 \ln(\text{Ageing}_t) + \beta_2 \ln(\text{GDP}_t) + \varepsilon_t \quad (3)$$

Equation 3 includes both the ageing population ratio and per capita GDP simultaneously, thereby capturing their combined effect. This specification serves as a robustness check to determine whether the results from single-variable models hold when both variables are included in the model.

$$\text{LRAgeing} = \frac{\beta_1}{1 - \alpha_1} \quad (4)$$

Equation 4 shows the total long-term effect of the permanent increase in the ageing population ratio on per capita pharmaceutical expenditures. The β_1 coefficient in the equation is estimated as a long-term multiplier, accounting for the continuity of pharmaceutical expenditures.

$$\text{LRGDP} = \frac{\beta_2}{1 - \alpha_1} \quad (5)$$

Equation 5 shows the long-run elasticity of pharmaceutical expenditures with respect to a permanent increase in per capita income. Here, the β_2 coefficient captures the cumulative effect of per capita income over the years.

RESULTS

In the empirical analysis section of the study, per capita pharmaceutical expenditures, per capita GDP, and the proportion of the population aged 65 and over were analysed using econometric methods in Stata, and the findings are presented below. The ageing variable is defined as the share of the population aged 65 and over, which reflects the demographic structure of the population. In studies examining health and pharmaceutical expenditures, demographic variables are often expressed as population shares to capture changes in the age structure (Konca et al., 2021). In addition, all variables are used in natural logarithms in order to reduce scale differences across variables and to allow the coefficients to be interpreted in percentage terms. The analyses began by examining the stationarity of the series, and in this context, the ADF (Augmented Dickey-Fuller) unit root test was applied.

Table 1: ADF Unit Root Test

Variables	t-statistics	5% critical value	p-value
ln(Expenditure)	-3.614	-3.600	0.028*
ln(GDP)	-2.661	-3.600	0.252
ln(Ageing)	-2.851	-3.600	0.179
Δln(GDP)	-3.233	-3.000	0.018*
Δln(Ageing)	-2.893	-3.000	0.046*

Source: Created by the author

Note: The Δ symbol indicates first differences. Series found to be stationary at the 5% significance level are marked with an asterisk (*). A logarithmic transformation has been applied to the series, denoted by ln.

According to the ADF unit root test results in Table 1, the p-value of the ln (Expenditure) series is 0.028, indicating that it is stationary at the level. In contrast, the p-values of the ln(GDP) and ln(Ageing) series in the ADF unit root test are 0.252 and 0.179, respectively, which are greater than the 5% significance level. Neither series is stationary at the level. The first differences of these two series were taken, and the p-values of Δln(GDP) and Δln(Ageing) were 0.018 and 0.046, respectively. Both values are lower than 0.05, indicating that the series become stationary in the first difference. In the continuation of the analysis, a single-variable dynamic regression model was preferred due to the mixed stationarity levels of the series and the limited sample size. Classical OLS standard errors can lead to biased results when heteroscedasticity or autocorrelation is present. In this context, the Newey-West HAC method was preferred.

Table 2: Single Variable Dynamic Regression (Ageing Population Ratio)

Variables	Coefficient	p-value
L.ln(Expenditure)	0.791	0.000
ln(Ageing)	0.470	0.197
Intercept	0.158	0.748

L denotes the lag operator, indicating a one-period lag in the variable.

Source: Created by the author

Table 2 shows that pharmaceutical expenditures, expressed as ln (Expenditure), exhibit strong persistence. The coefficient of the lagged dependent variable L.ln(Expenditure) is 0.791, which is highly significant. This indicates that the level of pharmaceutical expenditures in the previous year strongly influences pharmaceutical expenditures in the current year. For these reasons, it is understood that pharmaceutical expenditures are persistent data that do not change easily in the short term. This persistence can be explained by the continuity of treatments, repeat prescriptions, the presence and frequency of chronic diseases, and reimbursement mechanisms that maintain the level of pharmaceutical expenditures over time. When the short-term coefficient for the ageing population ratio was examined, it was 0.470 ($p=0.197$; $p>0.01$), yielding no statistically significant results. This indicates that an increase in the ageing population ratio does not lead to higher pharmaceutical expenditures in the same year. The expenditure-increasing effect of ageing does not emerge in the short term but may emerge

gradually and cumulatively over time.

Table 3: Single Variable Dynamic Regression (GDP)

Variables	Coefficient	p-value
L.ln(Expenditure)	0.889	0.000
ln(GDP)	0.217	0.320
Intercept	-1.587	0.395

Lag=1
Source: Created by the author

Table 3 shows that the coefficient of the lagged dependent variable is 0.889 and is statistically significant. This confirms the continuity of pharmaceutical expenditures. The Ln(GDP) coefficient is 0.217, and the p-value is 0.320, which is greater than 0.01. The result is not statistically significant. This indicates that per capita GDP in Turkey does not have a statistically significant short-term effect on per capita pharmaceutical expenditures. Drug prices, co-payments, reimbursement systems, and public regulations are thought to determine drug demand based on need, and income elasticity is considered weak, meaning sensitivity to income growth is low.

The lack of statistically significant fixed-term coefficients in both models indicates that past expenditure levels and the explanatory variables primarily explain changes in pharmaceutical expenditures. The short-term results presented in Table 2 and Table 3 reveal that past spending habits, the country's institutional structure in the health sector, and pricing mechanisms have a greater impact on pharmaceutical expenditures. In comparison, the ageing population and income growth may have a greater impact through long-term channels.

Table 4: Long-Term Effects

Long-Term Effect	Coefficient	Standard Error	p-value	95% Confidence Interval
LRAgeing (single variable)	2.252	0.999	0.024	[0.293, 4.211]
LRGDP (single variable)	1.970	1.636	0.228	[-1.235, 5.177]

Source: Created by the author

Short-term coefficients in dynamic regression models cannot alone provide a permanent effect; what is fundamentally important here is the long-term multiplier coefficient. Within this framework, long-term multipliers were calculated using the coefficients obtained from the two different dynamic regression models presented above. According to the long-term analysis findings, the LRAgeing coefficient is 2.252, and the p-value is 0.024. The result is significant at the 5% level, indicating that the ageing population ratio has a positive, statistically significant effect on per capita pharmaceutical expenditures. According to the findings, a 1% increase in the ageing population ratio increases per capita pharmaceutical expenditures by approximately 2.25% in the long term. This result shows that population ageing creates a lasting pressure on pharmaceutical expenditures. While an increase in the ageing population ratio has no significant effect in the short term, it leads to significant results in the long term. This situation shows that an increase in the ageing population ratio increases the demand for healthcare services and, consequently, pharmaceutical expenditures, and that this increase occurs

cumulatively.

The LRGDP coefficient is 1.970, and the p-value is 0.228. The p-value is greater than 0.01 and is therefore not statistically significant. Consequently, the existence of a long-term income effect cannot be established. The findings reveal that pharmaceutical expenditures in Turkey are more related to the structure of the population and the health status of society than to per capita income levels, and that they are more sensitive to these factors.

Table 5: Robustness Analysis: Short-Term

Variables	Coefficient	Standard Error	p-value
L.ln(Expenditure)	0.528	0.135	0.003
ln(Ageing)	2.326	1.052	0.052
ln(GDP)	-1.124	0.656	0.118
Intercept	9.067	4.963	0.098

Source: Created by the author

Table 5 shows that the coefficient of the lagged dependent variable is 0.528 and the p-value is 0.003. These values indicate that the continuity of pharmaceutical expenditures persists across different specifications. Thus, the reliability of the findings has been enhanced. The ln(Ageing) coefficient is 2.326 and the p-value is 0.052, indicating a marginally significant result at the 10% level. The ln(GDP) coefficient is -1.124 and the p-value is 0.118. The result is not statistically significant.

Table 6: Robustness Analysis: Long-Term

Long-Term Effect	Coefficient	Standard Error	p-value	95% Confidence Interval
LRAgeing	4.937	1.670	0.003	[1.663, 8.210]
LRGDP	-2.387	1.123	0.034	[-4.590, -0.184]

Source: Created by the author

The LRAgeing coefficient is 4.937 and the p-value is 0.003, indicating that the result is statistically significant and positive. This shows that the ageing population ratio has a permanent and significant effect on pharmaceutical expenditures. The findings reveal that the effect of the ageing population ratio variable is stable.

In the robustness specification, the long-term effect of the ageing population is positive and strongly significant. The long-term effect of income is negative and significant at the 5% level in this specification; this suggests that the income effect may be sensitive to the model, whereas the ageing effect is more stable.

CONCLUSION

Age, health status, employment status, access to healthcare services, having health insurance, and individuals' income levels are among the factors considered to influence pharmaceutical consumption (Öztürk et al., 2019). The direct effects of new technologies on life expectancy and quality of life, along with advances in medical

technology, have significantly increased pharmaceutical expenditures. One of the main reasons for the increase in pharmaceutical expenditure is the change in the age structure of the population. Particularly in developed countries where life expectancy has increased, the growth of the ageing population has driven up health expenditure. Pharmaceutical expenditure is increasing rapidly in two ways: both on the supply side (the pharmaceutical industry) and on the demand side (demographic, economic, etc.). For this reason, almost all countries are taking steps to reduce costs and control the rise in pharmaceutical expenditure through regulatory policies. This is primarily achieved through the reorganisation of health-related budgets and the imposition of price controls (Çalışkan, 2008, pp.70-71).

This study investigates the impact of the ageing population ratio and income level on pharmaceutical expenditures in Turkey for the period 2008-2022. The results of the single-variable dynamic regression, in which the ageing population ratio and per capita income variables were included separately in the model, revealed that per capita pharmaceutical expenditures are primarily dependent on past period expenditures. This situation suggests that pharmaceutical consumption shows some continuity, driven by ongoing treatments and chronic diseases. The study's findings show that the short-term effects of the ageing population ratio and per capita income variables are not statistically significant. This result indicates that short-term medication expenditure is determined more by current expenditure levels and institutional regulations than by population structure and per capita income.

In the study's long-term analyses, it was found that the proportion of the ageing population has a positive, statistically significant effect on per capita pharmaceutical expenditure. The analysis finds that the ageing population ratio increases over time, creating a lasting pressure on pharmaceutical expenditures. This result indicates that the financial impact of the growing ageing population on healthcare services becomes more pronounced in the long term rather than the short term. This situation may pose a significant risk to the sustainability of healthcare expenditures and financing.

The study's empirical findings offer implications for health policies. The strong, stable, positive long-term effect of the ageing population ratio among the variables indicates the need to consider demographic projections when planning health and pharmaceutical budgets. An ageing population, along with an increasing disease burden and multiple drug use, can lead to a structural increase in pharmaceutical expenditure. In this context, investments in preventive healthcare services for early disease diagnosis and prevention will reduce healthcare expenditure and, consequently, pharmaceutical expenditure in the long term. In addition, the use of equivalent medicines, informing patients and increasing health literacy within the scope of public health policies are necessary to prevent unnecessary medication use. Low health literacy leads to an inability to understand and use health information, resulting in unnecessary use of health services, non-compliance with treatment, incorrect medication use, and increased healthcare costs (Saygın et al., 2021, p.1560). This situation can increase pharmaceutical expenditures. In this context, public health policies that increase health literacy are critical. In this context, policy

tools such as increasing patient information activities, expanding health education programmes, training healthcare personnel in patient communication, making reliable health information accessible through digital channels, and providing clear and understandable information materials on medication use are crucial for improving health literacy. Within the context of these applications, savings in medication expenditures will also increase efficiency and financial performance in healthcare services (Uygun & Yiğit, 2017, p.289).

The study analyses the period 2008-2022 in Turkey and finds that the effect of the income variable is limited. This indicates that the current reimbursement and pricing systems play a significant role in shaping drug demand. However, the increase in demand associated with an ageing population underscores the need to review the effectiveness of reimbursement mechanisms regularly.

This study presents empirical findings by examining the ageing population ratio, representing the demographic structure, and the per capita income variable, representing the economic aspect, among the determinants of pharmaceutical expenditure. Studies in the literature focus on health expenditure and the ageing population, while studies addressing pharmaceutical expenditure are limited. The findings of this study reveal that an increase in the ageing population ratio affects pharmaceutical expenditures in the long term, consistent with the literature (Tamakoshi & Hamori 2015, p.725; Konca et al., 2021, p.315; Eryer, 2024, p.193). Due to data constraints, this study was conducted for the years 2008-2022, and the explanatory variables are limited to the ageing population ratio and per capita income. In future studies, explanatory variables could be expanded to include drug price indices, public reimbursement policies, and access to healthcare services.

REFERENCES

Beceren, E., Balcı İzgi, B., & Fırat, E. (2021). Sağlık ve kalkınma ilişkisi OECD ülkelerinde sağlık harcamalarını belirleyen faktörler. *Aksaray Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 13*(2), 1-10. https://doi.org/10.52791/aksarayiibd.915196

Çalışkan, Z. (2008). Referans fiyat ve ilaç piyasası. *Hacettepe Sağlık İdaresi Dergisi*, *11*(1), 49-75. https://izlik.org/JA34YG24GN

Eryer, A. (2024). Yaşlı nüfus ve sağlık harcamaları arasındaki ilişkinin belirlenmesi: Panel veri analizi. *Econder Uluslararası Akademik Dergi*, 8(2), 192-209. https://doi.org/10.35342/econder.1586805

Getzen, T. E. (1992). Population aging and the growth of health expenditures. *Journal of Gerontology*, *47*(3), 98-104. https://doi.org/10.1093/geronj/47.3.S98

Hayran, O. (2019). Koruyucu hizmetler sağlık harcamalarını azaltabilir mi?. *Journal of Biotechnology and Strategic Health Research*, *3*(3), 170-175. https://doi.org/10.34084/bshr.640902

Hermanowski, T., Bystrov, V., Staszewska-Bystrova, A., Szafraniec-Buryło, S. I., Rabczenko, D., Kolasa, K., & Orlewska, E. (2015). Analysis of trends in life expectancies and per capita gross domestic product as well as pharmaceutical and non-pharmaceutical healthcare expenditures. *Acta Pol Pharm*, *72*(5), 1045-50. https://ptfarm.pl/pub/File/Acta_Poloniae/2015/5/acta5_2015.pdf#page=229

Kartal, G. (2024). Türkiye'de Phillips eğrisinin geçerliliği: Çoklu yapısal kırılmalara dayalı ampirik bulgular. *İzmir İktisat Dergisi*, *39*(1), 114-138. https://doi.org/10.24988/ije.1302596

Kildemoes, H. W., Christiansen, T., Gyrd-Hansen, D., Kristiansen, I. S., & Andersen, M. (2006). The impact of population ageing on future Danish drug expenditure. *Health Policy*, *75*(3), 298-311. https://doi.org/10.1016/j.healthpol.2005.03.013

Konca, M., Balçık, P. Y. & Biçer, İ. (2021). Yaşlı nüfus ile sağlık harcamaları arasındaki ilişkinin incelenmesi: Panel veriye dayalı bir uygulama. *Iğdır Üniversitesi Sosyal Bilimler Dergisi, (26)*, 314-324. https://izlik.org/JA52AA54WW

Lopreite, M., & Mauro, M. (2017). The effects of population ageing on health care expenditure: A Bayesian VAR analysis using data from Italy. *Health Policy*, *121*(6), 663-674. https://doi.org/10.1016/j.healthpol.2017.03.015

Lopreite, M., & Zhu, Z. (2020). The effects of ageing population on health expenditure and economic growth in China: A Bayesian-VAR approach. *Social Science & Medicine*, *265*, 113513. https://doi.org/10.1016/j.socscimed.2020.113513

Lu, W. H., Lee, W. J., Chen, L. K., & Hsiao, F. Y. (2016). Comparisons of annual health care utilization, drug consumption, and medical expenditure between the elderly and general population in Taiwan. *Journal of Clinical Gerontology and Geriatrics*, *7*(2), 44-47. https://doi.org/10.1016/j.jcgg.2015.08.002

Morgan, S. G. (2005). Booming prescription drug expenditure: A population-based analysis of age dynamics. *Medical Care*, *43*(10), 996-1008. https://doi.org/10.1097/01.mlr.0000178217.84354.f1

Morgan, S. G. (2006). Prescription drug expenditures and population demographics. *Health Services Research*, *41*(2), 411-428. https://doi.org/10.1111/j.1475-6773.2005.00495.x

Newey, W. K., & West, K. D. (1987). Hypothesis testing with efficient method of moments estimation. *International Economic Review*, 777-787. https://doi.org/10.2307/2526578

OECD. (2023). *Health at a glance 2023: OECD indicators*. OECD Publishing. https://www.oecd.org/en/publications/health-at-a-glance_19991312.html

Okunade A.A., You X. & Koleyni K., (2018). Cross-country medical expenditure modeling using OECD panel data and ardl approach: Investigating GDP, technology, and aging effects. In B. H. Baltagi & F. Moscone (Eds.), *Health Econometrics*. Emerald Publishing Limited. https://doi.org/10.1108/S0573-855520180000294018

Öncebe, Şaban. (2024). The relationship between the elderly dependent population, healthcare expenditures, and domestic debt in Turkey. *ISPEC International Journal of Social Sciences & Humanities*, *8*(4), 103–122. https://doi.org/10.5281/zenodo.14506494

Öztürk, S., Başar, D., Özen, İ. C., & Çiftçi, A. Ö. (2019). Socio-economic and behavioral determinants of prescription and non-prescription medicine use: The case of Turkey. *DARU Journal of Pharmaceutical Sciences*, *27*(2), 735-742. https://doi.org/10.1007/s40199-019-00311-1

Palangkaraya, A., & Yong, J. (2009). Population ageing and its implications on aggregate health care demand: Empirical evidence from 22 OECD countries. *International Journal of Health Care Finance and Economics*, *9*(4), 391–402. https://doi.org/10.1007/s10754-009-9057-3

Pascual-Saez, M., Cantarero-Prieto, D., & Castañeda, D. (2017). Public health expenditure, GDP and the elderly population: A comparative study. *International Journal of Social Economics*, *44*(10), 1390-1400. https://doi.org/10.1108/IJSE-03-2016-0106

Saygın, E., Tolon, M., Doğan, B., & Atalay, K. D. (2021). Covid–19 pandemi döneminde e-sağlık okuryazarlığının incelenmesi üzerine bir araştırma. *Üçüncü Sektör Sosyal Ekonomi Dergisi*, *56*(3), 1559-1575. https://doi.org/10.15659/3.sektor-sosyal-ekonomi.21.08.1605

Sargan, J. D. (1980). Some tests of dynamic specification for a single equation. *Econometrica, 48*(4), 879–897. https://doi.org/10.2307/1912938

Semykina, A., & Wooldridge, J. M. (2013). Estimation of dynamic panel data models with sample selection. *Journal of Applied Econometrics*, *28*(1), 47-61. https://doi.org/10.1002/jae.1266

Tamakoshi, T., & Hamori, S. (2015). Health-care expenditure, GDP and share of the elderly in Japan: A panel cointegration analysis. *Applied Economics Letters*, *22*(9), 725–729. https://doi.org/10.1080/13504851.2014.972540

Tıraş, H. H., & Türkmen, S. (2024). İlaç harcamaları ve GSYİH ilişkisi: Kişi başı en fazla ilaç harcaması yapan ülkeler örneği. *The Journal of Academic Social Science*, *157*(157), 145-161. http://dx.doi.org/10.29228/ASOS.78009

Uygun, S., & Yiğit, V. (2017). Effective inventory management in hospital enterprises: An application for drug stocks. *Mehmet Akif Ersoy Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, *9*(18), 288-307. https://doi.org/10.20875/makusobed.302977

Zweifel, P., Felder, S., & Meiers, M. (1999). Ageing of population and health care expenditure: A red herring?. *Health Economics, 8*(6), 485-496. https://doi.org/10.1002/(SICI)1099-1050(199909)8:6%3C485::AID-HEC461%3E3.0.CO;2-4

InTraders International Trade Academic Journal

e-ISSN: 2667-4408 **www.intraders.org**

Volume: 9
Issue : 1
Research Article

Received: January 22, 2026
Revision: March 9, 2026
Accepted: April 2, 2026
DOI: https://www.doi.org/10.55065/intraders.1869742

A Multi-Criteria Evaluation of Employment-Focused Policy Packages in Türkiye in the Context of Energy Shocks

Serkan CANTÜRK[1]

Abstract

This study aims to prioritize deployable policy packages that address energy-price shocks and employment protection in Türkiye, with the objective of identifying which combinations of fiscal, social, and industrial policy instruments can be prioritized as relatively more effective in preserving jobs under energy volatility, based on expert-based multi-criteria assessments, while remaining feasible within fiscal and administrative constraints. A multi-criteria decision-making (MCDM) framework is employed to evaluate seven alternative policy packages at the portfolio level, based on expert judgments from seven specialists in labour economics, energy policy, public finance, and implementation, who populate a six-criterion decision matrix capturing expected unemployment reduction, time-to-impact, implementation feasibility, fiscal cost per job, targeting accuracy, and durability of effects; the matrix is normalized using benefit–cost-aware min–max procedures, criterion weights are derived through the Entropy method and compared with an equal-weight baseline for robustness, and policy packages are ranked using Simple Additive Weighting (SAW) with Additive Ratio Assessment (ARAS) as validation. The findings indicate consistent rankings across methods, showing that the package combining indexation thresholds, social energy tariffs, and structured debt restructuring provides the strongest immediate employment protection, followed by targeted energy-bill relief with short-time work arrangements and export support with foreign exchange risk hedging for energy-intensive SMEs, while structural measures such as industrial efficiency grants, reskilling programs, heat-pump and retrofit investments, and green public employment exhibit greater long-term durability but weaker short-run effectiveness. The study contributes by offering a portfolio-level multi-criteria evaluation of energy–employment policy packages for Türkiye and by providing an actionable sequencing framework distinguishing rapid stabilization instruments from longer-term resilience measures.

Keywords: *Energy-price shocks; Employment protection; Multi-criteria decision-making (MCDM); SAW–ARAS ranking.*

JEL Codes: *Q43, J38, C44, C02, C61*

There is no conflict of interest.
Ethics Permission Details: İstinye University. Social and Human Sciences Ethic Board, Meeting Date 9 January, 2025, Meeting No:2025/12 Decision No:25-149

[1] Asst. Prof. Dr. İstinye University, E-mail: serkan.canturk@istinye.edu.tr, OI: 0000-0002-7283-7227 , Contribution rates to the study 100 %.

Cite As: Cantürk, S. (2026). A multi-criteria evaluation of employment-focused policy packages in Türkiye in the context of energy shocks. *InTraders International Trade Academic Journal*, 9(1), 33–70. https://doi.org/10.55065/intraders.1869742

INTRODUCTION

Energy-price volatility has become a first-order macroeconomic and social risk for energy-importing economies such as Türkiye because it affects employment through explicit transmission channels that connect energy shocks to firms' cost structures, output decisions, and labor demand. When natural gas, electricity, and refined-product prices rise, firms' variable input costs increase immediately, raising unit costs and compressing profit margins. In sectors with limited pricing power, margin compression is commonly absorbed through cost containment rather than full pass-through, which translates into hiring freezes, reduced overtime, shorter hours, postponed investment, and—under sustained stress—layoffs. In sectors that attempt cost pass-through, higher output prices weaken sales volumes, reduce production, and lower derived demand for labor. These cost and demand mechanisms clarify why employment losses can occur even if the initial shock originates on the input side rather than from a fall in final demand. (Kilian & Zhou, 2023).

A second set of mechanisms operates through liquidity and distribution. Energy shocks tighten firms' cash-flow positions because energy bills adjust rapidly while revenues and contracts adjust with lags, increasing working-capital needs and liquidity risk—especially for SMEs and energy-intensive firms. When liquidity constraints bind and financing conditions tighten, firms reduce payroll commitments (hours, temporary contracts, new hiring, and eventually headcount) to preserve solvency**.** At the household level, higher utility and transport costs reduce real disposable income—particularly for liquidity-constrained households—cutting consumption and weakening demand in labor-intensive services. This household real-income channel feeds back into firms' revenues, reinforcing labor-demand reductions initiated by cost and liquidity pressures. Distributional channels can amplify these effects because losses are concentrated among vulnerable households and smaller firms, raising the likelihood of hour cuts and separations unless policy instruments quickly stabilize cash flows (Auclert et al., 2023).

These channels do not operate uniformly across Türkiye. Sector and regional heterogeneity shapes the severity and timing of labor-market adjustment: energy-intensive exporters face sharper margin compression when energy volatility coincides with exchange-rate movements and weak external demand; municipal service providers confront rising utility bills that can outpace earmarked transfers and threaten local employment; and households in poorly insulated dwellings experience disproportionate affordability stress, deepening demand-side contractions. Because energy-price volatility influences employment through multiple pathways, the policy challenge is to select packages that can simultaneously cushion firms' cost and liquidity stress while protecting household purchasing power to sustain demand. New administrative-data evidence also indicates that fine-grained targeting—linking social registries with metering or billing data—can materially improve incidence and reduce leakage, which is crucial when fiscal space is tight and volatility is recurrent (Fawcett et al., 2024).

Against this background, the purpose of this study is to produce a decision-oriented prioritization of feasible policy packages for Türkiye that maximize near-term unemployment mitigation per unit of time and budget while preserving macroeconomic discipline and administrative implementability. The analysis focuses on compact, deployable combinations that align with existing Turkish policy rails, including thresholded indexation paired with social tariffs and structured bill-debt workouts; targeted bill relief linked to short-time work (STW); export support with FX hedging for energy-intensive SMEs; industrial-efficiency grants paired with rapid reskilling vouchers; municipal intergovernmental transfer top-ups under clear guardrails; and heat-pump and building retrofit programs for low-income households and SME premises. The objective is not to claim a single universally best instrument, but to identify a ranked and sequenced portfolio that preserves the most jobs quickly at acceptable fiscal cost, with credible targeting and manageable implementation burden, and to test how this ordering changes under plausible shifts in weights and assumptions.

Methodologically, the study applies transparent, low-complexity multi-criteria decision methods—Simple Additive Weighting (SAW) and Additive Ratio Assessment (ARAS)—because they are auditable, interpretable, and decomposable into criterion contributions, allowing policy teams to see why a package ranks highly (Zavadskas & Turskis, 2010; Gül, 2021; İzgüden et al., 2022). A benefit/cost-aware normalized decision matrix evaluates policy packages on six criteria: expected unemployment reduction, time-to-impact, implementation feasibility, fiscal cost per job averted, targeting accuracy, and 24-month durability. Criteria weights are computed using Entropy and compared with an equal-weight baseline for robustness. Inputs are derived from a structured elicitation of seven spanning labor economics, energy/industry policy, SME/export finance, public budgeting, and implementation (including municipal delivery), calibrated against Turkish program realities and recent evidence on labor adjustment and targeting frictions (e.g., Osuna & García Pérez, 2022; Fawcett et al., 2024).

To clarify the study's analytical focus and guide the evaluation, the research is organized around the following questions, which frame employment protection under energy-price volatility in Türkiye as a practical policy-prioritization problem balancing speed, fiscal cost, feasibility, targeting accuracy, and durability.

RQ1. Which feasible policy packages provide the strongest near-term employment protection in Türkiye under energy-price volatility when evaluated jointly on speed, fiscal cost, feasibility, targeting accuracy, and durability?

RQ2. How do policy-package rankings change when criterion weights shift between objective (entropy-based) weighting and an equal-weight baseline?

RQ3. To what extent do SAW and ARAS produce concordant rankings of policy packages, and which criteria drive rank differences across methods?

RQ4. What sequencing strategy is implied by the highest-ranked packages, moving from rapid stabilizers to longer-horizon exposure-reduction measures under Türkiye's administrative and fiscal constraints?

The novelty of the study lies in providing a head-to-head, portfolio-level ranking of employment-focused energy policy packages tailored to Türkiye's fiscal and administrative constraints, rather than evaluating instruments in isolation. It contributes a replicable evaluation frame that can be updated as monitoring data arrive, a criteria set aligned with the observable trade-offs of energy volatility (speed, cost-effectiveness, feasibility, targeting precision, durability), and a robustness design that checks stability across weighting schemes and concordance across SAW and ARAS. The remainder of the paper situates the analysis within the literature on energy pass-through and labor-market transmission, details the alternatives/criteria/data and evaluation procedures, presents results with robustness checks, interprets trade-offs to derive sequencing guidance for Turkish conditions, and concludes with policy implications and priorities for micro-data evaluation and iterative updating under recurrent energy volatility.

LITERATURE REVIEW

Energy Shocks and Labour-Market Transmission

Energy price shocks reach the labour market through a web of cost, demand, expectation, and finance channels that do not move at the same speed or with the same intensity. When energy becomes more expensive, firms face higher production costs and squeezed margins, and many respond by raising output prices. How far pass-through can proceed depends heavily on wage-setting rules and institutions. In environments with widespread indexation or strong unions, wages react quickly, so real incomes and hiring decisions adjust sooner rather than with a long lag (Kilian & Zhou, 2023). At the same time, firms operate under heightened uncertainty. Clustered and repeated swings in energy markets make managers reluctant to invest or expand payrolls, reinforcing caution even in sectors that remain profitable on paper (Dokas et al., 2023; Christopoulos et al., 2021). The type of shock matters as well: disruptions in pipelines or LNG logistics propagate differently from demand booms, producing divergent labour outcomes under similar headline price increases (Alessandri & Gazzani, 2025).

Once energy-driven inflation seeps into core prices, households' real purchasing power declines, consumption is cut back, and service-sector jobs become more vulnerable—especially where social protection systems are thin or respond slowly (Škare et al., 2022). Policy and market design can either cushion or amplify these forces. Misalignments between EU gas procurement strategies and shifting global trade heightened the risk of sudden shortages and price spikes and prolonged uncertainty about disruption duration, making hiring freezes and deferred expansion rational responses (Cardinale et al., 2024). Supply-chain effects add another layer: energy bottlenecks raise the cost of raw materials and intermediate inputs and hit energy-intensive industries hardest, where layoffs can be both quick and concentrated (Min, 2022). Financial markets then feed back into real decisions; when energy-related equity prices become more volatile, borrowing costs rise and firms may scale back staff before profits visibly deteriorate (Son & Ryu, 2024). In combination, wage rules, uncertainty, physical bottlenecks, and financial frictions jointly determine how fast and how deeply labour markets adjust after an

energy shock.

Recent research strengthens the empirical basis for these mechanisms by showing that employment effects are heterogeneous and concentrated in exposed segments. Evidence for Europe indicates that electricity-cost increases can induce employment reallocation, with stronger effects in more energy-intensive activities and where competitive margins are tight (Bijnens, Hutchinson, & Saint Guilhem, 2026). Policy-facing analysis similarly emphasizes that enduring high energy prices can translate into job losses concentrated in energy-intensive sectors, reinforcing the relevance of cost exposure, pricing power, and adjustment costs for labour demand (Bijnens, Hutchinson, & Saint Guilhem, 2025). Cross-country business evidence links electricity price differentials to employment outcomes across European economies and highlights the role of economic structure in mediating labour impacts (Eurochambres Chief Economists Group, 2025; Eurochambres, 2025). These contributions are important for employment-protection design because they imply that vulnerability is patterned, not random, and that targeting and feasibility conditions can determine whether policies reach the segments where job losses concentrate.

Evidence from different regions further demonstrates that these channels interact with energy mix, import dependence, industrial structure, and institutional strength. In North America, gas price movements affect manufacturing and electricity generation, but employment responses depend on the technologies in use and the degree of trade integration (Brown et al., 2021). In Southeast Asia, energy price increases generate uneven output declines and supply-chain pressures, and local job losses reflect both input-price effects and exposure through global production networks (Nguyen et al., 2024). Europe has experienced a distinct configuration: rerouted LNG flows and weakened long-term fixed-price contracts intensified uncertainty, impeding investment in gas-dependent export sectors and making it harder to sustain employment when margins are slim (Cardinale et al., 2024). Capital markets offer additional signals because oil price fluctuations do not influence green-energy stocks as they might conventional equities, implying different investment and employment profiles between technology-rich firms and traditional energy producers (Zhou & Geng, 2021). Newer risk measures that incorporate external shocks and macro-financial linkages also sharpen identification of vulnerable worker groups and regions (Zhang & Zhou, 2024).

Energy volatility can also influence unemployment through aggregate dynamics that complement firm-level adjustment. Recent MF-VAR evidence links energy price fluctuation to surveyed unemployment outcomes in a transition context, supporting the view that volatility can affect labour markets through demand expectations and macro conditions as well as through direct production costs (Long et al., 2025). Macro-external channels shape adjustment space, because energy price shocks influence current-account balances depending on economic structure, energy dependency, and renewable development, which in turn can condition exchange rates and financing conditions relevant for labour demand (Nashi & Ouakil, 2025). These dynamics matter for Türkiye

because external financing constraints can tighten precisely when energy bills rise, amplifying pressure on firm cash flow and employment. They also reinforce why near-term employment protection and macro discipline must be considered jointly when choosing policy responses.

Policy design and macro stabilisation shape how much of an energy shock ultimately converts into job losses or prolonged unemployment. Fiscal and monetary coordination can mitigate real-income declines and stabilize demand, but instrument mix and timing are decisive for labour outcomes (Auclert et al., 2023; Kilian & Zhou, 2023). At the micro-institutional level, short-time work and temporary layoff schemes preserve firm–worker matches, reduce separation rates, and compress unemployment spikes when rules target exposure and administrative capacity supports rapid uptake (Osuna & García Pérez, 2022). Local fiscal multipliers transmitted through intergovernmental grants can sustain subnational employment during revenue shortfalls, particularly in labour-intensive public services, though effects hinge on formula design and cyclical conditions (Giertz & Kumar, 2024). Over longer horizons, public investment in infrastructure and public employment programs can counter hysteresis by maintaining attachment and creating complementary demand in exposed regions (Gasperin & Skidelsky, 2021). Yet transition-period labour bottlenecks arising from skill mismatches constrain reallocation and attenuate stimulus effects unless matching frictions are addressed explicitly (Lankhuizen et al., 2023).

Recent studies on volatility dynamics underscore that policy uncertainty and regime changes can intensify adjustment pressures. Carbon price volatility is shaped by climate policy, fossil-fuel, and renewable-energy shocks, illustrating that energy-related price processes can be driven by multiple interacting disturbances rather than a single source (Wang, Lu, Safi, & Li, 2025). Time-varying evidence further indicates that carbon markets' reactions to economic policy uncertainty and oil price shocks change across periods, implying that the relevant risk environment can shift and that decision frameworks benefit from robustness checks (Wang, Safi, Wang, & Zhang, 2025). Predictive work using hybrid statistical and machine learning approaches similarly highlights the importance of anticipating volatility regimes when planning policy timing and sequencing (Shang, Pang, & Wang, 2025). Nonlinear adjustment mechanisms also appear in the renewables domain: asymmetric threshold effects suggest that responses to energy price fluctuations can differ across growth regimes, complicating the expectation of proportional labour responses (Boulanouar, Essid, Farid, & Mahjoub, 2025). These findings collectively motivate evaluation designs that test ranking stability under alternative weights and assumptions.

Household-level channels and distributional targeting add a further layer to labour-market transmission by influencing effective labour supply and local demand. Energy poverty through high bill burdens and arrears reduces disposable income and may constrain job search or hours, while also depressing neighbourhood demand in services (Simshauser, 2022). Evidence from Spain suggests heating allowances can alleviate immediate hardship, but employment-relevant welfare gains depend on design features that minimize leakage and sustain liquidity during peak price episodes (Barrella et al., 2021). Social energy tariffs can improve health and economic

participation among vulnerable groups when calibrated to price dynamics and targeted accurately, with recent work exploring broader welfare implications (Jové-Llopis et al., 2025). Advances in smart-meter data enable sharper targeting of support to high-risk households, improving the efficiency of fiscal outlays and stabilizing local labour markets more effectively than blunt instruments (Fawcett et al., 2024). These distributional mechanisms provide the substantive basis for including targeting accuracy, time-to-impact, and durability as criteria in package evaluation.

Beyond relief, efficiency retrofits and electrification of end-uses (e.g., heat pumps) can generate longer-run bill reductions, strengthen resilience to future shocks, and create installation jobs, although time-to-impact and administrative complexity are typically higher than for cash-based measures (Zhou et al., 2021). Industrial energy-management interventions—ranging from digital twins and plant audits to motor and thermal system upgrades—lower exposure for SMEs and may dampen employment volatility by stabilizing operating costs (Yu et al., 2022; Patterson et al., 2022; Errigo et al., 2022; Kapp et al., 2022). At the macro edge, improvements in efficiency can attenuate the volatility of oil-linked price processes by altering demand elasticities, indirectly supporting labour-market stability (Usman et al., 2025). Structural change toward higher energy efficiency via industrial upgrading and coordination exhibits measurable gains that, if paired with re-skilling, can reorient employment toward less shock-sensitive activities (Xue et al., 2022). In open economies, international transmission of energy-linked input prices can also limit domestic control over cost conditions, reinforcing the relevance of exposure reduction and hedging-compatible strategies (Li, Chen, Long, & Huang, 2026).

Taken together, the transmission literature implies that employment protection under energy volatility is inherently a portfolio problem. Multiple objectives must be balanced simultaneously: rapid stabilization of firm cash flow and cost exposure, protection of household purchasing power and local demand, preservation of matches through retention tools, and maintenance of macro discipline when external balances and volatility shift. This motivates evaluating feasible policy packages jointly on speed, fiscal cost, feasibility, targeting accuracy, and durability (RQ1), testing how rankings change under alternative weighting schemes (RQ2), checking method concordance across SAW and ARAS (RQ3), and deriving sequencing guidance that starts with rapid stabilizers and shifts toward exposure reduction as capacity expands (RQ4).

Policy Instruments for Employment Protection under Energy Stress

Employment-preserving instruments under energy stress can be grouped into three complementary families: job retention schemes, targeted household support, and firm-side exposure reduction. Each family differs in timeline, administrative requirements, and the way it interacts with general-equilibrium channels. Evidence on job retention indicates that short-time work and temporary layoff schemes cushion separation rates when eligibility rules are well targeted and uptake is rapid, preserving firm–worker matches that would otherwise be irreversibly lost in high-volatility episodes (Osuna & García Pérez, 2022). From a macro-stabilization angle, coordinated

fiscal–monetary policy tempers real-income erosion and demand shortfalls that compound cost shocks, but instrument choice and timing are central for labour outcomes (Auclert et al., 2023). At sub-national level, intergovernmental grants transmit sizeable local fiscal multipliers to employment, particularly in labour-intensive public services, provided transfers are formula-driven and countercyclical (Giertz & Kumar, 2024). Because gas and electricity shocks differ in propagation and duration, policy menus should be adapted to shock type rather than relying on generic packages (Alessandri & Gazzani, 2025).

System-level diagnostics can aid such tailoring. Composite risk indicators that integrate exogenous shock exposure help identify jurisdictions where retention subsidies deliver the highest employment payoff per unit of fiscal cost (Zhang & Zhou, 2024). Regional case studies show that supply-chain structure matters for instrument efficacy: where manufacturing clusters are tightly linked to energy-intensive inputs, retention support may need to be paired with measures that stabilize intermediate-goods availability to prevent stop–start production cycles and repeated hiring reversals (Brown et al., 2021; Nguyen et al., 2024). Recent European evidence indicates that electricity-cost pressures can induce employment reallocation, implying that retention instruments may be especially valuable for preserving matches in the most exposed segments while other measures address the underlying competitiveness and exposure pressures (Bijnens et al., 2026). Cross-country business evidence also suggests that persistently high electricity prices are associated with stronger employment pressures in exposed industries, strengthening the case for rapid, targeted retention tools in the acute phase of shocks (Eurochambres Chief Economists Group, 2025; Eurochambres, 2025; Bijnens et al., 2025). Together, these findings imply that retention tools are most effective when embedded in a broader stabilization architecture that accounts for shock anatomy, fiscal capacity, and sectoral interdependencies.

A second policy family targets household energy stress to support effective labour supply and local demand. Social energy tariffs and bill-relief programs can improve health, liquidity, and labour-market participation among vulnerable groups, but their employment salience depends on accurate targeting and predictable duration rather than one-off cash injections (Jové-Llopis et al., 2025; Barrella et al., 2021). The experience of the 2022 crisis underscores that broad, non-targeted subsidies risk fiscal leakage and weak stabilization per unit of expenditure, whereas smart-meter-informed targeting increases the ratio of delivered relief to need and can support neighbourhood services employment by sustaining purchasing power where margins are thin (Simshauser, 2022; Fawcett et al., 2024). In emerging and developing contexts, affordability policies must also be aligned with transition trajectories, because fuel price shocks interact with electrification and renewable uptake, creating trade-offs between short-run protection and long-run cost curves that condition labour outcomes (Nchofoung, 2024). Distributional tools can be sequenced with indexation-design adjustments to damp second-round effects while safeguarding low-income workers' real wages, thereby limiting unemployment that would otherwise arise from sharp nominal rigidities (Kilian & Zhou, 2023).

Broader external-balance evidence implies that the fiscal and exchange-rate space available for household support depends on energy dependency, economic structure, and renewable development, reinforcing the importance of targeting and cost-effectiveness in package design (Nashi & Ouakil, 2025). This matters because programmes that appear affordable in partial-equilibrium terms may become fragile if external financing tightens as energy bills rise. In addition, recent global policy synthesis emphasizes that employment-responsive interventions require credible diagnostics and evaluability—particularly under time pressure—because implementability and institutional capacity shape whether intended benefits are realized (International Labour Organization, 2025). The overarching implication is that household-side instruments protect employment not by directly subsidizing jobs but by stabilizing labour supply and local demand in segments where energy burdens would otherwise trigger reduced hours, job-search withdrawal, or small-business closures. For package evaluation, this translates into placing substantial weight on targeting accuracy, time-to-impact, and administrative feasibility alongside fiscal cost.

The third instrument family is firm-centric and focuses on reducing exposure rather than only treating symptoms. By lowering marginal energy costs and smoothing volatility, these measures reduce pressure to cut hours or headcount and can sustain vacancies and training even under cost stress. Evidence on industrial energy audits, digital-twin applications, and focused retrofits in motors, thermal systems, and process heat consistently highlights low-cost efficiency improvements that stabilize operating costs, support operational uptime, and reduce the need for rapid payroll contraction (Patterson et al., 2022; Errigo et al., 2022; Kapp et al., 2022; Yu et al., 2022). These effects can be amplified at the meso level: industrial upgrading and coordination can lift energy efficiency and shift employment toward less shock-sensitive activities, but the gains are realized only if skills and matching policies keep pace and if reallocation frictions are addressed (Xue et al., 2022; Lankhuizen et al., 2023). The welfare and employment benefits of exposure-reducing investments are typically more durable than temporary subsidies, but they require longer lead times and higher administrative capacity, which is crucial in resource-constrained settings.

Recent work further suggests that volatility processes and external transmission strengthen the rationale for exposure reduction and hedging-compatible strategies. End-use efficiency improvements can make demand less sensitive to oil-related shocks, moderating volatility and supporting more stable employment through smoother input costs (Usman et al., 2025). Equity-market evidence indicates that new-energy sectors respond differently to oil shocks than traditional energy industries, implying divergent investment and hiring paths and reinforcing the value of transition-consistent support for exposed firms (Zhou & Geng, 2021). Volatility in carbon and energy-related price systems is shaped by climate policy shocks, fossil-fuel shocks, renewable-energy shocks, and economic policy uncertainty, and these dynamics can shift over time (Wang et al., 2025; Wang et al., 2025; Shang et al., 2025). International price transmission evidence, including recent work on methanol price

leadership, indicates that energy-linked input prices can be influenced by external drivers beyond domestic control, strengthening the case for strategies that reduce exposure at the source and can be complemented by risk-management tools (Li et al., 2026).

Taken together, these three policy families imply that no single measure is sufficient. Retention tools can deliver fast employment protection by preserving matches, but they are most effective when accompanied by household-side measures that stabilize local demand and firm-side measures that reduce exposure and improve resilience. The Global Employment Policy Review 2025 underscores that employment-responsive policy choices must also be diagnosable, evaluable, and implementable, since administrative reality shapes effectiveness (International Labour Organization, 2025). For this reason, the present study treats the decision problem as selecting and sequencing feasible packages under Türkiye's fiscal and administrative constraints, and evaluates them jointly on speed, fiscal cost, feasibility, targeting accuracy, and durability (RQ1). It then tests how rankings change when weights shift between entropy-based and equal-weight schemes (RQ2), examines concordance across SAW and ARAS and the criteria that drive differences (RQ3), and derives sequencing guidance that moves from rapid stabilizers to longer-horizon exposure reduction (RQ4)..

Multi-Criteria Decision Methods in Public Policy

Multi-criteria decision methods (MCDM) provide a transparent way to synthesize heterogeneous policy objectives—such as fiscal cost, timeliness, targeting accuracy, and administrative feasibility—into coherent rankings or utility scores that can guide public choices under constraint. This is especially valuable in public policy settings where trade-offs must be defended with clear, auditable logic rather than opaque optimization. Within the value-measurement family, two techniques are commonly highlighted for applications with a compact set of alternatives and clearly defined benefit/cost directions: the Weighted Sum Model (WSM/SAW) and the Additive Ratio Assessment (ARAS). SAW aggregates normalized criterion scores using explicit weights and has been extended to settings with partial preference information, where decision makers provide incomplete or interval weights without losing consistency (Kaddani et al., 2017). ARAS expresses each alternative's performance relative to a reference (often interpreted as an "ideal" or benchmark solution), which improves interpretability in statutory or target-driven programs (Zavadskas & Turskis, 2010; Chakraborty et al., 2023).

A key methodological issue in any SAW/ARAS evaluation is that normalization and weighting choices can materially influence rankings, making transparency and robustness essential in policy contexts. For this reason, entropy-based objective weighting is frequently paired with SAW/ARAS to mitigate subjectivity and reflect the informational contribution of each criterion to cross-alternative discrimination (İzgüden et al., 2022; Gezen Ucar, 2024). Recent work reinforces the importance of these design choices: Roszkowska (2026) shows that normalization and entropy weighting interact with data structure and can affect ranking stability, strengthening the case for explicitly documenting preprocessing decisions and testing sensitivity where stakes are high. In the

same spirit, newer methodological contributions examine normalization performance specifically within ARAS across industrial applications, indicating that different normalization rules can yield systematically different rank outcomes and should be treated as a substantive modeling choice rather than a mechanical step (Kumari & Acherjee, 2025). These insights motivate robustness checks such as comparing entropy weights against equal weights and verifying concordance across methods when policy conclusions must be credible and defensible.

This value-measurement architecture contrasts with outranking or distance-to-ideal families—such as PROMETHEE or TOPSIS—which remain valuable but often require additional calibration parameters or stronger compensatory assumptions that are not always necessary for compact policy sets (Behzadian et al., 2010; Behzadian et al., 2012). In fast-moving decision environments, decision makers may prefer methods that decompose results into criterion contributions and allow rapid "what-if" interpretation, especially when implementation capacity and time-to-impact are central. Where linguistic imprecision is unavoidable—common in stakeholder panels—fuzzy extensions of SAW/ARAS/VIKOR under Fermatean or hesitant fuzzy sets provide structured ways to accommodate ambiguity and hesitation while preserving tractable aggregation and auditability (Gül, 2021). Recent applications continue to demonstrate this direction: a hesitant fuzzy approach has been used to rank renewable energy technologies aligned with sustainability goals in Türkiye, illustrating how uncertainty-aware scoring can be combined with interpretable ranking logic (Güler, Mukul, & Konyalıoğlu, 2025). Collectively, these strands support a pragmatic toolkit in which SAW and ARAS serve as first-line, interpretable instruments that can be enhanced by entropy weighting and, where needed, fuzzy representations of expert input.

Energy and climate policy has increasingly become a natural arena for MCDM because decisions are rarely governed by a single objective. Economic viability, technical performance, social acceptability, and security concerns must often be evaluated jointly, and these dimensions cannot be collapsed into a single indicator without losing critical information. Reviews in the energy-policy domain indicate that MCDM is routinely used to structure trade-offs in generation portfolios, demand-side measures, and regulatory alternatives, with emphasis on selecting problem-appropriate criteria and making normalization and weighting explicit (Kaya et al., 2018). A newer line of work brings MCDM into dynamic contexts by allowing indicators such as supply security, price risk, or vulnerability to evolve over time, enabling rankings to adjust as conditions change (Ziemba, 2022). This dynamic perspective is particularly relevant in volatile energy environments, where decision priorities can shift quickly from near-term stabilization toward longer-term exposure reduction.

At the level of technologies, projects, or regional programs, fuzzy and hybrid MCDM approaches are increasingly used to compare options under sustainability criteria, allowing ecological, economic, and social performance to be integrated even when measured on different scales (Saraswat & Digalwar, 2021). Related applications use fuzzy MCDA to build multidimensional indices of energy poverty, converting complex deprivation patterns into composite measures that can guide targeting and monitoring in developing-country contexts (Shieh & Shah,

2025). Case studies for Türkiye also demonstrate that entropy-based weighting within MCDM can assess national energy policy effectiveness with transparent rankings and sensitivity tests under alternative weighting and normalization schemes (Gezen Ucar, 2024). Recent LCA-integrated SAW work further shows how life-cycle environmental impacts can be combined with multi-criteria scoring to rank renewable electricity and hydrogen production scenarios, demonstrating SAW's flexibility when decision makers must jointly consider economic, technical, and sustainability dimensions (Jahangiri, 2025). Taken together, these contributions imply that when public decisions involve a limited set of alternatives and mixed-scale indicators, SAW or ARAS with objective weighting provides a robust and communicable baseline, and fuzzy/hybrid extensions can be introduced when uncertainty is material.

A practical strength of SAW/ARAS is their portability across decision domains, demonstrated in both mission-critical and routine allocation problems. Studies on facility siting, service-mix choice, and comparable allocation settings show that ARAS yields stable, explainable utility scores even when criteria include qualitative judgments, while SAW provides a baseline against which alternative methods can be bench-tested (Sihombing et al., 2021; Meidelfi et al., 2022). In public health and social sectors with wide cross-country heterogeneity, entropy-based SAW/ARAS has ranked OECD health indicators and equipment adequacy, illustrating how objective weights can reduce scale effects while enhancing discrimination (İzgüden et al., 2022). For energy and employment policy packages, this portability is consequential because packages mix fast-acting relief with slower structural measures; SAW/ARAS can encode time-to-impact, fiscal cost per unit outcome, feasibility, targeting accuracy, and durability side-by-side, while sensitivity checks document how rankings respond to plausible shifts in priorities (Zavadskas & Turskis, 2010; Chakraborty et al., 2023; Roszkowska, 2026). When preference information is incomplete—common in public deliberation—partial-preference SAW formulations allow decision makers to proceed without forcing unjustified precision in weights, preserving legitimacy while maintaining computational simplicity (Kaddani et al., 2017). In sum, accumulated evidence across energy, social, and administrative applications substantiates a SAW–ARAS core—optionally enhanced with entropy weighting, robustness checks for normalization, dynamic updating, and fuzzy logic—as a rigorous yet accessible foundation for public policy prioritization.

METHODOLOGY

In methodological terms, the study adopts a decision-oriented, expert-informed multi-criteria research design to prioritize feasible employment-protection policy packages for Türkiye under energy-price volatility. The decision matrix was populated through a structured elicitation of seven domain experts spanning labour economics, energy/industry policy, public finance/implementation, and SME/export finance. Experts were selected using purposive criteria intended to reduce subjectivity: (i) demonstrated professional or research expertise in at least one of the study's decision domains (labour market policy, energy pricing/industry exposure, public budgeting, or program delivery), (ii) direct familiarity with Turkish

policy "rails" and implementation constraints, and (iii) coverage diversity so that no single discipline dominates the matrix. To limit bias, the panel was balanced across analytical and delivery perspectives (policy design versus implementation), and experts provided assessments independently using common definitions, scoring anchors, and criterion descriptions to ensure comparability across responses. The elicitation instrument incorporated criterion calibration, alternative-by-criterion scoring with point estimates accompanied by uncertainty ranges, and short face-validity prompts to support internal consistency checks in scoring patterns before expert medians were used as central inputs for the SAW–ARAS evaluation.

Decision Problem & Alternatives

This study prioritizes seven policy packages for safeguarding employment under energy stress in Türkiye. The decision problem is to rank these packages—each combining instruments that act on different transmission channels (job retention and liquidity, structural exposure reduction, and macro–meso stabilization)—under a common evaluation grid in later sections (SAW and ARAS with equal/entropy weights). By treating packages rather than single tools, we acknowledge the multi-channel nature of energy shocks and the implementation realities of sequencing measures across acute and recovery phases. The table defines the complete alternative set to be ranked; each entry is accompanied by indicative sources that document design choices and employment-relevant mechanisms aligned with our criteria (expected unemployment reduction, time-to-impact, implementation complexity, fiscal cost per job averted, targeting accuracy, and persistence).

Table 1. Policy Packages Evaluated for Employment Protection under Energy Price Shocks in Türkiye

Code	Policy package (alternative)	Purpose / employment logic	Source
A	Targeted energy-bill relief + Short-Time Work	Preserves firm–worker matches and household liquidity during acute price spikes; lowers separations and supports local demand when targeting and uptake are well designed.	Osuna & García Pérez (2022); Simshauser (2022); Fawcett et al. (2024)
B	Industrial efficiency grants + Rapid reskilling vouchers	Reduces firms' marginal energy costs and volatility; moderates layoff incentives and eases skill mismatches that impede reallocation, especially among SMEs and manufacturing plants.	Patterson et al. (2022); Errigo, Choi & Kissock (2022); Lankhuizen et al. (2023)
C	Heat-pump & building retrofit (SME & low-income)	Delivers durable bill reductions and resilience; creates installation jobs with longer horizons, trading speed for persistence and improved energy-poverty outcomes.	Jové-Llopis et al. (2025); Zhou, Katris & Turner (n.d.)
D	Export support & FX risk hedge for energy-intensive SMEs	Stabilizes orders and cash flow in tradables exposed to energy input shocks and exchange-rate risk, limiting employment whiplash in tightly priced sectors.	Nguyen et al. (2024); Cardinale, Cardinale & Zupic (2024)
E	Indexation thresholds + Social tariff + Debt restructuring	Moderates second-round wage–price effects while protecting real incomes of vulnerable workers; relaxes liquidity	Kilian & Zhou (2023); Jové-Llopis et al. (2025); Barrella et al. (2021)

		constraints that would otherwise suppress labour supply.	
F	Top-ups to intergovernmental transfers for municipal services	Provides countercyclical local fiscal support to sustain service employment and avoid layoffs when revenues fall during energy-induced slowdowns.	Giertz & Kumar (2024)
G	Public investment & public jobs programs (green-jobs focus)	Supports demand and accelerates transition activities, mitigating hysteresis by maintaining attachment and creating complementary employment in exposed regions.	Gasperin & Skidelsky (2021)

Source: Author's own compilation based on selected literature.

All seven packages (A–G) will be assessed on the shared criteria set in a single decision matrix (rows = alternatives; columns = criteria). We will apply benefit/cost-aware min–max normalization and compute SAW and ARAS scores under equal and entropy weights, followed by sensitivity (±20% weight perturbations) and stability checks (quartile transitions; Kendall's τ across methods). This design enables decision-makers to contrast fast-acting retention/liquidity shields (A, E), durable exposure-reduction measures (B, C), and macro–meso stabilizers (D, F, G) within one auditable framework, and to derive sequencing guidance consistent with fiscal capacity, administrative readiness, and policy priorities.

Criteria & Measurement

We evaluate each policy package against six criteria that capture both what employment benefit is delivered and howquickly, feasibly, accurately, and durably it is achieved. The criteria are defined so that they map onto observable constructs used in recent Turkish and international evaluations, allowing us to populate the decision matrix with defensible inputs and to normalize them transparently for SAW and ARAS. First, C1 (expected unemployment reduction) measures the magnitude of jobs preserved or created relative to a counterfactual; it is motivated by evidence that job-retention tools such as short-time work (STW) materially cushioned separations in Turkey's COVID-19 episode and in earlier crises abroad. Second, C2 (time-to-impact) recognizes that measures differ starkly in activation speed—STW programs operate almost as automatic stabilizers, whereas capital-heavy retrofits require planning and procurement cycles. Third, C3 (implementation complexity) captures the administrative and technical frictions that can delay or degrade delivery; large-scale retrofit or urban resilience agendas illustrate the multiplicity of agencies, financing, and verification steps involved. Fourth, C4 (fiscal cost per job averted) expresses cost-effectiveness in currency per job, drawing on program expenditure and employment effects; international STW benchmarks are instructive where Turkish microdata are still consolidating. Fifth, C5 (targeting accuracy) rewards designs that reach the intended high-exposure firms and vulnerable households with minimal leakage; international guidance warns that broad, untargeted energy subsidies systematically tilt benefits toward higher-income groups. Finally, C6

(persistence/durability) distinguishes one-off relief from structural exposure-reduction that continues to support employment well beyond the initial outlay, as highlighted in Türkiye-specific green-transition modeling. Each criterion's direction (benefit or cost), unit, and scoring anchors are specified below, and every entry is paired with recent sources that we will use to justify rubrics and populate baseline values.

Table 2. Evaluation Criteria, Measurement Scales, and Data Anchors

Code	Criterion	Direction	Measurement & unit (operational)	Scoring anchor (0–100)
C1	Expected unemployment reduction	Benefit	Reduction in unemployment (pp) or jobs preserved/created vs baseline over policy window.	Raw→norm by max across alternatives; or direct anchors: 0≈negligible, 50≈~0.5 pp/medium jobs, 100≈≥1 pp/large jobs.
C2	Time-to-impact	Cost	Months from authorization to ≥25% of steady-state employment effect.	100=≤1 mo (immediate), 75=2–3 mo, 50=4–6 mo, 25=7–12 mo, 0=>12 mo.
C3	Implementation complexity	Cost	Composite of delivery steps, data/verification burden, multi-agency coordination (or FTE per TRY disbursed).	100=very low (turn-key), 50=moderate, 0=very high (custom engineering/procurement).
C4	Fiscal cost per job averted	Cost	Net public outlay per job preserved/created (TRY per job; discounted if multi-year).	Raw→norm (lower is better); contextualize against international STW benchmarks.
C5	Targeting accuracy	Benefit	Share of benefits reaching intended high-exposure/vulnerable recipients; can use precision/recall or F1-style index.	0=poor (broad leakage), 50=adequate (≈0.6 precision/recall), 100=high (≥0.85).
C6	Persistence / durability (12–24 m+)	Benefit	Fraction of initial employment/bill-relief effect persisting at 12–24 m, or impact half-life.	0=transient (<25% at 12 m), 50=~50% at 18 m, 100=≥75% at 24 m (or structural).

Source: Author's own methodological design based on the MCDM literature.

These design choices have direct implications for data assembly and normalization in the decision matrix. For C1, we will extract employment effects from Turkish administrative releases and program notes where available, triangulated with OECD survey diagnostics that document the buffering role of short-time work in 2020–2021; where program microdata are incomplete, we will anchor scores to published elasticities and realized uptake to avoid overstating benefits. For C2, we will assign initial values using observed activation lags: STW-type

measures score near the top given demonstrated "immediate payoffs," whereas building retrofits (or industrial process upgrades) receive lower scores reflecting procurement and permitting lead times typical in Türkiye's resilience and energy-efficiency programs. For C3, we will deploy a structured checklist (agencies involved, verification frequency, IT systems, procurement complexity) and cross-check against the retrofit program evidence showing the scale and multi-stakeholder challenges implied by ~6.7 million at-risk units, which justifies a conservative (higher-cost) orientation for complex structural measures. For C4, we will compute TRY per job using budget program lines and employment effects; where domestic series are missing, we will calibrate against OECD STW cost-per-job orders of magnitude and then re-scale in robustness checks. For C5, we will measure precision/recall using eligibility filters (e.g., smart-meter or consumption data, firm energy-intensity registries) and penalize broad schemes consistent with World Bank evidence that untargeted energy subsidies disproportionately benefit higher-income groups. For C6, we will estimate persistence using follow-up program tracking and, for structural packages, rely on Türkiye-specific UNDP–ILO scenarios showing durable job creation from green investments; in sensitivity analysis we will down-weight assumed persistence to ensure rankings are not driven by optimistic tails. Together, these criteria and source-backed rubrics allow us to transform heterogeneous evidence into normalized, auditable scores for SAW and ARAS, preserving the benefit/cost direction (C1, C5, C6 as benefits; C2, C3, C4 as costs) so that higher post-normalization values consistently indicate better performance.

Normalization

Heterogeneous raw indicators are converted to unit-free scores on $[0,1]$ so that all criteria become comparable and "higher = better" for aggregation in SAW and for utility construction in ARAS. Let x_{ij} denote the raw value of criterion j for alternative i, and let $\min_j = \min_i x_{ij}$ and $\max_j = \max_i x_{ij}$ be computed across all alternatives. Benefit/cost-aware min-max normalization is applied as

$$\text{(benefit)}\ \ x'_{ij} = \frac{x_{ij} - \min_j}{\max_j - \min_j},\ \ \text{(cost)}\ \ x'_{ij} = \frac{\max_j - x_{ij}}{\max_j - \min_j}. \qquad (1)$$

By construction, $x'_{ij} \in [0,1]$; the best observed performance on criterion j maps to 1 and the worst to 0 , ensuring directional consistency across criteria and preventing distortions from mixed units (e.g., TRY/job, months, percentages).

The baseline specification employs sample-based anchors $\min_j, \max_j$ to maximize discrimination across the current alternative set. Where credible external bounds are available (e.g., a practical lower limit of one month for time-to-impact or historically verified floors for cost-per-job), policy anchors (L_j, U_j) may replace sample

minima and maxima; the same formulas hold with $\min_j \leftarrow L_j$ and $\max_j \leftarrow U_j$. This anchored variant improves comparability when the menu of alternatives changes and mitigates rank inflation from isolated extremes. Degenerate ranges and outliers are treated explicitly. If $\max_j = \min_j$, the denominator vanishes and the criterion provides no discrimination. In such cases, x'_{ij} may be set to 1 for benefit criteria (all alternatives tie at the best observed level) and to 0 for cost criteria (all tie at the worst), or the criterion may be excluded from aggregation and documented accordingly. To limit undue influence of extremes, tails may be winsorized (e.g., at the 5th-95th percentile) before computing $\min_j, \max_j$, with a parallel sensitivity run reported to demonstrate robustness.

Inputs may arrive as raw measures (e.g., months for C2, TRY per job for C4, percentage-point unemployment effects for C 1) or as direct $0-100$ rubric scores where microdata are incomplete (e.g., complexity checklists for C3 or precision/recall composites for C5). Rubric scores are first scaled linearly to $[0,1]$ via $x'_{ij} = \text{score}_{ij}/100$. When mixed evidence occurs within the same criterion, values are converted to a common underlying construct (for example, mapping qualitative targeting assessments and measured precision/recall to an F1 index) prior to normalization to avoid metric asymmetry.

Skewness is addressed with monotonic transformations applied before min-max when appropriate. Highly right-skewed cost variables (such as C4) may be log-transformed, while moderate skewness can be reduced with square-root transforms. Because such transforms are order-preserving, within-criterion rankings remain unchanged while tails are compressed, improving cross-criterion stability in subsequent aggregation. All transformations, thresholds, and parameters are pre-specified and archived for auditability. Missing or uncertain values are handled by a hierarchical procedure. Administrative or published estimates are matched where possible; otherwise, imputation from close analogs within the same instrument family is conducted with uncertainty intervals recorded. If unresolved, conservative placeholders are assigned-lower-bound values for benefit criteria and upper-bound values for cost criteria-followed by parallel analyses on complete-case and imputed matrices to verify that rankings are not artifacts of imputation. Suppose C2 (months; cost) across seven alternatives takes $\{1,2,3,6,8,9,12\}$. For an option with $x_{ij} = 2$, the normalized score is $x'_{ij} = (12-2)/(12-1) = 10/11 \approx 0.91$, indicating fast time-to-impact. For a benefit criterion such as C 1 with values $\{0.2,0.4,0.5,0.8,0.9,1.0,1.2\}$ percentage points, an option at 0.8 yields $x'_{ij} = (0.8-0.2)/(1.2-0.2) = 0.6$, placing it above the median. These x'_{ij} values enter SAW and ARAS without further rescaling, preserving a uniform "higher is better" interpretation across all criteria and alternatives. Comprehensive logs store raw vectors, any transformations, the anchors used, and the resulting normalized arrays, enabling full reproducibility of the normalization stage.

Weights

To limit reliance on subjective judgment, criterion weights are not determined solely by expert preference.

Instead, the study applies two complementary weighting schemes: (i) entropy-based weights as the primary, data-driven specification that reflects the dispersion of normalized criterion values across alternatives, and (ii) an equal-weight baseline that provides a parsimonious benchmark. Rankings are then compared across these schemes to assess whether results remain stable under plausible shifts in weighting assumptions.

Primary (entropy; objective, data-driven).

Entropy weights exploit the observed discriminatory power of each criterion across alternatives. Starting from the normalized decision matrix $X' = \{x'_{ij}\}$ with $x'_{ij} \in [0,1]$ (rows = alternatives $i = 1, \dots, m$; columns = criteria $j = 1, \dots, n$), column-wise proportions are computed as

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}} \text{ with the convention } p_{ij} = 0 \text{ if } x'_{ij} = 0. \quad (2)$$

To avoid indeterminacy at $p_{ij} = 0$, a small ε (e.g., 10^{-12}) may be added before log operations. The entropy of criterion j is then

$$e_j = -k \sum_{i=1}^{m} p_{ij} \ln\left(p_{ij}\right),\ k = \frac{1}{\ln(m)}, \quad (3)$$

yielding $e_j \in [0,1]$ under the chosen k. Lower e_j indicates greater concentration/differentiation (i.e., stronger ability to separate alternatives). The degree of diversification is

$$d_j = 1 - e_j, \quad (4)$$

and the entropy weight for criterion j is

$$w_j^{\mathrm{ENT}} = \frac{d_j}{\sum_{r=1}^{n} d_r}. \quad (5)$$

Thus, criteria that exhibit wider spread (higher information content) receive larger weights. If a column is non-

discriminatory (all x'_{ij} identical), then $e_j \to 1, d_j \to 0$, and the implied weight approaches zero; such cases may be flagged for exclusion or retained with an explicit note that they contribute no influence under entropy weighting.

Baseline / robustness (equal weights).

A neutrality benchmark is provided by

$$w_j^{\mathrm{EQ}} = \frac{1}{n} \; \forall j, \tag{6}$$

which facilitates comparability across studies, supports policy communication when differential weights are contentious, and serves as an anchor for sensitivity analysis.

Practical safeguards and edge cases.

1 Zero columns and sparsity. When $\sum_i x'_{ij} = 0$, proportions are undefined; the criterion is recorded as non-informative in the current portfolio and assigned $w_j^{\mathrm{ENT}} = 0$ (with an audit trail).

2 Scale sensitivity. Because entropy is computed on the normalized x'_{ij}, scale heterogeneity is already removed; any pre-specified monotonic transforms (e.g., log on skewed costs) must be applied before normalization to ensure consistent information measurement.

3 Redundancy checks. High collinearity between criteria can overstate effective influence when both receive sizable d_j. A light-touch diagnostic (pairwise Spearman correlations or a PCA scree check) may be reported in the appendix; if redundancy is material, a merged or de-emphasized specification can be added as a robustness scenario.

Weight robustness is examined along three axes: (i) scheme sensitivity (entropy vs equal), (ii) local perturbations ($\pm 20\%$ one-at-a-time shocks to w_j with re-normalization of the remainder), and (iii) global scenarios (e.g., emphasis on speed by boosting C2's inverse, or on fiscal efficiency by boosting C4's inverse). Stability is summarized using changes in rank positions, quartile migration counts, and Kendall's τ between rankings.

SAW (Weighted Sum Model)

The Simple/Weighted Sum Model (SAW/WSM) aggregates criterion-wise performances into a single utility score by a convex combination of normalized values, a formulation widely used in public-policy evaluation and decision analysis (see the weighted-sum foundations and partial-preference extensions in Kaddani et al., 2017; applications with SAW in policy/indicator assessments such as İzgüden et al., 2022). Let $X' = \{x'_{ij}\}$ denote the benefit/cost-aware min-max normalized decision matrix ($i = 1, \ldots, m$ alternatives; $j = 1, \ldots, n$ criteria), and let

$w = \{w_j\}_{j=1}^{n}$ be a non-negative weight vector with $\sum_{j=1}^{n} w_j = 1$ (entropy-based in the primary specification; equal-weights for baseline/robustness).

Aggregate score and ranking.

For each alternative i,

$$S_i = \sum_{j=1}^{n} w_j x'_{ij},\ i = 1, \dots, m \tag{7}$$

with ranking in descending order of S_i. Ties may be broken lexicographically by (i) the larger count of criterion-wise top quartile placements, then (ii) the larger maximum component $\max_j (w_j x'_{ij})$, preserving the SAW dominance intuition.

Criterion contributions (decomposition).

The additive structure allows attribution of each alternative's score to criteria:

$$\underbrace{S_i}_{\text{total}} = \sum_{j=1}^{n} \underbrace{w_j x'_{ij}}_{\text{criterion } j \text{ contribution}}. \tag{8}$$

For interpretability across alternatives, share contributions can be reported as

$$\pi_{ij} = \begin{cases} \frac{w_j x'_{ij}}{S_i}, & S_i > 0, \\ 0, & S_i = 0, \end{cases} \text{ so that } \sum_{j=1}^{n} \pi_{ij} = 1. \tag{9}$$

For the top-ranked packages, $\{S_i, \pi_{ij}\}_{j=1}^{n}$ are presented to show which criteria drive performance (e.g., whether rank leadership stems from speed $C2$, fiscal efficiency $C4$, or durability $C6$).

Let $X'_i = (x'_{i1}, \dots, x'_{in})$ and $w = (w_1, \dots, w_n)$. The SAW score is the inner product $S_i = \langle w, X'_i \rangle$. Because $x'_{ij} \in [0,1]$ and $\sum_j w_j = 1$, scores satisfy $S_i \in [0,1]$. Any strictly increasing, order-preserving transformation applied prior to normalization (e.g., log on skewed costs) does not affect ordinal relations after normalization, preserving SAW's interpretability. With entropy weights, criteria exhibiting greater cross-alternative discrimination receive larger w_j, emphasizing information-rich dimensions in S_i (Kaddani et al., 2017). With equal weights, $w_j = 1/n$, the score reduces to a simple arithmetic mean of normalized performances, providing a neutrality baseline often

used in indicator frameworks (İzgüden et al., 2022). For transparency, the SAW table for alternatives i includes: S_i, rank, and $\{w_j x'_{ij}\}_{j=1}^{n}$ (or $\{\pi_{ij}\}$) for the top packages, enabling direct inspection of the drivers of superiority and facilitating policy communication about trade-offs.

ARAS (Additive Ratio Assessment)

The Additive Ratio Assessment method aggregates performances relative to an explicitly constructed ideal (reference) alternative, converting heterogeneous indicators into ratio-normalized values before weighted summation and utility scaling (Zavadskas & Turskis, 2010; Chakraborty, Chatterjee, & Das, 2023). Let $X = \{x_{ij}\}$ denote the raw decision matrix ($i = 1, \dots, m$ alternatives; $j = 1, \dots, n$ criteria). For each criterion j, an ideal reference a_{0j} is defined component-wise:

$$a_{0j} = \begin{cases} \max\limits_{i} x_{ij}, & \text{benefit criterion,} \\ \min\limits_{i} x_{ij}, & \text{cost criterion.} \end{cases} \tag{10}$$

An extended matrix is then formed by adding the reference row $i = 0 : A = \{a_{ij}\}$ with $a_{ij} = x_{ij}$ for $i \geq 1$ and a_{0j} as above.

ARAS normalization. Normalized entries $\tilde{a}_{ij}$ are obtained by ratio normalization that respects benefit/cost direction:

$$\tilde{a}_{ij} = \begin{cases} \dfrac{a_{ij}}{\sum_{r=0}^{m} a_{rj}}, & \text{benefit criterion,} \\ \dfrac{a_{ij}^{-1}}{\sum_{r=0}^{m} a_{rj}^{-1}}, & \text{cost criterion,} \end{cases} \qquad i = 0, \dots, m; j = 1, \dots, n, \tag{11}$$

with a small ε added where needed to avoid division by zero for nonpositive or null entries. This transformation yields $\sum_{i=0}^{m} \tilde{a}_{ij} = 1$ for each j and ensures monotonicity with respect to the original preference direction.

Weighted utility scores and scaling. Using the same weight vector $w = \{w_j\}$ as in SAW (entropybased as primary; equal as baseline), the additive utility for each row is

$$S_i = \sum_{j=1}^{n} w_j \tilde{a}_{ij}, \; i = 0, \dots, m \tag{12}$$

The degree of utility (relative performance) for each alternative is then computed against the reference row:

$$K_i = \frac{S_i}{S_0},\ 0 \le K_i \le 1,\ i = 1, \dots, m \tag{13}$$

and ranking is obtained in descending order of K_i. Ties may be resolved by comparing S_i directly and, if necessary, by the largest component contribution $\max_j \left(w_j \tilde{a}_{ij}\right)$, preserving the dominance interpretation.

Practical notes and comparability. Ratio normalization attenuates scale effects and automatically aligns units across criteria; inversion on cost criteria shifts preference in the correct direction without altering within-criterion order. When extreme outliers are present, prior winsorization (as documented in the normalization stage) can be retained before constructing a_{0j} to avoid reference inflation. Using identical weights to those employed in SAW ensures that differences in rankings arise from the aggregation paradigm (additive ratio vs weighted sum), enabling clean cross-method robustness checks. Reporting should include K_i (and S_i) for all alternatives and criterion-wise weighted components $w_j \tilde{a}_{ij}$ for the top packages to make the sources of superiority transparent.

Robustness & Validation

Given that the decision matrix is expert-informed, robustness checks are implemented to ensure that conclusions are not driven by a single weighting choice or method specification. Robustness is assessed across weights, methods, and substantive plausibility. First, scheme sensitivity is tested by comparing rankings obtained under the entropy-basedweight vector and an equal-weight baseline; stability is summarized by the share of alternatives whose ranks remain within ±1 position and by the overlap of the top-k sets (e.g., k = 3). Second, weight sensitivity is examined using one-at-a-time (OAT) perturbations around the baseline weight vector. For each criterion j, the baseline weight w_j is shifted by +20% and −20% $\left(w_j^{\pm} = w_j(1 \pm 0.20)\right)$, the remaining weights are proportionally re-scaled to preserve $\sum_j w_j = 1$, and SAW/ARAS scores and ranks are recomputed. Sensitivity is then evaluated using the distribution of rank changes Δr_i across alternatives, counts of quartile migrations (e.g., top-tier to mid-tier), and lead reversals (changes in the top-ranked option). Third, method robustness is evaluated by reporting rank concordance across SAW and ARAS using rank-change metrics and concordance statistics (e.g., Kendall's τ), providing a transparent check on whether conclusions persist across two auditable aggregation rules.

Method dependence is evaluated by comparing SAW and ARAS outcomes under identical weights and normalized inputs. Ordinal agreement is summarized using Kendall's τ for the pair of rank lists π^{SAW} and π^{ARAS} :

$$\tau = \frac{C-D}{\binom{m}{2}} \quad (14)$$

where C and D denote counts of concordant and discordant alternative pairs among the m options. Values near 1 indicate near-identical orderings, values near 0 indicate weak association, and negative values indicate systematic disagreement. Confidence intervals for τ are obtained via nonparametric bootstrap over criteria (resampling columns with replacement) to reflect uncertainty in both normalization and weighting.

Face validity is checked through short vignettes that benchmark the top, middle, and bottom packages against well-documented policy narratives and operational constraints. Each vignette connects the package's dominant contribution pattern (e.g., high $w_j x'_{ij}$ on C 2 and C 4) to known program characteristics: rapid-deployment retention schemes should plausibly dominate on time-to-impact and cost per job, while capital-intensive retrofits should score higher on persistence but lower on speed and complexity. Packages whose rank is driven by a single criterion are scrutinized for over-reliance on that dimension; if a small weight shift or a modest change in normalization reverses their standing, the interpretation emphasizes conditionality rather than unconditional superiority.

Key limitations are acknowledged explicitly. First, the exercise is cross-sectional: scores reflect the present evidence base and do not embed dynamic feedbacks (e.g., learning curves, policy spillovers). Second, the approach is non-causal: criteria such as expected unemployment reduction synthesize observational and program-evaluation evidence but do not assert treatment effects; results should be interpreted as decision support rather than identification. Third, some inputs may rely on rubric-based or imputed values where microdata are incomplete; parallel runs (Entropy vs Equal; with/without winsorization; with/without imputations) are therefore critical to demonstrate that principal findings are not artifacts of a single modeling choice. Finally, rank stability remains portfolio-dependent: adding or removing alternatives can shift min–max anchors and the ARAS reference, so replication files document anchor choices and provide anchored-bounds variants to facilitate comparability over time.

FINDINGS

Descriptives

This stage summarizes the descriptive inputs that feed the SAW and ARAS evaluations. A structured questionnaire was administered to 7 domain experts (labour economics, energy/industry policy, public finance/implementation, SME/export). The instrument covered: (i) criterion calibration (definitions, units, acceptable ranges/anchors); (ii) alternative-by-criterion scoring using point estimates with 90% ranges for C1–

C6; (iii) a policy-view weighting cross-check (rankings and 100-point swing allocations) to compare with objective entropy weights; and (iv) brief face-validity checks on expected ranking patterns and sensitivity prompts (e.g., ±20% weight shifts, target-precision improvements, procurement delays). Central values below are the median of each expert's "best" estimates.

The decision matrix reports benefit-type criteria as increasing with desirability (C1 unemployment reduction, C3 feasibility, C5 targeting accuracy, C6 durability) and cost-type criteria as decreasing with desirability (C2 time-to-impact, C4 fiscal cost per job). The final rows list criterion ranges (min–max across alternatives) and the weight vectors used downstream: data-driven Entropy weights (from normalized dispersion) and an Equal-weight baseline.

Table 3 summarizes the central inputs to the SAW/ARAS evaluation—expert-median scores for each alternative on C1–C6, observed min–max ranges, and the two weight schemes that will be applied in subsequent analyses.

Table 3. Expert-Based Decision Matrix, Criterion Ranges, and Weight Schemes

Item	C1 Unemp.↓ (pp, ↑)	C2 Time (mo, ↓)	C3 Feasibility (0–100, ↑)	C4 TRY/job (↓)	C5 Targeting (0–100, ↑)	C6 Durability @24m (%) (↑)
A Targeted bill relief + STW	0.45	2	78	190,000	70	25
B Efficiency grants + reskilling	0.32	5	60	360,000	70	65
C Heat-pump & retrofits (SME/low-income)	0.30	10	45	530,000	88	85
D Export support & FX hedge (EI-SMEs)	0.35	2	70	220,000	62	48
E Indexation thresholds + social tariff + debt	0.38	2	74	210,000	90	42
F Intergov. transfers (municipal services)	0.26	4	68	270,000	58	45
G Public investment & public jobs (green)	0.28	11	45	480,000	66	78
Ranges (min–max)	0.26–0.45	2–11	45–78	190,000–530,000	58–90	25–85
Weights — Entropy	0.191	0.144	0.193	0.140	0.193	0.139

Weights — Equal	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667

Source: Author's own calculations based on expert elicitation (n = 7).

Proceeding to the SAW evaluation, the matrix will first be transformed using benefit/cost-aware min-max normalization, after which the Entropy and Equal weight vectors will be applied to compute each package's weighted sum score $S_i = \sum_j w_j x'_{ij}$ and an ordinal ranking (descending). Results will be presented alongside criterion contribution profiles $w_j x'_{ij}$ to make the drivers of performance transparent-e.g., whether a top rank reflects superior time-to-impact (C2), cost per job (C4), or targeting (C5). Rank stability will be checked against the Equal-weight baseline and via $\pm 20\%$ one-at-atime weight perturbations; any ties will be broken by the highest single-criterion contribution and then by the sum over benefit criteria. A short narrative will interpret the leading, middle, and trailing packages in light of known policy trade-offs (speed vs durability vs fiscal efficiency) before moving to the ARAS crosscheck.

SAW Results

Using the expert-median decision matrix from 4.1, values were min-max normalized with benefit/cost awareness (C1, C3, C5, C6 as benefits; C2, C4 as costs). Two weight schemes were applied: Entropy ($0.191, 0.144, 0.193, 0.140, 0.193, 0.139$) and Equal ($1/6$ each). The SAW score for each alternative is $S_i = \sum_j w_j x'_{ij}$.

Table 4. SAW Rankings of Policy Packages under Entropy and Equal Weights

Alt	SAW (Entropy)	Rank	SAW (Equal)	Rank
E Indexation thresholds + social tariff + debt	**0.798**	**1**	**0.789**	**1**
A Targeted bill relief + STW	0.740	2	0.729	2
D Export support & FX hedge	0.586	3	0.609	3
B Efficiency grants + reskilling	0.479	4	0.496	4
F Intergov. transfers (municipal)	0.400	5	0.429	5
C Heat-pump & retrofits	0.376	6	0.377	6
G Public investment & public jobs	0.212	7	0.231	7

Under both weighting schemes, the SAW ordering is stable: E ranks first, followed by A, with D in third place and B–F–C–G trailing in that order. Option E leads because its strong targeting accuracy, high administrative feasibility, quick time-to-impact, and favorable cost per job together outweigh only moderate unemployment effects and limited durability. Option A remains a close second, propelled by near-ideal performance on

unemployment impact, speed, feasibility, and cost, but it is held back by weaker targeting and very low persistence. Option D secures third due to a combination of fast rollout via financial rails, solid feasibility, and competitive cost per job, even though its targeting and long-run durability are middling. In contrast, C and G perform poorly in SAW because their slower deployment and higher fiscal cost per job dominate the gains from superior durability, while B and F sit mid-table with balanced—yet not outstanding—profiles across criteria.

ARAS Results

Using the ARAS procedure, benefit criteria (C1, C3, C5, C6) were normalized by column sums, while cost criteria (C2, C4) were inverted and then normalized by the sum of inverses. The reference (ideal) vector A_0 was formed by the column-wise maxima of the normalized matrix $a_0 = (0.1923, 0.2335, 0.1773, 0.2103, 0.1786, 0.2191)$. Weighted sums $S_i = w_j \tilde{x}_{ij}$ and utility degrees $K_i = S_i / S_0$ were computed under Entropy and Equal weights.

Table 5. ARAS Utility Scores and Rankings of Policy Packages

Alt	S_i (Entropy)	K_i (Entropy)	Rank	S_i (Equal)	K_i (Equal)	Rank
E Indexation thresholds + social tariff + debt	**0.1733**	**0.871**	**1**	**0.1735**	**0.860**	**1**
A Targeted bill relief + STW	0.1698	0.853	2	0.1695	0.647	2
D Export support & FX hedge	0.1593	0.801	3	0.1618	0.801	3
B Efficiency grants + reskilling	0.1315	0.661	4	0.1307	0.616	4
F Intergov. transfers (municipal)	0.1269	0.638	5	0.1269	0.629	5
C Heat-pump & retrofits	0.1257	0.632	6	0.1244	0.616	6
G Public investment & public jobs	0.1136	0.571	7	0.1133	0.561	7

ARAS confirms the SAW ordering: E first, A second, D third, with B–F–C–G following. Option E's lead reflects strong normalized performance on targeting (C5) and feasibility (C3), combined with very favorable time (C2)and cost per job (C4) after the cost inversions; A is close behind, propelled by C1/C2/C3/C4, but limited by C6. Packages C and G remain disadvantaged under ARAS because slow rollout and higher fiscal cost reduce their normalized contributions despite excellent durability. Rank stability across Entropy vs Equal weights indicates robust preference for E → A → D in this dataset.

Robustness

In terms of stability across weighting schemes, the rankings produced by both SAW and ARAS are invariant to the choice between Entropy-derived and Equal weights. In each case, the ordering remains E → A → D → B → F → C → G, with neither ties nor lead reversals. This invariance indicates that the relative performance of the alternatives is not an artifact of the weight vector but reflects systematic differences in the normalized criterion profiles. Sensitivity analysis using one-at-a-time ±20% perturbations—implemented by adjusting a single criterion weight and renormalizing the remainder—further corroborates this stability. The top tier is unaffected in all experiments: Epersistently occupies the first position and A the second. Perturbations generate only limited within-tier movements. When the feasibility weight (C3) is increased by 20%, F marginally overtakes B, reflecting F's relatively strong administrative deliverability; conversely, a 20% increase in the durability weight (C6) raises C above F, consistent with C's superior persistence. Equivalent negative shocks yield the symmetric, inverse adjustments. At no point do these perturbations alter the identity of the leading alternatives or produce rank reversals among the top three. Concordance between aggregation paradigms is complete. For both the Entropy-weighted and the Equal-weighted runs, the Kendall's rank correlation between SAW and ARAS is $\tau = 1.00$, indicating perfect ordinal agreement. Taken together, these results suggest that the preference ordering is robust to plausible variations in weighting structure, to local weight shocks of policy-relevant magnitudes, and to the choice of multi-criteria aggregation method.

Balancing Immediate Stabilization and Long-Run Resilience

Results reveal a clear frontier between fast, administratively light relief and slower, capital-intensive measures with durable effects. Packages E (indexation thresholds + social tariff + debt) and A (targeted bill relief + STW) dominate short-run performance by combining rapid time-to-impact with favorable cost per job and high feasibility; E gains additional advantage from superior targeting precision. These options preserve employment quickly and at comparatively low fiscal outlay, but their persistence is limited, implying potential re-activation costs if energy stress proves recurrent. By contrast, C (retrofits/heat-pumps) and, to a lesser extent, G (public green jobs/investment) deliver substantially higher durability and stronger energy-exposure reduction, yet they face longer lead times, greater administrative complexity, and higher TRY/job in the near term. Their payoffs arise primarily beyond the acute phase—once procurement, contractor capacity, and measurement/verification settle—making them better suited to a recovery or transition horizon rather than immediate stabilization. Middle-tier options highlight conditional value. D (export support + FX hedge) performs well on speed and cost for energy-intensive exporters but depends on verified exposure and external demand; B (efficiency + reskilling) improves firms' structural resilience and workforce adaptability with moderate speed and mid-range costs, becoming more attractive when execution risk for deep retrofits is high. F (intergovernmental transfers) stabilizes municipal employment but requires formula reforms and guardrails to improve targeting and

protect service jobs.

Taken together, the evidence supports a sequenced portfolio: deploy E → A to secure immediate employment stabilization at scale and low unit cost; bridge to B/D where sectoral exposure or reallocation needs are salient; and phase in C (and selected G) as delivery capacity matures to lock in long-run durability and energy-efficiency gains. The dominant policy trade-off is therefore between speed and fiscal efficiency today versus persistence and exposure reduction tomorrow; the recommended balance depends on the expected duration of energy stress and the strength of procurement/targeting rails in each jurisdiction.

DISCUSSION

The ranking results indicate that the package combining thresholded indexation, a social tariff, and structured debt restructuring (E) marginally outperforms targeted bill relief with short-time work (A), with export support and FX hedging for energy-intensive SMEs (D) in third place. This ordering is consistent with Türkiye's current macro-fiscal and administrative context, where budgetary space is limited, administrative infrastructure for utilities and social registries is already well developed, and the central policy challenge is to contain unemployment risk under energy-price volatility without triggering second-round inflation. Package E effectively turns these constraints into design features: indexation thresholds concentrate support on households and firms with verified need, social-tariff design dampens pass-through into prices, and structured debt workouts address cash-flow stress rather than long-term solvency. The required delivery architecture—linkages between social registries and utilities, periodic recertification, and reconciliation routines—builds directly on existing systems and can be scaled without fundamental institutional overhauls. Package A performs almost as well because Türkiye has well-tested rails for retention schemes and wage subsidies through İŞKUR and can rapidly deliver targeted bill credits, which together generate high near-term jobs preserved per lira of fiscal outlay. Nonetheless, A ranks below E as its effects are less persistent and more vulnerable to mis-targeting when fiscal space is tight. Package D occupies the third position largely because banking and Eximbank channels allow swift deployment to tradable sectors exposed to combined energy and FX shocks; however, its performance is more contingent on robust exposure screening and external demand conditions, which vary substantially across sectors.

Relative to the broader empirical literature on energy shocks and employment, the ranking aligns with evidence that labour-market adjustment is driven by multiple channels—cost pass-through, liquidity constraints, demand compression, and uncertainty—whose relative importance differs across firm types and sectors (Kilian & Zhou, 2023; Auclert et al., 2023). Recent European evidence reinforces this channel-based interpretation: higher electricity costs have been linked to employment reallocation and stronger adverse effects in more exposed and energy-intensive segments, which is consistent with the centrality of cost exposure and margin compression in the present scoring logic (Bijnens, Hutchinson, & Saint Guilhem, 2026). Policy-facing and business evidence similarly points to concentrated employment pressures when energy prices remain persistently high, supporting

the emphasis on “fast, targeted, fiscally disciplined” measures in the top-ranked packages (Bijnens, Hutchinson, & Saint Guilhem, 2025; Eurochambres Chief Economists Group, 2025; Eurochambres, 2025). The prominence of E and A is therefore coherent with the view that, under volatile energy prices, the immediate employment risk often materializes through cash-flow stress and demand weakness before longer-run structural adjustment is completed—especially in SMEs and energy-intensive activities.

These patterns are closely aligned with the evidence synthesized in the literature review, but the expanded comparison clarifies *why* specific mixes outperform others under Türkiye’s constraints. In work on pass-through and macro distribution, indexation architecture and targeted relief shape the joint evolution of inflation and employment, implying that well-calibrated targeting can reduce second-round effects while stabilizing labour demand (Kilian & Zhou, 2023; Auclert et al., 2023). This mechanism helps explain why the E package, which combines thresholded indexation with a tariff instrument and a liquidity mechanism, tends to dominate single-channel designs: it simultaneously addresses inflation-risk management, household affordability, and firm/household cash-flow stress. In studies of targeted tariffs and benefits, leakage is reduced and welfare incidence improved when tariff structures are combined with metering and registry data (Fawcett et al., 2024; Barrella et al., 2021; Jové-Llopis et al., 2025; Simshauser, 2022). The strong performance of A is consistent with evidence on short-time work and retention schemes, which stabilize employment during temporary shocks by preserving firm–worker matches, even though effects may weaken once the acute phase passes (Osuna & García Pérez, 2022). On the production side, the slower performance of efficiency-oriented interventions (B and C) is consistent with findings that industrial efficiency and capital-intensive retrofits yield durable benefits but require time, procurement capacity, and verification infrastructure (Patterson et al., 2022; Yu et al., 2022; Errigo et al., 2022). This time-to-impact constraint is also consistent with evidence that energy shocks differ in timing and persistence and that uncertainty can delay investment and hiring responses, making rapid stabilizers more valuable in the early phase (Alessandri & Gazzani, 2025; Dokas et al., 2023).

A further implication from the broader empirical literature is heterogeneity by sector, skill composition, and tradability, which helps interpret why D ranks above capital-intensive retrofit options under acute constraints.Tradable, energy-intensive SMEs can face a compounded shock when energy prices rise alongside exchange-rate volatility, tightening credit conditions and weakening external demand; in such settings, liquidity support and risk management can prevent premature layoffs even if they do not reduce exposure structurally. This logic is consistent with the evidence that energy-cost shocks generate uneven employment responses and can induce reallocation, implying that measures targeted to the most exposed segments can yield high near-term job retention per fiscal unit (Bijnens et al., 2026; Eurochambres Chief Economists Group, 2025). At the same time, the performance of D is plausibly more state-contingent than E or A, because external demand conditions, firm balance-sheet health, and the credibility of exposure verification determine whether support prevents layoffs or

becomes a windfall. This context dependence explains why D remains third rather than first even when deployment channels exist, and why the study's feasibility and targeting criteria are central for interpreting results.

At the heart of the ranking lies a familiar but sharpened trade-off: rapid unemployment relief with a low short-run fiscal and administrative footprint versus deeper, longer-term reductions in exposure that are more demanding to deliver. Packages E and A sit at the "fast response" end of this spectrum. They leverage existing information systems and programme infrastructures, which allows them to deliver support quickly, at relatively low cost per job preserved, and with manageable implementation risk. Their weakness is durability: unless they are periodically renewed, retargeted, or adjusted, their effects taper off. Packages C and, to a lesser degree, G occupy the opposite end. Once implemented, heat-pump installations and retrofit programmes lock in lasting reductions in energy bills and generate employment in installation, operations, and maintenance. Yet they reach beneficiaries more slowly and entail substantial upfront fiscal and administrative costs. The interaction between targeting depth and implementation burden also emerges clearly. Stricter eligibility—through thresholded indexation, regular recertification, and tight social-tariff criteria—increases administrative complexity but improves fairness and reduces leakage. By contrast, looser designs can be rolled out more rapidly, but the risk of windfalls and misallocation rises. This trade-off mirrors methodological insights in policy evaluation: high interpretability and fast deployability tend to be associated with simpler instruments, while deeper structural interventions require stronger measurement-and-verification capacity and longer planning horizons—precisely the tension encoded in the "time-to-impact" and "feasibility" criteria used here.

Methodologically, the alignment and occasional divergence with prior policy evidence can be interpreted through the lens of "mechanism coverage." Packages that score well across criteria are those that cover multiple transmission channels simultaneously—cash-flow stress, demand stabilization, and inflation containment—rather than addressing only one. This multi-channel coverage helps reconcile the result that E marginally outranks A: while both preserve jobs quickly, E directly targets affordability and liquidity while also limiting inflationary propagation through tariff design and thresholding, which becomes especially relevant in an environment where second-round risks constrain fiscal space (Kilian & Zhou, 2023; Auclert et al., 2023). In contrast, A is highly effective when shocks are temporary and administrative uptake is rapid, but its relative performance declines when persistence and targeting challenges become dominant, which explains its second position and supports the sequencing logic discussed below. Similarly, B and C align with studies emphasizing that efficiency measures reduce exposure and improve resilience, yet they diverge in short-run rank because the present decision problem prioritizes rapid employment protection under immediate volatility and constrained implementation capacity (Patterson et al., 2022; Yu et al., 2022; Errigo et al., 2022).

These trade-offs translate into contingent policy guidance rather than a single, context-free prescription. Under binding fiscal constraints, the analysis suggests that an E → A sequence is the most coherent stack. Thresholded indexation and social tariff combined with debt restructuring are activated first to secure precise incidence and macro-financial discipline, followed by targeted bill relief and short-time work to sustain employment quickly. Package D is then layered in selectively where firm-level exposure to energy and FX shocks is credibly documented. If repeated short but intense shocks are anticipated within a year, an A → E → D sequence becomes more appealing, as operational readiness and speed become primary and indexation thresholds and targeted tariffs provide a supporting role for distributional and inflation dynamics. For longer-term resilience objectives, C is gradually phased in for low-income households and small businesses in municipalities with sufficient administrative and technical capacity, while B accelerates exposure reduction in energy-intensive industries. Package G proceeds only where shovel-ready projects and co-financing are in place, given its more demanding implementation profile. Across scenarios, sequencing emerges as more decisive than the identity of any single instrument: fast stabilizers bridge the exposure window while structural measures ramp up and eventually take over. This sequencing logic is consistent with empirical evidence that energy shock impacts can be front-loaded in labour markets (via liquidity and uncertainty) while structural responses (efficiency, electrification, reskilling) unfold more slowly and are constrained by capacity and matching frictions (Lankhuizen et al., 2023).

Implementation risk can be managed through concrete, data-driven safeguards that directly target the mechanisms identified in the literature. For E and A, linking the social registry to utility consumption, requiring periodic recertification, publishing simple targeting dashboards, and setting explicit ceilings on allowable leakage can materially reduce mis-targeting, consistent with evidence on metering-based targeting (Fawcett et al., 2024). To limit windfalls and strategic behaviour in D, tax, customs, and utility data can be combined to construct verifiable screens for energy intensity and export shares, complemented by standardized templates and ex-post audits to restrain moral hazard. For B and C, the creation of accredited contractor pools, standardized measurement-and-verification protocols, and pilot “corridors” in selected municipalities can mitigate procurement and performance risk prior to scaling—directly addressing the verification and monitoring challenges highlighted in the industrial assessment and energy management literature (Patterson et al., 2022; Yu et al., 2022). Aligning the portfolio with existing policy infrastructures further reduces duplication: E builds on tariff regulation and debt-workout channels; A relies on İŞKUR wage-support mechanisms; D uses Eximbank and banking hedging products; and B and C mobilize municipal project-management offices and national efficiency programmes. Taken together, the expanded comparison suggests that the relative dominance of E and A is not only a function of scoring design, but also reflects a context-specific fit between Türkiye’s institutional delivery capacity and the multi-channel nature of energy-to-employment transmission under volatile prices. Under such arrangements, the portfolio can

enhance short-term job security while charting a credible path toward longer-term reduction in energy exposure in a way that is consistent with both empirical evidence and administrative realities in Türkiye.

CONCLUSION

This analysis shows that energy–employment policy packages can be compared systematically even when decision makers face scarce data, fiscal strain, and urgent timelines. By combining SAW and ARAS, the framework evaluates alternatives across employment impact, fiscal cost, feasibility, targeting accuracy, durability, and time-to-effectiveness, producing a consistent ordering of the leading packages. The highest-ranked options are indexed pricing thresholds, social tariffs for vulnerable users, and structured bill-debt restructuring; the next-best is targeted bill relief paired with short-time work under acute stress; and the third is export support with FX hedging for energy-intensive SMEs. The persistence of this ordering under both entropy-based and equal-weight schemes suggests that the leading options reflect stable performance profiles rather than being artifacts of a single weighting choice. At the same time, the rankings should be interpreted as indicative guidance for prioritization rather than definitive prescriptions, intended to support rapid, transparent decision-making under uncertainty.

Several limitations should be acknowledged explicitly. First, the decision matrix is based primarily on expert elicitation rather than comprehensive administrative microdata, so criterion scores inevitably reflect informed judgment and may vary with expert composition, information sets, and anchoring assumptions. Second, central values are derived from expert point estimates (with uncertainty ranges), meaning that unobserved heterogeneity across regions, sectors, and firm types may not be fully captured by the current scoring scales. Third, the framework is a static, ex-ante prioritization tool and does not model general-equilibrium feedbacks—such as inflation expectations, wage responses, credit tightening, or spillovers across supply chains—that can affect realized employment outcomes. Fourth, implementation feasibility and targeting accuracy are scored as structured assessments rather than audited delivery metrics, so on-the-ground constraints (registry quality, billing systems, municipal capacity, compliance, and take-up) could shift realized effectiveness relative to the ex-ante ranking.Finally, the results depend on the selected feasible set of policy packages and criteria; alternative package definitions, additional criteria (e.g., distributional equity or political acceptability), or different normalization rules could alter rankings. These limitations do not undermine the usefulness of the approach, but they imply that policy conclusions should be framed as a transparent starting point for prioritization and learning, not as final answers.

A key implication is that effective crisis management under energy-price shocks depends less on a single flagship instrument and more on synchronized measures that address cost pressure, cash-flow stress, and demand erosion at the same time. In the early phase of a sharp price rise, policymakers benefit from instruments that are deployable quickly and leverage existing Turkish policy rails: thresholded indexation, well-designed social

tariffs, and structured debt workouts, reinforced by targeted bill relief and short-time work schemes where exposure is verifiable. These measures can protect household liquidity and preserve firm–worker matches rapidly, while remaining administratively tractable under acute stress. As the shock phase stabilizes and fiscal and administrative space adjusts, the mix can shift toward resilience-building measures that reduce exposure at the source, including industrial efficiency support, export support with FX hedging for confirmed exposure, and targeted investments in heat pumps and building retrofits where municipal delivery capacity is adequate. In this sequencing logic, the short-term goal of preventing job losses is progressively linked to the longer-term goal of lowering vulnerability to volatile energy inputs.

Rather than offering a rigid rule, the framework is intended as a flexible decision aid that can be updated as conditions change. Shifts in macro-financial constraints, labour-market structure, and social priorities will alter the relative importance of criteria and may expand or restrict the feasible instrument set. Reapplying the SAW–ARAS evaluation under alternative budget envelopes, labour-market scenarios, or welfare constraints enables policymakers to test whether preferred packages remain robust or require adjustment. The model's transparent structure also helps social partners and civil-society stakeholders understand why specific combinations rise to the top, which objectives they prioritize, and what trade-offs are being accepted—supporting informed dialogue rather than technocratic closure.

Future research can extend this work in three practical directions. First, ex-ante rankings should be linked to ex-post outcomes by pairing policy rollouts with quasi-experimental or experimental evaluations using administrative data on households, firms, energy use, and employment to estimate realized cost-per-job metrics and validate or refine the scoring logic. Second, targeting performance should be tested directly as registry quality, metering coverage, and digital governance improve, allowing the feasibility and targeting criteria to be calibrated against observed delivery data rather than structured assessments. Third, as richer data become available, analysts can incorporate scenario-based ranges more formally, explore nonlinear effects, and update weights to reflect changing elasticities and priorities. With iterative updating, the approach can evolve from a one-off crisis response tool into a learning-oriented policy capability that supports Türkiye in aligning job-centred energy policy with changing budget constraints, market conditions, and societal expectations, moving gradually toward a more resilient configuration of its energy system and labour market.

REFERENCES

Alessandri, P., & Gazzani, A. (2025). Natural gas and the macroeconomy: not all energy shocks are alike. *Journal of Monetary Economics, 151*, 103749. https://doi.org/10.1016/j.jmoneco.2025.103749.

Auclert, A., Monnery, H., Rognlie, M., & Straub, L. (2023). Managing an energy shock: Fiscal and monetary policy (No. w31543). National Bureau of Economic Research. https://doi.org/ 10.3386/w31543.

Balcilar, M., Roubaud, D., & Shahbaz, M. (2019). The impact of energy market uncertainty shocks on energy transition in Europe. *The Energy Journal, 40*(1_suppl), 55-80. https://doi.org/10.5547/01956574.40.SI1.mbal

Barrella, R., Linares, J. I., Romero, J. C., Arenas, E. M., & Centeno, E. (2021). Does cash money solve energy poverty? Assessing the impact of household heating allowances in Spain. *Energy Research & Social Science, 80,* 102216. https://doi.org/10.1016/j.erss.2021.102216

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., & Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research, 200*(1), 198-215. https://doi.org/10.1016/j.ejor.2009.01.021

Behzadian, M., Otaghsara, S. K., Yazdani, M., & Ignatius, J. (2012). A state-of-the-art survey of TOPSIS applications. *Expert Systems with Applications, 39*(17), 13051-13069. https://doi.org/10.1016/j.eswa.2012.05.056

Bijnens, G., Hutchinson, J., & Saint Guilhem, A. (2025, May 5). *How enduring high energy prices could affect jobs*. European Central Bank (ECB) Blog. https://www.ecb.europa.eu/press/blog/date/2025/html/ecb.blog20250505~86c88d726c.en.html

Bijnens, G., Hutchinson, J., & Saint Guilhem, A. (2026). Navigating the carbon price shock: Electricity costs and employment reallocation in Europe. *Utilities Policy*, *99*, 102144.

Boulanouar, Z., Essid, L., Farid, S., & Mahjoub, L. B. (2025). Asymmetric threshold effects of economic growth on renewable energy in response to energy price fluctuations. *The Journal of Economic Asymmetries*, *31*, e00414. https://doi.org/10.1016/j.jeca.2025.e00414.

Brown, M., Siddiqui, S., Avraam, C., Bistline, J., Decarolis, J., Eshraghi, H., ... & Molar-Cruz, A. (2021). North American energy system responses to natural gas price shocks. *Energy Policy*, *149*, 112046. https://doi.org/10.1016/j.enpol.2020.112046.

Cardinale, R., Cardinale, I., & Zupic, I. (2024). The EU's vulnerability to gas price and supply shocks: The role of mismatches between policy beliefs and changing international gas markets. *Energy Economics*, *131*, 107383. https://doi.org/10.1016/j.eneco.2024.107383

Chakraborty, S., Chatterjee, P., & Das, P. P. (2023). Additive ratio assessment (Aras) method. In *Multi-Criteria Decision-Making Methods in Manufacturing Environments* (pp. 171–181). Apple Academic Press. https://doi.org/10.1201/9781003377030.

Christopoulos, A. G., Kalantonis, P., Katsampoxakis, I., & Vergos, K. (2021). COVID-19 and the energy price volatility. *Energies, 14*(20), 6496. https://doi.org/10.3390/en14206496.

Dokas, I., Oikonomou, G., Panagiotidis, M., & Spyromitros, E. (2023). Macroeconomic and uncertainty shocks' effects on energy prices: A comprehensive literature review. *Energies, 16*(3), 1491. https://doi.org/10.3390/en16031491.

Erbey, A., Fidan, Ü., & Gündüz, C. (2025). A robust hybrid weighting scheme based on IQRBOW and Entropy for MCDM: Stability and advantage criteria in the VIKOR framework. *Entropy, 27*(8), 867. https://doi.org/10.3390/e27080867.

Errigo, A., Choi, J. K., & Kissock, K. (2022). Techno-economic-environmental impacts of industrial energy assessment: Sustainable industrial motor systems of small and medium-sized enterprises. *Sustainable Energy Technologies and Assessments, 49,* 101694. https://doi.org/10.1016/j.seta.2021.101694.

Eurochambres Chief Economists Group. (2025). *Electricity prices and employment: A comparative analysis of EU countries* (Report). Eurochambres. https://www.eurochambres.eu/wp-content/uploads/2025/06/Electricity-Prices-and-Employment-A-Comparative-Analysis-of-EU-Countries-3.pdf

Eurochambres. (2025, June 17). *Electricity prices and employment across European countries* (Press release). Eurochambres. https://www.eurochambres.eu/publication/electricity-prices-and-employment-across-european-countries

European Commission. (2020). *Short-time work schemes in the EU: Stocktaking survey* (Study report). https://ec.europa.eu/social/BlobServlet?docId=22758&langId=en

Fawcett, T., Palmer, J., Terry, N., Boardman, B., & Narayan, U. (2024). Using smart energy meter data to design better policy: Prepayment meter customers, fuel poverty and policy targeting in Great Britain. *Energy Research & Social Science, 116*, 103666. https://doi.org/10.1016/j.erss.2024.103666

Gasperin, S., & Skidelsky, R. (2021). Reinstating fiscal policy for normal times: Public investment and public jobs programmes. *PSL Quarterly Review, 74*(296), 3–24. https://doi.org/10.13133/2037-3643/16863

Gedikli, C., Miraglia, M., Connolly, S., Bryan, M., & Watson, D. (2023). The relationship between unemployment and wellbeing: An updated meta-analysis of longitudinal evidence. *European Journal of Work and Organizational Psychology, 32*(1), 128–144. https://doi.org/10.1080/1359432X.2022.2134442

Gencer, D., & Akcura, E. (2022, May 13). *Amid energy price shocks, five lessons to remember on energy subsidies*. World Bank Blogs. https://blogs.worldbank.org/en/energy/amid-energy-price-shocks-five-lessons-remember-energy-subsidies

Gezen Ucar, M. (2024). Integrated entropy-based MCDM methods for investigating the effectiveness of Turkey's energy policies. *Energy Systems,* 1–30. https://doi.org/10.1007/s12667-024-00652-1

Giertz, S. H., & Kumar, A. (2024). The local fiscal multiplier of intergovernmental grants: Evidence from federal Medicaid assistance to states. *International Tax and Public Finance, 31*(5), 1204–1228.https://doi.org/10.1007/s10797-023-09787-9

Gül, S. (2021). Fermatean fuzzy set extensions of SAW, ARAS, and VIKOR with applications in COVID-19 testing laboratory selection problem. *Expert Systems, 38*(8), e12769. https://doi.org/10.1111/exsy.12769.

Güler, M., Mukul, E., & Konyalıoğlu, A. K. (2025). A hesitant fuzzy approach to renewable energy technology selection aligned with sustainable development goals in Turkey. *Sustainable Chemistry and Pharmacy, 48*, 102261. https://doi.org/10.1016/j.scp.2025.102261.

International Labour Organization. (2025). *Global employment policy review 2025: Do employment-responsive policies work? How impact assessments, diagnostics and dialogue contribute to the answer*. International Labour Organization. https://www.ilo.org/sites/default/files/2025-09/GERP_Full_report_2025_Web_ENG.pdf

İzgüden, D., Korucu, K. S., Söylemez, Ş. Ç., & Demir, M. (2022). OECD ülkelerinin sağlık göstergeleri ve sağlık ekipmanlarının entropi temelli ARAS ve SAW yöntemleri ile değerlendirilmesi. Süleyman Demirel Üniversitesi Vizyoner Dergisi, 13(35), 731-755. https://doi.org/10.21076/vizyoner.1002922.

Jahangiri, M. (2025). Life cycle assessment and SAW-Based ranking of renewable electricity and hydrogen production scenarios for sustainable residential architecture: A case study in kerman, Iran. *Energy*, 138767. https://doi.org/10.1016/j.energy.2025.138767.

Jové-Llopis, E., Trapero-Bertran, M., & Trujillo-Baute, E. (2025). Energy poverty and health: Does the social energy tariff help? *Energy Policy, 206*, 114762. https://doi.org/10.1016/j.enpol.2024.114762

Kaddani, S., Vanderpooten, D., Vanpeperstraete, J. M., & Aissi, H. (2017). Weighted sum model with partial preference information: Application to multi-objective optimization. *European Journal of Operational Research, 260*(2), 665–679. https://doi.org/10.1016/j.ejor.2017.01.028

Kapp, S., Choi, J. K., & Kissock, K. (2022). Toward energy-efficient industrial thermal systems for regional manufacturing facilities. *Energy Reports, 8*, 1377–1387.https://doi.org/10.1016/j.egyr.2021.11.102

Kaya, İ., Çolak, M., & Terzi, F. (2018). Use of MCDM techniques for energy policy and decision-making problems: A review. *International Journal of Energy Research, 42*(7), 2344–2372. https://doi.org/10.1002/er.4014

Kilian, L., & Zhou, X. (2023). A broader perspective on the inflationary effects of energy price shocks. *Energy Economics, 125*, 106893. https://doi.org/10.1016/j.eneco.2023.106893

Kumari, A., & Acherjee, B. (2025). Comparative Effectiveness of Data Normalization Methods in ARAS for Multi-Criteria Decision-Making Across Industrial Applications. *International Journal of Industrial Engineering: Theory, Applications and Practice*, *32*(4). https://doi.org/10.23055/ijietap.2025.32.4.10995.

Lankhuizen, M., Diodato, D., Weterings, A., Ivanova, O., & Thissen, M. (2023). Identifying labour market bottlenecks in the energy transition: A combined IO-matching analysis. *Economic Systems Research, 35*(2), 157–182. https://doi.org/10.1080/09535314.2022.2149344

Li, Q., Chen, H., Long, R., & Huang, Z. (2026). Who is leading the methanol price? The role of international transmission and energy price based on the PLBX model. *Energy*, 140145.

Long, T., Shao, L., Zhang, T., Chen, Z., Zhang, Y., Xing, J., & Zhang, Y. (2025). Energy Price Fluctuation and Urban Surveyed Unemployment in Transition Context: MF-VAR Evidence. *Sustainability*, *17*(22), 10017. https://doi.org/10.3390/su172210017.

Meidelfi, D., Idmayanti, R., Maulidani, F., Ilham, M., & Muhlis, F. A. (2022). Additive Ratio Assessment (ARAS) method in the selection of popular mobile games. International Journal of Advanced Science Computing and Engineering, 4(1), 56-66. https://doi.org/10.62527/ijasce.4.1.81.

Min, H. (2022). Examining the impact of energy price volatility on commodity prices from energy supply chain perspectives. *Energies*, *15*(21), 7957. https://doi.org/10.3390/en15217957

Nashi, R., & Ouakil, H. (2025). Energy price shocks and current account balances: What role for economic structure, energy dependency and renewable energy development?. *Sustainable Futures*, *9*, 100402.

Nchofoung, T. N. (2024). Oil price shocks and energy transition in Africa. *Energy Policy*, *184*, 113855. https://doi.org/10.1016/j.enpol.2023.113855

Nguyen, D. B., Nong, D., Simshauser, P., & Pham, H. (2024). Economic and supply chain impacts from energy price shocks in Southeast Asia. *Economic Analysis and Policy, 84*, 929–940. https://doi.org/10.1016/j.eap.2024.02.015

OECD. (2020, June 24). *Germany's short-time work scheme: Can its past success be replicated?* OECD Ecoscope. https://oecdecoscope.blog/2020/06/24/germanys-short-time-work-scheme-can-its-past-success-be-replicated/

OECD. (2021). *OECD Economic Surveys: Turkey 2021*. OECD Publishing. https://www.oecd.org/content/dam/oecd/en/publications/reports/2021/01/oecd-economic-surveys-turkey-2021_b37b3e78/2cd09ab1-en.pdf

Osuna, V., & García Pérez, J. I. (2022). Temporary layoffs, short-time work and COVID-19: The case of a dual labour market. *Applied Economic Analysis*, *30*(90), 248–262. https://doi.org/10.1108/AEA-05-2022-0115

Palaios, P., & Papapetrou, E. (2022). Oil prices, labour market adjustment and dynamic quantile connectedness analysis: Evidence from Greece during the crisis. *Journal of Economic Structures, 11*(1), 30. https://doi.org/10.1186/s40008-022-00290-0.

Patterson, M., Singh, P., & Cho, H. (2022). The current state of the industrial energy assessment and its impacts on the manufacturing industry. *Energy Reports, 8*, 7297–7311. https://doi.org/10.1016/j.egyr.2022.05.014

Roszkowska, E. (2026). Entropy and Normalization in MCDA: A Data-Driven Perspective on Ranking Stability. *Entropy*, *28*(1), 114.

Saboori, B., Gholipour, H. F., Rasoulinezhad, E., & Ranjbar, O. (2022). Renewable energy sources and unemployment rate: Evidence from the US states. *Energy Policy, 168*, 113155. https://doi.org/10.1016/j.enpol.2022.113155

Saraswat, S. K., & Digalwar, A. K. (2021). Evaluation of energy sources based on sustainability factors using integrated fuzzy MCDM approach. *International Journal of Energy Sector Management, 15*(1), 246–266. https://doi.org/10.1108/IJESM-07-2020-0005

Shang, D., Pang, Y., & Wang, H. (2025). Carbon price fluctuation prediction using a novel hybrid statistics and machine learning approach. *Energy*, *324*, 135581. https://doi.org/10.1016/j.energy.2025.135581

Shieh, H. S., & Shah, S. A. A. (2025). Developing a fuzzy MCDA-based multidimensional index to measure energy poverty in developing countries. *Social Indicators Research, 176*(2), 499–531. https://doi.org/10.1007/s11205-024-03439-7.

Sihombing, V., Nasution, Z., Al Ihsan, M. A., Siregar, M., Munthe, I. R., Siregar, V. M. M., ... & Asfar, D. A. (2021).Additive Ratio Assessment (ARAS) method for selecting English course branch locations. *Journal of Physics: Conference Series, 1933*(1), 012070. https://doi.org/10.1088/1742-6596/1933/1/012070.

Simshauser, P. (2022). Fuel poverty and the 2022 energy crisis. *Australian Economic Review, 55*(4), 503–514. https://doi.org/10.1111/1467-8462.12490.

Škare, M., Blažević Burić, S., & Sinković, D. (2022). Effects of Energy Price Shocks on Global Inflation: A Panel Structural VAR Approach. *Acta Montanistica Slovaca, 27*(4). https://doi.org/10.46544/AMS.v27i4.08.

Son, J., & Ryu, D. (2024). Energy price shocks and stock market volatility in an energy-importing country. *Energy & Environment*. https://doi.org/10.1177/0958305X241228514.

UNDP & ILO. (2022, June 28). *Social and Employment Impacts of Climate Change and Green Economy Policies in Türkiye* (Green Jobs Assessment Model). https://www.undp.org/turkiye/publications/social-and-employment-impacts-climate-change-and-green-economy-policies-turkiye

Usman, O., Ozkan, O., Nwani, C., Bekun, F. V., & Alola, A. A. (2025). Can household energy efficiency dampen crude oil price volatility in the United States? *PLOS ONE, 20*(1), e0307840. https://doi.org/10.1371/journal.pone.0307840.

Wang, X., Lu, F., Safi, A., & Li, X. (2025). Unraveling the dynamics of carbon price volatility: A comprehensive analysis of impacts from climate policy, fossil fuel and renewable energy shocks. *Energy Strategy Reviews, 62*, 101966. https://doi.org/10.1016/j.esr.2025.101966.

Wang, X., Safi, A., Wang, S., & Zhang, Y. (2025). How does carbon market react to economic policy uncertainty and oil price shocks? New evidence from a time-varying perspective. *International Review of Economics & Finance*, 104841. https://doi.org/10.1016/j.iref.2025.104841.

World Bank. (2021, December 21). *Towards Resilient Housing in Turkey – a Virtual Knowledge Exchange*. https://www.worldbank.org/en/events/2021/12/21/drmhubtokyo-towards-resilient-housing-in-turkey

Xue, L., Li, H., Xu, C., Zhao, X., Zheng, Z., Li, Y., & Liu, W. (2022). Impacts of industrial structure adjustment, upgrade and coordination on energy efficiency: Empirical research based on the extended STIRPAT model. *Energy Strategy Reviews, 43,* 100911. https://doi.org/10.1016/j.esr.2022.100911

Yu, W., Patros, P., Young, B., Klinac, E., & Walmsley, T. G. (2022). Energy digital twin technology for industrial energy management: Classification, challenges and future. *Renewable and Sustainable Energy Reviews, 161,* 112407. https://doi.org/10.1016/j.rser.2022.112407

Zavadskas, E. K., & Turskis, Z. (2010). A new additive ratio assessment (ARAS) method in multicriteria decision-making. *Technological and Economic Development of Economy, 16*(2), 159–172. https://doi.org/10.3846/tede.2010.10

Zhang, L. P., & Zhou, P. (2024). Reassessing energy security risk incorporating external shock: A variance-based composite indicator approach. *Applied Energy, 358,* 122665. https://doi.org/10.1016/j.apenergy.2024.122665

Zhou, L., & Geng, J. B. (2021). Dynamic effect of structural oil price shocks on new energy stock markets. *Frontiers in Environmental Science, 9,* 636270. https://doi.org/10.3389/fenvs.2021.636270

Ziemba, P. (2022). Energy security assessment based on a new dynamic multi-criteria decision-making framework. *Energies, 15*(24), 9356. https:// doi.org/10.3390/en15249356

InTraders International Trade Academic Journal

e-ISSN: 2667-4408 **www.intraders.org**

Volume: 9
Issue : 1
Research Article

Received: January 25, 2026
Revision: March 13, 2026
Accepted: April 11, 2026
DOI: https://www.doi.org/10.55065/intraders.1871374

The Effect of Economic Growth on Health Expenditures: A Panel Quantile Regression Approach[1]

Yasin ADEMOĞLU[2], Hayriye Esra AKYÜZ[3]

Abstract

In developing countries, health expenditures play a crucial role in improving access to healthcare services and reducing social inequalities. This study aims to examine the relationship between health expenditures and gross domestic product (GDP) per capita in Mexico, Indonesia, Nigeria, and Türkiye (MINT) using panel quantile regression analysis. To ensure that this relationship is not limited solely to direct effects and to capture the multidimensional nature of the health system more comprehensively, the study also considers the effects of various health indicators. Unlike traditional mean-based methods, this approach allows analysis of effects at different points along the conditional distributions of the variables. Empirical evidence indicates that the effects of GDP per capita, life expectancy at birth, fertility rate, mortality rate, and urban population on health expenditures in MINT countries are statistically significant across all quantiles except for the τ=0,10 quantile level (p<0,05). While increases in GDP per capita, mortality rate, and urban population are associated with significant increases in health expenditures, increases in life expectancy at birth and fertility rate are associated with significant decreases in health expenditures. In the lowest health expenditure group (τ=0,10), the weakening or disappearance of the effects of the predictors on health expenditures can be considered an expected outcome, possibly due to government support or the distinct structure of basic healthcare services. These findings highlight the heterogeneous effects of economic and demographic factors.

Keywords: *Gross domestic product, health expenditure, MINT countries, panel quantile regression*

JEL Codes: *C23, C51, I15*

INTRODUCTION

Health expenditures exhibit an upward trend due to rising expectations, technological advancements, and

There is no conflict of interest.

[1] * Corresponding author: Hayriye Esra AKYÜZ, heakyuz@beu.edu.tr

Funding: This study (Project No: BEBAP 2024.25) was financially supported by Bitlis Eren University.
Author contribution: YA and HEA; conceptualization, supervision, methodology, formal analysis, writing, review, and editing of the final text. All authors read the final paper and approved the submission.

[2] Bitlis Eren University, E-Mail: yasinademoglu56@gmail.com, OI: 0009-0003-4101-8020
[3] Assoc. Prof. Dr., Bitlis Eren University, E-Mail: heakyuz@beu.edu.tr, OI: 0000-0002-1784-5910

Cite As: Ademoğlu, Y., & Akyüz, H. E. (2026). The effect of economic growth on health expenditures: A panel quantile regression approach. *InTraders International Trade Academic Journal*, 9(1), 71–89.https://doi.org/10.55065/intraders.1871374

changes in income levels and population structures. In recent years, health spending has become a top priority for many countries, and efforts to secure resources for investments in this area have intensified. Human health is critical to the future of every country, so both developed and developing nations must allocate budgetary resources to healthcare services in line with their economic capacity. Technological advancements and the expansion of communication networks, which have become integral to daily life, have increased health awareness among populations. This development has significantly impacted health expenditures. While countries are making health expenditures, numerous international organizations are developing projects, conferences, and strategies to protect global health. In line with their development objectives, countries carefully examine their expenditures to efficiently utilize their limited resources and assess whether they are sufficient to achieve their economic goals (Filiz, 2010). Health is a multidimensional phenomenon shaped by the interaction of education, policy, and practice disciplines, extending beyond a purely theoretical framework. Promoting public health requires integrating educational processes that foster individual awareness, macro-level policies that standardize access to services, and operational practices that ensure clinical effectiveness (Yıldırım & Bulut, 2023). As a vital issue in daily life, health is also currently regarded as a cultural phenomenon. While earlier discourse focused primarily on disease, it later shifted toward health. More recently, this discourse has evolved into the concept of "heal" (Kurtdaş, 2016).

Throughout history, countries have striven to ensure their continued existence. Epidemics and incurable diseases have led to significant population declines in some countries in the past. Furthermore, low life expectancy at birth and low fertility rates have caused these countries to face existential challenges. These conditions are considered major factors threatening the future sustainability of nations. The failure to achieve the expected increases in the active labour force and fertility rates due to health-related problems has hindered countries' economic and demographic growth. Experiencing such periods has resulted in stagnation and even regression in countries' levels of development. To avoid these adverse effects, countries have sought to preserve and enhance their welfare levels by increasing health sector expenditures (Zerecan & Atakan, 2024). It is undeniable that health economics is an interdisciplinary field of synthesis that combines the clinical data provided by medical science with the rational analytical methods of economics and is fundamentally built on the efficient use of resources.

Health expenditures encompass a range of services, including hospital services, pharmaceuticals, preventive care, and rehabilitation. These expenditures vary worldwide in line with each country's economic structure, healthcare system, and implemented policies. For example, low- and middle-income countries tend to focus their health spending on emergency care and child health. In contrast, high-income countries prioritize age-related diseases and long-term care services (Akdur, 2008). Furthermore, the

importance of health spending has increased with the onset of the pandemic. During the pandemic, countries tested the resilience of their healthcare systems and realized that they needed to increase health spending. The pandemic clearly demonstrated the necessity of investing in healthcare services and their critical role in protecting public health (Ilıman, 2022).

In conclusion, growing populations, ageing societies, and advancements in health technology strain countries' spending capacities and intensify sustainability concerns. Therefore, accurately forecasting future health expenditure levels and growth rates is of paramount importance. The way countries organize their health spending reflects their economic conditions and their approaches to social justice and equity. From this perspective, increasing health spending, strengthening healthcare systems, and preparing for future health crises are critical to the continuity and sustainability of nations. Well-planned health expenditure strategies can improve health standards for individuals and societies while contributing to economic growth. Therefore, monitoring and managing health expenditures are regarded as fundamental components of national health policies (Yücel & Çalışkan, 2023). It requires providing quality healthcare services to all segments of society and makes healthcare expenditures among the highest costs for national economies. (Orak & Narin, 2023).

The objective of this study is to examine the impact of economic growth on health expenditures in MINT countries. To this end, this study will employ panel quantile regression analysis. This analysis will allow for the examination of the heterogeneous structure of the entire conditional distribution, in contrast to the focus of standard panel data models, which focus solely on the conditional mean of the dependent variable. The evaluation of the effects of key health indicators that reflect the health status of society and facilitate international comparisons, such as life expectancy at birth, fertility rate, and mortality rate, together with economic growth and urban population on health expenditures, will enable an assessment of whether the share allocated to health spending is effective and efficient. This evaluation will provide more detailed empirical evidence.

LITERATURE REVIEW

The number of studies examining the relationship between health budgets and the factors influencing these expenditures is steadily increasing. A review of the literature in this field reveals that most studies have examined the relationship between economic growth and health expenditures using panel data models. Panel data analysis is an indispensable methodological approach for understanding the impact of economic growth on health-sector investments and the complex interactions among the various factors that shape these expenditures. By accounting for differences across countries and changes over time, such studies yield more robust and comprehensive insights. In addition to contributing to academic literature, these

studies guide the formulation of health and economic policies. However, these models focus only on the conditional mean of health expenditures and do not allow analysis of the entire conditional distribution's heterogeneous structure. The following analysis of studies in the relevant literature provides a comprehensive perspective on the relationship between health expenditures and economic growth.

Sayılı et al. (2017) investigated Türkiye's position within OECD countries by comparing key health indicators and health expenditures. Their findings revealed that both male and female life expectancy and healthy life expectancy in Türkiye were significantly lower than the OECD average. In contrast, neonatal, under-five, and maternal mortality rates were significantly higher (Sayılı et al., 2017). Similarly, Güven et al. (2018) analyzed panel data from 32 MENA countries for the period 2000-2015. They found that health expenditures negatively affected economic growth, whereas infant mortality and life expectancy at birth positively affected growth. In line with these findings, Safkan (2020) examined economically fragile countries, including Brazil, India, Indonesia, South Africa, and Türkiye, and reported that per capita health spending positively influenced per capita income, while infant mortality had a negative and significant effect on economic growth; life expectancy at birth, however, was not significant.

Environmental factors have also been considered in this context. Kostak (2021) studied EU countries and found that CO_2 emissions drive health expenditures by causing environmental degradation. It highlights the need for policies to mitigate environmental damage. Similarly, Pehlivan et al. (2020) observed unidirectional causality from CO_2 emissions to health expenditures and per capita GDP in G20 countries. Künü and Levent (2023) further examined the relationships among economic growth, CO2 emissions, and health expenditures across EU countries. Li et al. (2022) investigated this relationship in BRICS countries.

Girgin (2022) focused on developed countries and analyzed panel data from 35 OECD countries spanning 2000-2019. He demonstrated that increases in public health expenditures were associated with higher economic growth, investments, labour force participation, and life expectancy at birth. Girgin (2022) also observed that the health indicators of developed countries were superior to those of developing countries. Sağlam and Kara (2023) examined how changes in health status affect public budgets. They found that in developed countries, higher elderly population ratios and out-of-pocket expenditures increase the share of public health spending. Conversely, increases in the human development index, crude birth rate, and private health expenditures reduce it. In less developed countries, life expectancy at birth and per capita out-of-pocket health expenditures increased the public health expenditure burden. Meanwhile, rising crude birth rates, private expenditures, and elderly ratios reduced it (Sağlam & Kara, 2023).

A multitude of studies have directly examined the interplay between health expenditures and economic growth. Çelik (2020) discovered that in G20 countries, increases in health expenditures positively affected

economic growth, suggesting that appropriate socio-economic conditions and investments in health and education enhance labour productivity. In a similar vein, Şen and Bingöl (2018) identified a positive relationship between economic growth and health expenditures in Türkiye for the period 2006–2017. This relationship was determined using indicators such as drug expenditures, health-related transfers, and medical supply costs (Şen & Bingöl, 2018). Akın (2007) also identified a positive correlation between life expectancy at birth and per capita GDP in Türkiye, while infant mortality, child mortality, and crude death rates demonstrated negative associations. Akar (2014) corroborated these findings using cointegration and vector error correction models, demonstrating a long-term significant relationship between health expenditures, their relative price, and economic growth, while short-term effects were not significant.

Cross-country analyses further underscore the intricacy of these interactions. Çalışkan (2009) analyzed OECD countries and found that, in addition to economic factors, non-economic factors such as education levels, demographic changes, and health policies significantly influence health expenditures. The study identified ageing populations and urbanization as driving factors for increased demand for healthcare services (Çalışkan, 2009). Daştan and Çetinkaya (2015) compared the health systems and expenditures of OECD countries, finding significant differences among countries. However, a direct link between health spending and health system efficiency was not consistently observed (Daştan & Çetinkaya, 2015). Arslan (2022) applied the Panel ARDL method to 36 OECD countries, thereby demonstrating that health expenditures, both public and private, significantly affected life expectancy at birth, infant mortality, and lost potential years of life in the long and short term. However, maternal mortality and preventable deaths were only partially significant (Arslan, 2022).

Other studies focusing on broader international contexts reinforce the positive role of health spending. Kılıç and Özbek (2018) analyzed OECD data for 1995–2013 using FMOLS and DOLS and concluded that health and education expenditures positively influence economic growth. According to Majdi (2014), the economic growth of 15 Northern and Southern countries from 1992 to 2010 was influenced by health expenditures. Şahbudak and Şahin (2015) observed a positive relationship between health expenditure share in GDP, life expectancy, and economic growth in BRIC countries (Şahbudak & Şahin, 2015). Haseeb et al. (2024) conducted a subsequent investigation of ASEAN countries, identifying both short- and long-term effects of economic growth, environmental pollution, and energy consumption on health and R&D expenditures.

Finally, country-specific analyses in Türkiye reveal consistent patterns. As indicated by Şahbudak and Şahin (2015), Şen and Bingöl (2018), and Akın (2007), both health indicators and expenditures significantly influence economic performance. A collective examination of these studies suggests a context-dependent yet crucial relationship between health expenditures, economic growth, demographic changes,

environmental factors, and health system characteristics. This relationship is imperative for informing policy decisions and enhancing health outcomes across diverse countries and regions.

DATA AND METHODOLOGY

This study examined the impact of per capita gross domestic product, life expectancy at birth, fertility rate, mortality rate, and urban population on health expenditures for the MINT countries (Mexico, Indonesia, Nigeria, and Türkiye) during the period 2000–2023. The analysis employed panel data methods to facilitate a comprehensive examination of the data. The dataset under consideration has a cross-sectional dimension of i=4 and a time dimension of t=24, resulting in a total of n=96 observations. Prior to analysis, the natural logarithms of all variables were taken. The data were analyzed using Stata/BE 18, and the Type I error rate was set at $\alpha=0.05$. The variables utilized in the analyses were obtained from the World Bank's World Development Indicators database, and exhaustive details are provided in Table 1.

Table 1: Variable Definitions

Variables	Explanations	Abbreviation	Source
Health expenditures	% of GDP	HE	World Bank-World Development Indicators
Per capita gross domestic product	Current US$	GDP	
Life expectancy at birth	Year	LEB	
Fertility rate	Number of live births per woman	FR	
Mortality rate	Number of deaths of children under five Years of age per 1,000 live births	MR	
Urban population	% of the total population	UP	

Source: Created by the authors

The panel data regression model to be used in this study is as follows in Eq. (1):

$$\log HE_{it} = \alpha_i + \beta_1 \log GDP_{it} + \beta_2 \log LEB_{it} + \beta_3 FR_{it} + \beta_4 MR_{it} + \beta_5 UP_{it} + \varepsilon_{it}, \quad i=1,2,\ldots,4;\ t=1,2,\ldots,24 \qquad (1)$$

In this Model, i denotes the countries in the cross-sectional data, t denotes the time period, α_i denotes country-specific differences, and ε_{it} denotes the error term.

In some econometric analyses, it is common to use cross-sectional and time-series data separately. However, an exclusive focus on a single dimension may be considered a limitation. This development has led to the emergence of panel data, a methodological advancement that facilitates the integration of cross-sectional and time-series observations (Baltagi, 2021). The use of panel data is widely acknowledged as a costly, time-consuming, and analytically challenging endeavour. The incorporation of both the time and cross-sectional unit dimensions in panel data introduces numerous challenges during data collection

(Tatoğlu, 2016). Conversely, the utilization of panel data facilitates the adjustment of individual heterogeneity by accounting for fixed, though unobservable, factors inherent in both cross-sectional and time-series data. The time dimension facilitates a more precise evaluation of the direction of cause-and-effect relationships. Let *i* and *t* denote the cross-sectional units and time periods, respectively. Also, the panel regression model with dependent variable *Y* and independent variable *X* can be expressed as follows:

$$Y_{it} = \alpha_{it} + \sum_{k=1}^{K} \beta_{kit} X_{kit} + u_{it}, \quad i = 1,2,\dots,N; t = 1,2,\dots,T; k = 1,2,\dots,K \tag{2}$$

Panel Quantile Regression

Quantile regression is a statistical and econometric method that extends traditional regression analysis by estimating the effects of independent variables at different points along the distribution of the dependent variable, rather than focusing solely on the mean (Koenker, 2005). This approach is beneficial for capturing heterogeneous effects across observations and for examining variations at the lower and upper tails of the distribution. Therefore, quantile regression offers a more comprehensive assessment of variable effects and addresses limitations of traditional regression methods (Koenker & Machado, 1999).

The simple linear quantile regression model is as follows in Eq. (3):

$$F^{-1}(\tau/X) = \alpha + \beta X + F_{\varepsilon}^{-1}(\tau) \tag{3}$$

where the value $F^{-1}(\tau/X)$ represents the τth conditional quantile of the dependent variable derived from the inverse of distribution $F(Y/X)$, while $F_{\varepsilon}^{-1}(\tau)$ denotes the error term associated with the τth quantile.

Let Y_i be a random variable that is independent and identically distributed, following a symmetric *F* distribution function, represented as (Koenker & Hallock, 2001):

$$Y = \beta + \varepsilon_i \tag{4}$$

In Eq. (4), the τth sample quantile is obtained by minimizing Eq. (5).

$$min_{\beta} \frac{1}{n} \left\{ \sum_{i:y_{i \geq \beta}} \tau |y_i - \beta| + \sum_{i:y_{i<\beta}} (1-\tau)|y_i - \beta| \right\} \tag{5}$$

In this case, the resulting Model can be expressed as a linear regression model as shown in Eq. (6).

$$Y_i = \acute{x}_{\iota}\beta + \varepsilon_i \tag{6}$$

The τth quantile regression is estimated as shown in Eq. (7) by minimizing Eq. (8).

$$min_{\beta} \frac{1}{n} \left\{ \sum_{i:y_{i \geq \acute{x}_{\iota}\beta}} \tau |y_i - \acute{x}_{\iota}\beta| + \sum_{i:y_{i<\acute{x}_{\iota}\beta}} (1-\tau)|y_i - \acute{x}_{\iota}\beta| \right\} \tag{7}$$

$$min_{\beta} \frac{1}{n} \{ \sum_{i=1}^{n} \rho_{\tau}(y_i - x_i\beta) \} \tag{8}$$

Quantile regression coefficients indicate the impact of a one-unit change in an explanatory variable on the dependent variable at a given quantile. Conventional techniques for pooled data are susceptible to heterogeneity. Panel quantile regression is a methodological framework that integrates panel data with quantile regression, offering a flexible analytical approach. These models can be classified as either fixed effects or correlated random effects, thereby enabling the unobserved individual effects to be associated with the explanatory variables. The fixed effects panel quantile regression was introduced by Koenker (2004), with individual effects estimated via a narrowing function. In contrast to standard fixed effects models, quantile regression provides unbiased and efficient estimates when linear regression assumptions are violated (Acar & Topdağ, 2022).

EMPIRICAL RESULTS

This section presents the empirical findings from the methods employed in the study and evaluates them within the framework of the research questions.

Table 2: Descriptive Statistics for MINT Countries

Country	HE	GDP	LEB	FR	MR	UP
Mexico	5,6643	9787,6520	73,9562	2,2630	18,8263	78,2240
	0,4392	1521,6060	1,2006	0,2769	4,7985	2,1016
	4,4491	7473,9324	70,1330	1,8030	10,7330	74,7220
	6,3130	13926,1136	74,8320	2,7160	28,2000	81,5820
Indonesia	2,7412	2825,9709	68,4688	2,3938	33,3385	50,6510
	0,4377	1368,3118	1,2365	0,1297	10,1932	5,1013
	1,8530	739,0039	65,7500	2,1530	16,3240	42,0020
	3,7064	4940,5498	70,5180	2,6570	52,0000	58,5720
Nigeria	3,5692	1891,2838	50,9079	5,7435	136,8448	44,7063
	0,5925	742,9623	1,9165	0,4136	22,3730	6,0554
	2,4906	563,0471	47,1930	4,5290	101,5760	34,8400
	5,0536	3200,9528	53,6990	6,1390	182,5000	54,2830
Türkiye	4,6290	9109,1367	75,2427	2,1269	18,6845	71,4686
	0,4650	2867,8282	1,9031	0,2455	8,8719	3,9502
	3,7630	3100,4590	71,8610	1,2400	4,2290	64,7410
	5,4900	12985,7532	78,4750	2,5320	37,6000	77,4630
Total	4,1509	5903,5109	67,1439	3,1318	51,9236	61,2625
	1,2060	4000,7042	9,8903	1,5444	51,3417	14,7213
	1,8530	563,0471	47,1930	1,2400	4,2290	34,8400
	6,3130	13926,1136	78,4750	6,1390	182,5000	81,5820

For each country, the rows report the mean, standard deviation, minimum, and maximum values, respectively.
Source: Created by the authors

A collective evaluation of the economic, health, and demographic indicators of the MINT countries reveals several noteworthy observations. First, Mexico's health expenditures as a percentage of its GDP stand at 5.66%, the highest among the MINT countries. Second, Mexico boasts the highest GDP per capita among the MINT countries, reaching USD 9787,65. Third, Mexico's life expectancy at birth is 73,96 years, a moderately high figure. Fourth, Mexico's fertility rate stands at 2,26, a notably high figure. Fifth, Mexico's

infant mortality rate is 18,83, the lowest among the MINT countries. Finally, Mexico has a high urban population ratio of 78,22%, a statistic that is also notably high. In Indonesia, the proportion of health expenditures to the nation's GDP is modest at 2,74%, the GDP per capita is the lowest at USD 1368,31, the life expectancy at birth is 68,47 years, the fertility rate is high at 2,39, the infant mortality rate is high at 33,34, and the urban population ratio is low at 50,65%. Nigeria's performance stands in contrast to other nations, exhibiting a low health expenditure ratio of 3,57%, a modest GDP per capita of USD 1891,28, a life expectancy at birth of 50,91 years, a high fertility rate of 5,74, an infant mortality rate of 136,84, and a low urban population ratio of 44,71%. Within the context of Türkiye, the allocation of health expenditures to GDP is moderate at 4,63%, while GDP per capita among the MINT countries is notably high at USD 9109,14. The life expectancy at birth is 75,24 years, the fertility rate is moderate at 2,13, the infant mortality rate is 18,68, and the urban population ratio is 71,47% (Table 2).

When health indicators among the MINT countries are examined, it is noteworthy that Mexico and Türkiye exhibit relatively better health outcomes. This situation reflects the effectiveness of health policies and the strength of health systems in both countries. On the other hand, the need for further improvement in the health sector in Indonesia and Nigeria reveals the challenges faced by their health systems and the presence of broader public health issues. It is understood that greater investment has been made in factors such as access to healthcare services, health infrastructure, and the quality of healthcare personnel in Mexico and Türkiye, which have contributed to improvements in health indicators. Moreover, programs such as immunization, preventive healthcare services, and health education have improved health outcomes in these countries.

In contrast, issues such as limited access to healthcare services, financial barriers, and the sustainability of the health system in Indonesia and Nigeria contribute to the relatively poor performance of health indicators in these countries. In these contexts, substantial improvements are required in areas such as infectious diseases, malnutrition, and maternal and child health. Indonesia and Nigeria should develop comprehensive health policies to strengthen their health systems. These policies should aim to expand access to healthcare services and improve health infrastructure. At the same time, increasing investments in the health system will enhance the quality of healthcare services. The more effective involvement of public–private partnerships and international aid organizations, through both financial support and training programs, in these countries will be reflected in improved societal health and well-being. In conclusion, the health indicators of Mexico and Türkiye demonstrate the effectiveness of their health policies, while the implementation of the proposed strategies for overcoming health-related challenges in Indonesia and Nigeria will be of great importance in improving overall quality of life.

In panel data analyses, testing for unit roots is critical. To determine the level at which the variables are

stationary, first identify cross-sectional dependence and then select the appropriate first- or second-generation unit root test. There are numerous tests available in the literature for assessing cross-sectional dependence, and the choice of test varies depending on the time and cross-sectional dimensions (Pesaran, 2015). In this study, the use of two diagnostic tests enabled a detailed examination of interactions at different levels of the data. Since the time dimension exceeds the cross-sectional dimension, the Breusch-Pagan (1980) LM test results were considered, while the Pesaran (2004) CD test results were also reported for comparison purposes.

Table 3: Cross-Sectional Dependence

Variables	Breusch-**Pagan LM**	**Pesaran CD**
HE	21,311***	1,4316**
GDP	104,28***	10,185***
LEB	53,434***	4,9814***
FR	63,051***	7,0784***
MR	139,99***	11,831***
UP	142,82***	11,951***

*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.
Source: Created by the authors

To investigate correlations across countries, cross-sectional dependence was examined using the Breusch-Pagan LM and Pesaran CD tests, confirming its presence in the panel (p<0,05). Consequently, second-generation unit root tests were deemed necessary to assess the stationarity of the variables (Table 3).

Table 4: Testing for slope heterogeneity

	Test statistics	***p*-value**
Δ	14,643	0,000
Δ_{adj}	16,908	0,000
Δ (HAC)	-2,669	0,008
Δ_{adj} (HAC)	-3,082	0,002

Source: Created by the authors

In Table 4, the test results for the null hypothesis "H_0: the slope coefficients are homogeneous" indicate that the panel exhibits heterogeneity.

Table 5: Unit Root Test Results

Variable	**Level**		**I(1)**	
	Intercept	**Intercept&Trend**	**Intercept**	**Intercept&Trend**
HE	-1,102 (0,912)	-2,555 (0,299)	-2,721 (0,024)	-2,833 (0,030)
GDP	-1,209 (0,872)	-1,564 (0,946)	-1,555 (0,001)	-2,066 (0,000)
LEB	-1,991 (0,317)	-2,091 (0,681)	-2,496 (0,045)	-2,968 (0,038)
FR	0,016 (0,985)	0,096 (0,925)	-0,281 (0,000)	-0,293 (0,001)
MR	-2,606 (0,051)	-3,042 (0,058)	-2,659 (0,032)	-1,470 (0,005)
UP	-1,213 (0,870)	-2,863 (0,117)	-3,465 (0,000)	-3,695 (0,001)
CIPS	-1,478	-2,287	-4,300	-4,219

Source: Created by the authors

When the results of the second-generation unit root analysis presented in Table 5 are examined, the null

hypothesis of a unit root could not be rejected for all variables at the level (p>0,05). In contrast, it was rejected for the first differences of the variables (p<0,05). The critical values are -3,10***, -2,86**, and -2,73* for the intercept & trend Model, and -2,57***, -2,33**, and -2,21* for the only intercept model, corresponding to significance levels of 1%, 5%, and 10%, respectively (Pesaran, 2007).

Table 6: Panel Data Regression Analysis Results

Pooling Model				
Variable	**Estimate**	**Standard error**	**t-test statistic**	**p-value**
Intercept	-2,5843	2,0428	-1,2651	0,209
GDP	0,1393	0,0729	1,9104	**0,059***
LEB	-0,8058	0,5047	-1,5965	0,113
FR	-0,1235	0,2581	-0,4787	0,633
MR	0,2133	0,1114	1,9149	**0,058***
UP	1,3600	0,2346	5,7958	**0,001*****
Total Sum of Squares= 8,9848, Residual Sum of Squares= 2,3598, R^2= 0,7373, Adjusted R^2=0,7227, F-test statistic=50,5328, p-value <0,001				
Random Effect Model				
Intercept	13,2201	2,591242	5,1019	**0,001*****
GDP	0,2079	0,050363	4,1281	**0,001*****
LEB	-3,7977	0,735884	-5,1608	**0,001*****
FR	0,1111	0,209215	0,5311	0,595
MR	0,0581	0,078615	0,7398	0,459
UP	0,4969	0,284855	1,7445	**0,081***
Total Sum of Squares= 1,6453, Residual Sum of Squares= 1,0717, R^2=0,3962, Adjusted R^2=0,3330, χ^2-test statistic=48,1704, p-value <0,001				
Oneway (individual) effect Within Model				
Intercept	14,4394	2,6554	5,4377	**0,001*****
GDP	0,2072	0,0502	4,1241	**0,001*****
LEB	-4,1634	0,7646	-5,4451	**0,001*****
FR	0,1703	0,2117	0,8045	0,423
MR	0,0457	0,0787	0,5816	0,562
UP	0,5709	0,2886	1,9778	**0,051***
Total Sum of Squares=1,637, Residual Sum of Squares= 1,0307, R^2=0,4074, Adjusted R^2=0,3453, F- test statistic=10,236, p-value <0,001, Chow F=37,4, p<0,001, Breusch-Pagan LM test χ^2=1,4438, p=0,2295, Hausman test χ^2= 60,304, p<0,001				
Driscoll Kraay tahmin yöntemi				
Intercept	14,4394	1,9622	7,3588	**0,001*****
GDP	0,2072	0,0525	3,9432	**0,001*****
LEB	-4,1634	0,4634	-8,9845	**0,001*****
FR	0,1703	0,2020	0,8431	0,4014
MR	0,0457	0,0790	0,5792	0,5638
UP	0,5709	0,2817	2,0266	**0,0456****
Total Sum of Squares=1,637, Residual Sum of Squares= 1,0307, R^2=0,4074, Adjusted R^2= 0,3453, F- test statistic=33,6365, p-value <0,001				

Source: Created by the authors; *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively

In Table 6, parameter estimates are reported for the classical, random-effects, and fixed-effects models for the MINT countries. The results indicate that the models are generally statistically significant (p<0,001).

In both the random effects and fixed effects models, GDP, LEB, and UP are found to be statistically significant determinants of health expenditures, whereas in the classical Model, GDP, MR, and UP are significant. The significance levels of the variables are presented in the table. Moreover, when the results of the Chow/F test, the Breusch-Pagan Lagrange Multiplier test, and the Hausman test are considered together, it is determined that the fixed effects model provides more reliable results (Table 6). The test results regarding the presence of unit and/or time effects in the Model are presented in Table 7.

Table 7: Results of unit and/or time effects tests

Test	Unit	Time	Unit & Time
Lagrange Multiplier Test - (Breusch-Pagan)	1,4438 (0,001)	2,3495 (0,1253)	3,7933 (0,0501)
Lagrange Multiplier Test - (Honda)	1,2016 (0,001)	1,5328 (0,0626)	1,9335 (0,0665)

( ): statistically significant value;
Source: Created by the authors

Based on the results presented in Table 7, it is determined that the Model contains unit effects (p<0,05) but does not include time effects (p>0,05). The results of the model-assumption tests are presented in Table 8.

Table 8: Results of the heteroskedasticity, autocorrelation, and normality tests in the fixed effects model

Variable	Test statistic	*p*-value
HE	0,095	0,033
GDP	0,177	0,000
LEB	0,248	0,000
FR	0,303	0,000
MR	0,139	0,000
UP	0,152	0,000
Modified Wald χ^2 =51,18, p< 0,001, Breusch-Pagan BP=79,659, p<0,001		
Bhargava/Franzini/Narendranathan Panel Durbin-Watson DW = 1,2762		
Baltagi/Wu LBI = 1,3825		

Source: Created by the authors

In the one-way fixed effects model, the results of the modified Wald test indicate heteroskedasticity. In contrast, those of the Bhargava et al. (1982) Panel Durbin-Watson test and the Baltagi and Wu LBI test indicate the presence of autocorrelation (Table 8). Considering the results obtained using the Driscoll and Kraay estimator, which is robust to these assumption violations, GDP, LEB, and UP are found to have a significant effect on health expenditures in the MINT countries (p<0,05). In the Model estimated with robust standard errors, the explanatory variables account for approximately 40,7% of the variation in health expenditures (Table 6). Additionally, the results of the Kolmogorov-Smirnov normality analysis indicate that the variables do not follow a normal distribution (p<0,05). The box plots for each variable, presented

in Figure 1, further validate this result.

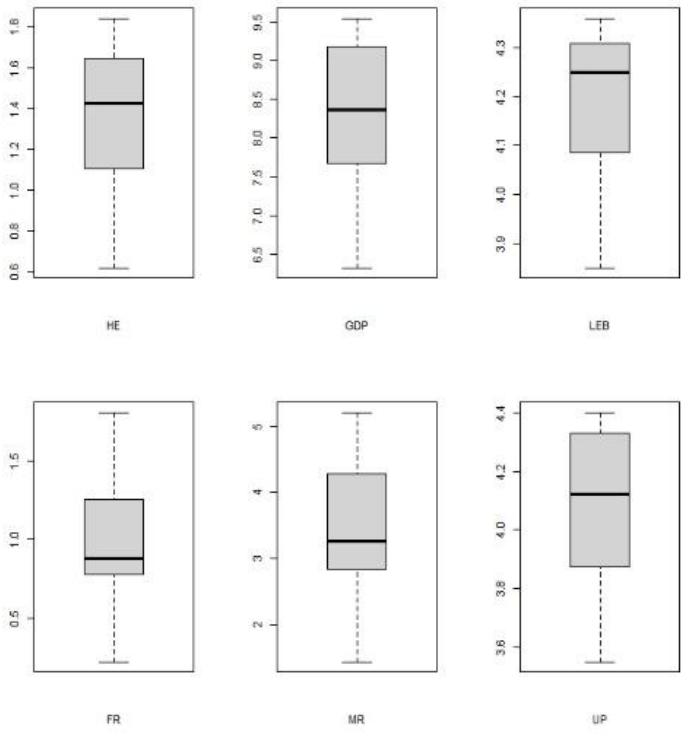


Figure 1: Box plots for the HE, GDP, LEB, FR, MR, and UP
Source: Created by the authors

Given that the normality assumption for the variables is not satisfied, it is inadvisable to interpret the parameter estimates obtained using the Driscoll-Kraay estimator. Instead, the estimates based on the quantile regression approach should be considered. The results of the panel quantile regression analysis, as well as the heterogeneity-robust panel quantile regression analysis based on the Machado-Santos Silva (MSS) test, are presented in Table 9.

The results of the quantile regression analysis for identifying the determinants of health expenditures are presented in Table 9. To assess heterogeneity across quantile regressions for varying quantile values, the Machado-Santos Silva (MSS) heterogeneity test was applied. The analysis revealed that the quantiles τ=0,10, 0,25, 0,50, 0,75, and 0,95 exhibited heterogeneity (p<0,05). Consequently, this study obtained robust estimates that account for heterogeneity and presents the parameter estimates in Table 9.

Table 9: Quantile Regression Analysis

Variable	τ=0,10		τ=0,25		τ=0,50		τ=0,75		τ=0,95	
	Estimate (std. error)	Test statistic (*p*-value)	Estimate (std. error)	Test statistic (*p*-value)	Estimate (std. error)	Test statistic (*p*-value)	Estimate (std. error)	Test statistic (*p*-value)	Estimate (std. error)	Test statistic (*p*-value)
GDP	0,2832	2,74	0,2525	3,28	0,2033	3,80	0,1586	2,18	0,1108	0,92
	(0,1032)	**(0,000)**	(0,076)	**(0,001)**	(0,0535)	**(0,000)**	(0,0728)	**(0,030)**	(0,1203)	**(0,000)**
LEB	-25,360	-1,39	-31,943	-2,33	-42,484	-4,45	-52,076	-4,03	-62,326	-2,88
	(-18,224)	(0,164)	(-13,690)	**(0,020)**	(0,9543)	**(0,000)**	-12,927	**(0,000)**	-21,641	**(0,004)**
FR	-0,0868	-0,22	0,0010	0,01	0,1417	0,70	0,2697	0,97	0,4065	0,90
	(0,3945)	(0,826)	(0,2925)	**(0,001)**	(0,2029)	(0,485)	(0,2777)	(0,331)	(0,4521)	(0,368)
MR	0,1720	0,99	0,1265	0,97	0,0535	0,59	-0,0128	-0,10	-0,0837	-0,42
	(0,1742)	**(0,000)**	(0,1300)	**(0,000)**	(0,0904)	(0,554)	(0,1231)	**(0,000)**	(0,2016)	**(0,025)**
UP	0,4856	0,80	0,5344	1,20	0,6126	1,99	0,6838	1,61	0,7599	1,11
	(0,6083)	**(0,000)**	(0,4464)	**(0,000)**	(0,3084)	**(0,047)**	(0,4254)	**(0,000)**	(0,6824)	**(0,000)**
Pseudo R^2	0,6386		0,6079		0,6067		0,5446		0,5441	
MSS χ^2 test stat.	12,408		13,946		11,186		0,789		7,995	
p-value	0,002		0,001		0,004		0,044		0,018	
Heterogeneity-Robust Panel Quantile Regression										
GDP	0,3093	3,72	0,2726	3,9	0,1167	1,75	0,0530	0,84	0,1133	3,73
	(0,0832)	**(0,000)**	(0,0882)	**(0,003)**	(0,0667)	**(0,043)**	(0,0632)	**(0,044)**	(0,0304)	**(0,000)**
LEB	-0,6103	0,51	-0,7841	-1,94	-0,7557	-2,30	-14,857	-4,56	-28,645	-7,56
	(-11,877)	(0,609)	(0,4033)	**(0,055)**	(0,3279)	**(0,023)**	(0,3260)	**(0,000)**	(0,3788)	**(0,000)**
FR	-0,1809	-0,32	-0,7212	-3,57	-0,4362	-2,21	-0,3174	-2,56	-0,5510	-7,59
	(0,5613)	(0,748)	(0,2018)	**(0,001)**	(0,1969)	**(0,029)**	(0,1241)	**(0,012)**	(0,0726)	**(0,000)**
MR	0,4239	1,80	0,5404	5,77	0,4235	4,78	0,3846	7,25	0,4020	13,61
	(0,2353)	**(0,075)**	(0,0936)	**(0,000)**	(0,0885)	**(0,000)**	(0,0530)	**(0,000)**	(0,0295)	**(0,000)**
UP	0,8285	-1,74	14,532	5,54	18,867	10,28	21,373	13,77	21,977	19,19
	(-4,9621)	**(0,085)**	(0,2623)	**(0,010)**	(0,1835)	**(0,000)**	(0,1551)	**(0,000)**	(0,1145)	**(0,000)**
Pseudo R^2	0,6708		0,6989		0,7172		0,6515		0,5917	

Source: Created by the authors

According to these results, GDP is significant at the 95% confidence level across all quantile levels of health expenditures in the MINT countries. Holding other variables constant, a 1% increase in GDP raises health expenditures by 0,28% at the $\tau = 0,10$ quantile, 0,25% at the $\tau = 0,25$ quantile, 0,20% at the $\tau = 0,50$ quantile, 0,15% at the $\tau = 0,75$ quantile, and 0,11% at the $\tau = 0,95$ quantile. It indicates that higher levels of health expenditures are associated with smaller increases. The LEB and FR variables are not significant at the lower quantile level ($\tau = 0,10$), while their effects on health expenditures become statistically significant at $\tau = 0,25$ and higher quantile levels. On the other hand, MR and UP are significant across all quantile levels.

In conclusion, based on the parameter estimates from the heterogeneity-robust panel quantile regression analysis, GDP, LEB, FR, MR, and UP have statistically significant effects on health expenditures at all quantile levels except τ=0,10 in the MINT countries. Increases in GDP, MR, and UP raise health expenditures, whereas increases in LEB and FR reduce health expenditures (Table 9).

DISCUSSION AND CONCLUSION

While the literature has primarily focused on the impact of health expenditures on variables such as economic growth, this study examines the effects of factors including GDP per capita, life expectancy at birth, fertility rate, mortality rate, and urban population on health expenditures in the MINT countries. Based on the tests of the model assumptions, it was determined that a heterogeneity-robust panel quantile regression analysis should be employed for modelling the data. According to the results of this study, increases in GDP per capita, the under-five infant mortality rate, and the urban population are associated with higher health expenditures. In contrast, increases in life expectancy at birth and the fertility rate are associated with lower health expenditures. These findings are largely consistent with previous studies. For instance, Girgin (2022) reports a positive relationship between health expenditures and economic growth in OECD countries, while similar positive relationships are observed in G20 countries (Çelik, 2020), in Türkiye (Şen & Bingöl, 2018), in OECD countries (Kılıç & Özbek, 2018), and in BRIC countries (Şahbudak & Şahin, 2015). While Girgin (2022) finds a positive relationship between life expectancy at birth and health expenditures, this contradicts the present study's results.

Moreover, Sayılı et al. (2017) emphasize that both per capita income and the share of income allocated to health are important for increasing health expenditures. Similarly, Alkaya and Gülbahar (2022) find a positive and significant effect of GDP per capita on health expenditures. In contrast, Akar (2014) reports no significant short-term relationship between health expenditures, their relative prices, and economic growth, but finds a significant long-term association. Güven et al. (2018), focusing on MENA countries, identify a negative relationship between health expenditures and economic growth. Overall, while the positive effect of GDP per capita on health expenditures found in this study aligns with the majority of prior research, the negative impact of life expectancy and fertility rates on health expenditures partially diverges from previous findings, highlighting contextual

differences across countries and regions.

Across all quantile levels in this study, an increase in the under-five infant mortality rate was associated with higher health expenditures. This positive relationship between the two variables contrasts with the findings of Sever and İğdeli (2019) and Eryer and Ata (2024). On the other hand, Şantaş et al. (2021) report that increases in health expenditures in OECD countries are associated with higher infant mortality rates, whereas Evirgen (2023) finds that increased health expenditures reduce under-five child mortality. Similarly, this study's results indicate that health expenditures increase with urban population growth across all quantiles in the MINT countries. Comparable studies have also found that higher urban populations are associated with increased health expenditures in OECD countries (Acar & Topdağ, 2022) and in Türkiye (Kılıç & Kurt, 2020). However, some studies report no statistically significant relationship between urban population growth and health expenditures (Ecevit & Çetin, 2022).

Empirical evidence indicates that higher per capita gross domestic product in MINT countries is associated with higher health expenditures; therefore, policies that promote economic growth should be developed in these countries. It is recommended that governments allocate a larger share of public budgets to expand healthcare investments, strengthen health systems, and improve access to health services. On the other hand, since an increase in life expectancy at birth reduces health expenditures, long-term health policies should be developed to address the healthcare needs of an ageing population, and preventive healthcare programs should be established to enhance elderly individuals' access to health services. The reduction in health expenditures associated with an increase in the fertility rate can be explained by the prevalence of extended family structures or the activation of social support systems. Moreover, as higher fertility rates generally imply a larger proportion of young people, it can be argued that health expenditures may decline due to the provision of preventive healthcare services and to lower utilization of healthcare services by younger individuals. In this context, the integration of social services with healthcare systems and international aid organizations should be ensured, and greater investment in preventive healthcare services is recommended. If an increase in the under-five mortality rate leads to higher health expenditures, this should be regarded as a serious public health concern. Therefore, greater resources should be allocated to child health, immunization programs should be strengthened, and awareness campaigns focusing on maternal and child health should be expanded. In addition, early diagnosis and intervention programs should be developed. Regular health check-ups during pregnancy and the postnatal period should be ensured, and mothers and infants at risk should be identified and closely monitored.

Furthermore, access policies should be implemented to facilitate access to healthcare services for individuals in rural areas who face difficulties. All families with infants should be offered training programs to improve health literacy. Finally, continuous professional development opportunities should be offered to existing healthcare personnel through in-service training programs. Since the increase in urban population leads to higher health

expenditures, it is necessary to expand the number of healthcare facilities, improve the quality of healthcare services, and enhance public health awareness in urban areas to facilitate access to care. Moreover, health-related factors should be explicitly considered in urban planning processes.

REFERENCES

Acar, T., & Topdağ, D. (2022). OECD ülkelerinde sefalet endeksi ve ekonomik kalkınma ekseninde sağlık harcamalarının belirleyicileri: Toplamsal olmayan sabit etkili panel kantil regresyon yaklaşımı. *Sosyal Siyaset Konferansları Dergisi, 82,* 267–286. https://doi.org/10.26650/jspc.2022.82.946640

Akar, S. (2014). Türkiye'de sağlık harcamaları, sağlık harcamalarının nisbi fiyatı ve ekonomik büyüme arasındaki ilişkinin incelenmesi. *Yönetim ve Ekonomi Dergisi*, *21*(1), 311–322. https://doi.org/10.18657/yecbu.70940

Akdur, R. (2008). Sağlık harcamaları. *Bilim ve Ütopya*, *14*(170), 1–8. 14-akdur-r-sag-lik-harcamalari-bilim-ve-u-topya-14170-14-19-ag-ustos-2008.pdf

Akın, C. S. (2007). *Effect of the health and health expenditure on economy, Turkish health sector and expenditures for health* [Master's thesis, Çukurova University].

Alkaya, A., & Gülbahar, H. O. (2022). Sağlık harcamaları üzerinde sağlık harcamalari belirleyicileri etkisi: OECD ülkeleri panel regresyon analizi. *Üçüncü Sektör Sosyal Ekonomi Dergisi*, *57(1)*, 47–67. https://doi.org/10.15659/3.sektor-sosyal-ekonomi.22.01.1712

Arslan, A. (2022). *Panel data analysis of the effect of health spending on health indicators: the case of oecd countries* [Master's thesis, İzmir Bakırçay University].

Baltagi, B.H. (2021). *Econometric analysis of panel data* (6th ed.). Springer, Cham. https://doi.org/10.1007/978-3-030-53953-5

Bhargava, A., Franzini, L., & Narendranathan, W. (1982). Serial correlation and the fixed effects model. *The Review of Economic Studies*, *49*(4), 533–549. https://doi.org/10.2307/2297285

Breusch, T.S., & Pagan, A.R. (1980). The lagrange multiplier test and its applications to model specilcation tests in econometrics. *Review of Economic Studies*, *47*(1), 239–253. https://doi.org/10.2307/2297111

Çalışkan, Z. (2009). OECD ülkelerinde sağlık harcamaları: Panel veri analizi. *Erciyes Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *34*, 117–137. https://izlik.org/JA47SP25WA

Çelik, A. (2020). G20 ülkelerinde sağlık harcamalarının ekonomik büyüme üzerindeki etkisinin analizi. *Yönetim ve Ekonomi Dergisi*, *27*(1), 1–20. https://doi.org/10.18657/yonveek.594695

Daştan, İ., & Çetinkaya, V. (2015). OECD ülkeleri ve Türkiye'nin sağlık sistemleri, sağlık harcamaları ve sağlık göstergeleri karşılaştırması. *Sosyal Güvenlik Dergisi*, *5*(1), 104–134. https://izlik.org/JA92BU36AG

Ecevit, E., & Çetin, M. (2022). Ekonomik büyüme, yenilenebilir enerji tüketimi, finansal gelişme ve kentleşmenin sağlık harcamaları üzerindeki etkisi: Türkiye ekonomisi üzerine bir zaman serisi kanıtı. *Sosyal Bilimler Metinleri, 2022*(2), 84–98. https://doi.org/10.56337/sbm.1109342

Eryer, A., & Ata, A. Y. (2024). Sağlık harcamaları ve gelir dağılımının bebek ölüm hızı üzerine etkisi: OECD ülkeleri üzerine ekonometrik bir inceleme. *Kahramanmaraş Sütçü İmam Üniversitesi Sosyal Bilimler Dergisi*, *21*(1), 174–189. https://doi.org/10.33437/ksusbd.1358615

Evirgen, Ö. (2023). Türkiye'de cepten yapılan sağlık harcamaları ile kamu sağlık harcamalarının ölüm oranları üzerine etkileri: Bölgesel analiz. Başkent Üniversitesi Sağlık Bilimleri Fakültesi Dergisi, 8(1), 73–87. https://izlik.org/JA63JG77XZ

Filiz, Y. (2010). *Ekonomik büyüme ve sağlık harcamaları ilişkisi* [Yüksek lisans tezi, Atılım Üniversitesi].

Girgin, O. (2022). *The impact of healthcare expenditures on economic growth, investments, labor force and life expectancy* [Master's thesis, Karamanoğlu Mehmetbey University].

Güven, D., Şimşek, T., & Güven, A. (2018). Sağlık yönetimi kapsamında sağlık harcamalarının ekonomik büyüme üzerine etkisi: MENA ülkeleri üzerine bir panel regresyon analizi. *Sosyoekonomi*, *26*(37), 33–55. https://doi.org/10.17233/sosyoekonomi.2018.03.02

Haseeb, M., Kot, S., Hussain, H. I., & Jermsittiparsert, K. (2024). Impact of economic growth, environmental pollution, and energy consumption on health expenditure and R&D expenditure of ASEAN countries. *Energies*, *17*(12), 2879. https://doi.org/10.3390/en17122879

Ilıman, T. (2022). Türkiye'de nüfus artışının toplam sağlık harcamaları üzerindeki etkisi: 2000-2020 teorik analiz örneği. *III. Uluslararası Farklı Boyutlarıyla Sağlık Konferansı: Sağlık Turizminin Dünü, Bugünü ve Geleceği*, ss. 44–57, 22-23 Aralık 2022, Çanakkale.

Kılıç, C., & Kurt, Ü. (2020). Kentleşmenin sağlık harcamaları üzerindeki etkisi: Türkiye için ARDL sınır testi yaklaşımı. *Kafkas Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *11*(21), 290–305. https://doi.org/10.36543/kauiibfd.2020.014

Kılıç, R., & Özbek, R. İ., (2018). Sağlık ve eğitim hizmetleri ile ekonomik büyüme ilişkisi: OECD ülkeleri uygulaması. *Ordu Üniversitesi Sosyal Bilimler Enstitüsü Sosyal Bilimler Araştırmaları Dergisi*, *8*(2), 369–391. https://izlik.org/JA28XC82FR

Koenker, R. (2004). Quantile regression for longitudinal data. *Journal of Multivariate Analysis*, *91*(1), 74–89. https://doi.org/10.1016/j.jmva.2004.05.006

Koenker, R. (2005). *Quantile regression* (Vol. 38). Cambridge University Press.

Koenker, R., & Hallock, K. F. (2001). Quantile regression. *Journal of Economic Perspectives*, *15*(4), 143–156. https://doi.org/10.1257/jep.15.4.143

Koenker, R., & Machado, J. A. (1999). Goodness of fit and related inference processes for quantile regression. *Journal of the American Statistical Association*, *94*(448), 1296–1310. https://doi.org/10.1080/01621459.1999.10473882

Kostak, P. (2021). *Causal relationships between CO2 emissions, health expenditures and economic growth: A study on EU countries* [Master's thesis, Nevşehir Hacı Bektaş Veli University].

Kurtdaş, M. Ç. (2016). "Sağlıklı Yaşam!" sloganı etrafında şekillenen yeni tüketim biçimleri. *Sosyolojik Düşün*, *1*(1), 1–10. https://izlik.org/JA47KT28JH

Künü, S., & Levent, C. (2023). Sağlık harcamaları, CO_2 emisyonu ve ekonomik büyüme ilişkisi: Seçilmiş AB ülkeleri örneği. *Uluslararası Ekonomi ve Yenilik Dergisi*, *9*(1), 95–110. https://doi.org/10.20979/ueyd.1202332

Li, F., Chang, T., Wang, M. C., & Zhou, J. (2022). The relationship between health expenditure, CO_2 emissions, and economic growth in the BRICS countries-based on the Fourier ARDL model. *Environmental Science and Pollution Research*, *29*(8), 10908–10927. https://doi.org/10.1007/s11356-021-17900-w

Majdi, M. (2014). The relationship between efficiency of healthcare costs and economic growth: Empirical validation from Mediterranean countries. *Management Studies and Economic Systems*, *1*(1), 1–13. https://www.msaes.org/article_5988_dfbfa7ddcfffeb581f50edcf9a0204bb.pdf

Orak, F., & Narin, M. (2023). Türkiye'de sağlık harcamaları ve sağlık harcamalarını etkileyen faktörler: 2000-2021 dönemi. *5. Uluslararası Antalya Bilimsel Araştırmalar ve Yenilikçi Çalışmalar Kongresi*, ss.969–980, 26-28 Temmuz 2023, Antalya.

Pesaran, M. H. (2004). *General diagnostic tests for cross-section dependence in panels*, Cambridge Working Papers in Economics. https://docs.iza.org/dp1240.pdf

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics, 22*(2), 265–312. https://doi.org/10.1002/jae.951

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews, 34*(6-10), 1089–1117. https://doi.org/10.1080/07474938.2014.956623

Safkan, E. (2020). *The effect of health expenditures on growth: A panel regression analysis on fragile five countries* [Master's thesis, Çukurova University].

Sağlam, Ş., & Kara, O. (2023). Sağlık statüsündeki değişimler kamu harcama bileşenini etkiler mi? gelişmiş ülkeler üzerine bir uygulama. *Hacettepe Sağlık İdaresi Dergisi*, *26*(3), 575–596. https://izlik.org/JA29DN36RR

Sayılı, U., Sayman, Ö. A., Vehid, S., Köksal, S. S., & Erginöz, E. (2017). Türkiye ve OECD ülkelerinin sağlık göstergeleri ve sağlık harcamalarının karşılaştırılması. *Online Türk Sağlık Bilimleri Dergisi*, *2*(3), 1–12. https://doi.org/10.26453/otjhs.321742

Sever, E., & İğdeli, A. (2019). Sağlık harcamaları, sağlık çıktıları ve ekonomik büyüme ilişkisi: Türkiye örneği. *Akademik Araştırmalar ve Çalışmalar Dergisi*, *11*(20), 246–259. https://doi.org/10.20990/kilisiibfakademik.533164

Şahbudak, E., & Şahin, D. (2015). Sağlık ve ekonomik büyüme arasındaki ilişkinin analizi: BRIC ülkeleri üzerine bir panel regresyon analizi. İşletme ve İktisat Çalışmaları Dergisi, 3(4), 154–160. https://izlik.org/JA42RX36FG

Şantaş, F., Şantaş, G., & Demirgil, B. (2021). Kamu sağlık harcamasının üç temel sağlık göstergesine etkisi: OECD ülkeleri üzerine bir panel regresyon analizi. *Dicle Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *11*(21), 73–84. https://doi.org/10.53092/duiibfd.869689

Şen, A., & Bingöl, N. (2018). Sağlık harcamaları ve ekonomik büyüme ilişkisi: Türkiye örneği. *Akademik Yaklaşımlar Dergisi*, *9*(1), 89–106. https://izlik.org/JA69XK56YF

Tatoğlu, F.Y. (2016). *Panel veri ekonometrisi Stata uygulamalı* (7. Baskı). Beta Basım Yayım.

Yıldırım, N., & Bulut, M. (2023). Sağlık kavramına eleştirel bakış. *Sağlık ve Toplum*, *33*(2), 55–62. https://ssyv.org.tr/wp-content/uploads/2023/08/6-Saglik-Kavramina-Elestirel-Bakis.pdf

Yücel, M. H., & Çalişkan, Z. (2023). Türkiye'de sağlık harcamalarının ARIMA yöntemi ile tahmini. *Fiscaoeconomia*, *7*, 552–580. https://doi.org/10.25295/fsecon.1350399

Zerecan, P., & Atakan, C. (2024), Ülkelerin sağlık harcamalarının faktör analizi ile değerlendirilmesi. *Sosyal Güvence Dergisi*, *12*(24), 1196–1227. https://doi.org/10.21441/sosyalguvence.1469273

InTraders International Trade Academic Journal

e-ISSN: 2667-4408 **www.intraders.org**

Volume: 9
Issue : 1
Research Article

Received: January 27, 2026
Revision: March 30, 2026
Accepted: April 21, 2026
DOI: https://www.doi.org/10.55065/intraders.1873038

How Does ESG Uncertainty Affect Green Finance: Evidence from High ESG-Performance Countries

Çisem BEKTUR[1]

Abstract

The ongoing climate crisis has made sustainable development a strategic element of economic policies, leading to the adoption of green finance, an approach based on environmental, social, and governance (ESG) standards instead of traditional financial methods. The aim of this study is to examine the effects of environmental protection on green finance and to evaluate them within the framework of inflation and financial development variables. The analysis covers seven countries (Australia, Belgium, France, Germany, Ireland, the Netherlands, and Sweden) that scored 85 points or higher in the ISESG 2025 global ESG ranking and covers the period 2002-2021. The Fourier Panel KPSS stationarity test and Westerlund & Edgerton's cointegration test are utilised in the study. Long-term coefficients are then obtained through AMG and rCCE estimators. The analysis results reveal a long-term relationship between the variables and significant heterogeneity among countries. The findings indicate that ESG uncertainty negatively impacts green finance in Ireland and Sweden, however, positively impacts it in Belgium. Considering the results of both coefficient estimates, inflation is found to have a negative impact on green finance only in Germany, while financial development has played a supportive role in Ireland and the Netherlands. Therefore, the analyses reveal that high ESG performance alone does not guarantee the stability of green finance, and ESG uncertainty plays a decisive role in this process. This study aims to contribute to the literature by being the first to directly examine the empirical relationship between country-specific ESGUI and green finance, focusing on the group of countries with the highest ESG scores.

Keywords: *Green Finance, ESG-Related Uncertainty Index (ESGUI), Inflation, Financial Development, Cointegration Test*

JEL Codes: *Q56, C580*

INTRODUCTION

Today, the global economy has reached an irreversible point due to the depletion of natural resources and the climate crisis. This situation has transformed sustainable development from a choice into the most strategic element of economic policies. At this point, green finance (GRF) systems have stepped in, eliminating the

There is no conflict of interest.

[1]Asst. Prof. Dr. ,Sakarya University, E-Mail : cisembektur@sakarya.edu.tr, OI: 0000-0001-9220-5932

Cite As: Bektur, Ç. (2026). How does ESG uncertainty affect green finance: Evidence from high ESG-performance countries. *InTraders International Trade Academic Journal, 9*(1), 90–106. https://doi.org/10.55065/intraders.1873038

traditional financial systems' disregard for their destructive environmental impacts and replacing them with an approach based on environmental, social, and governance (ESG) standards. GRF systems have become the strongest driving force in the transition to a low-carbon economy, using capital not solely for profit but for a cleaner environment (Chen & Chen, 2021). Studies examining the relationship between ESG and GRF have indicated that, on the one hand, firms' ESG scores are important in shaping green bond issuances and investor capital allocation processes (Zheng et al., 2023; Wang & Wang, 2022). On the other hand, it has been demonstrated that ESG performance does not always positively influence GRF, information asymmetry and inadequate reporting practices increase the risk of greenwashing, raising debates about the reliability of ESG indicators (Zhang & Zhang, 2026, Kathan et al., 2025).

On the other hand, the development of GRF is not limited solely to firm-level ESG indicators, however is also significantly influenced by macroeconomic conditions (Le et al., 2023). Inflation (INF) and the monetary policies implemented as a result directly affect the cost and return expectations of green investments. Increased interest rates during periods of high inflation raise the capital costs of green projects, making it more difficult to finance these investments and limiting the volume of GRF (Ergün, 2024). In addition, macroeconomic uncertainty could strengthen investors' risk-aversion tendencies, reducing demand for green financial instruments.

The level of financial development (FD) also stands out as a decisive factor in the spread of GRF. Developed financial systems facilitate access to long-term and low-cost funds necessary for green projects and support the implementation of sustainable infrastructure investments. However, studies examining the direct effects of FD on GRF are limited in the literature (Al-Mulali et al., 2015; Fernandes et al., 2021).

The aim of this study is to comprehensively analyse the relationship between GRF and ESG uncertainty (ESGUI), and to evaluate this relationship within the framework of key macroeconomic variables such as INF and FD. The study aims to contribute to the literature by revealing the effects of ESG indicators on GRF, and to offer implications for policymakers and investors on increasing the effectiveness of GRF. Previous studies largely focus either on firm-level ESG scores or sector-specific green finance in selected countries, with cross-country analyses including macroeconomic controls such as inflation and financial development largely neglected. Furthermore, although ESG performance is frequently examined, the impact of ESGUI as an independent factor affecting national-level GRF has rarely been empirically tested. Moreover, given that ESGUI is indirectly linked to national ESG performance, this study examines countries with high ESG scores, providing insights for a significant subset of countries that are underrepresented in the literature.

LITERATURE REVIEW

This study will primarily address research focusing on the GRF-ESG relationship. Following this, previous research on the limited number of ESGUI studies will be presented. Finally, the impact of two other economic indicators found in the literature that may be related to GRF, namely INF and FD, will be examined.

Green Finance And ESG

Both ESG performance and ESG uncertainty play a decisive role in green finance in terms of volume, direction, and cost. While strong ESG performance can positively impact green finance in certain cases, it may also have negative effects under different conditions. Two theories that reveal the relationship between GRF and ESG performance are "signal theory" and "stakeholder theory". Signal theory posits that in an environment of information asymmetry, firms send reliable signals that present themselves as high-quality to investors (Arhinful et al., 2025; Dutordoir et al., 2024). It suggests that firms attract investors who care about sustainability and the environment through green financing instruments they issue (Ajour El Zein et al., 2020). High ESG scores, issued green bonds, and net-zero commitments made by companies regarding sustainability and a clean environment all send positive signals to the markets (Tron et al., 2025).

Stakeholder theory argues that companies have a responsibility not only to their shareholders but to all their stakeholders. ESG is a reflection of stakeholder expectations. The firm must consider the expectations of all stakeholders (Freeman, 2010). ESG is a measurable, reportable, and auditable form of the demands asserted by stakeholders (Donaldson & Preston, 1995). Green finance enables investment in projects that benefit society by providing funding to stakeholders. This increases stakeholder trust in the company and improves its social acceptability (Sun et al., 2025; Lee & Raschke, 2023). In other words, investment in ESG does not only consider financial risk but also environmental and social impacts, and combines stakeholder expectations with financial returns (OECD, pg 14, 2020).

Some studies demonstrating the positive effects of ESG on GRF are as follows:

Mustafa et al. (2025), in their study, have examined companies in China operating in sectors that cause significant pollution and have found that companies with high ESG performance are able to obtain more bank loans, increase green loan applications, and reduce credit costs. GRF not only provides financing to businesses to promote green technology but can also improve companies' ESG performance. Increased ESG performance increases both social and environmental awareness, paving the way for the development of GRF (Shen, 2025). Another study conducted in China has shown that while ESG scores increase green innovation efforts by institutions, they also degrade their quality. It is shown that ESG scores provide confidence to investors, facilitating easier access to green finance (Chen & Yue, 2024).

On the other hand, studies identifying the negative impacts of ESG on GRF are also present in the literature. The development of ESG reports and the increasing demand for green finance in the market have brought "greenwashing" problems to the forefront. In this context, Liu et al. (2024) have examined ESG reports and firms' greenwashing practices in the Chinese market for the year 2022. The results show that greenwashing is increasing. They have revealed that this increase is caused by insufficient information disclosure, information asymmetry, and firms' preference for pursuing their short-term interests. Kathan et al. (2025) have aimed to demonstrate that companies with high ESG scores are more inclined towards greenwashing by examining the greenwashing practices of STOXX Europe 600 components between 2015 and 2023. The study has found a significantly positive correlation between apparent environmental performance and ESG scores, but a negative correlation with actual performance. This suggests that ESG scores are not sufficient to measure true environmental impact and may even mislead investors who prioritise high ESG scores.

From an uncertainty perspective, Nawaz and Su (2026) have confirmed that sustainability uncertainty plays a significant role in the growth and promotion of GRF. Akadiri and Özkan (2026) have further confirmed that green bonds and carbon pricing mechanisms mitigate the negative impact of ESGUI on clean energy markets and reduce uncertainty. Luo et al. (2026) have also found in their study that ESGUI is the strongest source of uncertainty, particularly increasing volatility in ESG and green bond markets. Wang et al. (2026) have identified a negative association between ESGUI and green bond yields in the short term, contrast with a positive relationship in the medium and long term, and additionally found that the hedging effectiveness of ESGUI increased in the long term. Moreover, Dou et al. (2025) have found that GRF positively influences artificial intelligence, thereby contributing to a reduction in ESGUI. Das et al. (2025) have demonstrated that the combined effects of geopolitical, climate, and ESG risks are strongly and positively associated with government green bond issuance.

Green Finance, Inflation and Financial Development

The effects of inflation on green finance are mostly negative, and this effect varies depending on the level of inflation and the government's monetary policy. High inflation leads to tight monetary policies and consequently to increased interest rates, raising the discount rate on green investments and potentially causing their cancellation, thus negatively impacting green finance. High interest rates increase the cost of sustainable investments, delaying the green transition and hindering the possibility of achieving price stability. The way to combat high inflation is through a "greener and cheaper" monetary policy approach (Aguila & Wullweber, 2024).

Chen & Lin (2024) have examined the impact of tight monetary policy on renewable energy using quarterly data from the US between 1990 and 2023. The results have demonstrated that tight monetary policy caused a decrease in the volume of renewable energy production. Czipf (2025) investigates how changes in interest rates affect the net present value and internal rate of return of green projects and has found that high interest rates lead to a failure to generate returns on green projects. This situation reduces the attractiveness of green finance.

On the other hand, high inflation is a state of uncertainty for investors. In this uncertain environment, investors will want to avoid risk and will reduce their demand for green bonds accordingly (Köycü, 2025). Aleknevičienė et al. (2025) have investigated the effects of uncertainty indices on the green bond market during the Russia-Ukraine war. The authors have concluded that uncertainties such as the unpredictability of high inflation make the market more sensitive, lead to changes in investor behaviour, and could negatively impact demand for green bonds.

Another situation is that increasing inflation raises input prices, thereby increasing the cost of green projects and making financing more difficult. This leads to increased risk perception among investors, reducing demand for green finance (Handler & Shandy, 2023). Berk et al. (2023) have established that rising inflation and interest rates will lead to a decrease in the yield spread between green and traditional bonds, in other words, a contraction in greenium. This also reduces demand for green bonds.

Furthermore, the pressure on policy interventions regarding climate change is leading to debates among central banks about whether it is necessary to pursue a monetary policy for a green environment. These green monetary policies are not explicitly included in the goals of central banks. The main goal of most is financial stability. Green credit incentives are relegated to the background, limiting green finance. Therefore, environmental goals conflict with monetary policy goals (Rosa, 2025). While green money policies could have positive environmental impacts when inflation is low, it has been observed that tight monetary policies outpace environmental policy tools during periods of high inflation (Aguila & Wullweber, 2024).

While there are studies in the literature examining the environmental impacts of FD and GRF variables, studies demonstrating the direct effects of FD on GRF are quite limited. A country's FD is an important factor in terms of its environmental sustainability. Stronger environmental performance depends on increasing green investments within a developed financial system (Farooq et al., 2024). Developed economies can easily access the financial resources needed for infrastructure investments in all kinds of green technologies related to green finance and sustainability. A study covering the period 1990-2020 in 21 OECD countries has concluded that FD increased GRF (Khan et al., 2024). Therefore, the impact of FD on GRF plays a very important role in terms of sustainable finance and environmental practices.

Based on studies presented in the literature, this study proposes the following hypotheses regarding the effects of ESGUI, INF, and FD on GRF:

H1: ESGUI has a negative and statistically significant effect on GRF.

H2: INF has a negative and statistically significant effect on GRF.

H3. FD has a positive and statistically significant effect on GRF.

To provide empirical evidence for the proposed hypotheses, the following section elaborates on the data, model specification, and econometric framework employed in this study.

DATA AND METHODOLOGY

Data

This study offers a relatively new perspective on the impact of ESG country-based sustainability uncertainty on green finance. The study examines seven countries (Australia, Belgium, France, Germany, Ireland, the Netherlands, and Sweden) in the top performers category (scoring above 85) according to ISESG's 2025 global ESG ranking, covering the period 2002-2021. We estimate that ESG sustainability uncertainty (ESGUI), inflation (INF), and financial development (FD) affect green finance (GRF) in these countries. The following model is developed to test this prediction:

$$GRF_{it} = \beta_0 + \beta_1 LNESGUI_{it} + \beta_2 INF_{it} + \beta_3 FD_{it} + \varepsilon_{it} \quad (1)$$

Here, while i denotes the countries, t denotes the time. ε_{it} is the error term. $\beta_0, \beta_1, \beta_2, and\ \beta_3$ denote the coefficients of the constant, ESGUI, INF, and FD, respectively. Only the ESGUI variable is used in its natural logarithmic form. The definitions and the sources of the variables are displayed in Table 1.

Table 1: Variable Definitions and Sources

Variables	Definition	Sources
Dependent variable		
Green Finance (GRF)	Government expenditures on environmental protection is used as a proxy for GRF (% of GDP).	https://unctadstat.unctad.org/datacentre/dataviewer/US.GovExpenditures Access date: 15.01.2026
Independent variables		
ESG-Based Sustainability Uncertainty (ESGUI)	This index ranges from the maximum value of 100 to the minimum value of 0. It is obtained from Ongan et. al. (2025).	https://www.policyuncertainty.com/sustainability_index.html Access date: 15.01.2026
Inflation (INF)	Annual percentage change in the consumer price index	World Bank's World Development Indicators. Access date: 15.01.2026

Financial Development (FD)	Composite index measuring the depth, access, and efficiency of financial institutions and financial markets	IMF Financial Development Database. Access date: 15.01.2026

Source: Created by the author

The descriptive statistics of the variables are provided in Table 2.

Table 2: Descriptive Statistics

Variables	Mean	Maximum	Minimum	Std. Dev.	VIF
GRF	0,883107	1,747000	0,348000	0,373260	
ESGUI	30,13635	70,94463	14,61446	8,110169	1,015
INF	1,644907	4,885745	-4,447547	1,218774	1,051
FD	0,760855	0,967435	0,588145	0,084945	1,055

Source: All values are calculated by the author via EVIEWS program.

There are 140 observations (20 years and 7 countries) in total. Since the calculated VIF values are less than 5, there is no multicollinearity problem. The GRF variable exhibits a maximum of 1,747, a minimum of 0,348, and an average of 0,883. On the other hand, the ESGUI variable ranges from 14,614 to 70,944, with an average value of 30,136. The INF and FD variables have a maximum of 4,885 and 0,967, a minimum of -4,447 and 0,588, and an average of 1,644 and 0,760, respectively. The standard deviations of GRF, ESGUI, INF and FD variables are 0,373, 8,110, 1,218 and 0,084, respectively.

METHODOLOGY

In panel data analysis, it is first necessary to conduct cross-sectional dependence (CSD) of variables and heterogeneity of slopes. After analysing the CSD of the model and variables via the CDLM1 (Breusch & Pagan, 1980), CDLM2, and Pesaran's CD tests (Pesaran, 2004) given in Eq 2;

$$CD = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^{2} \qquad CD_{LM1} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\hat{\rho}_{ij}^{2}-1\right)$$

$$CD_{LM2} = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^{2} \qquad (2)$$

The hypothesis valid for all three tests above is as follows:

H_0: there is no CSD and H_1: there is CSD.

Then, the slope heterogeneity test is applied by utilising two Delta test statistics proposed by Pesaran & Yamagata (2008):

$$\widehat{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S}-k}{\sqrt{2k}}\right) \quad \text{and} \quad \widehat{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\tilde{S}-E(\tilde{z}_{\widehat{it}})}{\sqrt{var(\tilde{z}_{\widehat{it}})}}\right) \tag{3}$$

Here, $E(\tilde{z}_{\widehat{it}}) = k,\ var(\tilde{z}_{\widehat{it}}) = \frac{2k(T-k-1)}{T+1}$ and $\tilde{S}$ is the changed statistics of Swamy (1970). Homogeneity and heterogeneity are the null and alternative hypotheses, respectively.

At the second step of the analyses, the stationarity of the variables is examined through Fourier KPSS test introduced by Nazlıoğlu & Karul (2017), a panel-adapted version of the Fourier KPSS test proposed by Becker et al. (2006). This test, called FPKPSS, accounts for structural breaks and CSD. Unlike other tests, the null hypothesis advocates stationarity. Heterogeneity is allowed between the sections in the panel.

They employed the following deterministic term to account for smooth structural breaks:

$$\alpha_i(t) = a_i + \gamma_{1i} sin\left(\frac{2\pi kt}{T}\right) + \gamma_{2i} cos\left(\frac{2\pi kt}{T}\right) \tag{4}$$

The KPSS procedure introduced by Becker et. al. (2006) is as follows, which can estimate country-specific statistics with k:

$$\eta_i(k) = \frac{1}{T^2}\sum_{t=1}^{T}\frac{\tilde{S}_{it}(k)^2}{\tilde{\sigma}_{\varepsilon i}^2} \tag{5}$$

where, $\tilde{S}_{it}(k) = \sum_{j=1}^{T}\tilde{\varepsilon}_{ij}$ and $\tilde{\sigma}_{\varepsilon i}^2$ is the estimation of the long-run variance of ε_{it}. The panel statistics $FP(k)$ with the average of the individual statistics developed by Nazlıoğlu & Karul (2017) is as follows:

$$FP(k) = \frac{1}{N}\sum_{i=1}^{N}\eta_i(k) \tag{6}$$

Although several cointegration methods are available in empirical studies to examine long-term relationships, second-generation tests that allow CSD and structural breaks are particularly advantageous. Therefore, in this study, Westerlund & Edgerton (WE) (2008) cointegration test has been applied to control the three basic difficulties of panel data, namely CSD, autocorrelation and structural breaks.

The WE (2008) test has been composed from the Lagrange multiplier (LM)-based unit root tests presented by Schmidt & Phillips (1992), Ahn (1993), and Amsler & Lee (1995).

$$y_{it} = \alpha_i + \eta_i t + \delta_i D_{it} + x'_{it}\beta_i + (D_{it}x_{it})'\gamma_i + z_{it} \tag{7}$$

$$x_{it} = x_{it-1} + \omega_{it} \tag{8}$$

where, $i = 1, \dots, N$ and $t = 1, \dots, T$ denote panel members and the time period, respectively. While α_i and β_i are constant and trend coefficients term before the break, δ_i and γ_i display the change after the break. D and ω_{it} are the dummy variable and error term, respectively.

The following three equations compose the error term z_{it}, which considers CSD through the inclusion of common factors (Dobnik, 2011).

$$z_{it} = \lambda_i' + F_t + v_{it} \quad (9)$$

$$F_{jt} = \rho_j F_{jt-1} + u_{jt} \quad (10)$$

$$\phi_i(L)v_{it} = \phi_i v_{it-1} + e_{it} \quad (11)$$

Here, F_t and F_{jt} are r- dimensional common factor vector where $j = 1, \dots r$. λ_i denotes a matched factor of factor loadings. $\phi_i(L)$ is defined as a numeral polynomial in the lag operator L. The following equation is the cointegration model, which is robust against serial correlation:

$$\Delta\hat{S}_{it} = constant + \phi_i\hat{S}_{it-1} + \sum_{J=1}^{p_i}\phi_{ij}\Delta\hat{S}_{it-j} + error \quad (12)$$

where $\hat{S}_{it}$ is the error term. Two panel LM-based test statistics defined by WE (2008) are as follows:

$$LM_{\phi}(i) \coloneqq T\hat{\phi}_i\left(\frac{\hat{\omega}_i}{\hat{\sigma}_i}\right) \quad (13)$$

$$LM_{\tau}(i) \coloneqq \left(\frac{\hat{\phi}_i}{SE(\hat{\phi}_i)}\right) \quad (14)$$

Here, $\hat{\phi}_i$ and $\hat{\sigma}_i$ are the least square estimators and the estimated standard errors, respectively.

In the final step of the study, the panel and country-specific coefficients are estimated via augmented mean group (AMG) estimator introduced by Eberhardt & Teal (2010). Subsequently, the regularized common correlated effect (rCCE) estimator proposed by Juodis (2022) is applied as a robustness check.

EMPIRICAL RESULTS

The CSD test and homogeneity test results are displayed in Table 3. According to the CSD results, the null hypothesis that there is no CSD is rejected, indicating that CSD must be taken into consideration in subsequent analyses. Before investigating the existence of cointegration between variables, it is essential to examine the homogeneity of the slope coefficients in the cointegration equation. The Pesaran & Yamagata (2008) homogeneity test results point out heterogeneous slopes. Namely, country-based analyses are warranted.

Table 3: Cross-Section Dependency and Slope Homogeneity Test Results

Variables	CD	CD_{LM1}	CD_{LM2}
GRF	107,9682*(0,0000)	13,41949*(0,0000)	1,276430 (0,2018)
LNESGUI	60,34726*(0,0000)	6,071414*(0,0000)	4,013817*(0,0001)
INF	169,6406*(0,0000)	22,93575*(0,0000)	12,84791*(0,0000)

FD	89,18778*(0,0000)	10,52160*(0,0000)	6,275593*(0,0000)
Panel	82,13238*(0,0000)	9,432932*(0,0000)	1,377938 (0,1682)
Slope Homogeneity		Statistics	
$\hat{\Delta}$		4,317* (0,0000)	
$\hat{\Delta}_{adj}$		4,946* (0,0000)	

Source: All values are calculated by the author via EVIEWS and GAUSS programs. p-values are in the brackets. *p<0,01.

The FPKPSS stationarity test proposed by Nazlıoğlu and Karul (2017) accounts for CSD and has the advantage of capturing smooth structural breaks due to its Fourier-based nature. According to the FPKPSS stationarity test results shown in Table 4, the basic hypothesis defending stationarity is rejected at the level but cannot be rejected at least at the 10% significance level at the first differences. This indicates that all variables are non-stationary at the level and are stationary at their first differences, i.e., I(1).

Table 4: FPKPSS Stationary Test Results

Variables	Level (I(0))	First differences (I(1))
GRF	9,524 (2,22e-016)*	-0,7418 (0,7709)
LNESGUI	8,116 (2,22e-016)*	1,056 (0,1456)
INF	3,121 (0,0009025)*	-0,08789 (0,5350)
FD	10,99 (2,22e-016)*	-1,062 (0,8559)

Source: All values are calculated by the author via GAUSS program. * denotes the rejection of the null hypothesis at 1% significance level. The frequency parameter k=5 in the Fourier approximation is selected. Regarding the estimation of the long-run variance, the i.i.d. is employed.

Based on the FPKPSS stationary test outcomes, the WE (2008) test is employed to assess the presence of cointegration in the panel. As displayed in Table 5, the null hypothesis of no cointegration is rejected. Thereby, the results provide evidence of cointegration in the panel model. This reveals the existence of a long-term relationship among the variables.

Table 5: Panel Cointegration Test Results

Westerlund & Edgerton (2008)				
	LM_{τ}	p-value	LM_{φ}	p-value
Level-shift	-2,291**	0,011	-2,878*	0,002
LM Bootstrap				

	Test statistics	p-value
	4,972	0,650

Source: All values are calculated by the author via GAUSS program. * and ** denote p<0,01 and p<0,05, respectively. Model with a max number of 5 factors. The null hypotheses of the WE (2008) and LM Bootstrap tests indicate no cointegration and cointegration in the model, respectively. The bootstrap is based on 1000 replications.

Additionally, the dates of structural breaks for each country are also reported in Table 6.

Table 6: WE (2008) Structural Breaks

Countries	Break Years	Countries	Break Years
Australia	2013	Ireland	2010
Belgium	2010	Netherland	2008
France	2008	Sweden	2004
Germany	2019		

Source: All values are calculated by the author via GAUSS program.

With the existence of long-term movement revealed, long-term coefficient estimation in the model has become possible. The AMG and RCCE estimation results are reported in Table 7 and Table 8, respectively.

Table 7: AMG Long-Run Coefficient Estimation Results

Countries	LNESGUI	INF	FD
Australia	-0,1014007	-0,0332025	-1,1619
Belgium	**0,4081399***	-0,0027316	-0,4064122
France	-0,0327038	-0,0314418*	0,7187729*
Germany	0,0154318	**-0,0224036****	-0,2236609
Ireland	**-0,2454135***	0,0321779**	**4,381425***
Netherland	-0,0566853	0,0088191	**1,812626***
Sweden	**-0,0929544*****	0,0009621	-0,4341744
Panel	-0,0150837	-0,0068315	0,6695252

Source: All values are calculated by the author via GAUSS program. *, **, and *** denote the p-value<1%, p-value<5%, and p-value<10%, respectively.

Table 8: rCCE Long-Run Coefficient Estimation Results

Countries	LNESGUI	INF	FD
Australia	-0,069919	-0,0693947	-2,415249**
Belgium	**0,6612339***	0,0647921	-2,638936**
France	-0,1132431	-0,0442915	0,3690265
Germany	0,0007237	**-0,0461044*****	-0,3627696
Ireland	**-0,2894218*****	0,0054712	**3,919787***
Netherland	-0,0724719	0,0599554**	**1,692306***
Sweden	**-0,1959209***	-0,0075219	-0,5899201**
Panel	-0,0112884	-0,0052991	-0,0036792

Source: All values are calculated by the author via GAUSS program. *, **, and *** denote the p-value<1%, p-value<5%, and p-value<10%, respectively.

According to the results, a positive relationship is found between GRF and ESGUI in Belgium, while a negative relationship is observed in Ireland and Sweden. In Belgium, a 1% increase in ESGUI increases GRF by 0,6612 units, while in Ireland it decreases it by 0,2894 units and in Sweden by 0,1959 units. This means that, as expected, increased ESG uncertainty in Ireland and Sweden negatively affects GRF. Inflation is found to be statistically significant only in Germany, exhibiting a negative relationship with GRF. When INF increases by 1 unit in Germany, it reduces GRF by 0,0461 units. Furthermore, FD exerts a significant and positive effect on GRF for Ireland and the Netherlands, implying that higher levels of FD have a beneficial role in promoting GRF. Here, a 1-unit increase in FD results in an increase of 3,9198 units in Ireland and 1,6923 units in the Netherlands.

CONCLUSION AND POLICY RECOMMENDATIONS

This study offers a unique contribution to the literature by examining the effects of ESGUI on GRF in countries with high ESG performance. Analyses for the period 2002–2021, covering a group of countries including Australia, Belgium, France, Germany, Ireland, the Netherlands, and Sweden, reveal that high ESG performance alone does not guarantee the stability of GRF, and that ESG uncertainty plays a critical role in this process.

Empirical findings indicate a long-term cointegration relationship between GRF, ESGUI, INF, and FD variables. Moreover, the results point to significant heterogeneity across countries. ESGUI has a statistically significant and negative effect on GRF in Ireland and Sweden. This suggests that increased ESG weakens investor confidence, negatively impacting long-term green investment decisions. Green projects, particularly those with long payback periods, face a higher risk perception in an uncertain environment, leading to a contraction in GRF flows.

In contrast, a positive relationship is found between ESGUI and GRF in Belgium. This finding reveals that the impact of ESGUI is not one-sided and that country-specific institutional structures, regulatory frameworks, and financial systems could determine the direction of this relationship. The Belgian example indicates that in countries with strong institutional capacity, reducing ESGUI necessitates strengthening environmental spending and GRF mechanisms. On the other hand, contrary to expectations, this positive correlation obtained in Belgium can be explained by the fact that ESG uncertainty is perceived in the markets not only as a risk but also as an opportunity signal. In this context, uncertainty can be perceived not only as a risk factor but also as a market reassessment and pricing mechanism (Luo et al., 2026). Another factor that could explain the positive impact is that, within the framework of the EU Green Deal, the EU Commission encouraged green investment even during periods of uncertainty (European Commission, 2020).

From a macroeconomic perspective, INF is found to have a negative and significant impact on GRF only in Germany. This result indicates that tight monetary policies and rising interest rates could limit the volume of GRF by increasing the financing costs of green investments. However, the lack of significant INF in other countries suggests that strong institutional structures and policies might partially protect GRF against macroeconomic fluctuations. On the other hand, FD is found to play a supportive role for GRF in Ireland and the Netherlands. This finding confirms that developed and deep financial systems contribute to the spread of GRF by facilitating access to long-term and low-cost resources.

From a policy perspective, the results indicate that enhancing ESG performance alone is insufficient for the sustainability of GRF; mitigating ESGUI is also critical. In this context, policymakers should prioritize improving ESG performance and reducing ESG-related uncertainty. In countries where ESGUI negatively impacts GRF, increased transparency and institutional coordination could restore investor confidence. Furthermore, integrating policies that support FD with GRF strategies will significantly increase the effectiveness of GRF instruments.

In conclusion, this study demonstrates that incorporating ESGUI into GRF analyses, uncertainty could have decisive and country-specific effects on GRF, even in countries exhibiting high ESG performance. The findings suggest that GRF-related policies should adopt country-specific and uncertainty-aware strategies rather than uniform approaches. In this context, the study makes a significant contribution to the sustainable finance literature.

For future research, this study primarily used the share of public environmental protection expenditures in GDP as an indicator of GRF. Future studies could test the robustness of these findings by using alternative and more detailed GRF indicators such as green bond issuance volume, green loan amount, sustainable fund size, or private sector green investments. Furthermore, this study only included countries with high ESG performance (2002-2021). Future studies could extend the sample to include developing countries or those with low to medium ESG performance in order to examine whether the impact of ESGUI on GRF differs according to country development

level. Such comparative analyses could provide more comprehensive insights for policy design. The relationship between ESGUI and GRF is modelled as unidirectional, but potential risks of endogeneity or reverse causality could not be completely eliminated. The increase of GRF may affect ESGUI, or there may be concurrent interactions between the measured variables. It is suggested that future studies address this issue more systematically.

REFERENCES

Aguila, N., & Wullweber, J. (2024). Greener and cheaper: Green monetary policy in the era of inflation and high interest rates. *Eurasian Economic Review*, *14*(1), 39–60. https://doi.org/10.1007/s40822-024-00266-y

Ahn, S. K. (1993). Some tests for unit roots in autoregressive-integrated-moving average models with deterministic trends. *Biometrika 80*(4), 855–868. https://doi.org/10.1093/biomet/80.4.855

Ajour El Zein, S., Consolacion-Segura, C., & Huertas-Garcia, R. (2020). The role of sustainability in brand equity value in the financial sector. *Sustainability*, *12*(1), 254. https://doi.org/10.3390/su12010254

Akadiri, S. S., & Özkan, O. (2026). Navigating uncertainty: the impact of ESG factors on clean energy markets and investment dynamics. *Corporate Social Responsibility and Environmental Management, 33(1)*, 1270-1285. https://doi.org/10.1002/csr.70227

Aleknevičienė, V., Staugaitis, A. J., Gudaitienė, R., & Bendoraitytė, A. (2025). How do the uncertainties affect the connectedness between the green bond market and conventional financial markets? Evidence from the Russian-Ukrainian war. *Green Finance*, *7*(4), 634. https://doi.org/10.3934/GF.2025024

Al-Mulali, U., Saboori, B., & Ozturk, I. (2015). Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy Policy*, *76*, 123–131. https://doi.org/10.1016/j.enpol.2014.11.019

Amsler, C., & Lee, J. (1995). An LM test for a unit root in the presence of a structural change. *Econometric Theory*, *11*(2), 359–368. https://doi.org/10.1017/S026646660000921X

Arhinful, R., Mensah, L., Amin, H. I. M., Obeng, H. A., & Gyamfi, B. A. (2025). The strategic role of sustainable finance in corporate reputation: A signaling theory perspective. *Sustainability*, *17*(11), 5002. https://doi.org/10.3390/su17115002

Becker R., Enders W., & Lee, J. (2006). A stationarity test in the presence of an unknown number of smooth breaks. *Journal of Time Series Analysis*, *27*(3), 381–409. https://doi.org/10.1111/j.1467-9892.2006.00478.x

Berk, N., Sarılı, S., & Yıldırtan, D. C. (2023). Do green bonds perform better than conventional bonds?. *WIT Transactions on Ecology and the Environment*, *261*, 129–135. https://doi.org/10.2495/ESUS230111

Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. *Review of Economic Studies*, *47*(1), 239–253. https://doi.org/10.2307/2297111

Chen, X., & Chen, Z. (2021). Can green finance development reduce carbon emissions? Empirical evidence from 30 Chinese provinces. *Sustainability*, *13*(21), 12137. https://doi.org/10.3390/su132112137

Chen, S. S., & Lin, T. Y. (2024). Monetary policy and renewable energy production. *Energy Economics*, *132*, 107495. https://doi.org/10.1016/j.eneco.2024.107495

Chen, P., & Yue, C. (2024). Construction of green finance's ESG evaluation system for rural innovation and entrepreneurship. *International Journal of Low-Carbon Technologies*, *19*, 2646-2655. https://doi.org/10.1093/ijlct/ctae209

Czipf, C. (2025). The impact of changing energy prices, interest rates, and investment costs on the net present value and internal rate of return for alternative energy projects. *Discover Sustainability*, *6*(1), 161. https://doi.org/10.1007/s43621-025-00921-7

Das, N., Pradhan, R. P., & Janjua, L. R. (2025). Climate commitments and market risks: Analysing the drivers of sovereign green bond issuance in India. *Finance Research Letters*, *90* 109365. https://doi.org/10.1016/j.frl.2025.109365

Dobnik, F. (2011). Energy consumption and economic growth revisited: Structural breaks and cross-section dependence. *Ruhr Economic Papers,* (No. 303). https://hdl.handle.net/10419/61681

Donaldson, T., & Preston, L. E. (1995). The stakeholder theory of the corporation: Concepts, evidence, and implications. *Academy of Management Review*, *20*(1), 65–91. https://doi.org/10.5465/amr.1995.9503271992

Dou, J., Su, C. W., Li, W., & Dou, J. (2025). Green finance and artificial intelligence: Catalysts for promoting sustainability?. *Economic Analysis and Policy*, *88*, 13-25. https://doi.org/10.1016/j.eap.2025.08.037

Dutordoir, M., Li, S., & Neto, J. Q. F. (2024). Issuer motivations for corporate green bond offerings. *British Journal of Management*, *35*(2), 952–973. https://doi.org/10.1111/1467-8551.12747

Eberhardt, M., & Teal, F. (2010). Productivity analysis in global manufacturing production. *Discussion Paper 515, Department of Economics, University of Oxford*. https://ora.ox.ac.uk/objects/uuid:ea831625-9014-40ec-abc5-516ecfbd2118

European Commission (2020). Finance and the Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal_en (Accessed March 30, 2026).

Ergün, H. O. (2024). Yeşil finansın belirleyicileri: Yeşil tahvil üzerine bir araştırma. *6. International Liberty Interdisciplinary Studies Conference*, November 29-30, 2024, New York. https://www.libertyacademicbooks.com/libertyconference

Farooq, F., Sajid, M., Faheem, M., & Khan, K. H. (2024). Evaluating the influence of green growth, foreign direct investment and financial development towards sustainable environment: Evidence by green finance theory. *Bulletin of Business and Economics (BBE)*, *13*(2), 44–52. https://doi.org/10.61506/01.00297

Fernandes, C. I., Veiga, P. M., Ferreira, J. J., & Hughes, M. (2021). Green growth versus economic growth: Do sustainable technology transfer and innovations lead to an imperfect choice?. *Business Strategy and the Environment*, *30*(4), 2021–2037. https://doi.org/10.1002/bse.2730

Freeman, R. E. (2010). *Strategic management: A stakeholder approach*. Cambridge University Press.

Handler, B., & Shandy, M. (2023). Rising costs' impact on renewable power generation. https://doi.org/10.25676/11124/177127

ISESG. (2025). *Global ESG ranking 2025*. https://www.isesg.org/global-esg-ranking-2025. (Accessed January 20, 2026).

Juodis, A. (2022). A regularization approach to common correlated effects estimation. *Journal of Applied Econometrics*, *37*(4), 788–810. https://doi.org/10.1002/jae.2899

Kathan, M. C., Utz, S., Dorfleitner, G., Eckberg, J., & Chmel, L. (2025). What you see is not what you get: ESG scores and greenwashing risk. *Finance Research Letters*, *74*, 106710. https://doi.org/10.1016/j.frl.2024.106710

Khan, N., Karim, S., Chan, L. F., & She, L. (2024). Green horizons: Overcoming political risks with strategic environmental management and financial innovation. *Journal of Environmental Management*, *368*, 122224. https://doi.org/10.1016/j.jenvman.2024.122224

Köycü, E. (2025). Possible effects of uncertainty factors on green bond returns. *Pamukkale Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, (68),* 131–146. https://doi.org/10.30794/pausbed.1611428

Le, T. N. L., Goodell, J. W., Khalfaoui, R., Abakah, E. J. A. & Doğan, B. (2023). The impact of economic outlook on green finance: Insights from linkages between green and inflation-indexed bonds. *Environment, Development and Sustainability*, *27*(3), 6507–6538. https://doi.org/10.1007/s10668-023-04153-5

Lee, M. T., & Raschke, R. L. (2023). Stakeholder legitimacy in firm greening and financial performance: What about greenwashing temptations?. *Journal of Business Research, 155*, 113393. https://doi.org/10.1016/j.jbusres.2022.113393

Liu, Q., Luo, X., & Su, M. (2024). Analysis of the "greenwashing" phenomenon in the ESG investment environment. *Highlights in Business, Economics and Management, 40*, 1161–1170. https://doi.org/10.54097/s5zf4q16

Luo, K., Peng, L., & Zhou, F. (2026). Sustainability uncertainty and the dynamics of green asset markets. *Journal of Innovation & Knowledge, 100999*. https://doi.org/10.1016/j.jik.2026.100999

Mustafa, H., Chen, C., Atqa, A. A., Li, X., Qin, Z., Alhasnawi, M. Y., & Lin, Z. (2025). The influence of ESG performance on banking credit decisions: Empirical from highly polluting enterprises in China. *Future Business Journal, 11*(1), 254. https://doi.org/10.1186/s43093-025-00672-x

Nawaz, A., & Su, C. W. (2026). Sustainability uncertainty and the fragility of green finance: Bootstrap rolling-window and quantile-on-quantile evidence from green bond. *Spanish Journal of Finance and Accounting/Revista Española de Financiación y Contabilidad*, 1-23. https://doi.org/10.1080/02102412.2026.2619316

Nazlıoğlu, S., & Karul, C. (2017). A panel stationarity test with gradual structural shifts: Re-investigate the international commodity price shocks. *Economic Modelling, 61*, 181–192. https://doi.org/10.1016/j.econmod.2016.12.003

OECD. (2020). *ESG investing: Practices, progress, and challenges.* https://www.oecd.org/content/dam/oecd/en/publications/reports/2020/09/esg-investing-practices-progress-and-challenges_8a73d683/b4f71091-en.pdf (Accessed December 17, 2025).

Ongan, S., Gocer, I., & Işık, C. (2025). Introducing the new ESG-based sustainability uncertainty index (ESGUI). *Sustainable Development, 33(3),* 4457-4467. https://doi.org/10.1002/sd.3351

Pesaran, M. H. (2004). General diagnostic tests for cross section dependence in panels. *CESifo Working Paper Series No. 1229; IZA Discussion Paper No. 1240*.

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics, 142*(1), 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010

Rosa, S. M. (2025). Green monetary policy measures and central bank mandates: A comparative political economy analysis. *Politics and Governance*, *13*, 8919. https://doi.org/10.17645/pag.8919

Schmidt, P., & Phillips, P. C. (1992). LM tests for a unit root in the presence of deterministic trends. *Oxford bulletin of economics and statistics, 54*(3), 257–287.

Shen, Y. (2025). The synergy between ESG and green finance. *Proceedings of ICEMGD 2025 Symposium: Innovating in Management and Economic Development*. https://doi.org/10.54254/2754-1169/2025.LH25192

Swamy, P. A. (1970). Efficient inference in a random coefficient regression model. *Econometrica 38*(2), 311–323. https://doi.org/10.2307/1913012

Sun, G., Sulemana, I., & Agyemang, A. O. (2025). Examining the impact of stakeholders' pressures on sustainability practices. *Management Decision*, *63* (11), 3967–3995. https://doi.org/10.1108/MD-06-2023-1008

Tron, A., Franceschi, L. F., Colantoni, F., & Paolone, F. (2025). ESG dynamics: Assessing the link between sustainability practices and the cost of capital. *Corporate Social Responsibility and Environmental Management*, *32*(4), 5038–5053. https://doi.org/10.1002/csr.3231

Wang, S., & Wang, D. (2022). Exploring the relationship between ESG performance and green bond issuance. *Frontiers in public health*, *10*, 897577. https://doi.org/10.3389/fpubh.2022.897577

Wang, T., Chang, H., & Liu, L. (2026). Sustainability Uncertainty and Green Asset Returns: Implications for Financial Market Stability. *Emerging Markets Finance and Trade*, 1-15. https://doi.org/10.1080/1540496X.2026.2614999

Westerlund, J., & Edgerton, D. L. (2008). A simple test for cointegration in dependent panels with structural breaks. *Oxford Bulletin of Economics and Statistics*, *70*(5), 665–704. https://doi.org/10.1111/j.1468-0084.2008.00513.x

Zhang, X., & Zhang, Z. (2025). ESG performance and "Greenwashing": An analysis of the mediating effect of supply chain finance. *Finance Research Letters*, *89*, 109255. https://doi.org/10.1016/j.frl.2025.109255

Zheng, J., Jiang, Y., Cui, Y., & Shen, Y. (2023). Green bond issuance and corporate ESG performance: Steps toward green and low-carbon development. *Research in International Business and Finance*, *66*, 102007. https://doi.org/10.1016/j.ribaf.2023.102007

InTraders International Trade Academic Journal

e-ISSN: 2667-4408 **www.intraders.org**

Volume: 9
Issue : 1
Research Article

Received: February 2, 2026
Revision: April 22, 2026
Accepted: May 5, 2026
DOI: https://www.doi.org/10.55065/intraders.1880290

The Environmental Impacts of Capital Flows, Growth Rhythms, and Innovation: Findings from Türkiye[1]

İbrahim Halil POLAT[2], Mahir TOSUNOĞLU[3], Muhamed Sabri DOĞAN[4]

Abstract

This study examines how foreign direct investment (FDI), economic growth, and R&D-based innovation affect carbon dioxide (CO_2) emissions in Türkiye, motivated by the growing importance of cross-border capital mobility, technological change, and scale effects in environmental economics. The study contributes to the literature in three ways. First, it jointly estimates long-run equilibrium and short-run adjustment within an ARDL bounds testing and error-correction (ECM) framework, rather than relying on single-period averages. Second, it shows that innovation, when combined with energy-intensive production expansion, can raise emissions. Third, it links the environmental impact of FDI to its qualitative and sectoral composition, thereby informing the pollution haven–pollution halo debate for Türkiye. Using annual data from 1996 to 2023, the ARDL results indicate a stable long-run relationship among the variables. The long-run estimates show that higher FDI inflows, faster economic growth, and greater R&D expenditure are associated with higher CO_2 emissions. Alternative robustness estimators confirm these results. Short-run ECM results indicate that deviations from the long-run equilibrium are corrected relatively quickly, with convergence occurring within approximately 16 months. The Toda–Yamamoto causality test identifies unidirectional causality running from FDI, economic growth, and innovation to CO_2 emissions. Overall, the findings suggest that Türkiye's development trajectory remains carbon-intensive and that growth and investment strategies lacking explicit sustainability constraints may increase carbon intensity. Policy implications highlight the need to redirect FDI towards cleaner sectors, enhance energy efficiency, and accelerate the adoption of green technologies to align economic modernisation with the Sustainable Development Goals.

Keywords: *Foreign direct investment, economic growth, innovation, ARDL*

JEL Codes: *F21, O40, Q53, C22, O30*

INTRODUCTION

Greenhouse gas emissions from both developed and developing countries have recently emerged as a major driver

There is no conflict of interest. All authors contributed equally to the study.

[1] Corresponding author: Muhamed Sabri Doğan, muhamedsabridogan@gmail.com
[2] Asst. Prof. Dr., Hakkari University, E-Mail: ibrahimhalilpolat@hakkari.edu.tr OI: 0000-0001-9785-160X
[3] PhD Candidate, Ege University, E-Mail: mtosunoglu00@gmail.com, OI: 0000-0002-9941-0151
[4] PhD, Independent Researcher, E-Mail : muhamedsabridogan@gmail.com OI: 0000-0002-7303-6915

Cite As: Polat, İ. H., Tosunoğlu, M., & Doğan, M. S. (2026). The environmental impacts of capital flows, growth rhythms, and innovation: Findings from Türkiye. *InTraders International Trade Academic Journal*, *9*(1), 107-135. https://doi.org/10.55065/intraders.1880290

of global warming and accelerating disruptions in the climate system. This has led policymakers to focus increasingly on controlling and reducing carbon-based emissions. At the same time, safeguarding intergenerational justice has become increasingly complex due to the rapid decline of natural resources, the persistence of energy-intensive growth models, and the widespread diffusion of unsustainable consumption patterns globally. These pressures weaken the environmental and economic foundations of sustainable development and threaten long-term sustainable prosperity. In response to this global challenge, the United Nations adopted the Sustainable Development Goals (SDGs) in 2015, providing countries with a shared roadmap extending to 2030. Rather than reducing development objectives to growth performance alone, the SDG framework advances a transformational perspective that aims to align production and consumption systems with the planet's carrying capacity. In this context, among the 17 goals, Goal 13 (climate action) is a core pillar of environmental sustainability by minimising climate risks; therefore, it plays an essential role in the practical implementation of the sustainable development agenda (Iqbal et al., 2023).

Climate change has evolved beyond being merely an environmental problem and has become a structural development issue that directly shapes economic growth models, investment preferences, and technological transformation processes. While industrialisation, urbanisation, and the expansion of global production networks have improved countries' economic performance, they have simultaneously intensified environmental pressures. This dynamic places the tension between the environmental costs of economic growth and the objectives of sustainable development at the center of economic analysis (Balsalobre-Lorente et al., 2018; Mensah et al., 2018). In particular, carbon dioxide (CO_2) emissions stand out as the primary driver of climate change due to their long atmospheric lifetime and their dominant share of total greenhouse gas emissions, accounting for approximately 75 per cent. For this reason, CO_2 emissions are widely regarded as the most common and critical indicator for measuring the environmental impacts of economic activities (International Energy Agency [IEA], 2023; Intergovernmental Panel on Climate Change [IPCC], 2023). This general trend is also supported by up-to-date data published at both global and national levels. According to IEA reports, global CO_2 emissions increased by approximately 49 per cent from 2000 to 2023, while per capita CO_2 emissions rose from about 4 tons to 4.29 tons over the same period (IEA, 2023). Accordingly, CO_2 emissions are among the main factors responsible for environmental degradation and global warming (Syed & Bouri, 2022). In parallel, CO_2 emissions adversely affect human health (Jiang et al., 2019), making it imperative for every country to understand the factors influencing CO_2 emissions to achieve sustainable environmental, social, and economic development.

In light of these considerations, the literature on the drivers of CO_2 emissions has reached a relatively mature stage. In particular, variables such as economic growth, foreign direct investment (FDI), and innovation or technological change play a decisive role (Aghion et al., 2016; Fernández et al., 2018; Shahbaz et al., 2018). Economic growth tends to raise emissions by expanding production volume and energy demand, yet the

magnitude of this effect depends mainly on the energy sources used and the carbon intensity of production technologies (Kızılkaya et al., 2016; Mensah et al., 2018). FDI supports economic growth through capital accumulation and the expansion of productive capacity; however, its environmental impacts vary by the sectors receiving investment and the environmental policies in place (Gökmenoğlu & Taspinar, 2016; Boateng et al., 2024). In this respect, the environmental effects of FDI are not unidirectional. On the one hand, relocating polluting activities to countries with weaker environmental regulations may give rise to a pollution-haven effect (Shahbaz et al., 2015; Bekun et al., 2024). On the other hand, through the transfer of advanced technologies and cleaner production processes, FDI can improve environmental performance through a pollution-halo effect (Siripi et al., 2024; Li & Zhou, 2025). Similarly, innovation exerts a dual effect on CO_2 emissions. In theory, innovation can reduce carbon emissions by increasing energy efficiency and promoting the adoption of clean technologies (Romer, 1986; Tekbaş & Yıldırım, 2023). However, as innovation expands production scale and intensifies energy use, it may also increase emissions (Adebayo & Kirikkaleli, 2021; Gültekin, 2023).

In Türkiye, the effects of economic growth, FDI, and innovation on CO_2 emissions are of critical importance to both academics and policymakers. In Türkiye, which is highly dependent on energy imports and sustains its growth largely through energy-intensive sectors, the balance between economic expansion and environmental sustainability is fragile (Kızılkaya et al., 2016; Gültekin, 2023). This fragility becomes even more pronounced as Türkiye integrates into global capital flows. According to World Bank data, net FDI inflows into Türkiye amounted to approximately 11.7 billion US dollars as of 2024 (World Bank, 2024b). While these foreign capital inflows can support economic growth, their effects on CO_2 emissions may vary depending on sectoral allocation and the environmental policies in place.

Figure 1 shows the Turkish economy's growth over the last three decades, presenting per capita GDP. Accordingly, during the 1996–2023 period, per capita GDP generally trended upward, gaining momentum particularly after the mid-2000s. This growth was accompanied by an expansion in production scale and rising energy demand, creating a basis for a simultaneous rise in environmental pressures. Indeed, Figure 2 shows the upward trajectory of CO_2 emissions in Türkiye over the same period. Therefore, the coexistence of economic growth and rising CO_2 emissions over the past 30 years necessitates evaluating economic growth alongside its environmental costs. Meanwhile, the FDI graph for Türkiye in Figure 3 for the 1996–2023 period shows that foreign capital inflows fluctuated but generally increased over time. A notable surge in FDI inflows is observed, particularly in the mid-2000s, whereas a more volatile pattern emerges in the post-global financial crisis period. This volatility suggests that the effects of FDI on CO_2 emissions may not be unidirectional or linear. Accordingly, it is necessary to assess the effects of FDI within the sectors receiving investment and the production technologies employed. The share of R&D expenditures in GDP, an indicator of innovation, is shown in Figure 4. As shown, the share of R&D expenditures in Türkiye has increased, particularly since the 2000s. This trend may contribute

to greater technological intensity in production processes and, in the long run, to higher energy efficiency. However, whether the increase in R&D expenditures mitigates CO_2 emissions depends on the nature of innovation and the extent to which it is oriented towards environmentally friendly technologies.

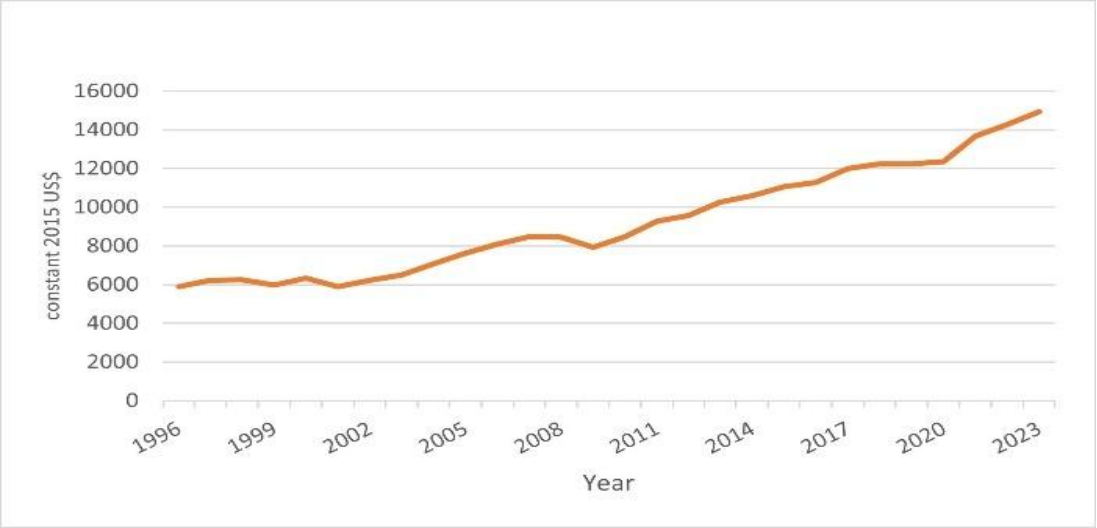


Figure 1: Trend of per capita GDP in Türkiye

Source: World Bank, 2025c.

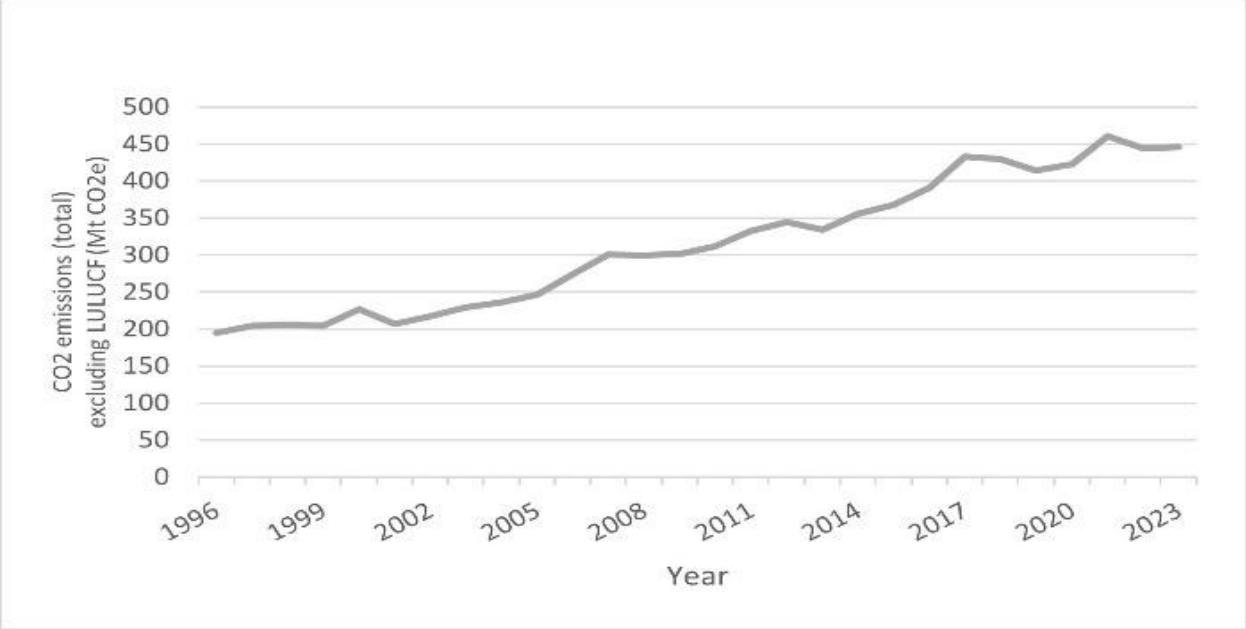


Figure 2: Trend of CO_2 emission growth in Türkiye

Source: World Bank, 2025a.

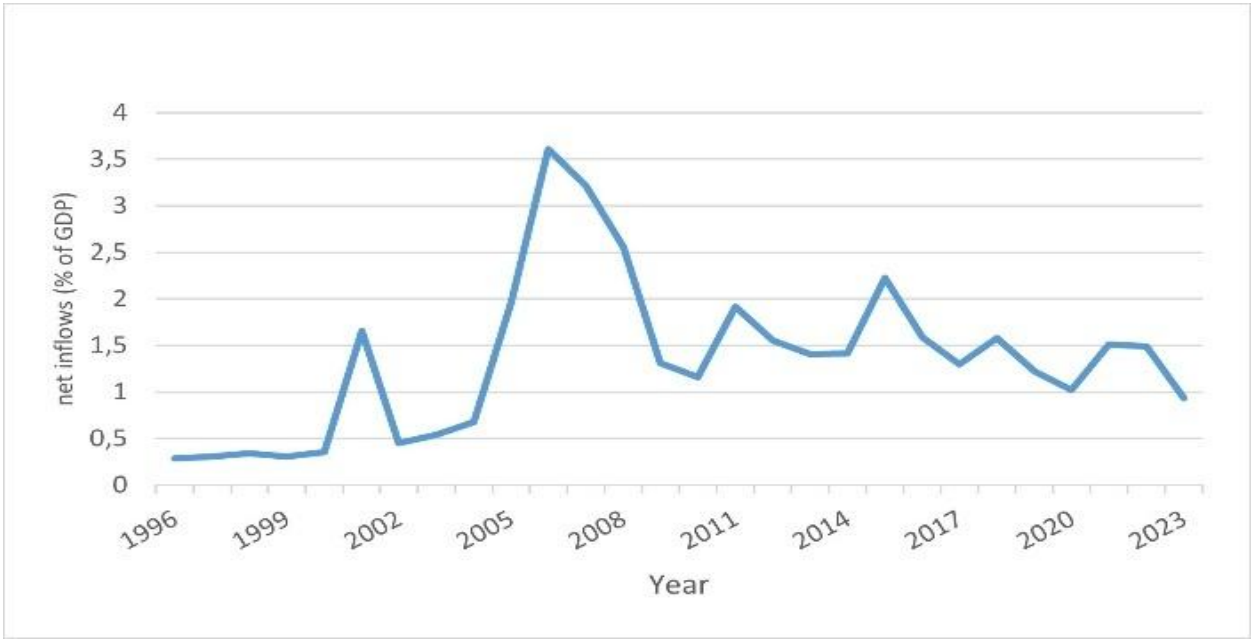


Figure 3: Trend of foreign direct investment in Türkiye

Source: World Bank, 2025b.

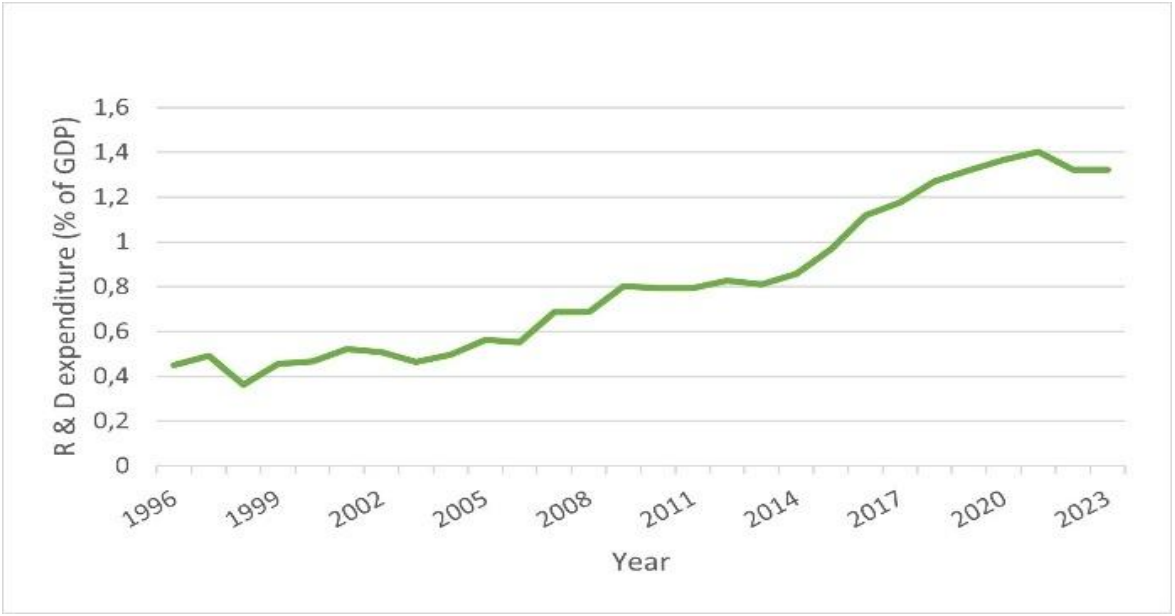


Figure 4: Trend of R&D expenditures in Türkiye

Source: World Bank, 2025d.

Within this framework, the study aims to analyse the relationships among CO_2 emissions, economic growth, foreign direct investment (FDI), and innovation in Türkiye for the period 1996–2023, considering both short- and long-run dynamics. To identify the long-run equilibrium relationship among the variables and the short-run adjustment process, the analysis employs the ARDL approach and an error-correction model (ECM). The primary rationale for preferring the ARDL methodology lies in its ability to accommodate variables with different orders of integration and its suitability for data sets with a relatively limited time dimension (Pesaran et al., 2001;

Narayan, 2005). Subsequently, the robustness of the ARDL findings is examined using the FMOLS, DOLS, and CCR estimators to verify the direction of the relationships. Lastly, the "Toda–Yamamoto (1995) causality test" is used to examine causal relationships between the variables.

This study makes several important contributions to the existing literature. First, unlike much of the previous research that examines economic growth, foreign direct investment (FDI), or innovation separately, this study analyzes their joint effects on CO_2 emissions within a single empirical framework, providing a more comprehensive understanding of their interaction in the Turkish context. Second, by employing the ARDL bounds testing approach together with an error correction mechanism and multiple robustness estimators such as FMOLS, DOLS, and CCR, the study offers consistent evidence on both long run relationships and short run dynamics. Third, the findings challenge the widely held assumption that technological progress necessarily improves environmental quality, showing instead that innovation may increase CO_2 emissions when it is associated with energy intensive production structures. Fourth, the study shows that the environmental impact of FDI depends not only on its volume but also on its qualitative and sectoral composition, contributing to the broader debate on the environmental effects of foreign investment. Finally, by focusing on Türkiye over the period 1996 to 2023, the study provides up to date and policy relevant evidence for a developing and energy dependent economy, thereby addressing an important gap in the country specific literature.

The paper is organised as follows. Section 2 reviews the relevant literature. Section 3 outlines the data, defines the variables, and describes the econometric methodology. Section 4 presents the empirical results. Finally, Section 5 concludes the study and discusses the policy implications.

LITERATURE REVIEW

As global warming and environmental degradation intensify, the roles of economic growth, foreign direct investment (FDI), and innovation in shaping environmental sustainability have attracted greater attention. The expansion of economic activity raises production volumes and energy demand, thereby bringing environmental costs to the fore. At the same time, the direction and magnitude of these effects vary with the technologies employed and the structure of investment. As a result, the relationships between economic growth and the environment, technological development and the environment, and FDI and the environment have gained prominence in the literature. In countries characterised by energy-intensive production structures and a high dependence on energy imports, the environmental consequences of foreign capital inflows and technological development become more pronounced. In this context, Türkiye is an important case from both scholarly and policy perspectives, given its efforts to balance economic growth with climate policies. Accordingly, empirical studies focusing on Türkiye and examining the impacts of economic growth, FDI, and innovation on CO_2 emissions provide important evidence on the nature of the environment–economy nexus across different periods and methodological approaches.

When the literature on Türkiye is examined, it becomes evident that the effects of economic growth, foreign direct investment (FDI), and technological development on CO_2 emissions vary across periods and structural conditions. For instance, Gökmenoğlu and Taspinar (2016), using data from 1974 to 2010 and an ARDL error-correction framework, report that both economic growth and FDI are associated with increases in CO_2 emissions in Türkiye. Similarly, Benli (2020) analyses the effects of economic growth and FDI on carbon emissions for the period 1974–2014 and reports that both economic growth and FDI increase carbon emissions. Qoyash and Eren (2022) examine the effects of FDI and technological innovation on CO_2 emissions in Türkiye for the 1990–2019 period using the dynamic ARDL simulation method, and their results indicate that both FDI and technological innovation positively affect CO_2 emissions. Tekbaş and Yıldırım (2023) investigate the effects of innovation and economic growth on CO_2 emissions in 13 developing countries, including Türkiye, during 2000–2009. Their findings show that innovation increases CO_2 emissions in Türkiye, whereas economic growth mitigates them. Gültekin (2023) analyses the effects of innovation and economic growth on carbon emissions in Türkiye using the ARDL bounds testing approach and finds that economic growth positively affects CO_2 emissions, while innovation reduces them. Finally, Coşkun et al. (2025), using annual data from 1984 to 2019, find that technological innovation currently contributes to an increase in CO_2 emissions, with a 1% rise in innovation leading to a 0.061% increase in environmental degradation, while also identifying an inverted U-shaped relationship between economic growth and environmental degradation. Moreover, the literature also includes studies reporting conflicting findings. For instance, Haug and Ucal (2019) examine the effects of FDI on CO_2 emissions in Türkiye. Based on the results of linear and nonlinear ARDL models, they find that FDI has significant asymmetric effects on per capita CO_2 emissions, while no statistically significant long-run effects of FDI are detected. In addition, increases in real GDP per capita have led to a reduction in CO_2 emissions over the past decade. Uğur (2022), on the other hand, shows that FDI contributes positively to CO_2 emissions in Türkiye over the period 1974–2015, thereby confirming the pollution haven hypothesis, while also finding support for the Environmental Kuznets Curve hypothesis, indicating that economic growth has a negative effect on CO_2 emissions beyond a certain threshold. Koçak (2024) investigates the impact of environmental technological innovation on CO_2 emissions in Türkiye for the period 1990–2018 using the ARDL bounds testing approach and the Toda–Yamamoto causality test. The findings reveal that environmental technological innovation reduces CO_2 emissions and has a mitigating effect on global warming. Similarly, Atılgan (2025) examines the impact of environmental technological innovation on global warming in BRIC (Brazil, Russia, India, and China) countries and Türkiye over the period 1992–2020. The panel results indicate that a 1% increase in environmental technological innovation reduces CO_2 emissions by approximately 0.238%, whereas a 1% increase in GDP raises CO_2 emissions by about 0.150%. Overall, these studies indicate that the environment–economy relationship in Türkiye is not unidirectional and is closely linked to period-specific conditions and the process of structural transformation.

Recent empirical studies focusing on Türkiye further reinforce the complexity of these relationships. While many studies show that economic growth and foreign direct investment (Kılıçarslan & Dumrul, 2017) tend to increase CO_2 emissions due to the persistence of energy-intensive production structures (Topal, 2024), others suggest that technological progress and foreign investment can contribute to environmental improvement under certain institutional and structural conditions. In particular, recent studies emphasize that the impact of foreign direct investment cannot be assessed solely in terms of its volume, but must also take into account the sectors invested and the technologies used (Çamkaya et al. 2022). These mixed findings imply that the environmental impacts of growth (Çamkaya, 2024; Polat, I. H., 2026), investment, and innovation are highly sensitive to factors such as sectoral composition, regulatory quality, and the direction of technological change (Bozatlı, 2026; Coşkun et al. 2025). Therefore, the current literature does not present a completely consistent picture for Turkey and underlines the need for a more integrated empirical framework that considers these key determinants together. These conflicting findings clearly demonstrate that there is no consensus in the literature regarding the direction of these relationships in Türkiye.

On the other hand, the literature also includes studies focusing on other individual countries. For instance, Khan et al. (2020) analyse the relationship between technological innovation and CO_2 emissions in China for the 1970–2010 period using the ARDL approach and conclude that technological innovation reduces CO_2 emissions. Adebayo and Kirikkaleli (2021) apply wavelet analysis to Japanese data for the 1990–2015 period to examine the relationship between technological innovation and CO_2 emissions, finding that technological innovation increases CO_2 emissions in Japan. Using a similar wavelet-based approach, Adebayo et al. (2022) investigate the link between innovation and CO_2 emissions in Portugal from 1980 to 2019 and find a positive relationship across all frequency scales. For Nigeria, Osinusi et al. (2024) investigate the effects of FDI and economic growth on carbon emissions over the 1981–2023 period. The ARDL findings indicate that FDI has no significant impact on emissions in the short run but increases emissions over the long run, a relationship that is further strengthened by economic growth. Focusing on India, Tripathy et al. (2025) analyse the period from 1980 to 2014 and find that FDI inflows raise CO_2 emissions via both direct effects and indirect pathways involving energy consumption, industrial composition, and high-carbon technologies. Finally, Zhu et al. (2025) examine the effects of city-level technological innovation indicators on CO_2 emission intensity in China using spatial econometric methods and show that higher levels of technological innovation reduce CO_2 emission intensity both within cities and in neighbouring regions.

Cross-country studies further underscore the heterogeneous nature of the environment–economy relationship. Kivyiro and Arminen (2014) investigate causal links among CO_2 emissions, economic development, and foreign direct investment (FDI) in six Sub-Saharan African countries (the Republic of the Congo, the Democratic Republic of the Congo, Kenya, South Africa, Zambia, and Zimbabwe) over the 1971–2009 period. Their ARDL

results indicate that FDI increases CO_2 emissions in some countries but reduces them in others. Balsalobre-Lorente et al. (2018), using panel data for five European countries (Germany, France, Italy, Spain, and the United Kingdom) from 1985–2016, find that energy innovation harms CO_2 emissions, whereas economic growth has a positive effect. Mensah et al. (2018) analyse the effects of economic growth and innovation on CO_2 emissions in 28 OECD countries for the 1990–2014 period using the fully modified ordinary least squares (FMOLS) method and report that economic growth leads to higher emissions in many OECD countries, while innovation plays a significant role in reducing CO_2 emissions in most cases. Nguyen et al. (2020), also employing the FMOLS method, examine determinants of carbon emissions in 13 G20 countries for the 2000–2014 period and find that factors such as FDI, technology, and innovation expenditures help mitigate emissions, whereas economic growth increases CO_2 emissions. Li and Zhou (2025), analysing 39 countries using quantile regression, show that FDI increases emissions in low-CO_2 countries but reduces them in high-CO_2 countries due to technology-transfer effects. Ayaydın et al. (2025) examine the effects of FDI on clean energy and the green transition in BRICS-T countries over 1990–2021, using FMOLS and DOLS, and find that FDI supports the green transition by reducing CO_2 emissions. Doran et al. (2025) focus on 27 European Union countries during 2017–2023 and analyse the relationship between innovation and CO_2 emissions across the primary, secondary, and tertiary sectors. Their results indicate that R&D expenditures and specific innovation indicators reduce emissions in some sectors while increasing them in others, particularly in energy and services, thereby emphasising the context-dependent nature of the innovation-environment relationship.

Overall, the literature suggests that policy mixes tailored to countries' structural and institutional characteristics are critical for achieving low-carbon objectives, particularly when addressing the effects of innovation, FDI, and economic growth on carbon emissions. Supporting sustainable development goals aligned with each country's economic and technological capacity can therefore help reduce carbon emissions. Focusing on the Turkish case, this study demonstrates that innovation, economic growth, and FDI may be positively associated with CO_2 emissions. Although previous studies report varying directions and magnitudes of these effects on CO_2 emissions, the present study contributes to the ongoing debate by offering a more precise, context-specific assessment for Türkiye, thereby filling a gap in the literature on Turkey's unique economic and environmental conditions. The following hypotheses are examined in this study:

H1: Foreign direct investment has a positive and statistically significant effect on carbon emissions in Türkiye.

H2: Economic growth has a positive and statistically significant effect on carbon emissions in Türkiye.

H3: Innovation has a positive and statistically significant effect on carbon emissions in Türkiye.

METHODOLOG

This section outlines the methodological framework used to assess the effects of foreign direct investment, economic growth, and innovation on carbon emissions in Türkiye. Descriptive statistics and pairwise correlations are first reported to provide preliminary insights into the coherence of the specified model. The analysis then proceeds with unit root testing to assess the variables' stationarity and the underlying time-series features of the data. The study next adopts the ARDL bounds testing procedure, chosen for its flexibility with small sample sizes and mixed orders of integration, to identify long-run linkages among the variables and to present the model structures developed for the analysis. The short-run dynamics are then addressed using an error-correction model (ECM), discussed in a separate subsection, which shows how deviations from the long-run equilibrium are corrected over time. To ensure the robustness of the results, additional tests, such as FMOLS, DOLS, and CCR, are conducted, providing validation for the identified relationships. Finally, the analysis concludes by applying the Toda–Yamamoto (1995) causality test to examine causal relationships among the variables, further strengthening the credibility of the findings.

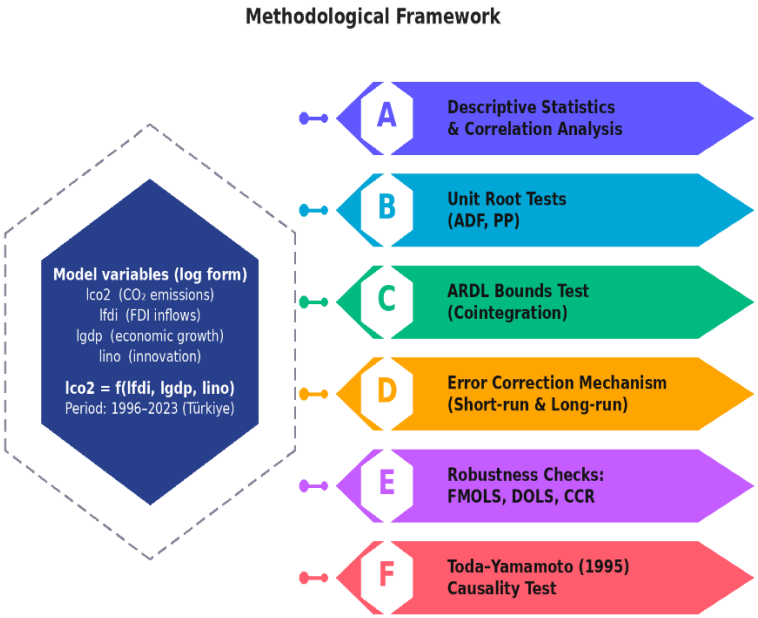


Figure 5: Methodological Framework

Source: Created by the author(s).

Unit Root Tests

If time-series variables are non-stationary, regression models based on such data may produce spurious relationships that do not reflect the underlying reality. Therefore, before estimating any statistical model, it is essential to test whether all series are stationary. To assess the stationarity of the series, this study applies unit root tests as outlined by Gujarati (2004). Accordingly, both the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests are used (Dickey & Fuller, 1981; Phillips & Perron, 1988).

The ADF test is evaluated under three alternative model specifications. To address autocorrelation, lagged differences of the dependent variable are included in the regression, and the appropriate lag length is selected using information criteria. The test accounts for autocorrelation parametrically and computes the test statistic accordingly (Dickey & Fuller, 1981). The PP test is widely used as an alternative procedure for assessing the presence of a unit root. Its test statistic is calculated using nonparametric adjustments to correct for serial correlation and heteroskedasticity. These adjustments do not alter the asymptotic distribution of the statistic; therefore, the PP test shares the same critical values as the ADF test and is considered more robust in many applications (Phillips & Perron, 1988). The hypothesis structure is identical in both tests. In unit root testing, the null hypothesis assumes the existence of a unit root, while the alternative hypothesis implies stationarity. A rejection of the null, therefore, signals a stationary series, whereas a non-rejection points to a unit root. The main differences between the ADF and PP tests arise from their methodological foundations. The ADF test is a parametric approach that requires selecting an appropriate lag structure, whereas the PP test uses nonparametric corrections and does not involve lag selection. Furthermore, the PP test is more robust to heteroskedasticity in the disturbance terms, thereby enhancing its power in many empirical contexts (Phillips & Perron, 1988).

Autoregressive Distributed Lag (ARDL) Bounds Test

A large proportion of economic time series are non-stationary in levels and contain unit roots (Johansen & Juselius, 1990). Models estimated directly on such series may produce spurious regression results, generating relationships that do not exist in reality (Granger & Newbold, 1974). A common approach to reducing this risk is to apply first-difference transformations to the series. However, differencing weakens the time-related information in the series and may distort the structural relationships among variables (Tarı & Yıldırım, 2009). Consequently, even if the series are non-stationary in levels, it is essential to assess whether they move together in the long run, implying cointegration. In the literature, approaches such as those suggested by Eriçok and Yılancı (2013) are widely used for this purpose.

Among cointegration testing methods, the ARDL bounds testing approach stands out for several advantages. Its most important advantage is that it can be applied regardless of whether the variables are integrated of order zero or one, I(0) or I(1) (Pesaran et al., 2001). This flexibility reduces the need to determine the order of integration of the variables precisely in advance. Compared with the Engle–Granger approach, the ARDL bounds test offers more favourable statistical properties because it is conducted within the framework of an unrestricted error-correction model (UECM) (Narayan & Narayan, 2005), making the method more attractive in practice. In addition, it has been shown to produce reliable results even in small samples. Extensive Monte Carlo simulations demonstrate that the bounds test outperforms the Engle–Granger and Johansen cointegration tests in samples with limited observations (Narayan & Smyth, 2005b).

The ARDL bounds test is based on a class of autoregressive distributed lag models. Although it does not directly address endogeneity, it follows a three-step procedure. First, the presence of a cointegration relationship among

the variables is examined. If cointegration is detected, the second step is to estimate the long-run ARDL model to obtain the long-run coefficients. In the final step, short-run dynamics are estimated using the ECM (Narayan & Smyth, 2006). For the model employed in this study, the ECM equation adapted within the ARDL framework is given as follows:

$$\Delta lco2_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta lco2_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta lfdi_{t-i} + \sum_{i=1}^{p} \beta_{3i} \Delta lgdp_{t-i} + \sum_{i=1}^{p} \beta_{4i} \Delta \text{lino}_{t-i} + \beta_5 lco2_{t-1} + \beta_6 lfdi_{t-1} + \beta_7 lfdi_{t-1} + \beta_8 \text{lino}_{t-1} + \varepsilon_t \quad (1)$$

As specified in the equations, Δ denotes the difference operator, β_0 represents the constant, β_{1i} through β_{4i} capture short-run dynamics, and β_5 through β_8 reflect long-run relationships. The error term is given by ε_t, and p denotes the lag order for the dependent and independent variables. In the bounds testing approach, the F-test is sensitive to the choice of lag length (Bahmani-Oskooee & Goswami, 2003). Accordingly, the optimal lag length for the variables is determined based on information criteria (Narayan & Narayan, 2005).

Once the appropriate lag length is selected, the F-test evaluates whether the level and lagged values of both the dependent and independent variables are jointly statistically significant (Narayan & Narayan, 2005). At this stage, the significance of lagged variables in the model is examined. The primary objective of the test is to assess the validity of the null hypothesis that there is no long-run cointegration among the variables. In other words, the test serves as the primary hypothesis test for determining whether a long-run equilibrium relationship is present among the series. The null hypothesis tested in the model is expressed in the following equation.

$$H_0: \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0 \quad (2)$$

The results of the F-test are compared with the critical values reported by Pesaran et al. (2001). However, because these critical values were developed for large samples, Narayan (2005) provided alternative critical values that are more appropriate for small samples. If the F-statistic exceeds the upper bound, the null hypothesis is rejected, and cointegration among the variables is accepted. If the F-statistic falls below the lower bound, the null hypothesis is accepted. When the statistic lies between the lower and upper bounds, no definitive conclusion can be drawn (Narayan & Narayan, 2005). After confirming cointegration, an ARDL model is estimated to obtain the long-run coefficients of the independent variables. The lag length is determined using the Akaike information criterion, and the resulting model is expressed in the following equation.

$$lco2_t = \beta_0 + . \sum_{i=.1}^{p} \beta_{1i} lco2_{t-i} + . \sum_{i=.1}^{p} \beta_{2i} lfdi_{t-.i} + . \sum_{i=1}^{p} \beta_{3i} lgdp_{t-.i} + . \sum_{i=1}^{p} \beta_{4i} \text{lino}_{t-.i} + \varepsilon_t \quad (3)$$

In the equations, β_0 denotes the long-run intercept coefficient, β_{1i}–β_{4i} denote the long-run coefficients, p denotes the lag length, and ε_t denotes the long-run error term.

Error Correction Mechanism

The error-correction approach is an effective way to address cointegration issues within a single-equation framework, particularly when the parameters of interest are weakly exogenous. As proposed by Banerjee et al. (1998), the test is formulated as an ECM derived from the OLS (Ordinary Least Squares) coefficient of the lagged

dependent variable within an augmented ARDL structure. Once the long-run coefficients are identified using the ARDL bounds testing approach, an ECM is constructed to estimate the short-run dynamics and the speed of adjustment toward long-run equilibrium (Narayan & Narayan, 2005). The error-correction equations for the model used in this study are presented below.

$$\Delta lco2_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta lco2_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta lfdi_{t-i} + \sum_{i=1}^{p} \beta_{3i} \Delta lgdp_{t-i} + \sum_{i=1}^{p} \beta_{4i} \Delta \text{lino}_{t-i} + \beta_1 ECT_{t-1} + \varepsilon_t \quad (4)$$

In the equation above, β_{1i}–β_{4i} denote the short-run coefficients, p is the relevant lag length, β_0 is the short-run intercept, and ε_t is the short-run error term. The coefficient β_1 represents the speed of adjustment, indicating the proportion of a short-run shock that is corrected in the long run. If the coefficient on the error correction term (ECT_{t-1}) lies between 0 and −1, the system converges smoothly towards the long-run equilibrium. If the coefficient lies between −1 and −2, convergence occurs through damped oscillations around the equilibrium. Values below −2 or above 0 indicate divergence from equilibrium (Alam & Quazi, 2003).

Robustness Check Tests

In this study, the ARDL findings are examined through robustness checks. For this purpose, Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR) estimation techniques are employed. As with conventional cointegration frameworks, FMOLS, DOLS, and CCR are applicable only when the underlying series are stationary in first differences (Erdoğan et al., 2018). However, under cointegration, standard errors from Ordinary Least Squares (OLS) estimates are often biased. Initially proposed by Phillips and Perron for time-series modelling, the FMOLS estimator is a regression-based approach for obtaining efficient parameter estimates in cointegrated systems (Phillips & Perron, 1988).

The FMOLS estimator developed by Hansen and Phillips (1990) is particularly effective at correcting biases arising from serial correlation and endogeneity between the regressors and the error term. Similarly, the DOLS estimator proposed by Stock and Watson (1993) is an important technique for eliminating endogeneity between the explanatory variables and the error term.

On the other hand, the CCR estimator developed by Park (1992) is designed to address biases associated with conventional OLS estimation. The CCR approach aims to asymptotically eliminate endogeneity by transforming the variables using the long-run covariance matrix. This transformation is particularly used to address endogeneity arising from long-run correlations (Mehmood et al., 2014).

Toda–Yamamoto (1995) Causality Tests

After determining the direction of the coefficients from ARDL results and robustness checks, causal relationships among the variables are examined using the Toda–Yamamoto (1995) causality test. The Toda–Yamamoto approach provides reliable results regardless of the stationarity and cointegration properties of the series in Granger causality analysis. Traditional Granger causality tests rely on the assumption of stationarity and may

yield biased results when applied to integrated or cointegrated processes. In this context, Toda and Yamamoto (1995) developed a method that preserves the asymptotic distribution properties of standard Wald tests by incorporating augmented lag lengths into a Vector Autoregressive (VAR) framework. Dolado and Lütkepohl (1996) further supported this framework by examining the reliability of Wald tests, particularly in the presence of cointegration.

The method is based on determining the maximum order of integration d_{max} of the series, followed by selecting the optimal lag length k according to information criteria. A VAR model is then estimated in levels by including $k + d_{max}$. The models estimated for x and y are presented in the following equations.

$$y_t = \phi_1 + \sum_{i=1}^{k+d_{max}} \psi_{1i} y_{t-i} + \sum_{i=1}^{k+d_{max}} \omega_{1i} x_{t-i} + e_{1t} \quad (5)$$

$$x_t = \phi_2 + \sum_{j=1}^{k+d_{max}} \psi_{2j} x_{t-j} + \sum_{i=1}^{k+d_{max}} \omega_{2j} y_{t-j} + e_{2t} \quad (6)$$

Here, k denotes the optimal lag length, and d_{max} represents the maximum order of integration of the series, that is, the highest degree of differencing required to achieve stationarity across the variables. The terms x and y denote two distinct time series, ϕ_1 and ϕ_2 denote the intercept terms, and ψ_{1i}–ψ_{2j} and ω_{1i}–ω_{2j} denote the coefficients associated with the lagged values of the respective variables. The test is applied only to the coefficients corresponding to the first k lags. The null hypothesis (H_0) is that x does not Granger-cause y, indicating no causal relationship from the independent variable to the dependent variable (Toda & Yamamoto, 1995). In this formulation, H_0 corresponds to the case in which the lagged coefficients of the x series are jointly equal to zero, as shown in the following equation:

$$H_0: \omega_{1i} = \omega_{2i} = \cdots = \omega_{1i} = 0 \quad (7)$$

One of the most important advantages of the Toda–Yamamoto (1995) approach is that it provides reliable statistical inference regardless of the series' integration order and cointegration properties. By reducing biases from incorrect differencing or errors in cointegration testing, this method offers a robust framework for causality analysis (Rambaldi & Doran, 1996).

Data Set and Model

Drawing on annual observations from 1996 to 2023, this study examines how foreign direct investment, economic growth, and innovation affect carbon emissions in Türkiye. The variables include total carbon dioxide emissions, foreign direct investment (net inflows as a percentage of GDP), GDP per capita (constant 2015 US dollars), and research and development expenditure (as a percentage of GDP). Details of variable abbreviations, indicators, measurement units, model specifications, and data sources are provided in Table 1 below.

Table 1: Variable Description

Abbreviation	Variable	Measurement	Role	Source
lco₂	Carbon emissions	Carbon dioxide (CO_2) emissions (total) excluding LULUCF (Mt CO_2e)	Dependent	WDI
lfdi	Foreign direct investment	Foreign direct investment, net inflows (% of GDP)	Independent	WDI
lgdp	Economic growth	GDP per capita (constant 2015 US$)	Independent	WDI
lino	Innovation	Research and development expenditure (% of GDP)	Independent	WDI

Source: Created by the author(s).

The dependent variable in this study is carbon emissions, defined as the total CO_2 released into the atmosphere from human activities. Carbon emissions are closely linked to production and energy consumption, and environmental pressure generally rises with economic growth. For this reason, carbon emissions are a key indicator of environmental sustainability.

Foreign direct investment is included as an independent variable, measured as its share of gross domestic product. It contributes to economic growth by increasing capital accumulation and productivity. However, because short-term capital flows can create financial vulnerability, the quality and sustainability of the investment structure are critical. Economic growth is measured by real GDP per capita, which reflects an economy's level of welfare and productive capacity. Rising income levels may indirectly affect carbon emissions by increasing energy demand and production activity. Innovation is also included as an independent variable, measured by research and development expenditure as a percentage of GDP. R&D activities are essential for developing technologies that enhance energy efficiency and reduce environmental impacts. In this respect, innovation is considered a factor that strengthens the balance between economic growth and environmental quality (World Bank, 2024a).

The model is developed from the existing literature. A correlation analysis is conducted to provide preliminary insights into the direction and strength of linear relationships among the variables. This analysis provides a foundation for subsequent econometric tests by outlining the general framework of interactions among the variables (Tosunoğlu, 2024). Within this framework, all variables are consistently measured. Table 2 below summarises the descriptive statistics and correlations of the variables included in this study.

Table 2: Descriptive Statistics and Correlation Relationships of the Variables

Variables	lco₂	lfdi	lgdp	lino
lco₂	1			
lfdi	0.57	1		
lgdp	0.98	0.53	1	
lino	0.97	0.51	0.96	1
Mean	5.712	0.109	9.083	-0.286

Standard Deviation	0.289	0.700	0.297	0.423
Minimum	5.271	-1.186	8.676	-1.017
Maximum	6.133	1.288	9.597	0.338
Number of observations (N): 28				

Source: Created by the author(s).

The preliminary assessment based on the descriptive statistics indicates that all variables are free of outliers. According to the correlation results, the relationships between lco_2 and lfdi, lgdp, and lino are positive, with correlation coefficients of 57%, 98%, and 97%, respectively. The robust correlation between carbon emissions and economic growth is particularly noteworthy. Likewise, the similarly high correlation between carbon emissions and innovation is equally striking. These findings point to a strong structural relationship within the proposed model.

As a preliminary assessment, the relatively low correlation coefficients among the independent variables suggest the absence of a serious multicollinearity problem. Nevertheless, to provide a more robust evaluation, multicollinearity was further examined using the Variance Inflation Factor (VIF) test. The corresponding VIF results are presented in Table 3.

Table 3: VIF Test Results

Variables	VIF	1/VIF
Lfdi	1.385	0.722
Lgdp	1.753	0.570
lino	1.901	0.526
Mean	1.679	

Source: Created by the author(s).

According to the VIF results, the Variance Inflation Factor values for all variables are below the critical threshold of 5 (VIF < 5). This indicates that multicollinearity is not a significant concern among the variables included in the model.

Time-series methods, including the ARDL bounds testing procedure and the error correction model (ECM), are used to examine how foreign direct investment, economic growth, and innovation influence environmental outcomes, particularly carbon emissions, in Türkiye. These methods are widely used in the literature because they deliver robust, effective results with relatively few observations (N = 28). The mathematical form of the model used in the study is presented below.

$$lco2 = f(lfdi, lgdp, lino) \quad (8)$$

In the function above, lco_2 represents the model's dependent variable, while lfdi, lgdp, and lino denote the explanatory variables included in this study. For this study, all variables are log-transformed, allowing the estimated coefficients to be interpreted as elasticities (Polat et al., 2025).

FINDINGS AND DISCUSSION

One of the main advantages of the ARDL bounds testing approach is that it can be applied regardless of whether the variables under investigation are integrated of order I(0) or I(1) (Pesaran et al., 2001; Akpınar & Çelik, 2025). However, to assess the applicability of the ARDL bounds test, unit root tests were first conducted to account for the possibility that the series might be integrated of order I(2). The results of the unit root tests are as follows:

Table 4: Unit Root Test Results

	ADF		PP	
Variables	**c**	**c/t**	**c**	**c/t**
lco₂	-0.862	-2.434	-0.951	-2.402
lfdi	-2.372	-2.298	-2.299	-2.289
lgdp	0.413	-4.402**	0.4127	-2.548
lino	-0.384	-2.278	-0.384	-3.623**
Δlco₂	-5.904***	-5.821***	-6.221***	-6.171***
Δlfdi	-5.757***	-4.634***	-6.304***	-7.879***
Δlgdp	-4.761***	-4.878***	-4.761***	-4.878***
Δlino	-7.222***	-7.155***	-7.222***	-7.155***
Notes: For the ADF test, the maximum lag length was set to 3 and selected based on the Akaike Information Criterion (AIC). Values in parentheses indicate probability values. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. For the PP test, the bandwidth was determined using the Newey–West method, and the Bartlett kernel estimator was employed.				

Source: Created by the author(s).

Based on the ADF and PP test results, the variables exhibit a unit root at the level but become stationary after first differencing. Accordingly, all series are I(1), and since none are I(2), the ARDL bounds test is appropriate. The corresponding results are presented in Table 5 below.

Table 5: ARDL Bounds F-Test Results

Model	**Optimal Lag Length**	**F-statistic**	**Bounds Test Critical Values**		**Decision**
			I(0)	**I(1)**	
$lco2 = f(lfdi, lgdp, lino)$	(1, 2, 1, 0)	5.124	3.615	4.913	Cointegration

Source: Created by the author(s).

Table 4 presents the ARDL bounds test results for the model under study. At the 5% significance level, the critical bounds for the F-statistic are 3.615 (lower) and 4.913 (upper). As the observed F-statistic exceeds the upper bound, the null hypothesis of no cointegration is rejected, indicating a long-run equilibrium relationship among the variables at the 5% significance level.

Given the confirmed long-run cointegration relationship indicated by the ARDL bounds F-test, long-run ARDL estimates are then carried out. For the F-test findings to be considered robust, the estimated models must satisfy essential statistical assumptions. The diagnostic checks used to evaluate these assumptions, along with their findings, are shown in Table 6 below.

Table 6: Diagnostic Tests of the ARDL Models

Test	Hypothesis	Test statistics
Ramsey Reset	No model specification error.	0.423 (0.5244)
Breusch-Godfrey LM	No autocorrelation problem.	0.018913 (0.9813)
Breusch- Pagan LM	No heteroskedasticity problem.	0.800 (0.5976)
Notes: Values reported in parentheses are the probability values of the F-statistics.		

Source: Created by the author(s).

The results of the diagnostic tests indicate that the null hypotheses cannot be rejected. Accordingly, it is concluded that the model does not exhibit autocorrelation or heteroskedasticity and that there is no model specification error. Finally, it is necessary to verify whether the series' parameter estimates satisfy the stability criteria. For this purpose, the stability of the estimated ARDL model and the presence of possible structural breaks are assessed using the CUSUM (cumulative sum control chart) and CUSUMSQ (cumulative sum of squares) tests developed by Brown et al. (1975). Based on the graphical evidence, it is concluded that there is no structural break in the estimated coefficients at the 5% significance level and that the coefficients are stable over the sample period. The results of the CUSUM and CUSUMSQ tests are presented in Figure 6.

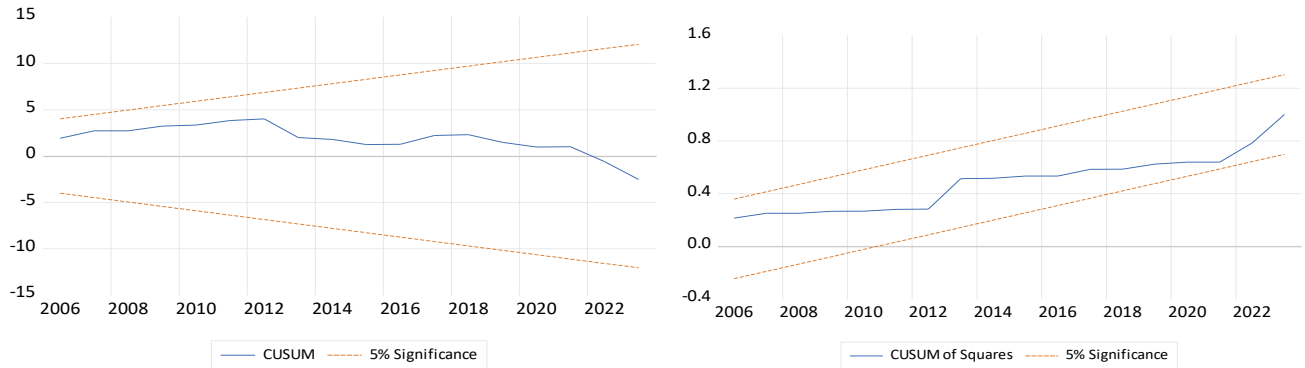


Figure 6: CUSUM and CUSUM (Q) Plots for Model 1

Source: Created by the author(s).

Once a long-run cointegration relationship among the variables was identified using the ARDL bounds F-test, the long-run ARDL coefficients were then calculated. The results are reported in Table 7 below. All coefficients are statistically significant at the 1% level. The results indicate that a 10% increase in lfdi raises lco_2 by approximately 0.6%, a 10% increase in lgdp raises lco_2 by about 5%, and a 10% increase in lino increases lco_2 by around 3%.

Table 7: Long-Run ARDL Coefficient Estimates

Variables	Coefficients	Standard Error	t-Statistic	Probability
lfdi	0.058***	0.018	2.857	0.0105
lgdp	0.417***	0.126	3.312	0.0039
lino	0.304***	0.083	3.659	0.0018
Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.				

Source: Created by the author(s).

Table 8 presents the error-correction model (ECM) results, which measure the speed at which deviations from the long-run equilibrium are corrected.

Table 8: Error Correction Model Results

Variables	Coefficient	Standard error	t-Statistic	Probability
ECTt-1	-0.809***	0.166	-4.889	0.0001
Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.				

Source: Created by the author(s).

The table above presents the error-correction model (ECM) coefficients for the constructed model. ECT_{t-1} denotes the coefficient of the model's error correction term and is estimated at -0.809. As this value lies between -1 and -2, according to Alam and Quazi's (2003) approach, it indicates that the system exhibits damped oscillations around the equilibrium as it converges to the long-run balance.

Although the error-correction coefficient appears statistically significant, interpreting its significance based solely on the p-value is unreliable. Therefore, a boundary test should also be applied to the t-statistic. This test is conducted to assess the effectiveness of the ECT_{t-1} coefficient in the adjustment process towards the long-run equilibrium.

Table 9: Error Correction Coefficient t-Bound Test

t-Statistic	Critical Values of the Bound Test	
	I (0)	**I (1)**
-4.889	-3.43	-4.37

Source: Created by the author(s).

Table 9 above presents the t-bound tests of the error-correction coefficient for the constructed model. Accordingly, at the 1% significance level, the critical values for the t-statistic are -3.43 for the lower bound and -4.37 for the upper bound. In this case, the ECT_{t-1} coefficient is statistically significant at the 1% level, indicating that the model is effective.

This implies that a short-term deviation is corrected approximately 1.25 years (1/0.8) later, restoring the long-run equilibrium. Therefore, any short-term deviation in the model is corrected in roughly 16 months, reaching long-

term balance. The ARDL findings have been validated through FMOLS, DOLS, and CCR robustness tests. The results of these robustness tests are presented in Table 10.

Table 10: Robustness Check Estimation Results

Model	Variables	Coefficients	Standard Error	t-Statistic	Probability
FMOLS	**lfdi**	0.042***	0.013	3.277	0.003
	lgdp	0.496***	0.098	5.080	0.000
	lino	0.282***	0.067	4.195	0.000
DOLS	**lfdi**	0.028*	0.015	1.951	0.062
	lgdp	0.564***	0.113	4.992	0.000
	lino	0.260***	0. 078	3.322	0.000
CCR	**lfdi**	0.046***	0.014	3.380	0.000
	lgdp	0.444***	0.116	3.843	0.000
	lino	0.311***	0.076	4.060	0.000
Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.					

Source: Created by the author(s).

The FMOLS and CCR findings are statistically significant at the 1% level, and their coefficient signs and magnitudes closely match the ARDL results, providing strong support. The DOLS results are statistically significant at the 10% level, and their coefficient signs and magnitudes are also very close to those of the ARDL findings, again providing substantial support. Both the ARDL and robustness test results clearly indicate that FDI, LGDP, and LINO have a positive effect on LCO_2. In addition to determining the direction of these relationships, causality was examined using the Toda–Yamamoto (1995) causality test. The results of this test are presented in Table 11.

Table 11: Toda–Yamamoto (1995) Causality Test Results

Hypotesis	Stat.	Prob.
lfdi is not a Granger cause of lco_2	8.426**	0.014
lgdp is not a Granger cause of lco_2	35.247***	0.000
lino is not a Granger cause of lco_2	28.370***	0.000
lgdp is not a Granger cause of lfdi	6.224**	0.044
lfdi is not a Granger cause of lino	8.642**	0.013
lgdp is not a Granger cause of lino	15.528***	0.000
VAR Model Specification		
VAR (1 3) Model	**Stat.**	**Prob.**
Het: No heteroskedasticity	149.306	0.717
Aut1: No first-order autocorrelation	19.069	0.308
Aut2: No second-order autocorrelation	9.585	0.901
Roots of Characteristic Polynıminal: No root lies outside the unit circle. Var satisfies the stability condition.	0.991, 0.924, 0.924, 0.890, 0.841, 0.841, 0.723, 0.723, 0.580, 0.580, 0.527, 0.322	
Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.		

Source: Created by the author(s).

The table above presents the Toda–Yamamoto (1995) causality test results. Before conducting these tests, the appropriate VAR model was determined by selecting the optimal lag length. The optimal lag length was found to be (1 3), and no issues of heteroskedasticity or autocorrelation were detected. Additionally, the characteristic polynomial roots were all within the unit circle (<1.00), indicating that the model satisfies the stability condition. After confirming the suitable VAR specification, the Toda–Yamamoto (1995) causality test results were obtained. According to these results, LINO is a Granger cause of LCO_2; LFDI is a Granger cause of LCO_2; and LGDP is a Granger cause of LCO_2 (LFDI → LCO_2, LGDP → LCO_2, LINO → LCO_2). Furthermore, LGDP is a Granger cause of LFDI; LGDP is a Granger cause of LINO; and LFDI is a Granger cause of LINO (LGDP → LINO, LGDP → LFDI, LFDI → LINO). To enhance clarity and readability, these relationships are visualised in the schematic diagram below.

Overall, the empirical findings can be interpreted as follows. The results obtained from the ARDL long-run estimates (Table 7) and supported by the robustness checks (Table 10) consistently indicate that economic growth, foreign direct investment, and innovation exert a positive and statistically significant effect on CO_2 emissions in Türkiye. Furthermore, the causality results (Table 11) reveal that these variables are not only associated with carbon emissions but also act as driving forces behind environmental degradation.

These findings suggest that technological innovation in Türkiye has not yet been sufficiently oriented towards environmentally sustainable outcomes. Although innovation is theoretically expected to reduce carbon emissions through improvements in energy efficiency and the adoption of cleaner technologies, the empirical results indicate that, in the Turkish context, innovation is still largely associated with production expansion and energy-intensive activities. This implies that the current structure of innovation is more growth-driven than environmentally driven. In this regard, the positive impact of innovation on CO_2 emissions can be interpreted as evidence that green innovation policies and environmentally focused R&D investments remain relatively limited. Therefore, the environmental effectiveness of innovation in Türkiye appears to depend not only on the level of R&D expenditure but also on its direction and sectoral composition.

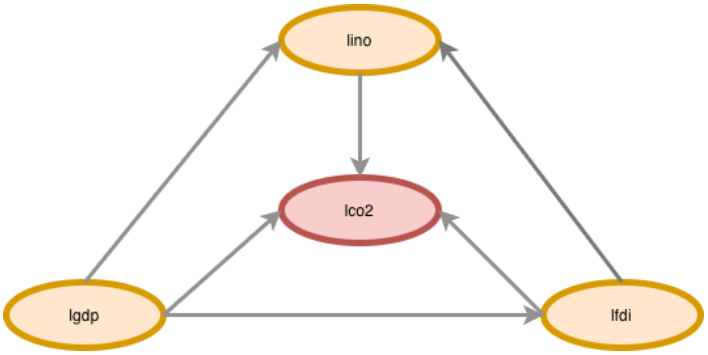


Figure 7: Toda-Yamamoto (1995) Causality Test Schematic

Source: Created by the author(s).

CONCLUSION AND POLICY RECOMMENDATIONS

This study examined the complex relationships among carbon emissions, FDI, economic growth, and innovation in Turkey over the period 1996–2023 using the ARDL bounds testing approach and the error-correction mechanism. The relationships identified by the ARDL tests were subsequently supported by robustness checks (FMOLS, DOLS, CCR). Finally, the Toda–Yamamoto causality test was employed to analyse the causal relationships among the variables. Consistent with the research objectives and the hypotheses proposed in this study, the ARDL results indicate that, at the 1% significance level, a 10% change in LFDI, LGDP, and LINO increases LCO_2 by approximately 0.6%, 4.1%, and 3.0%, respectively. The robustness tests further confirmed these findings by showing consistent signs and magnitudes of the coefficients. The Toda–Yamamoto (1995) causality test results reveal unidirectional Granger causality from LFDI, LGDP, and LINO to LCO_2 (LFDI → LCO_2, LGDP → LCO_2, LINO → LCO_2), as well as unidirectional causality among the explanatory variables themselves (LGDP → LINO, LGDP → LFDI, LFDI → LINO).

The findings suggest that production and growth dynamics in the Turkish economy remain heavily reliant on high-carbon-intensive sectors, indicating that economic expansion has occurred at the expense of environmental sustainability. In particular, FDI tends to flow into energy-intensive rather than environmentally friendly technologies, a key determinant of this outcome. Similarly, the current innovation structure prioritises production capacity over environmental efficiency, limiting its potential to reduce carbon emissions. Examining short-term dynamics shows that temporary deviations in the system are corrected within approximately 16 months, returning to the long-run equilibrium. This indicates the presence of an adjustment mechanism between environmental and economic indicators in Turkey, although long-term sustainability policies are not yet fully embedded. These results underscore the importance of rapid policy responses and effective intervention strategies to mitigate short-term shocks.

In light of these findings, promoting environmentally friendly, low-carbon technologies in energy-intensive sectors is essential to reduce carbon emissions and support sustainable economic growth in Turkey. Environmental criteria should guide FDI allocation, particularly by directing foreign investments towards low-carbon and high-tech sectors such as renewable energy, energy efficiency technologies, and sustainable infrastructure. Similarly, innovation policies should prioritise environmentally oriented R&D activities, including green technologies and clean production processes, rather than focusing solely on production expansion. Moreover, strengthening economic and environmental mechanisms that can absorb temporary fluctuations while maintaining long-run balance will facilitate sustainable transformation in high-carbon sectors.

Comparing the study's findings with the existing literature, the observed positive effect of LGDP on LCO_2 aligns with previous studies (Gökmenoglu & Taşpınar, 2016; Mensah et al., 2018; Benli, 2020; Nguyen et al., 2020; Gültekin, 2023), whereas findings suggesting that LGDP reduces LCO_2 do not align with the literature (Tekbaş

& Yıldırım, 2023). This indicates that the impact of economic growth on CO_2 emissions varies across countries or country groups, and that during the study period, environmental considerations were not a primary factor in Turkey's economic growth dynamics. Similarly, the finding that LFDI increases LCO_2 is consistent with prior studies (Kivyiro & Arminen, 2014; Benli, 2020; Qoyash & Eren, 2022), whereas findings suggesting a reduction in LCO_2 do not align with the literature (Nguyen et al., 2020; Ayaydın et al., 2025). FDI during the examined period exerted environmental pressure in Turkey, supporting the pollution haven hypothesis. The observed positive effect of LINO on LCO_2 is consistent with previous studies (Adeyabo & Kirikkaleli, 2021; Qoyash & Eren, 2022; Tekbaş & Yıldırım, 2023), whereas findings suggesting a reduction in LCO_2 are inconsistent with the literature (Mensah et al., 2018; Khan et al., 2020; Gültekin, 2023; Zhu et al., 2025). Although the impact of innovation on environmental dynamics varies across countries and country groups, in developing Turkey, policies prioritising innovation for environmental mitigation remain relatively limited.

This study faced certain limitations, the most important of which was the data period of 1996–2023. This period was selected because research and development data for Turkey are available without interruption only since 1996. Consequently, data consistency was ensured within this period. Although the sample size of 28 observations is relatively small, this limitation was addressed by applying the ARDL bounds testing approach, which is effective in small samples and accounts for the structure of the Turkish dataset.

Overall, the findings emphasise the need to integrate economic growth and FDI policies with environmental sustainability objectives. Promoting technology-driven innovation to reduce carbon emissions, accelerating the energy transition, and implementing investment policies that incorporate environmental criteria will play a critical role in Turkey's pursuit of low-carbon development. Moreover, the share of foreign investment in innovation should be carefully considered, as FDI can increase emissions and contribute to environmental pollution. Therefore, the role of foreign investment in technological advancement is highly significant. Future studies should examine how FDI and innovation dynamics affect the environment across countries with varying levels of development, providing valuable insights into the complex relationship among FDI, innovation, and environmental outcomes. These findings highlight that the environmental impact of growth and investment in Türkiye is not only a matter of scale but also critically depends on the quality and direction of economic and technological transformation.

Data availability

Data will be made available on request

REFERENCES

Adebayo, T. S., & Kirikkaleli, D. (2021). Impact of renewable energy consumption, globalisation, and technological innovation on environmental degradation in Japan: Application of wavelet tools. *Environment, Development and Sustainability*, 23(11), 16057-16082. https://doi.org/10.1007/s10668-021-01322-2

Adebayo, T. S., Oladipupo, S. D., Adeshola, I., & Rjoub, H. (2022). Wavelet analysis of the impact of renewable energy consumption and technological innovation on CO_2 emissions: Evidence from Portugal. *Environmental Science and Pollution Research*, 29(16), 23887–23904. https://doi.org/10.1007/s11356-021-17708-8

Aghion, P., Dechezleprêtre, A., Hemous, D., Martin, R., & Van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry. *Journal of Political Economy*, 124(1), 1–51. https://doi.org/10.1086/684581

Akpınar, A., & Çelik, N. (2025). OECD ülkelerinde cari açık sorunu ve çözüm önerileri: DFE-ARDL panel model bulguları. *Dokuz Eylül Üniversitesi İşletme Fakültesi Dergisi*, 26(1), 46–66. https://doi.org/10.24889/ifede.1515316

Alam, I., & Quazi, R. (2003). Determinants of capital flight: An econometric case study of Bangladesh. *International Review of Applied Economics*, 17(1), 85–103. https://doi.org/10.1080/713673164

Atılgan, D. (2025). Çevresel teknolojik inovasyonun küresel ısınma üzerine etkisi: BRIC ve Türkiye ülkeleri üzerine ampirik bir inceleme. *Süleyman Demirel Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, (52), 1-14. https://doi.org/10.61904/sbe.1591309

Ayaydın, H., Ergün, T., Barut, A., Erdem, A., & Pilatin, A. (2025). FinTech-driven green energy transition, foreign direct investment, and ecological footprint in BRICST countries. *Scientific Reports*, 15(1), 34838. https://doi.org/10.1038/s41598-025-18898-8

Bahmani-Oskooee, M. M., & Goswami, G. G. (2003). A disaggregated approach to test the J-curve phenomenon: Japan versus her major trading partners. *Journal of Economics and Finance*, 27(1), 102–113. https://doi.org/10.1007/bf02751593

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., & Farhani, S. (2018). How economic growth, renewable electricity and natural resources contribute to CO_2 emissions? *Energy Policy*, 113, 356–367. https://doi.org/10.1016/j.enpol.2017.10.050

Banerjee, A., Dolado, J., & Mestre, R. (1998). Error-correction mechanism tests for cointegration in a single-equation framework. *Journal of Time Series Analysis*, 19(3), 267–283. https://doi.org/10.1111/1467-9892.00091

Bekun, F. V., Gyamfi, B. A., Olasehinde-Williams, G., & Yadav, A. (2024). Revisiting the foreign direct investment-CO_2 emissions nexus within the N-EKC framework: Evidence from South Asian countries. *Sustainable Futures*, 8, 100357. https://doi.org/10.1016/j.sftr.2024.100357

Benli, M. (2020). Türkiye'de doğrudan yabancı yatırımlar, karbon emisyonu ve iktisadi büyüme: Veriye dayalı bir analiz. *Uluslararası Ekonomi ve Yenilik Dergisi*, 6(1), 35–59. https://doi.org/10.20979/ueyd.617746

Boateng, E., Annor, C. B., Amponsah, M., & Ayibor, R. E. (2024). Does FDI mitigate CO_2 emissions intensity? Not when institutional quality is weak. *Journal of Environmental Management*, 354, 120386. https://doi.org/10.1016/j.jenvman.2024.120386

Bozatlı, O. (2026). The relationship between environmental taxes and ecological footprint in Türkiye: An analysis in the context of the EKC hypothesis. *Cumhuriyet Üniversitesi İktisadi ve İdari Bilimler Dergisi*, 27(1), 119-132. https://doi.org/10.37880/cumuiibf.1820332

Brown, R. L., Durbin, J., & Evans, J. M. (1975). Techniques for testing the constancy of regression relationships over time. *Journal of the Royal Statistical Society*: Series B (Statistical Methodology), 37(2), 149–163. https://doi.org/10.1111/j.2517-6161.1975.tb01532.x

Çamkaya, S. (2024). Yenilenebilir enerji ve sanayileşmenin çevre üzerindeki etkisinin STIRPAT-Kaya-EKC hipotezi çerçevesinde analizi: AARDL Modelinden kanıtlar. *Bingöl Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 8(1), 107-125. https://doi.org/10.33399/biibfad.1359874

Çamkaya, S., Polat, İ. H., & Polat, Ü. (2022). Are foreign direct investments effective on environmental quality in Turkey? An approach with non-linear ardl method. *İktisadi İdari ve Siyasal Araştırmalar Dergisi*, 7(17), 30-46. https://doi.org/10.25204/iktisad.1023839

Coşkun, M. F., Konat, G., & Yilanci, V. (2025). Investigation of the role of technological innovation in reducing carbon dioxide damage in Turkey with Fourier tests: Testing the Kuznets curve hypothesis. *Environment, Development and Sustainability*, 1-25. https://doi.org/10.1007/s10668-025-06137-z

Dickey, D. A., & Fuller, W. A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica: Journal of the Econometric Society*, 1057–1072. https://doi.org/10.2307/1912517

Dolado, J. J., & Lütkepohl, H. (1996). Making Wald tests work for cointegrated VAR systems. *Econometric Reviews*, 15(4), 369–386. https://doi.org/10.1080/07474939608800362

Doran, N. M., Bădîrcea, R. M., Jianu, E., Antoniu, M. E., Ciobanu, R. M., & Ciobanu, Ș. C. F. (2025). Unveiling CO_2 Emission Dynamics Under Innovation Drivers in the European Union. *Sustainability*, 17(8), 3463. https://doi.org/10.3390/su17083463

Erdoğan, L., Tiryaki, A., & Ceylan, R. (2018). Türkiye'de uzun dönem ekonomik büyümenin belirleyicilerinin ARDL, FMOLS, DOLS ve CCR yöntemleriyle tahmini. *Hacettepe Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 36(4), 39–57. https://doi.org/10.17065/huniibf.336371

Eriçok, R. E., & Yılancı, V. (2013). Eğitim harcamaları ve ekonomik büyüme ilişkisi: Sınır testi yaklaşımı. *Bilgi Ekonomisi ve Yönetimi Dergisi*, 8(1), 87–101. https://izlik.org/JA94TN69FR

Fernández, Y. F., López, M. F., & Blanco, B. O. (2018). Innovation for sustainability: the impact of R&D spending on CO_2 emissions. *Journal of Cleaner Production*, 172, 3459–3467. https://doi.org/10.1016/j.jclepro.2017.11.001

Gökmenoğlu, K., & Taspinar, N. (2016). The relationship between CO_2 emissions, energy consumption, economic growth and FDI: The case of Turkey. *The Journal of International Trade & Economic Development*, 25(5), 706–723. https://doi.org/10.1080/09638199.2015.1119876

Granger, C. W. J., & Newbold, P. (1974). Spurious regressions in econometrics. *Journal of Econometrics*, 2, 111–120. https://doi.org/10.1016/0304-4076(74)90034-7

Gujarati, D. N. (2004). *Basic econometrics* (4th ed.). McGraw-Hill.

Gültekin, H. (2023). Finansal gelişme, inovasyon ve CO_2 emisyonları: ARDL sınır testi yaklaşımı. *Econder Uluslararası Akademik Dergi*, 7(1), 25–39. https://doi.org/10.35342/econder.1269394

Hansen, B. E., & Phillips, P. C. B. (1990). Estimation and inference in models of cointegration: A simulation study. *Advances in Econometrics*, 8, 225–248.

Haug, A. A., & Ucal, M. (2019). The role of trade and FDI for CO_2 emissions in Turkey: Nonlinear relationships. *Energy Economics*, 81, 297-307. https://doi.org/10.1016/j.eneco.2019.04.006

IEA (2023). International Energy Agency. *Emissions*. Available at https://www.iea.org/world/emissions

IPCC (2023). Intergovernmental Panel on Climate Change. *Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Available at https://www.ipcc.ch/report/ar6/syr/

Iqbal, M., Chand, S., & Ul Haq, Z. (2023). Economic policy uncertainty and CO_2 emissions: A comparative analysis of developed and developing nations. *Environmental Science and Pollution Research*, 30(6), 15034–15043. https://doi.org/10.1007/s11356-022-23115-4

Jiang, Y., Zhou, Z., & Liu, C. (2019). Does economic policy uncertainty matter for carbon emissions? Evidence from US sector level data. *Environmental Science and Pollution Research*, 26(24), 24380–24394. https://doi.org/10.1007/s11356-019-05627-8

Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration with applications to the demand for money. *Oxford Bulletin of Economics and Statistics*, 52, 169–210. https://doi.org/10.1111/j.1468-0084.1990.mp52002003.x

Khan, Z., Ali, M., Kirikkaleli, D., Wahab, S., & Jiao, Z. (2020). The impact of technological innovation and public-private partnership investment on sustainable environment in China: Consumption-based carbon emissions analysis. *Sustainable Development*, 28(5), 1317–1330. https://doi.org/10.1002/sd.2086

Kılıçarslan, Z., & Dumrul, Y. (2017). Foreign direct investments and CO_2 emissions relationship: the case of Turkey. *Business and Economics Research Journal*, 8(4), 647-660. https://doi.org/10.20409/berj.2017.73

Kızılkaya, O., Sofuoğlu, E., & Çoban, O. (2016). Ekonomik büyüme, enerji tüketimi ve çevre kirliliği analizi: Türkiye örneği. *Kırıkkale Üniversitesi Sosyal Bilimler Dergisi*, 6(2), 255–272. https://izlik.org/JA92RT65HT

Kivyiro, P., & Arminen, H. (2014). Carbon dioxide emissions, energy consumption, economic growth, and foreign direct investment: Causality analysis for Sub-Saharan Africa. *Energy*, 74, 595–606. https://doi.org/10.1016/j.energy.2014.07.025

Koçak, E. (2024). Çevresel teknolojik inovasyonun küresel isınma üzerindeki etkisine ilişkin bir inceleme: Türkiye'den kanıtlar. *Fiscaoeconomia*, 8(2), 478-494. https://doi.org/10.25295/fsecon.1405227

Li, L., & Zhou, H. (2025). The impact of foreign direct investment on carbon emissions in economies along the belt and road. *Sustainability*, 17(13), 5905. https://doi.org/10.3390/su17135905

Mehmood, B., Feliceo, A., & Shahid, A. (2014). What causes what? Aviation demand and economic growth in Romania: Cointegration estimation and causality analysis. *Romanian Economic and Business Review*, 9(1), 21–34.

Mensah, C. N., Long, X., Boamah, K. B., Bediako, I. A., Dauda, L., & Salman, M. (2018). The effect of innovation on CO_2 emissions of OCED countries from 1990 to 2014. *Environmental Science and Pollution Research*, 25(29), 29678-29698. https://doi.org/10.1007/s11356-018-2968-0

Narayan, P. K. (2005). The saving and investment nexus for China: Evidence from cointegration tests. *Applied Economics*, 37(17), 1979–1990. https://doi.org/10.1080/00036840500278103

Narayan, P. K., & Narayan, S. (2005). Estimating income and price elasticities of imports for Fiji in a cointegration framework. *Economic Modelling*, 22, 423–438. https://doi.org/10.1016/j.econmod.2004.06.004

Narayan, P. K., & Smyth, R. (2005a). Electricity consumption, employment and real income in Australia: Evidence from multivariate Granger causality tests. *Energy Policy*, 33(9), 1109–1116. https://doi.org/10.1016/j.enpol.2003.11.010

Narayan, P. K., & Smyth, R. (2005b). Trade liberalisation and economic growth in Fiji: An empirical assessment using the ARDL approach. *Journal of the Asia Pacific Economy*, 10(1), 96–115. https://doi.org/10.1080/1354786042000309099

Narayan, P. K., & Smyth, R. (2006). What determines migration flows from low-income to high-income countries? An empirical investigation of Fiji–U.S. migration, 1972–2001. *Contemporary Economic Policy*, 24(2), 332–342. https://doi.org/10.1093/cep/byj019

Nguyen, T. T., Pham, T. A. T., & Tram, H. T. X. (2020). Role of information and communication technologies and innovation in driving carbon emissions and economic growth in selected G-20 countries. *Journal of Environmental Management*, 261, 110162. https://doi.org/10.1016/j.jenvman.2020.110162

Osinusi, K. B., Ajayi, E. G., & Sokunbi, A. R. (2024). Foreign direct investment and carbon emissions nexus in Nigeria: What role does fiscal policy play? Alvan *Journal of Social Sciences*, 1(1), 1–16. https://doi.org/10.32065/fucjef

Park, J. Y. (1992). Canonical cointegrating regressions. *Econometrica*, 60(1), 119–143. https://doi.org/10.2307/2951679

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16(3), 289–326. https://doi.org/10.1002/jae.616

Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*, 75(2), 335–346. https://doi.org/10.1093/biomet/75.2.335

Polat, İ. H. (2026). The New Drivers of CO_2 Emissions in BRIC Countries: Assessing the Role of Economic Policy Uncertainty, Clean Energy Consumption and Financial Development. *İktisadi İdari ve Siyasal Araştırmalar Dergisi*, 29, 292-315. https://doi.org/10.25204/iktisad.1835684

Polat, İ. H., Tosunoğlu, M., & Gümüş, M. (2025). The balancing act: Can corruption control and accountability save public efficiency in India? *Eskişehir Osmangazi Üniversitesi Sosyal Bilimler Dergisi*, 26(2), 464–490. https://doi.org/10.17494/ogusbd.1682596

Qoyash, F. K., & Eren, M. (2022). Türkiye'de teknolojik inovasyon ve yenilenebilir enerji tüketiminin çevre kirliliği üzerine etkisi. *Ardahan Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 4(2), 110-118. https://izlik.org/JA76KM94WX

Rambaldi, A. N., & Doran, H. E. (1996). *Testing for Granger non-causality in cointegrated systems made easy* (Working paper). Department of Econometrics, University of New England.

Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of Political Economy*, 94(5), 1002–1037. https://doi.org/10.1086/261420

Shahbaz, M., Nasir, M. A., & Roubaud, D. (2018). Environmental degradation in France: The effects of FDI, financial development, and energy innovations. *Energy Economics*, 74, 843–857. https://doi.org/10.1016/j.eneco.2018.07.020

Shahbaz, M., Nasreen, S., Abbas, F., & Anis, O. (2015). Does foreign direct investment impede environmental quality in high-, middle-, and low-income countries? *Energy Economics*, 51, 275–287. https://doi.org/10.1016/j.eneco.2015.06.014

Siripi, H., Kuuwill, A., & Tamakloe, M. D. (2024). Economic growth and environmental sustainability: The role of foreign direct investment and technological innovation on carbon emissions in Ghana. *Research in Globalisation*, 9, 100260. https://doi.org/10.1016/j.resglo.2024.100260

Stock, J. H., & Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica*, 61(4), 783–820. https://doi.org/10.2307/2951763

Syed, Q. R., & Bouri, E. (2022). Impact of economic policy uncertainty on CO_2 emissions in the US: Evidence from bootstrap ARDL approach. *Journal of Public Affairs*, 22(3), e2595. https://doi.org/10.1002/pa.2595

Tarı, R., & Yıldırım, D. Ç. (2009). Döviz kuru belirsizliğinin ihracata etkisi: Türkiye için bir uygulama. *Yönetim ve Ekonomi Dergisi*, 16(2), 95–105. https://izlik.org/JA22SB33TP

Tekbaş, M., & Yıldırım, M. (2023). Gelişmekte olan ülkelerde inovasyon ve ekonomik büyümenin CO_2 emisyonu üzerine etkisi. *JOEEP*:*Journal of Emerging Economies and Policy*, 8(2), 507–516. https://izlik.org/JA69YJ86EW

Toda, H. Y., & Yamamoto, T. (1995). Statistical inference in vector autoregressions with possibly integrated processes. *Journal of Econometrics*, 66(1–2), 225–250. https://doi.org/10.1016/0304-4076(94)01616-8

Topal, S. (2024). LCC hipotezi çerçevesinde türkiye'de kirlilik siğinaği ve kirlilik hale hipotezlerinin sinanmasi. *Uluslararası Yönetim İktisat ve İşletme Dergisi*, 20(2), 418-436. https://doi.org/10.17130/ijmeb.1414228

Tosunoğlu, M. (2024). The relationship between technological innovation and economic growth in EU countries: A system GMM approach. *Verimlilik Dergisi*, 58(4), 651–662. https://doi.org/10.51551/verimlilik.1440264

Tripathy, P., Brahmi, M., Pallayil, B., & Mishra, B. R. (2025). Mediating Effects of Foreign Direct Investment Inflows on Carbon Dioxide Emissions. *Economies*, 13(1), 18. https://doi.org/10.3390/economies13010018

Uğur, M. S. (2022). The relationship between foreign direct investment, economic growth, energy consumption and CO_2 emissions: Evidence from ARDL model with a structural break for Turkey. *Ege Academic Review*, 22(3), 337-352. https://doi.org/10.21121/eab.1100759

World Bank. (2024a). *World Bank Metadata Glossary: World Development Indicators (NE.CON.GOVT.ZS).* https://databank.worldbank.org/metadataglossary/world-development-indicators/series/NE.CON.GOVT.ZS

World Bank. (2024b). *World Development Indicators*. World Bank. https://databank.worldbank.org/source/world-development-indicators

World Bank. (2025a). *Carbon dioxide (CO_2) emissions (total) excluding LULUCF (Mt CO_2e) – Türkiye (EN.GHG.CO2.MT.CE.AR5)*. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators

World Bank. (2025b). *Foreign direct investment, net inflows (% of GDP) – Türkiye (BX.KLT.DINV.WD.GD.ZS).* World Development Indicators. https://databank.worldbank.org/source/world-development-indicators

World Bank. (2025c). *GDP (constant 2015 US$) – Türkiye (1996–2023). World Development Indicators*. https://databank.worldbank.org/source/world-development-indicators

World Bank. (2025d). *Research and development expenditure (% of GDP) – Türkiye (GB.XPD.RSDV.GD.ZS).* World Development Indicators. https://databank.worldbank.org/source/world-development-indicators

Zhu, X., Che, J., Niu, X., Cao, N., & Liu, M. (2025). Study on the effect of technological innovation on carbon emission intensity in 278 prefecture-level cities in China. *Scientific Reports*, 15(1), 1–17. https://doi.org/10.1038/s41598-025-99370-5

APPENDIX

List of Abbreviations

ABBREVIATION/ SYMBOL	DESCRIPTION
ABD	United States of America
ADF	Augmented Dickey-Fuller
ARDL	Autoregressive Distributed Lag Test
CCR	Canonical Cointegrating Regression
CCR	Canonical Cointegrating Regression
CO_2	Carbon Dioxide Emissions
CUSUM	Cumulative Sum Control Chart
CUSUMSQ	Cumulative Sum of Squares
DOLS	Dynamic Ordinary Least Squares
OLS	Ordinary Least Squares
FDI	Foreign Direct Investment
FMOLS	Fully Modified Ordinary Least Squares
G-20	Group of 20
GDP	Gross Domestic Product/ Economic Growth
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCO_2	Carbon Emissions
LİNO	Innovation
N	Number of Observations
OLS	Ordinary Least Squares
PP	Phillips-Perron
R&D	Research and Development
SDG	Sustainable Development Goals
UECM	Unrestricted Error Correction Model
VAR	Vector Autoregressive

InTraders International Trade Academic Journal

e-ISSN: 2667-4408 **www.intraders.org**

Volume: 9
Issue : 1
Research Article

Received: February 18, 2026
Revision: March 28, 2026
Accepted: May 16, 2026
DOI: https://www.doi.org/10.55065/intraders.1892005

Export Diversification, Economic Globalisation, and Capital Formation as Drivers of Real Income: Evidence from BEM Countries

Ömer DORU[1]

Abstract

The purpose of this study is to investigate the effect of export diversification (ED) on economic growth (EG) in 10 Big Emerging Market (BEM) economies using new-generation econometric methods. The methodology uses Panel Quantile Regression and the Common Correlated Effects (CCE) estimator to examine the impact of independent variables across different quantiles of the growth distribution. In addition, to capture country-specific dynamics, the Kónya (2006) SUR-based panel causality test is employed. The findings reveal that ED, fixed capital formation, and economic globalisation have positive effects on EG across quantiles. The causality results further indicate that the direction of the relationship between ED and growth differs across countries, with both unidirectional and bidirectional causal linkages identified. The main contribution of this study is to provide a comprehensive analysis of the ED–growth nexus by examining different growth quantiles and accounting for cross-sectional dependence and country heterogeneity using new-generation econometric methods. The results highlight the importance of ED policies for achieving sustainable economic growth in emerging market economies.

Keywords: *Export Diversification, Economic Growth, Economic Globalisation, BEM Economies*

JEL Codes: *F1, F6, O1, O4*

INTRODUCTION

The pursuit of economic growth (EG) has been identified as a fundamental objective of national development, with foreign trade recognized as one of the most substantial determinants of this process. A substantial consensus exists within the extant literature on the direct impact of foreign trade on EG (Balassa, 1978; Edwards, 1998; Frankel & Romer, 1999). These effects are examined within the framework of the export-led growth hypothesis, which posits that exports enable countries to expand production capacity, access external resources, and enhance

There is no conflict of interest.

[1] Asst. Prof. Dr. Mardin Artuklu University, E-Mail : omerdoru@artuklu.edu.tr, OI: 0000-0001-8119-4908 Contribution rates to the study 100 %.

Cite As: Doru, Ö. (2026). Export diversification, economic globalisation, and capital formation as drivers of real income: Evidence from BEM countries. *InTraders International Trade Academic Journal*, *9*(1), 136-158. https://doi.org/10.55065/intraders.1892005

competitiveness in global markets. The determining role of exports on EG has been examined from different perspectives in the theoretical framework.

Classical foreign trade theories, particularly Ricardo's theory of comparative advantage and the factor endowment theory, argue that countries should specialise in certain products to gain a competitive advantage. According to this approach, EG can be achieved through export orientation and specialisation in specific products (Krugman et al., 2018). However, modern approaches have revealed that exporting product diversity, rather than specialisation, is more effective for growth, especially in developing countries (Cadot et al., 2011; Hausmann et al., 2007).

Foreign trade diversification can be achieved by countries focusing on different product groups and ensuring diversity in foreign markets. Export diversity can make countries' export baskets more resistant to external shocks by allowing trade in a wider range of products (Imbs & Wacziarg, 2003). This approach has become increasingly significant in modern trade theory, especially within the framework of the "new trade theories." Krugman (1991) and Romer (1990) emphasise that economies of scale and product diversification are among the main factors supporting EG. In this framework, ED is considered a strategic factor that ensures EG's sustainability and increases foreign trade volume.

The relationship between ED and EG is examined in the literature within a bidirectional interaction framework. On the one hand, an increase in product diversity triggers EG by increasing production capacity and technological advancement level (Imbs & Wacziarg, 2003); on the other hand, high growth rates enable the development of new sectors and the expansion of the export portfolio (Cadot et al., 2011). This mutual interaction is of strategic importance for policymakers, especially in emerging market economies.

The effect of diversification or concentration of the export structure on growth varies depending on a country's level of development. In developing countries, ED plays a critical role in ensuring the sustainability of growth. This is because the foreign trade of these countries is generally based on a limited number of low-value-added and commodity-based products (Hesse, 2008). The concentration of exports in a limited range of products renders these countries more susceptible to external shocks. However, an increase in product diversification presents a significant opportunity to develop new sectors and maintain resilience in the face of global fluctuations (Hausmann et al., 2007; Lederman & Maloney, 2012). Considering this context, ED is not only a foreign trade strategy for developing countries, but also a fundamental factor for structural transformation and stable EG (Aditya & Acharyya, 2013). On the other hand, since developed countries already have a diversified and high-technology-intensive export structure, the main dynamic supporting growth in these economies is export concentration through deepening and specialisation in certain high-value-added sectors (Persson & Wilhelmsson, 2016). For example, Germany's stability in automotive and machinery-equipment exports, Switzerland's global leadership in the pharmaceuticals and chemical sectors, or Japan's specialisation in precision electronic products

indicates that EG in developed countries can be sustained through export concentration. In this regard, export concentration contributes positively to EG in developed economies by enhancing productivity through competitiveness and economies of scale (Agosin, 2009; Parteka & Tamberi, 2013).

In the literature, the differences arising from countries' levels of development are also supported by empirical evidence. For instance, Hesse (2008) demonstrates that ED has a crucial and positive impact on EG in low-income countries, whereas this effect weakens in high-income economies. Similarly, Cadot et al. (2011) show that ED is more effective in the early stages of growth, but as income levels increase, specialisation becomes more prominent. Imbs and Wacziarg (2003) also define the relationship between ED and per capita GDP as an "inverted U". Accordingly, in the early stages of development, ED increases EG; however, after a certain income level, the process tends to shift towards export intensification. Therefore, ED is considered a critical strategy for developing countries due to its positive effects on EG (Gozgor & Can, 2016a).

The goal of the present study is to determine the contributions of ED and globalisation to EG processes in big emerging market economies using new-generation econometric methods. These countries have been selected for their high growth rates in recent years, increasing foreign trade volumes and their prominent role in global supply chains. These countries represent approximately 46% of the world population, more than 30% of global GDP and 25% of global exports (World Bank, 2025). There are also notable differences in their export structures. For instance, according to the Herfindahl-Hirschman Index (HHI) data provided by UNCTAD, countries such as China, Türkiye, and India have experienced an increase in ED over the past three decades, whereas commodity-intensive economies like Brazil and Indonesia exhibit a tendency toward export concentration (UNCTAD, 2025). These differences show that the impact of export structure on EG varies across countries.

Despite the growing body of literature on ED and EG, several important gaps remain. First, existing studies predominantly focus on average effects, thereby overlooking distributional heterogeneity across different levels of EG. Second, the joint role of ED, economic globalisation, and capital formation has not been sufficiently examined within a unified empirical framework, particularly in the context of BEM economies.

This study contributes to the literature in several important ways. It employs panel quantile regression to capture heterogeneous effects of ED across different growth quantiles. In addition, it accounts for cross-sectional dependence and slope heterogeneity using advanced panel data techniques, including the CCE estimator and the Kónya (2006) causality test. By incorporating economic globalisation and capital formation alongside ED, the study provides a more comprehensive analysis of growth dynamics in emerging economies. Furthermore, the country-specific causality results offer policy-relevant insights that cannot be obtained from conventional panel estimators.

The remainder of the paper is structured as follows: Section 2 reviews the relevant literature; Section 3 presents

the data, methodology, and empirical findings; and Section 4 provides conclusions and policy implications.

LITERATURE REVIEW

The relationship between ED and EG has attracted considerable attention in both theoretical and empirical literature. Despite the relatively limited number of studies directly focusing on this nexus, a broad consensus has emerged suggesting that ED constitutes a significant driver of economic performance, particularly in developing economies.

From a theoretical perspective, the positive role of ED in fostering EG can be explained through several complementary mechanisms. Early contributions such as Love (1986) emphasise that diversification enhances economic stability by reducing vulnerability to external shocks. Similarly, Acemoglu and Zilibotti (1997) argue that diversification allows risks to be distributed across a broader investment portfolio, thereby supporting higher income levels. In endogenous growth theory, Romer (1990) conceptualises diversification as an expansion in the variety of intermediate inputs, thereby increasing productivity and fostering long-term growth. Supporting this view, Sarin et al. (2020) demonstrate, through a meta-analysis, that ED positively affects EG in the vast majority of empirical cases, reinforcing the robustness of this relationship.

Empirical evidence at the country level largely supports the growth-enhancing role of ED. For instance, Herzer and Nowak-Lehnmann (2006) provide evidence from Chile that ED significantly contributes to growth within a Cobb–Douglas production framework. Similar findings are reported for Malaysia (Arip et al., 2010), Cameroon (Forgha et al., 2014), South Africa (Mudenda et al., 2014), Mauritius (Sannassee et al., 2014), Ethiopia (Tesfay, 2016), and Morocco (Lotfi & Karim, 2017), all indicating a positive association between diversification and economic performance. In the case of Nigeria, Duru and Ehidiamhen (2018) confirm a positive but statistically insignificant effect, suggesting that country-specific structural factors may influence the strength of this relationship.

Evidence from Türkiye remains mixed. Acaravcı and Kargı (2015) find no long-run relationship or causality between ED and EG. In contrast, subsequent studies by Altun and Benli (2021) and Doru and Dabakoğlu (2025) report a positive impact of ED on growth. Similarly, while Ali et al. (2023) find no significant effect in Sudan, studies on Bangladesh (Azam & Azam, 2023) and Zimbabwe (Zhou & Nyandoro, 2023) reveal strong positive effects, indicating that the ED–EG nexus is highly context-dependent.

The direction of causality between ED and EG has also been investigated, although the literature remains relatively limited in this regard. Siddiqui (2018) identifies a unidirectional causality from ED to EG in Pakistan, while Shadab (2021) reports similar findings for the United Arab Emirates. However, other studies suggest bidirectional or growth-led diversification dynamics, implying that the interaction between ED and EG may vary across countries and development stages.

Beyond individual-country analyses, a substantial body of research focuses on country groups, offering more generalisable insights. Gutiérrez de Pineres and Ferrantino (2000) document a positive relationship between ED and EG in Latin America, while Feenstra and Kee (2004) show that a 1% increase in ED leads to a measurable increase in productivity across 34 countries. Similarly, Agosin (2009) finds that ED significantly promotes growth in East Asian and Latin American economies. Studies focusing on European Union countries (Misztal, 2011) and BRICS economies (Naudé & Rossouw, 2011; Siswana & Phiri, 2021) also confirm the growth-enhancing role of diversification. In addition, evidence from Central and Eastern European transition economies indicates that the growth effects of export structure are time-dependent. While export concentration supported growth prior to the 2008 global financial crisis, ED became more effective in mitigating growth slowdowns in the post-crisis period (Gurgul & Lach, 2013).

Further evidence highlights the importance of development level and structural conditions in shaping the export diversification–growth nexus. Aditya and Acharyya (2013) show that both ED and export composition are important determinants of EG, with their effects varying with the level of export concentration, suggesting a nonlinear relationship. Similarly, Trinh and Thuy (2021) identify a threshold effect: ED promotes EG only after exceeding a certain level, while its impact remains insignificant below this threshold. In a broader cross-country context, Gozgor and Can (2016b, 2017) provide additional evidence that ED positively affects growth across different income groups and exhibits significant causal relationships. However, country-specific evidence suggests that this relationship may not be uniform; for instance, Sunaryati (2015) finds that while EG Granger-causes ED in some ASEAN countries, no causal relationship is detected in others, pointing to heterogeneous dynamics across economies. Taken together, these findings suggest that the growth effects of ED are conditional rather than uniform, depending on countries' structural characteristics and development stages.

However, not all studies reach consistent conclusions. For example, Benli (2020) fails to detect a long-run relationship in emerging markets, while Carrasco and Tovar-García (2021) find no significant impact of ED on growth in developing countries. In contrast, McIntyre et al. (2018) argue that diversification primarily reduces output volatility rather than directly enhancing long-term growth. These mixed findings suggest that the ED–EG relationship is influenced by methodological differences, country-specific characteristics, and institutional factors.

More recent studies continue to support the positive role of ED. Fu et al. (2017) show that diversified export structures contribute to higher growth in Chinese provinces, while Lee and Zhang (2022) demonstrate that ED enhances growth and reduces volatility in low-income countries. Similarly, Hamed et al. (2014), Rondeau and Roudaut (2014), Matezo et al. (2021), and Alshomaly and Shawaqfeh (2020) provide strong empirical evidence supporting the growth-enhancing effects of diversification, particularly in developing and emerging economies.

Overall, the empirical literature suggests that ED generally supports EG, although the strength and direction of

this relationship vary across countries and income levels. Moreover, most existing studies rely on conventional econometric approaches that focus on average effects and may overlook distributional heterogeneity, cross-sectional dependence, and nonlinear dynamics. In this context, there remains a clear need for studies that employ advanced panel data techniques capable of capturing these complexities, particularly in the case of BEM economies. Accordingly, the present study contributes to the literature by jointly analysing ED, economic globalisation, and capital formation using panel quantile regression and country-specific causality methods, thereby providing a more comprehensive and distribution-sensitive assessment of growth dynamics in emerging economies.

METHOD, DATA, AND ANALYSIS

In this study, the impact of export product diversification, gross fixed capital formation, and economic globalisation on GDP per capita has been examined using panel data analysis for the period 1995-2022, within the context of big emerging economies (Argentina, Brazil, China, India, Indonesia, Mexico, Poland, South Africa, South Korea, and Türkiye). The mathematical expression of the econometric model, which is used in the present study, is given below:

$$\mathrm{LnGDP}_{it} = \beta_0 + \beta_1 \mathrm{LnDIV}_{it} + \beta_2 \mathrm{LnGFCF}_{it} + \beta_3 \mathrm{LnEGLB}_{it} + \mu_{it} \quad (1)$$

In Equation (1), Ln denotes the natural logarithm, the i sub-indices represent the cross-sectional dimension (countries), and t denotes the time dimension. The model parameters β_0, β_1, β_2, and β_3 correspond to the estimated coefficients, while μ represents the error term. The variables used in the analysis, along with detailed explanations, are provided in Table 1.

Table 1. Explanation of the Variables Included in the Model

Country/ Period	Variables	Explanations	Shorts	Source
(Big Emerging Countries) 1995-2022	Economic Growth	GDP per capita (constant 2015 US$)	GDP	World Bank
	Export Diversification	Herfindahl-Hirschman Index	DIV	UNCTAD
	Gross Fixed Capital Formation	% of GDP	GFCF	World Bank
	Economic Globalisation	Index	EGLB	KOF Swiss Economic Institute

Source: Created by Author

ED is proxied by the Herfindahl–Hirschman Index (HHI), which measures export concentration. Higher values of the index indicate greater concentration (i.e., lower diversification), whereas lower values correspond to a more diversified export structure. Therefore, a negative coefficient of the HHI-based variable implies a positive effect of ED on EG.

In this study, firstly, a cross-section dependency test has been carried out, and the appropriate unit root test has been used according to the results that were obtained. Subsequently, a homogeneity test was carried out, followed by a cointegration test that allows for heterogeneity in the slope coefficients. After the cointegration test, some estimators have been used to determine the effect of the long-run relationship. The methodological framework employed in the present study is outlined in Figure 1.

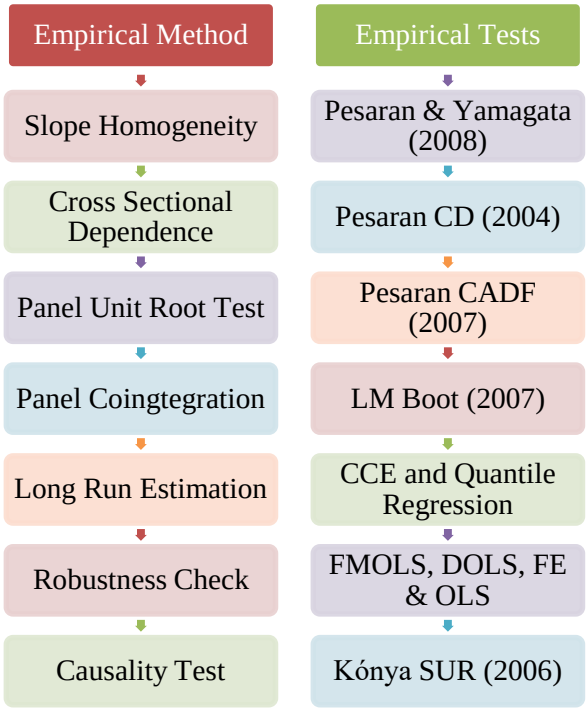


Figure 1: Steps of the Empirical Analysis

Source: Created by Author

The variables used in the model and the econometric tests applied in the methods section are discussed in this section, and a summary flow of the analysis process is shown in Figure 1. In addition, the descriptive statistics for the variables are presented in Table 2.

Table 2. Descriptive Statistics

	GDP	DIV	GFCF	EGLB
Mean	8.773352	-0.716839	3.156184	3.890875
Median	8.989668	-0.729809	3.123840	3.916187
Maximum	10.42497	-0.306620	3.795911	4.291983
Minimum	6.430848	-0.995935	2.481622	2.982807
Std. Dev.	0.861095	0.152813	0.305054	0.208856
Skewness	-0.721994	0.196191	0.165644	-0.963711
Kurtosis	3.156249	2.217110	2.058478	5.435072
Jarque-Bera	24.61102	8.946921	11.62251	112.5196
Probability	0.000005	0.011408	0.002994	0.000000
Observations	280	280	280	280

Source: Created by Author

According to Table 2, the highest standard deviation is observed for the GDP per capita variable. The mean value of GDP is approximately 8.9896, the minimum value is 6.4308, and the maximum value is 10.4249. The standard deviation is 0.861. When analysing the Skewness and Kurtosis coefficients, it was observed that many variables' values fall outside the ±1.5 limits.

In empirical analyses, determining the distribution characteristics of variables is of great importance. This is because appropriate estimation methods must be selected for series that do not exhibit a normal distribution. The analysis indicates that the data do not follow a normal distribution. The results of the Jarque-Bera normality test also support this finding. The null hypothesis, stating that the data are normally distributed for all variables, has been rejected.

Whether the parameters of the established model are homogeneous or heterogeneous plays an important role in selecting the appropriate cointegration tests and estimation methods to be applied to the model. Therefore, it is necessary first to perform homogeneity tests in order to determine the appropriate tests to be employed in the analysis. It is seen that Swamy $\hat{S}$, a Hausman-type test developed by Swamy (1971), which is one of the first studies in the literature to test homogeneity, has been used. This test has been used to examine the homogeneity of slope coefficients. The representation of the Swamy's $\hat{S}$ test is presented as follows (Yerdelen Tatoğlu, 2017: 246-247):

$$\hat{S} = X^2_{k(N-1)} = \sum_{i=1}^{N}\left(\hat{\beta}_i - \bar{\beta}^*\right)' \hat{V}_i^{-1}(\hat{\beta}_i - \bar{\beta}^*) \qquad (2)$$

Pesaran and Yamagata (2008) enhanced and standardised the Swamy (1971) test. In doing so, the Swamy (1971) test was first modified under slope homogeneity. Pesaran and Yamagata (2008) standardised the Delta test in the form of (Δ). The representation of the modified test is as follows:

$$\hat{S} = \sum_{i=1}^{N}\left(\hat{\beta}_i - \hat{\beta}_{WFE}\right)' X_I' \frac{M_T X_i}{\tilde{\sigma}_i^2}(\hat{\beta}_i - \hat{\beta}_{WFE}) \qquad (3)$$

In Equation (3), denotes the pooled OLS estimator and represents the weighted fixed effect pooled estimator. denotes the estimator. Thus, the Swamy test has been enhanced and contributed to the literature as the Delta (Δ) test. Moreover, this test is acknowledged to provide more reliable and robust results.

The Delta ($\hat{\Delta}$) test proposed by Pesaran and Yamagata (2008) is used for large sample sizes. The representation of this test is represented in Equation (4):

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\hat{S} - k}{\sqrt{2k}}\right) \qquad (4)$$

The $\hat{\Delta}_{Adj}$ test statistic, which is used for small sample sizes, is presented in Equation (5).

$$\hat{\Delta}_{Adj} = \sqrt{N}\left(\frac{N^{-1}\hat{S} - E(\tilde{z}_{iT})}{\sqrt{Var(\tilde{z}_{iT})}}\right) \qquad (5)$$

$E(\tilde{z}_{iT}) = k, Var(\tilde{z}_{iT}) = \frac{2k(T-k-1)}{(T+1)}$, where N is the cross-sectional dimension. $\widehat{S}\ is$ the dispersion statistic. k indicates the number of explanatory variables. That is, it shows the number of regressors. $Var(\tilde{z}_{iT})$ denotes the standard error. The hypotheses of this test are formulated to assess the homogeneity of slope coefficients across cross-sectional units. The null hypothesis (H_0) states that the slope coefficients are homogeneous, indicating that all cross-sectional units share the same relationship between the dependent and independent variables ($\beta i = \beta$). In contrast, the alternative hypothesis (H_1) asserts that the slope coefficients are not homogeneous ($\beta i \neq \beta$), implying that the effect of the independent variable varies across different units.

If the p-value obtained from the analysis is greater than 0.05, $H0$ cannot be rejected, indicating that the cointegration coefficients are considered to be homogeneous. However, if the p-value is less than 0.05, H_0 is rejected, indicating that the cointegration coefficients are heterogeneous.

Table 3: Results of Delta Homogeneity Test

Test	Test Statistic	Probability Value
$\hat{\Delta}$	19.443	0.000*
$\hat{\Delta}_{Adj}$	24.453	0.000*

Note: * denotes 1% significance levels.
Source: Created by Author

According to the Delta test results presented in Table 3, the estimated test statistics lead to the rejection of the null hypothesis (H_0) at the 1% significance level for both the intercept and the slope coefficients. Consequently, the alternative hypothesis (H1) is accepted. Based on these results, it is concluded that the slope coefficients in the model are heterogeneous at the 1% significance level.

One of the primary tests that must be carried out in empirical studies using panel data analysis is to examine the cross-sectional dependence (CSD) among the series. Because, with globalisation, the speed of interaction among countries increases, this interaction prepares the ground for the integration of their commercial and financial systems. As a consequence of integration, crises and shocks occurring in one country can also affect other countries. This situation illustrates the relationship among cross-sectional units and highlights the importance of CSD. In the model, the CSD test assesses whether a shock in one country in the panel affects the other countries. In the absence of CSD, first-generation unit root tests are applied, whereas the presence of CSD necessitates the use of second-generation unit root tests.

The literature offers various approaches for examining CSD, and one of the earliest among these is the Lagrange Multiplier (LM) test introduced by Breusch and Pagan (1980), which is typically applied when the number of cross-sectional units is smaller than the number of time periods (N<T). The formulation of this test is presented as follows:

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{P}_{ij}^2 \qquad (6)$$

The LM test is not applicable when the number of cross-sectional units equals or exceeds the number of time periods (N = T or N > T). Instead of this test, the Pesaran (2004) CDLM test is used. The equation for this test is presented below:

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}} \sum_{i+1}^{N-1} \sum_{j=i+1}^{N} \left(T_{\hat{\mathcal{P}}_{ij}^2} - 1 \right) \qquad (7)$$

LMadj, which is another method used to detect CSD, was developed by Pesaran et al. (2008) to address the biased results produced by the LM and CDLM tests. This test is applicable in panels where the cross-sectional dimension is either greater or smaller than the time dimension (N>T or N<T). The representation of the LMadj test is as follows:

$$LM_{adj} = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{(T-k)\hat{\mathcal{P}}_{ij}^2 - \mu_{Tij}}{v_{Tij}} \qquad (8)$$

The following hypotheses are tested to determine the presence of CSD. Accordingly, the null hypothesis (H_0) states that there is no CSD in the panel. The alternative hypothesis (H_1), on the other hand, asserts that there is dependence between cross-sectional units.

Table 4: Results of the CSD Test for the Variables

Test	GDP		DIV		GFCF		EGLB	
	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.
Breusch-Pagan LM	961.79	0.0000*	424.12	0.0000*	197.18	0.0000*	537.83	0.0000*
Pesaran scaled LM	96.63	0.0000*	39.962	0.0000*	16.041	0.0000*	51.949	0.0000*
Bias-corrected scaled LM	96.45	0.0000*	39.777	0.0000*	15.856	0.0000*	51.764	0.0000*
Pesaran CD	30.78	0.0000*	-1.6435	0.1003	5.0806	0.0000*	11.385	0.0000*

Note: * denotes 1% significance levels.
Source: Created by Author

Table 4 shows the result of the CSD test for each variable. The fact that all obtained probability values are below 1% has led to the rejection of H_0, the null hypothesis that the series does not exhibit CSD, at the 1% significance level. Therefore, CSD has been detected across all series, and the corresponding test outcomes for the model are presented in Table 5.

Table 5: Results of the CSD Test for the Model

Test	Statistics	Prob.
LM (Breush, Pagan 1980)	102.9	0.0000*
CD (Pesaran 2004 CD)	4.844	0.0000*
Lm_{adj} (Pesaran vd. 2008)	15.41	0.0000*

Note: * denotes 1% significance levels.
Source: Created by Author

As seen in Table 5, the results obtained from the CSD test for the model are statistically significant at the 1% significance level. The model's significance indicates that the null hypothesis (H_0) is rejected, thereby confirming the presence of CSD within the model. This finding indicates the presence of CSD in the model and suggests that a shock or crisis arising in one of the countries included in the sample could also have an impact on other countries.

Due to the presence of CSD, the stationarity of the series will be tested using the CADF/CIPS unit root test, a second-generation test.

The CADF test, as proposed by Pesaran (2007), was utilized to assess whether the series contains a unit root. In this test, the lagged cross-sectional averages of the ADF regression are also taken into account. After the estimation of the CADF test, the series' stationarity is determined based on the CIPS statistic, which is obtained by averaging the results. The representation of the CIPS statistic, which is the simple arithmetic mean of the CADF test statistic, is calculated as follows (Yerdelen Tatoğlu, 2017: 86):

$$\text{CIPS}(N,T) = \frac{1}{N}\sum_{i=1}^{N} t_i(N,T) = \frac{\sum_{i=1}^{N} \text{CADF}_i}{N} \qquad (9)$$

In Equation (9), N symbolises the cross-sectional dimension, T represents the time dimension and (N, T) represents the cross-section CADF statistic value. The hypotheses associated with this test are designed to determine the stationarity properties of the series. Under the null hypothesis (H_0), the series are assumed to contain a unit root and are therefore non-stationary. In contrast, the alternative hypothesis (H1) posits the absence of a unit root and, thus, stationarity.

Table 6: Results of the CIPS Unit Root Test at Level

Variables	The Form of the Test	CIPS Statistics	Test Critical Values		
			1%	5%	10%
LnGDP	Constant	-1.225	-2.57	-2.33	-2.21
	Constant & Trend	-1.410	-3.1	-2.86	-2.73
LnDIV	Constant	-1.011	-2.57	-2.33	-2.21
	Constant & Trend	-2.374	-3.1	-2.86	-2.73
LnGFCF	Constant	-2.031	-2.57	-2.33	-2.21
	Constant & Trend	-2.309	-3.1	-2.86	-2.73
LnEGLB	Constant	-2.442	-2.57	-2.33	-2.21
	Constant & Trend	-3.055	-3.1	-2.86	-2.73

Source: Created by Author

The CIPS test statistic values of all variables in Table 6 are smaller than the critical values (CIPS statistic < Critical Value). These results indicate that H_0, the null hypothesis, cannot be rejected for the variables under both the constant and the constant & trend models. For achieving stationarity, the first differences of the series have been taken. The series with the first differences taken are presented in Table 7.

Table 7: Results of the CIPS Unit Root Test at First Difference

Variables	The Form of the Test	CIPS Statistics	Test Critical Values		
			1%	5%	10%
ΔLnGDP	Constant	-3.506*	-2.57	-2.33	-2.21
	Constant & Trend	-3.822*	-3.1	-2.86	-2.73
ΔLnDIV	Constant	-5.182*	-2.57	-2.33	-2.21
	Constant & Trend	-5.352*	-2.96	-2.76	-2.66
ΔLnGFCF	Constant	-4.268*	-2.57	-2.33	-2.21
	Constant & Trend	-4.389*	-2.96	-2.76	-2.66
ΔLnEGLB	Constant	-4.944*	-2.57	-2.33	-2.21
	Constant & Trend	-4.848*	-3.1	-2.86	-2.73

Note: * denotes 1% significance levels.
Source: Created by Author

As seen in Table 7, when the first-difference CIPS statistic values of all variables are compared with the critical values, the absolute value of the CIPS statistics is greater than that of the critical values (|CIPS statistic| > |Critical Value|). These results indicate that the null hypothesis H_0 is rejected for both the variables with constant and with constant and trend, and therefore all variables are stationary at 1% significance level. In addition, the fact that I(1) is stationary in the first differences of the series shows that the condition for cointegration analysis is met.

Cointegration analysis enables testing of the long-run relationships among variables. In this study, the LM bootstrap panel cointegration test developed by Westerlund and Edgerton (2007), which accounts for CSD and heterogeneity, is employed. The specification of the cointegration test is presented as follows:

$$LM_N^+ = \frac{1}{NT^2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{\omega}_i^{-2} s_{it}^2 \qquad (10)$$

In this Equation (10), T denotes the time dimension, N represents the sample size, s_{it}^2 refers to the fractional sum of the error terms, and $\hat{\omega}_i^{-2}$ indicates the long-run variance of the error terms. The null hypothesis (H_0) posits the existence of a cointegration relationship between the variables, which is corroborated when the bootstrap p-value exceeds 0.05. Conversely, the alternative hypothesis (H_1) suggests the absence of a cointegration relationship among the variables, which is considered to be valid when the bootstrap p-value is less than 0.05.

Table 8: Lm Bootstrap Cointegration Test

Conditions	LM Statistics	Bootsrap p-value	Asymp p-value
Constant	2.880	0.880	0.002
Constant and Trend	3.240	0.990	0.001

Note: The bootstrap is based on 1000 replications.
Source: Created by Author

Table 8 presents the outcomes of the LM bootstrap cointegration test, which evaluates whether a long-term cointegration relationship exists among the variables. When CSD and heterogeneity are present, the bootstrap p-value is taken into consideration. According to the results, the bootstrap p-value is greater than 0.05 (bootstrap p-value > 0.05). Therefore, the null hypothesis (H_0) cannot be rejected. Consequently, it is concluded that there is a long-term relationship between the variables of GDP, DIV, GFCF, and EGLB in the model and that the variables

move together in the long term.

In the case of a cointegration relationship between series, different estimators are employed to assess the strength of the relationship. In this study, the impact of independent variables on the dependent variable has been analysed. Common Correlated Effect (CCE) estimator and quantile regression have been used to perform this analysis to measure the degree of influence of the long-run relationship. The panel CCE estimator is used when the series are non-stationary at the level, there is CSD, and the slope coefficients are heterogeneous. There is a long-run relationship between the series (Pesaran, 2006).

Conventional methods may offer initial insights into cross-sectional dependency and slope heterogeneity; however, they can be limited when relationships are nonlinear or data contain skewness and outliers. In such cases, quantile regression provides a robust alternative by estimating the conditional median or other quantiles of the dependent variable, rather than the mean, which is sensitive to extreme values. This approach allows for a more accurate analysis of distributional characteristics, particularly when assessing typical outcomes like median income in the presence of outliers. Since the mean is highly sensitive to extreme values, it may not always provide a reliable summary of data distributions, especially in the presence of outliers. For example, in income datasets, a small number of very high earners can disproportionately raise the average, making it unrepresentative of the general population's typical income. In such situations, quantile regression offers a more robust alternative by estimating the median or other quantiles, thus providing a clearer picture of the underlying distribution (Nica et al., 2023).

The least squares method (OLS) is one of the fundamental techniques widely used in econometric analysis. However, the presence of outliers in economic variables and their deviation from normal distribution make it difficult for this method to produce reliable results. The OLS method is inadequate, especially when error terms are not normally distributed and long-tailed distributions exist. As an alternative to such situations, Koenker and Bassett Jr. (1978) developed the quantile regression method. The quantile regression method has been adapted to panel data by Koenker (2004), and in this context, a fixed-effect panel quantile regression model has been developed. In the model, the conditional functions of the responses of observations on units are constructed as follows:

$$Qy_{it}(\tau|x_{it}) = \alpha_i + x'_{it}\beta(\tau) \qquad (11)$$

The model, $Qy_{it}(\tau|x_{it})$ represents the τ'th quantile of dependent variable, x_{it} represents the vector of independent variables, α_i denotes individual effects, τ quantiles, $\beta(\tau)$ denotes the regression coefficient of the corresponding quantile.

$$\min_{(\alpha,\beta)} \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{i=1}^{N} w_k \rho_{\tau_k}\left(y_{it} - \alpha_i - x'_{it}\beta(\tau_k)\right) \qquad (12)$$

The above Equation (12) represents fixed-effect panel quantile-regression; here, i represents countries (N), T represents the number of observation for each country, k denotes quantile index and x represents the matrix of independent variable which can be called explanatory variables. y_{it} denotes the dependent variable, x_{it} denotes p-vector of common variables, w_k denotes the control of the relative effects of quantiles in estimating individual fixed effects (α_i), and $\rho_\tau(u) = u(\tau - I(u < 0)$ represents the piecewise linear quantile loss function.

Table 9: The Results of CCE Test

Dependent Variables	Common Correlated Effects Mean Group (CCE)	
	Coefficients	t-statistics
LnDIV	-0.1746578***	-1.75
LnGFCF	0.2903037*	4.74
LnEGLB	-0.0596798	-1.53

Note: *, **, *** denote 1%, 5%, 10% significance levels respectively.
Source: Created by Author

Table 9 presents the panel cointegration estimation results for the overall model using the Common Correlated Effects (CCE) estimator. The results indicate that the coefficients of LnDIV and LnGFCF are statistically significant and consistent with theoretical expectations. In contrast, the coefficient of LnEGLB is statistically insignificant, suggesting that its average effect on EG is not robust across the panel.

The coefficient of LnDIV is negative and statistically significant. However, it should be noted that the diversification variable is measured using the Herfindahl–Hirschman Index (HHI), where higher values indicate greater export concentration and lower values reflect higher diversification. Therefore, the negative coefficient implies that an increase in ED (i.e., a decrease in concentration) is associated with higher EG. This finding is fully consistent with the theoretical literature emphasising the role of diversification in promoting structural transformation and growth.

In terms of magnitude, the results suggest that a 1% increase in ED (proxied by a decrease in the HHI index) increases EG by approximately 0.17%. In comparison, a 1% increase in gross fixed capital formation leads to a 0.30% increase in EG.

Table 10: The Results of Quantile Regression

Variables	Quantile levels								
	10th	20th	30th	40th	50th	60th	70th	80th	90th
LnDIV	-0.615**	-0.667*	-0.699*	-0.751*	-0.817*	-0.878*	-0.947*	-1.004*	-1.061*
	(0.036)	(0.007)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
LnGFCF	0.933*	0.908*	0.893*	0.868*	0.836*	0.807*	0.774*	0.746*	0.719*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)
LnEGLB	0.908*	0.900*	0.896*	0.889*	0.879*	0.871*	0.861*	0.853*	0.845*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: * and ** denote 1%, 5% significance levels respectively. The values with *'s are coefficients. ( ) represents the p-values of the estimated coefficients.
Source: Created by Author

Table 10 reports the panel quantile regression results across different quantiles of the EG distribution (0.10–0.90). The findings reveal that the coefficients of LnDIV, LnGFCF, and LnEGLB are statistically significant across all quantiles, although their magnitudes vary along the distribution. The coefficient of LnDIV is negative and statistically significant at all quantile levels. Given that ED is proxied by the Herfindahl–Hirschman Index (HHI), where higher values indicate greater export concentration, this negative coefficient implies that greater ED promotes EG. Moreover, the absolute magnitude of the coefficient increases across higher quantiles, rising from -0.615 at the 10th quantile to -1.061 at the 90th quantile. This pattern suggests that the growth-enhancing effect of diversification becomes stronger at higher levels of income, indicating its increasing importance in more advanced stages of economic development.

The coefficient of LnGFCF is positive and statistically significant across all quantiles. However, its magnitude declines gradually from 0.933 at the lower quantile to 0.719 at the upper quantile, indicating that the contribution of physical capital accumulation to EG is more pronounced at lower income levels. This finding highlights the fundamental role of capital formation in the early stages of development. Similarly, the coefficient of LnEGLB is positive and statistically significant across all quantiles, although it exhibits a slight downward trend, decreasing from 0.908 at the 10th quantile to 0.845 at the 90th quantile. This suggests that economic globalisation contributes positively to growth across the entire distribution, but its marginal impact diminishes at higher income levels.

It is important to note that the results from the CCE estimator and the panel quantile regression differ for the economic globalisation variable (LnEGLB). While the CCE estimator suggests that the average effect of economic globalisation is statistically insignificant, the quantile regression results indicate a positive and statistically significant effect across all quantiles. This apparent discrepancy can be attributed to methodological differences between the two approaches. The CCE estimator captures the average effect across cross-sectional units and may therefore mask underlying heterogeneity in the data. In contrast, panel quantile regression provides distribution-specific estimates and is more sensitive to non-linearities, heterogeneity, and extreme values. Accordingly, the significance of LnEGLB across quantiles suggests that the impact of economic globalisation varies across different levels of EG, which cannot be fully captured by mean-based estimators. This finding highlights the importance of employing distribution-sensitive methods in analysing growth dynamics.

Overall, the findings indicate that the effects of ED, capital formation, and economic globalisation on EG are not uniform across the distribution. In particular, the growing impact of diversification at higher quantiles underscores its critical role in sustaining growth at more advanced stages of development. In contrast, the declining effect of capital formation suggests that its importance is more pronounced in earlier stages. These results underscore the need to account for distributional heterogeneity when analysing growth dynamics.

Table 11: Robustness Check Tests

Independent Variables	FMOLS		DOLS		FE	
	Coeff.	Prob. Value	Coeff.	Prob. Value	Coeff.	Prob. Value
lnDIV	-0.964	0.0000*	-1.122	0.0000*	-0.837	0.000*
lnGFCF	0.677	0.0000*	0.619	0.0000*	0.827	0.000*
lnEGLB	0.221	0.0173**	0.114	0.4285	0.877	0.000*

Note: * and ** denote 1%, 5% significance levels, respectively. The values with *'s are coefficients. ( ) represents the p-values of the estimated coefficients. The dependent variable in the model is lnGDP.
Source: Created by Author

As shown in Table 11, the estimates obtained from the FMOLS, DOLS, and FE methods are consistent with one another. Moreover, the coefficient estimates of all three estimators are statistically significant at the 1% level. The coefficients of the independent variables are also consistent with the expectations, and the coefficient of DIV is negative, while the coefficients of the other independent variables (GFCF and EGLB) are positive. These findings are consistent with theoretical assumptions. According to the results estimated, a 1% rise in DIV increases EG by approximately 0.96% to 1.12%. Likewise, a 1% rise in GFCF increases EG by around 0.67% to 0.82%. A 1% rise in EGLB variable increases EG by 0.11% to 0.87%.

Based on the findings which are obtained from analysis conducted in present study, it is concluded that increases in DIV, GFCF, and EGLB positively affect EG.

To examine the direction of causality between the variables, the Kónya (2006) panel causality test is employed. This method is based on the Seemingly Unrelated Regressions (SUR) framework and allows for country-specific causal inference while accounting for cross-sectional dependence. An important advantage of this approach is that it does not require pre-testing for unit roots or cointegration. The optimal lag length in the model is determined based on the Akaike Information Criterion (AIC). The corresponding causality results are reported in Table 12.

Table 12: The Results of Kónya (SUR) Causality Test

Countries	**GDP→DIV**			**DIV→GDP**			**Result**
	Wald	1%	5%	Wald	1%	5%	
Argentina	0.025	0.090	0.086	3.980	6.692	5.603	✗
Brazil	2.747	4.522	4.472	10.356*	1.593	0.963	DIV→GDP
China	9.771**	0.042	0.027	1.453**	1.771	1.433	GDP ⇄ DIV
India	2.036*	0.105	0.089	25.001*	2.675	1.372	GDP ⇄ DIV
Indonesia	8.005*	1.255	1.201	14.476*	4.477	2.254	GDP ⇄ DIV
Mexico	0.416	1.549	1.520	5.017*	2.877	1.896	DIV→GDP
Poland	0.152	1.679	1.579	0.523	3.902	2.014	✗
South Africa	8.249*	2.839	2.799	0.433	2.310	1.500	GDP→DIV
South Korea	4.883	5.303	5.214	9.086*	2.012	1.362	DIV→GDP
Türkiye	3.279*	1.345	1.313	6.076*	1.564	0.823	DIV→GDP
Countries	**EGLB →GDP**			**GDP→ EGLB**			**Result**
	Wald	1%	5%	Wald	1%	5%	
Argentina	18.806*	14.769	14.646	2.483*	0.307	0.205	EGLB ⇄ GDP

Brazil	1.863*	0.355	0.342	0.741*	0.600	0.473	EGLB ⇄ GDP
China	65.241*	0.470	0.408	6.361*	4.300	2.682	EGLB ⇄ GDP
India	6.039*	2.178	2.092	0.359	2.167	1.591	EGLB →GDP
Indonesia	2.680*	0.229	0.203	24.767*	0.328	0.260	EGLB ⇄ GDP
Mexico	3.885*	0.406	0.391	12.077*	0.680	0.372	EGLB ⇄ GDP
Poland	0.094	0.765	0.693	22.791*	2.130	1.314	GDP→ EGLB
South Africa	1.326*	0.348	0.341	7.183*	0.218	0.143	EGLB ⇄ GDP
South Korea	0.678*	0.680	0.654	1.454*	0.209	0.150	EGLB ⇄ GDP
Türkiye	3.648*	0.078	0.073	5.799*	0.648	0.443	EGLB ⇄ GDP
Countries	**GFCF→ EGLB**			**EGLB →GFCF**			**Result**
	Wald	1%	5%	Wald	1%	5%	
Argentina	1.023	11.522	10.947	0.865*	0.345	0.295	EGLB →GFCF
Brazil	0.994*	0.236	0.148	0.009	1.525	1.366	GFCF→ EGLB
China	7.486*	1.786	1.441	0.014	4.054	3.473	GFCF→ EGLB
India	6.970*	1.192	0.934	0.552**	0.610	0.533	GFCF ⇄ EGLB
Indonesia	8.311*	2.622	2.329	1.865*	0.802	0.694	GFCF ⇄ EGLB
Mexico	0.824**	1.087	0.802	3.659*	0.579	0.491	GFCF ⇄ EGLB
Poland	10.626*	0.376	0.247	0.157	0.984	0.758	GFCF→ EGLB
South Africa	1.671*	0.219	0.133	0.554*	0.348	0.288	GFCF ⇄ EGLB
South Korea	0.362*	0.07	0.041	0.513	2.640	2.387	GFCF→ EGLB
Türkiye	0.819	1.700	1.398	15.937*	0.830	0.746	EGLB →GFCF
Countries	**DIV→GFCF**			**GFCF→DIV**			**Result**
	Wald	1%	5%	Wald	1%	5%	
Argentina	3.936*	1.453	0.922	0.077	0.175	0.151	DIV→GFCF
Brazil	0.011	3.422	2.113	0.541	7.381	7.079	✗
China	1.031*	0.793	0.427	0.25	0.864	0.527	DIV→GFCF
India	8.005*	6.901	4.004	0.004	0.26	0.197	DIV→GFCF
Indonesia	17.793*	9.715	5.143	19.258*	2.154	1.965	DIV⇄ GFCF
Mexico	6.405*	0.902	0.656	0.065	2.042	1.592	DIV→GFCF
Poland	0.079	1.580	1.226	2.132**	2.296	1.809	GFCF→DIV
South Africa	1.709	3.442	2.410	1.229	4.642	3.886	✗
South Korea	3.068**	3.472	1.364	1.021	6.292	6.089	DIV→GFCF
Türkiye	0.047	2.612	1.564	20.721*	1.703	1.541	GFCF→DIV
Countries	**DIV→EGLB**			**EGLB →DIV**			**Result**
	Wald	1%	5%	Wald	1%	5%	
Argentina	1.401	8.703	6.215	0.020	0.166	0.145	✗
Brazil	2.912**	2.819	2.372	0.059	6.479	5.843	DIV→EGLB
China	0.124	1.561	0.867	0.515*	0.203	0.142	EGLB →DIV
India	11.798*	5.125	4.465	1.115*	0.026	0.021	DIV⇄ EGLB
Indonesia	26.066*	9.243	5.513	2.309*	1.782	1.584	DIV⇄ EGLB
Mexico	9.458*	0.684	0.405	0.142	1.955	1.695	DIV→ EGLB
Poland	1.647	2.813	2.012	0.165	2.805	1.954	✗
South Africa	0.614	2.597	1.671	0.004	3.441	3.334	✗
South Korea	6.472*	1.962	1.198	2.133	6.420	6.073	DIV→ EGLB
Türkiye	0.614	1.492	0.753	14.805*	1.688	1.433	EGLB →DIV
Countries	**GDP→GFCF**			**GFCF→GDP**			**Result**
	Wald	1%	5%	Wald	1%	5%	
Argentina	0.585*	0.103	0.095	4.757*	0.207	0.156	GDP ⇄GFCF
Brazil	0.137	1.429	1.381	0.037	0.52	0.409	✗
China	21.694*	2.936	2.811	0.594	1.513	1.207	GDP→GFCF
India	0.161	0.233	0.208	0.056	1.731	1.336	✗
Indonesia	0.529*	0.49	0.449	1.162*	0.372	0.278	GDP ⇄ GFCF

Mexico	1.040*	0.377	0.365	2.205*	0.408	0.268	GDP ⇄ GFCF
Poland	2.330*	0.412	0.363	13.915*	0.785	0.584	GDP ⇄ GFCF
South Africa	0.056	0.582	0.561	0.312*	0.153	0.090	GFCF→GDP
South Korea	11.962*	1.743	1.703	0.001	0.176	0.144	GDP→GFCF
Türkiye	5.367*	0.673	0.651	7.812*	0.276	0.235	GDP ⇄ GFCF

Note: * and ** denote 1%, 5% significance levels respectively. "⇄" denotes bidirectional causality. "→" i unidirectional causality.
Source: Created by Author

The causality results provide important insights into the dynamic interaction between ED and EG. The presence of bidirectional causality between GDP and ED in countries such as China, India, Indonesia, and Türkiye suggests a mutually reinforcing mechanism. In these economies, diversification stimulates EG by expanding production capabilities and reducing structural vulnerabilities, while higher growth levels, in turn, facilitate further diversification through technological upgrading and sectoral expansion.

In contrast, the unidirectional causality from ED to EG observed in countries such as Brazil, Mexico, and South Korea indicates that diversification is a key driver of growth. Still, economic expansion does not necessarily lead to further diversification. This may reflect structural rigidities or a continued reliance on specific sectors despite growth. On the other hand, the presence of a causal relationship between EG and ED, as observed in South Africa, implies that growth itself creates the conditions for diversification, such as increased investment capacity and structural transformation. However, in this case, diversification does not play a leading role in driving growth.

Finally, the absence of a significant causality relationship in some countries suggests that the diversification–growth nexus may be weak or mediated by country-specific institutional, structural, or external factors. Overall, these findings highlight that the relationship between ED and EG is highly heterogeneous and context-dependent, implying that uniform policy prescriptions may not be effective across different economies.

CONCLUSIONS AND POLICY IMPLICATIONS

This study investigates the impact of ED, gross fixed capital formation, and economic globalisation on EG in BEM economies over the period 1995–2022. Using advanced panel data techniques that account for cross-sectional dependence and heterogeneity, including the Common Correlated Effects (CCE) estimator, panel quantile regression, and the Kónya (2006) causality test, the study provides a comprehensive and distribution-sensitive analysis of growth dynamics.

The empirical findings reveal that ED, capital formation, and economic globalisation are important determinants of EG, although their effects are not uniform across the distribution. The quantile regression results show that the positive impact of ED becomes stronger at higher levels of EG, indicating its increasing importance in more advanced stages of development. In contrast, the effect of capital formation is more pronounced at lower quantiles, highlighting its fundamental role in the early stages of development. Economic globalisation is found to have a positive and robust effect across all quantiles, although its marginal contribution slightly declines as

income levels increase. This is also consistent with the finding that the impact of economic globalisation differs between mean-based and distribution-based estimations.

The causality analysis further indicates that the relationship between ED and EG is not uniform across countries, with both unidirectional and bidirectional dynamics observed. These findings suggest that the diversification–growth nexus is highly context-dependent and shaped by country-specific structural and institutional conditions. In some cases, ED acts as a driver of growth, while in others, EG itself facilitates diversification processes. This variation highlights the importance of considering country-specific development paths when evaluating the growth effects of export structures.

These findings can be more explicitly interpreted within the framework of endogenous growth theory and the structural transformation literature. In line with endogenous growth models, ED enhances EG by expanding productive knowledge, fostering innovation, and facilitating technological upgrading (Romer, 1990). By enabling economies to move into more sophisticated, higher-value-added sectors, diversification strengthens productivity dynamics and long-term growth potential. Furthermore, the heterogeneous effects observed across quantiles provide strong support for the structural transformation perspective. The increasing impact of diversification at higher quantiles suggests that as economies develop, growth becomes more dependent on complexity, sectoral upgrading, and diversification of production structures.

In contrast, the declining effect of capital formation across quantiles indicates that physical capital accumulation is more critical in the early stages of development, when basic production capacity and infrastructure are being established. Therefore, the results imply that the determinants of EG are inherently stage-dependent and that diversification, capital accumulation, and global integration operate as complementary but evolving mechanisms throughout the development process. This reinforces the view that growth processes are inherently nonlinear and dependent on structural transformation dynamics.

Overall, this study contributes to the literature by providing a comprehensive and distribution-sensitive analysis of the export diversification–growth nexus in BEM economies. Unlike conventional approaches, the use of panel quantile regression and country-specific causality analysis reveals that the effects of ED, capital formation, and economic globalisation are inherently heterogeneous and stage-dependent. These findings offer important implications for both theory and policy, suggesting that growth strategies should be tailored to the structural characteristics and development levels of individual economies.

REFERENCES

Acaravcı, A., & Kargı, G. (2015). Türkiye'de ihracatın çeşitlendirilmesi ve ekonomik büyüme. *Uluslararası Ekonomi ve Yenilik Dergisi*, *1*(1), 1-16. https://doi.org/10.20979/ueyd.182891

Acemoglu, D., & Zilibotti, F. (1997). Was Prometheus unbound by chance? Risk, diversification, and growth. *Journal of Political Economy*, *105*(4), 709-751. http://dx.doi.org/10.1086/262091

Aditya, A., & Acharyya, R. (2013). Export diversification, composition, and economic growth: Evidence from cross-country analysis. *The Journal of International Trade & Economic Development*, *22*(7), 959-992. https://doi.org/10.1080/09638199.2011.619009

Agosin, M. R. (2009). Export diversification and growth in emerging economies. *Cepal Review*, *97*(4), 115-131. https://hdl.handle.net/11362/11322

Ali, S., Murshed, S. M., & Papyrakis, E. (2023). Oil, export diversification and economic growth in Sudan: evidence from a VAR model. *Mineral Economics*, *36*(1), 77-96. https://doi.org/10.1007/s13563-022-00310-w

Alshomaly, I., & Shawaqfeh, W. (2020). The effect of export diversification on the economic growth of West-Asian Arab countries. *Journal of Social Sciences*, *9*(2), 429-450. https://doi.org/10.1016/j.jacceco.2014.09.002

Altun, M., & Benli, M. (2021). İhracatta ürün çeşitliliği ve Türkiye'nin büyüme performansı. *Dumlupınar Üniversitesi Sosyal Bilimler Dergisi*, *67*, 138-158. https://doi.org/10.51290/dpusbe.786102

Arip, M. A., Yee, L. S., & Abdul Karim, B. (2010). *Export diversification and economic growth in Malaysia* (MPRA Paper No. 20588). Munich Personal RePEc Archive. https://mpra.ub.uni-muenchen.de/id/eprint/20588

Azam, M., & Azam, S. (2023). Export diversification and economic growth in Bangladesh. *Journal of Empirical Studies*, *10*(1), 1-18. https://doi.org/10.18488/66.v10i1.3291

Balassa, B. (1978). Exports and economic growth: further evidence. *Journal of Development Economics*, *5*(2), 181-189. https://doi.org/10.1016/0304-3878(78)90006-8

Benli, M. (2020). Export diversification and economic growth: Evidence from emerging economies. *Erciyes Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *55*, 285-298. https://doi.org/10.18070/erciyesiibd.609237

Breusch, T., & Pagan, A. (1980). The lagrange multiplier test and its applications to model specification in econometrics. *Review of Economics Studies*, *47*(1), 239-253. https://doi.org/10.2307/2297111

Cadot, O., Carrère, C., & Strauss-Kahn, V. (2011). Export diversification: what's behind the hump?. *Review of Economics and Statistics*, *93*(2), 590-605. https://doi.org/10.1162/REST_a_00078

Carrasco, C. A., & Tovar-García, E. D. (2021). Trade and growth in developing countries: the role of export composition, import composition and export diversification. *Economic Change and Restructuring*, *54*(4), 919-941. https://doi.org/10.1007/s10644-020-09291-8

Doru, Ö., & Dabakoğlu, M. (2025). Neo-klasik büyüme teorisi bağlamında ihracat çeşitliliğinin ekonomik büyümeye etkisi: Türkiye üzerine ampirik bir inceleme. In Ş. Nas (Ed.), *Dış ticaret ve makro ekonomik göstergeler: Güncel tartışmalar* (ss. 37–54). Mardin Artuklu Üniversitesi Yayınevi.

Duru, I. U., & Ehidiamhen, P. O. (2018). Empirical investigation of the impact of export diversification on economic growth: Evidence from Nigeria, 1980-2016. *Journal of Economics, Management and Trade*, *21*(7), 1-24. https://hal.science/hal-05423183v1

Edwards, S. (1998). Openness, productivity and growth: what do we really know?. *The Economic Journal*,

108(447), 383-398. https://doi.org/10.1111/1468-0297.00293

Feenstra, R., & Kee, H. L. (2004). *Export variety and country productivity* (No. 3412). The World Bank. https://doi.org/10.1596/1813-9450-3412

Forgha, N. G., Sama, M. C., & Atangana, E. M. (2014). The effects of export diversification on economic growth in Cameroon. *International Invention Journal of Arts and Social Sciences*, *1*(3), 54-69.

Frankel, J. A., & Romer, D. (1999). Does Trade Cause Growth?. *American Economic Review*, *89*(3). https://doi.org/10.1257/aer.89.3.379

Fu, D., Wu, Y., & Zhang, Y. (2019). Does export diversification matter for China's regional growth?. *The Singapore Economic Review*, *64*(04), 863-882. https://doi.org/10.1142/S0217590817450023

Gozgor, G., & Can, M. (2016a). Effects of the product diversification of exports on income at different stages of economic development. *Eurasian Business Review*, *6*, 215-235. https://doi.org/10.1007/s40821-016-0045-5

Gozgor, G., & Can, M. (2016b). Export product diversification and the environmental Kuznets curve: evidence from Turkey. *Environmental Science and Pollution Research*, *23*, 21594-21603. https://doi.org/10.1007/s11356-016-7403-9

Gozgor, G., & Can, M. (2017). Causal linkages among the product diversification of exports, economic globalization and economic growth. *Review of Development Economics*, *21*(3), 888-908. https://doi.org/10.1111/rode.12301

Gurgul, H., & Lach, L. (2013). Export diversification and economic growth in transition: lessons from the 2008 financial crisis in CEE. *Metody Ilościowe w Badaniach Ekonomicznych*, *14*(1), 137-149. https://qme.sggw.edu.pl/article/view/3583

Hamed, K., Hadi, D., & Hossein, K. (2014). Export diversification and economic growth in some selected developing countries. *African Journal of Business Management*, *8*(17), 700-704. http://dx.doi.org/10.5897/AJBM2012.397

Hausmann, R., Hwang, J., & Rodrik, D. (2007). What you export matters. *Journal of Economic Growth*, *12*, 1-25. https://doi.org/10.1007/s10887-006-9009-4

Herzer, D., & Nowak-Lehnmann D, F. (2006). What does export diversification do for growth? An econometric analysis. *Applied Economics*, *38*(15), 1825-1838. https://hdl.handle.net/10419/23861

Hesse, H. (2008). *Export diversification and economic growth* (Commission on Growth and Development Working Paper No. 21). Commission on Growth and Development. https://openknowledge.worldbank.org/handle/10986/28040

Imbs, J., & Wacziarg, R. (2003). Stages of diversification. *American Economic Review*, *93*(1), 63-86. https://doi.org/10.1257/000282803321455160

Koenker, R. (2004). Quantile regression for longitudinal data. *Journal of Multivariate Analysis*, *91*, 74-89. https://doi.org/10.1016/j.jmva.2004.05.006

Koenker, R. & Bassett Jr., G. (1978). Regression Quantiles. *Econometrica*, *46*(1), 33-50. https://doi.org/10.2307/1913643

Kónya, L. (2006). Exports and growth: Granger causality analysis on OECD countries with a panel data approach. *Economic Modelling*, *23*(6), 978-992. https://doi.org/10.1016/j.econmod.2006.04.008

Krugman, P. (1991). Increasing returns and economic geography. *Journal of Political Economy*, *99*(3), 483-499. https://doi.org/10.1086/261763

Krugman, P. R., Obstfeld, M., & Melitz, M. J. (2018). *International economics: Theory and policy* (11th ed.).

Pearson.

Lederman, D., & Maloney, W. F. (2012). *Does what you export matter? In search of empirical guidance for industrial policies*. World Bank. https://doi.org/10.1596/978-0-8213-8491-6

Lee, D., & Zhang, H. (2022). Export diversification in low-income countries and small states: Do country size and income level matter?. *Structural Change and Economic Dynamics*, *60*, 250-265. https://doi.org/10.1016/j.strueco.2021.11.017

Lotfi, B., & Karim, M. (2017). Export diversification and economic growth in Morocco: An econometric analysis. *Applied Economics and Finance*, *4*(6), 27-35. https://doi.org/10.11114/aef.v4i6.2673

Love, J. (1986). Commodity concentration and export earnings instability: A shift from cross-section to time series analysis. *Journal of Development Economics*, *24*(2), 239-248. https://doi.org/10.1016/0304-3878(86)90090-8

Matezo, E., Makengo, B., & Muhole, A. (2021). The influence of export diversification on economic growth: A case of Southern African development community (SADC). *American Journal of Industrial and Business Management*, *11*(07), 829-845. https://doi.org/10.4236/ajibm.2021.117051

McIntyre, A., Li, M. X., Wang, K., & Yun, H. (2018). *Economic benefits of export diversification in small states* (IMF Working Paper No. 18/86). International Monetary Fund. https://doi.org/10.5089/9781484351017.001

Misztal, P. (2011). Export diversification and economic growth in European Union member states. *ACTA Scientiarum Polonorum Oeconomia*, *10*(2), 55-64. https://aspe.sggw.edu.pl/article/view/605

Mudenda, C., Choga, I., & Chigamba, C. (2014). The role of export diversification on economic growth in South Africa. *Mediterranean Journal of Social Sciences*, *5*(9), 705-712. https://doi.org/10.5901/mjss.2014.v5n9p705

Naudé, W., & Rossouw, R. (2011). Export diversification and economic performance: evidence from Brazil, China, India and South Africa. *Economic Change and Restructuring*, *44*, 99-134. https://doi.org/10.1007/s10644-010-9089-1

Nica, E., Poliakova, A., Popescu, G. H., Valaskova, K., Burcea, S. G., & Constantin, A. L. D. (2023). The impact of financial development, health expenditure, CO2 emissions, institutional quality, and energy Mix on life expectancy in Eastern Europe: CS-ARDL and quantile regression Approaches. *Heliyon*, *9*(11), e21084. https://doi.org/10.1016/j.heliyon.2023.e21084

Parteka, A., & Tamberi, M. (2013). What determines export diversification in the development process? Empirical assessment. *The World Economy*, *36*(6), 807-826. https://doi.org/10.1111/twec.12064

Persson, M., & Wilhelmsson, F. (2016). EU trade preferences and export diversification. *The World Economy*, *39*(1), 16-53. https://doi.org/10.1111/twec.12354

Pesaran, M. H. & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, *142*(1), 50-93. https://doi.org/10.1016/j.jeconom.2007.05.010

Pesaran, M. H. (2004). *General diagnostic tests for cross section dependence in panels* (Cambridge Working Papers in Economics No. 0435). Faculty of Economics, University of Cambridge. https://doi.org/10.17863/CAM.5113

Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica*, *74*(4), 967-1012. https://doi.org/10.1111/j.1468-0262.2006.00692.x

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265-312. https://doi.org/10.1002/jae.951

Pesaran, M. H., Ullah, A., & Yamagata, T. (2008). A bias-adjusted LM test of error cross-section independence.

The Econometrics Journal, *11*(1), 105-127. https://doi.org/10.1111/j.1368-423X.2007.00227.x

Pineres, S. A. G. D., & Ferrantino, M. (2000). The commodity composition of export portfolios: A comparative analysis of Latin America. *Latin American Business Review*, *1*(3), 1-15. https://doi.org/10.1300/J140v01n03_01

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, *98*(5), S71-S102. https://doi.org/10.1086/261725

Rondeau, F., & Roudaut, N. (2014). What diversification of trade matters for economic growth of developing countries. *Economics Bulletin*, *34*(3), 1485-1497. https://econpapers.repec.org/RePEc:tut:cremwp:201407

Sannassee, R. V., Seetanah, B., & Lamport, M. J. (2014). Export diversification and economic growth: the case of Mauritius. *In Connecting to Global Markets* (pp. 11-23). WTO iLibrary. https://doi.org/10.30875/0beb76b7-en

Sarin, V., Mahapatra, S. K., & Sood, N. (2020). Export diversification and economic growth: A review and future research agenda. *Journal of Public Affairs*, *22*(3), e2524. https://doi.org/10.1002/pa.2524

Shadab, S. (2021). The nexus between export diversification, imports, capital and economic growth in the United Arab Emirates: An empirical investigation. *Cogent Economics & Finance*, *9*(1), 1914396. https://doi.org/10.1080/23322039.2021.1914396

Siddiqui, A. H. (2018). Export diversification and growth in Pakistan: An Empirical investigation from 1972-to 2015. *Business & Economic Review*, *10*(01), 107-132. https://doi.org/10.22547/BER/10.1.5

Siswana, S., & Phiri, A. (2021). Is export diversification or export specialization responsible for economic growth in BRICS countries?. *The International Trade Journal*, *35*(3), 243-261. https://doi.org/10.1080/08853908.2020.1842823

Sunaryati, S. (2015). Export diversification and economic growth in ASEAN. *Journal Ekonomi & Studi Pembangunan*, *16*(2), 119-131. https://journal.umy.ac.id/index.php/esp/article/view/1207

Swamy, P. (1971). *Statistical Inference in Random Coefficient Regression Models*. New York: Springer.

Tesfay, T. G. (2016). The contribution of export diversification for economic growth in Ethiopia. *Journal of Economics and Sustainable Development*, *7*(21), 21-26. https://www.iiste.org/Journals/index.php/JEDS/article/view/34153/35122

Trinh, P. T. T., & Thuy, H. T. T. (2021). Export diversification and economic growth: A threshold regression approach for emerging markets and developing countries. *Economic Journal of Emerging Markets*, *13*(2), 188-199. https://doi.org/10.20885/ejem.vol13.iss2.art8

UNCTAD. (2025). *UNCTADstat database*. https://unctadstat.unctad.org/

Westerlund, J., & Edgerton, D. L. (2007). A panel bootstrap cointegration test. *Economics Letters*, *97*(3), 185-190. https://doi.org/10.1016/j.econlet.2007.03.003

World Bank. (2025). *World Development Indicators*. World Bank Open Data. https://data.worldbank.org/

Yerdelen Tatoğlu, F. (2017). *Panel Zaman Serileri Analizi Stata Uygulamalı*, Beta, İstanbul.

Zhou, H., & Nyandoro, J. M. (2023). Export diversification and economic growth: Evidence from Zimbabwe. *Botswana Journal of Economics*, *15*(1), 1-9. https://doi.org/10.5897/BOJE2022.0007

InTraders International Trade Academic Journal

e-ISSN: 2667-4408 **www.intraders.org**

Volume: 9
Issue : 1
Research Article

Received: February 20, 2026
Revision: March 31, 2026
Accepted: May 20, 2026
DOI: https://www.doi.org/10.55065/intraders.1894388

Causality Analysis Between the Net Error and Omission Component and Turkiye's Foreign Trade Balance: 1990-2024 Period

Mustafa KAVACIK[1]

Abstract

The purpose of this paper is to investigate the significance of the "net errors and omissions" (NEO) component in Turkiye's balance-of-payments for 1990 to 2024 and its relation to the foreign trade balance. Although the NEO item is theoretically considered a statistical adjustment for measurement errors, timing differences, and data incompleteness, the permanence and positive sign of this item in Turkiye have led to speculation about the existence of covert capital flows. This study answers the question if the NEO item is merely a reflection of statistical discrepancies or if it reflects changes in foreign trade dynamics. In methodology, the Toda-Yamamoto causality technique was used for annual data, and the analysis was performed using EViews. The results indicate that there is unidirectional causality from foreign trade balance to NEO item, but not vice versa. These findings imply that the NEO item does not function as an active factor in shaping the foreign trade performance, but as a "follower" vis-à-vis the foreign trade balance. As a rule, the NEO is considered as a mere statistical adjustment item on the reactive side and not as a driver on the main side of macroeconomic analysis, and also an indicator that reflects structural transformation in Turkiye's statistics and exposes inconsistencies. In conclusion, this study gives new empirical evidence for Turkiye by revealing that the trade balance-NEO item causal relationship is unidirectional (from the trade balance to NEO), in other words, NEO acts as a result variable, not as a determinant of the foreign trade balance.

Keywords: *Foreign Trade Balance, Net Errors and Omissions, Toda-Yamamoto Causality Test, Turkiye*

JEL Codes: *F14, F32, C22*

INTRODUCTION

The balance-of-payments is a country's international accounts and normally includes a number of main items such as current transactions, capital accounts and financial accounts. But the total of these items may be different from zero for a number of reasons. In that case the NEO fills the gap. The NEO item represents measurement errors and omissions in the data or the source of funds unknown movement of fundsources of fundsmovement of

There is no conflict of interest.

[1] Asst. Prof. Dr. , Necmettin Erbakan University, E-Mail : mustafa.kavacik@erbakan.edu.tr, OI: 0000-0003-3782-8154
Contribution rates to the study 100 %.

Cite As: Kavacık, M. (2026). Causality analysis between the net error and omission component and Türkiye's foreign trade balance: 1990–2024 period. *InTraders International Trade Academic Journal*, 9(1), 159–174. https://doi.org/10.55065/intraders.1894388

funds that cannot be identified, or their origin (Çıplak, 2005, p. 3; Eğilmez, 2012, p. 1).

Looking at Turkiye's balance-of-payments data, it appears that the NEO item has grown considerably, particularly since the early 2000s. For instance, in 2011 the NEO item soared to around $12 billion (Eğilmez, 2012, p. 1). Is the phenomenon the result of statistical errors or does it reflect unaccounted capital flows? This issue has been a controversial subject in Turkiye's balance-of-payments studies.

The elevated NEO item may bring into question the quality of the balance-of-payments data. In particular, the NEO item is always large and a positive number can be interpreted as indicating unspecified foreign currency inflows (Eğilmez, 2013, p. 1). It is a manifestation of a residue that is both too large and systematically aligned to be accounted for by measurement errors alone.

The literature lists factors such as timing errors, deficiencies in customs declarations, unrecorded transactions, and survey errors among the determinants of the NEO item (Çıplak, 2005, p. 3; Eğilmez, 2012, p. 1). However, there are only a limited number of empirical studies on whether these factors fully explain the high NEO item. This gap indicates that the NEO item needs to be addressed more broadly in economic analyses.

This study fills an important gap in the literature by explicitly investigating the direction of causality between the Net Error and Omission (NEO) item and the trade balance for Turkiye; the matter has largely been scrutinized, if at all, indirectly or under wider multivariate toolkit so far. Previous research on NEO has focused on its determinants (i.e., exchange rates, tourism revenues, or capital flows) or treated it as a statistical residual; however, there is little empirical evidence on whether NEO is a driving force on foreign trade dynamics in itself, or merely an effect, especially using data updated up to 2024. For this purpose, the research arbitrarily limits itself to two variables (NEO, trade balance) in order to obtain a direct causal relationship independent of other variables or the interaction of various control variables; this approach aimed at capturing causality is good in itself, since causalities are often left ambiguous in multivariate specifications. Methodologically, this study is innovative in that it adopts the Toda-Yamamoto causality procedure, which facilitates the formation of valid inferences independent of the integration properties of the series and eliminates pretest biases associated with traditional Granger causality or cointegration-based models. Furthermore, the integration of a long time period (1990–2024) with this approach enables a more accurate and structurally robust assessment of causality, thereby contributing to both the empirical and methodological literature.

The paper initially discusses the conceptual foundation of the NEO question and its evolution in Turkiye, and then introduces an application for the period 1990–2024. The analysis was conducted in EViews, and causality was assessed using the Toda-Yamamoto test. These results aim to reveal the causal relationship between the NEO item and the foreign trade balance.

This research aims to emphasise that the NEO item is not only a balancing item but also an important indicator

for Turkiye's foreign trade balance and balance-of-payments policies. Furthermore, an empirical analysis of the foreign trade balance, which has been shown in various studies to have a causal relationship with the NEO item, will contribute to the literature and guide policymakers.

LITERATURE REVIEW

Foreign Trade Balance

The foreign trade balance is the difference between a country's exports and imports over a specific period. If exports exceed imports, there is a foreign trade surplus; otherwise, there is a foreign trade deficit (Eğilmez, 2013, p. 1). This balance is considered an important indicator of a country's commercial relations with the outside world.

In Turkiye's case, the foreign trade balance has been showing a deficit for many years. For instance, Turkiye's foreign trade deficit was nearly USD 82.17 billion in 2024 (TUIK, 2025). This points to structural challenges including the need for the Turkish economy to boost its export capacity and reduce its reliance on imports.

The foreign trade balance is directly influenced by the exports to imports ratio. The literature underlines that this relation is pronounced not only in quantity but also in statistical characteristics (e.g. product composition, level of technology) (Demir, 2020, p. 890). It is expected that such a change in Turkiye's import and export structure will have significant implications for multilateral trade deficits and/or surpluses in the medium to long term.

Another factor to be considered in the determination of the foreign trade balance is the rate of import increase. If imports (particularly intermediate and capital goods) are expanding rapidly and exports are not increasing at the same pace, then the foreign trade deficit will be increasing. This reflects a structural break in import-dependent sectors in Turkiye (Demir, 2020, p. 897). By the way, increasing import prices particularly energy or raw materials can have adverse effect on the foreign trade balance (Temiz, 2009, p. 120).

Moreover, the export to import ratio is often considered in the literature as a key indicator to evaluate the performance of foreign trade. When it comes to balance of trade, the rise in this ratio means the country has found a balanced structure in foreign trade (Aydın et al., 2015, s. 5).In Turkiye, this ratio And it is directly influenced by the changes in the exchange rate and especially global demand; it fluctuates periodically.

The foreign trade balance is greatly influenced by exchange rates, income levels, and shifts in the demand from abroad. Empirical evidence indicates that inflation and exchange rate dynamics play a significant role in shaping foreign trade performance in Türkiye, affecting both import costs and export competitiveness (Çakmaklı, 2025, p. 8). It also behaviorally smooths out current account deficits in the face of positive external demand shocks (Balassa-Samuelson mechanism) or, during downturns, makes capital account outflows more volatile (Demir, 2020, p. 895). Additionally, rising domestic demand may increase the demand for imports, which in turn undermines the trade surplus (Tunçsiper & Rençber, 2017, p. 626).

The Customs Union process has had structural effects on Turkiye's foreign trade. After the adoption of the Customs Union, Turkiye's imports and exports changed both quantitatively and qualitatively (Temiz, 2009, p. 117). In particular, the increase in consumption and in imports of intermediate goods stood out as a result of this process.

In terms of the sustainability of the foreign trade balance, financing external deficits and maintaining foreign exchange reserves also play critical roles. Turkiye's foreign trade deficit may also lead to a long-term current account deficit, thereby creating macroeconomic fragility (Çakal, 2019, p. 42). Accordingly, the foreign trade balance is not only the outcome of trading relations but is tightly intertwined with macro structural and policy issues.

In the past, Turkiye's foreign trade by country has been subject to a pattern of reshuffle. The analyses for the period 2019–2023 show that there are significant differences between the groups of countries the country imports from and exports to; above all, the growth in trade with some developing countries is note worthy (Oğuz, 2024, s. 2822). This is important to see which foreign partners dominate the deficit in the foreign trade.

Net Error and Omission Item

Net Errors and Omissions (NEO) is an item item that is the counterpart to the balance in the balance-of-payments tables and is used to make the sum of the current, capital, and financial accounts equal to the official recording of the figures. This is a statistical difference, related to different factors like "measurement errors" of the statistics, unregistered transactions, or timing differences in data collection due to seasonal patterns (Şahin, 2022, p. 105; Emeç et al., 2023, p. 672). Furthermore, the configuration of international financial connections is also important in explaining external account imbalances. Kubelec and Sá (2010) show that countries' external balance sheets are affected not only by trade flows but by the country of residence exposure in cross-border financial assets and liabilities. This multilayered nature may create asymmetries and underreporting of international transactions, which contributes to the statistical discrepancies in balance of payments.In this context, the NEO item can be viewed as capturing the incompleteness of measurements representing the entire spectrum of global financial integration.

Findings of the study Emeç et al. (2023) reveal that Turkiye's NEO item realized an average surplus during the period of 1984-2021, however it was highly volatile. That is, in that year the line item broke a record high of approximately USD 22.7 billion. Such large magnitudes mean that NEO is not caused just by small technical errors.

It has been stressed that the NEO item can show both positive and negative deviations. Positive deviation is said to happen if some transactions are underinvoiced or some inflows of foreign exchange are smuggled out of the books. Negative divergences can also arise when outflows or liabilities are understated (Emeç et al., 2023, p. 680; Keşap & Sandalcılar, 2021, p. 155). This is important to consider in analysis of NEO.

Panel studies in the international literature have focused on the sustainability and fundamental determinants of the NEO item. An analysis by Ding and Tang (2019) of 98 countries concluded that the NEO item is stationary under root tests and therefore exhibits a stable long-term structure. The study stated that institutional quality has a significant effect on this sustainability, regardless of income groups.

Keşap and Sandalcılar (2021), in their study specific to Turkiye, examined the 2008-2020 period using the ARDL cointegration method and found a long-term cointegration relationship between the NEO indicator and variables such as tourism revenues, export revenues, and non-resident deposits. The study concluded that the effect of the foreign deposits variable on NEO is stronger than that of other variables.

In his study using annual data from selected countries (e.g., India, Philippines, USA), Şahin (2022) observed that the volume of foreign trade (total imports + exports) negatively affected the NEO item; that is, as the volume of foreign trade increased, the magnitude of the deviation (NEO) decreased. However, this effect varies across countries—in some, the NEO magnitude may increase as foreign trade volume increases.

The NEO is active periods associated with economic shocks, exchange rate volatility, and external demand shocks. In the Turkish economy, factors such as high inflation and economic uncertainty have contributed to dollarization and external imbalances, which may also be associated with discrepancies observed in balance-of-payments statistics (Önen & Meral, 2022). Emeç et al. (2023) reported that a positive shock in exchange rate volatility positively affects NEO in the short-run. Such effects indicate that NEO is not simply an accounting mistake, but that it is also connected to macroeconomic forces.

Furthermore, the political economy aspect of the NEO item, which relates to "malicious intent" or non-transparency of institutions, has been analyzed. In their analysis, Yılmaz and Kahveci (2024) contend that NEO values are consistently greater in nations characterized by rampant corruption, and that NEO serves in these nations to hide current account deficits or cover volatilities in the financial account.

The size and volatility of NEO depend, however, on the data-collection capacity of the country, on the quality of its statistical agencies, on the structure of its foreign trade and on the transparency of its financial transactions.The results from panel data estimations indicate that the quality of institutions, controls and technical capability are some of the most significant attributes (Ding & Tang, 2019, p. 5-6).

The nature and significance of the Net Errors and Omissions (NEO) item in the balance-of-payments accounts can be also explained by drawing upon the relevant contributions in the international literature. Cuddington (1986) links NEO to capital flight and other unrecorded financial flows and argues that discrepancies in the external accounts may represent real economic behavior and not just measurement errors. Similarly, Global Financial Integrity (Kar & Freitas, 2012) reports stress the importance of trade misinvoicing and illicit financial flows as the main sources of errors and omissions in the balance of payments systems, which reiterates the suspicion that NEO may include concealed cross-border transactions.

Siranova and Tiruneh (2018) and Siranova et al. (2021) show that the NEO can exhibit regularities associated with the dynamics of capital flight and the ties between international financial networks, mainly in emerging and transition economies. In the same way, Ding and Tang (2017) present an overview of the literature, stressing that NEO is not just a residual statistical instrument and could enjoy long-term persistence along with systematic causes, such as the quality of institutions and the state of macroeconomy.

Besides, the global financial system also contributes significantly to the NEO behavior. Studies such as Cerutti et al. (2017) underscore the fact that swings in the global financial cycle and capital flow volatility can have second round effects in the balance-of-payments gap. Furthermore, the conceptual and methodological framework of the IMF (2019) highlights that NEO results from a mixture of errors in measurement, timing differences, and undisclosed transactions and therefore should be considered in both a statistical and an economic perspective.

Siranova (2024) suggests that the statistical discrepancy in balance of payments accounts may act as a balancing item for net foreign asset positions, as opposed to being a random error term in measurement errors. This viewpoint emphasizes that omitted or underestimated financial flows can be invisibly included in measures of foreign balance through the NEO item. Accordingly, the NEO may reflect not just data limitations but also the structural nature of international financial integration, thereby justifying its inclusion as a non-negligible (albeit indirect) element of the foreign balance.

The international experience therefore suggests that the NEO item captures a multifaceted relationship between foreign trade, capital flows, the quality of institutions and measurement error, which is consistent with viewing it as a potentially informative (though indirect) proxy for external sector imbalances.

Consequently, the literature illustrates that the NEO item is not just error/measurement, it is influenced by activities such as the volume of foreign trade, exchange rate volatility, transparency information, and institutional framework. In the case of Turkiye, non-resident deposits, export revenues and other such factors have been identified as having considerable impact on NEO. These studies imply that the NEO item is a significant factor that should not be ignored in the study of the foreign trade balances, but they do not indicate whether the "alert" produced by it is as severe as given by them.

Balance-of-Payments, Crises, and Informal Capital Flows

The balance-of-payments (BOP) is the fundamental accounting identity that records all of a country's cross-border transactions (trade in goods and services, income transfers, capital and financial movements, etc.) during a given period; in theory, the current account + financial/capital account + official reserve changes should equal zero. However, in practice, deviations arise from recording, timing, and valuation issues, as well as unrecorded transactions, and these deviations are offset by the Net Errors and Omissions (NEO) item. Crisis literature emphasises that capital flows can reverse abruptly when external vulnerabilities—particularly short-term foreign currency debt, insufficient reserves, and speculative positions—accumulate. This process can lead to a sudden

stop or reversal of capital flows, causing rapid deterioration in the balance-of-payments. In such crises, large and sudden fluctuations in the NEO item may be observed, as official records may not immediately capture short-term and hidden movements (IMF, 2019; Cerutti et al., 2017).

In Turkiye, the currency crisis in late 2018 and the subsequent external vulnerabilities reversed the typical behavior of the net error and omission item; that is, this item did not fill the financing gaps it had historically indicated, but rather exacerbated the financial squeeze. The OECD, examining movements between 2014 and 2020, noted that NEO negatively affected the financing balance in 2018 (OECD, 2021, p. 26).

The reasons for the large deviations in the NEO item in the balance-of-payments regulation and international studies are multidimensional: (i) recording/reporting deficiencies and timing differences, (ii) hidden capital flight through invoice manipulation, (iii) production sharing and offshore transactions by multinational companies, (iv) deposit movements in host countries, and (v) the inability to compile new financial instruments. The IMF's BOPCOM study (2019) indicates that NEO may stem from these factors and that countries need to strengthen both existing data sources and mirror statistics controls when assessing NEO.

Studies on unreported capital movements and illicit financial flows (IFF) take NEO as a measurement which may also capture such flows in a roundabout way; for instance, Global Financial Integrity (GFI) reports and World Bank compilations highlight that trade misinvoicing and balance-of-payments discrepancies are the main conduits for illicit financial flows and that the item NEO captures a portion of these. While these studies do not consider NEO alone to be determinative in measuring illicit financial flows, they clearly state that it is an important indicator (GFI, 2019, p. 32; Collin, 2019).

Empirical studies have frequently tested the relationships between NEO and macro variables (exchange rate volatility, external debt stock, tourism revenues, foreign deposit movements, etc.). Some Turkiye-focused studies have shown that exchange rate volatility and domestic residents' foreign deposit transfers have significant effects on NEO; they also show that NEO increases in magnitude during crisis periods (Akçay & Güngen, 2019). So, NEO is regarded as an “early warning” tool for policy analysts.

In managing balance-of-payments crises, interpreting NEO has two implications for policymakers: if NEO is largely attributable to measurement errors, statistical adjustments and data compilation improvements take precedence; but if the NEO largely reflects real, unrecorded capital movements, macro-prudential measures, capital flow management, and international cooperation come to the fore (IMF BOPCOM, 2019, p. 13; GFI, 2019, p. 33). Therefore, improving data quality and cross-checking with mirror statistics should be part of the policy package.

The global financial cycle and risk appetite also influence NEO behavior: NEO may exhibit significant negative deviations when hot money inflows to developing countries decline amid global liquidity squeezes (Cerutti et al., 2017). Therefore, NEO should be interpreted not only at the national level but also in the context of international liquidity conditions.

In terms of policy implications specific to Turkiye, the continuity and directional variability of NEO are important: a consistently positive/negative NEO indicates a structural problem in the external financing model or a lack of recording and reporting; as a result, reserve management, foreign exchange liquidity policies, and data transparency reforms should be priority policy areas (OECD, 2021, p. 26; Akçay & Güngen, 2019, p. 52). Furthermore, the regular sharing of mirror statistics through international cooperation effectively increases NEO transparency (IMF BOPCOM, 2019, p. 25).

In conclusion, the relationship among the balance-of-payments, crises, and informal capital flows is multi-layered. Beyond being a technical balancing item, NEO serves as an indicator of liquidity crunches, informal money movements, and data-collection deficiencies during crisis periods; therefore, NEO should be carefully examined in both empirical analyses and policy assessments. The empirical part of this study also aims to reveal the direction and strength of the relationship between NEO and Turkiye's trade balance during the period 1990–2024.

DATA AND METHODOLOGY

Data Set

This study uses annual data covering the period 1990–2024 for the Turkish economy. The data were compiled from the World Bank and International Monetary Fund (IMF) databases. In selecting the data, we considered both continuity and reliability. We focus on this period because the 1990s marked Turkiye's move toward economic openness and liberal capital movements.

Variables

The dependent variable used in the study is the Trade Balance (Balance). This variable is defined as exports (X) minus imports (M). A positive figure means a surplus, and a negative indicates a deficit in foreign trade. The foreign trade balance is an important index to reflect the level of the national economy dependent on foreign trade and the pressure of current transactions (Kaya & Çiçekçi, 2023).

The Net Error and Omission (NEO) variable has been used as the independent variable. NEO represents capital movements of unknown origin in balance of payments statistics. It generally refers to unrecorded foreign exchange inflows and outflows, recording errors, and untraceable transactions in financial flows. In the Turkish economy, the NEO item frequently shows high values and is regarded as an important indicator of transparency in capital flows and unrecorded money movements.

Consequently, we arranged the dataset so as to capture quantitatively and in time the evolution of Turkiye's foreign trade and capital flows. For the analysis, we have been converted the variables to absolute values and logarithmic form.

Methodology

In this paper, we investigate the extent to which the NEO and Trade Balance (Balance) in Turkiye are associated during 1990–2024. The purpose of the analysis is to show empirically if there is any causality between two

major constituents of the balance-of-payments. For this purpose, the Toda-Yamamoto (1995) Causality approach was used. First, the maximum integration order of the variables, d-max, and the optimal lag length were determined, and then the VAR(k+d-max) model was estimated. Causality relationships were tested using the Wald test applied only to the first lag coefficients.

The model's equations were constructed as follows:

$$LnBalance_t = a_0 + \sum_{i=1}^{k+d_{max}} a_{1i}\ LnBalance_{t-i} + \sum_{i=1}^{k+d_{max}} a_{2i}\, LnNEO_{t-i} + \varepsilon_{1t} \quad (1)$$

$$LnNEO_t = \beta_0 + \sum_{i=1}^{k+d_{max}} \beta_{1i}\ LnNEO_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_{2i}\, LnBalance_{t-i} + \varepsilon_{2t} \quad (2)$$

Here:

- *Balance*: Trade balance,
- *NEO*: Net error and omission item,
- ε_t: error term.

In the analysis, the Augmented Dickey-Fuller (ADF) unit root test was applied in the first stage to determine whether the series was stationary. Non-stationary series were made stationary by differencing. the analysis included an examination of bidirectional causality.

FINDINGS

Descriptive Statistics

As shown in Table 1, the Balance of Trade (Balance) variable has a negative average value, confirming that Turkiye experienced a chronic trade deficit during the 1990–2024 period. The negative average value of the NEO variable indicates that informal capital inflows primarily financed the foreign exchange deficit (TCMB, 2016, p. 16).

Table 1. Descriptive Statistics

Variables	Mean	Median	Maximum	Minimum	Jarque-Berra	Skewness	Kurtosis
Balance	-46.410.576	-43.294.182	-5.161.947	-109.540.825	2,734 (0,255)	-0,477066	2,018000
NEO	-65,2	-468	28821	-17830	17,638 (0,000148)	0,976179	5,877948

Source: Created by the author

Unit Root Test

The stationarity of the time series was analyzed using the Augmented Dickey-Fuller (ADF) unit root test. If the absolute value of the ADF test statistic is below the critical values proposed by McKinnon, the null hypothesis indicating the presence of a unit root cannot be rejected, and it is concluded that the series is non-stationary. If the null hypothesis cannot be rejected, the series must be differenced and retested for unit roots. This process is repeated until the series becomes stationary and the null hypothesis is rejected. If the levels of the time series are non-stationary but their first differences are stationary, the series are said to be first-order integrated, i.e., I(1) (Mensah & Okyere, 2020, p. 877).

Table 2. Unit Root Test Results-1

ADF Unit Root Test, Level Values						
		Test Statistic	**p Values**	**Critical Values**		
				%1	**%5**	**%10**
LnBalance I(0)	***None***	0,4741	*0.8123*	-2,6327	-1,9507	-1,6111
	Intercept	-2,0075	*0,2824*	-3,6329	-2,9484	-2,6129
	Trend and Intercept	-2,8054	*0,2049*	-4,2436	-3,5443	-3,2047
LnNEO I(0)	***None***	1,0466	*0,9189*	-2,6392	-1,9517	-1,6106
	Intercept	-0,8866	*0,7795*	-3,6537	-2,9571	-2,6174
	Trend and Intercept	-6,0370	***0,0001***	-4,2529	-3,5485	-3,2071

Source: Created by the author

Note: The probability value is Mackinnon's (1996) one-tailed p-value, the maximum lag length is 8, and the appropriate lag length was selected using the Akaike Information Criterion (AIC).

Table 2 shows the stationarity levels of the logarithm of the Balance and NEO variables. According to the ADF test results, the Balance is not stationary at the level and contain a unit root, but it becomes stationary when its first difference is taken ($p<0.05$). This finding indicates that the Balance series are stationary at the I (1) level. The ADF Unit Root Test results for the first differences are presented in Table 3.

Table 3. Unit Root Test Results-2

ADF Unit Root Test, First Differences						
ΔLnBalance I(1)	***None***	8,0483	***0.0000***	-2,6369	-1,9513	-1,6107
	Intercept	-8,2253	***0,0000***	-3,6463	-2,9540	-2,6158
	Trend and Intercept	-8,1327	***0,0000***	-4,2627	-3,5530	-3,2096
ΔLnNEO I(1)	***None***	-6,7970	***0,0000***	-2,6392	-1,9517	-1,6106
	Intercept	-6,9324	***0,0000***	-3,6537	-2,9571	-2,6174
	Trend and Intercept	-6,8283	***0,0000***	-4,2733	-3,5578	-3,2124

Source: Created by the author

Although the ADF test results suggest that the LnNEO variable appears to be constant at the trend and intercept level, this variable is not stationary in either the model at none or the model containing only an intercept. In terms of order of integration, this paper takes a conservative/robust stance and analyzes all the models at the same time rather than relying on a single outcome. Since adding a deterministic trend may bias the test towards the rejection of the unit root null hypothesis, the stationarity of LnNEO in level is taken with a grain of salt under this model. Consequently, LnNEO is modeled as an I(1) variable, in line with the findings from alternative specifications. In addition, the Toda–Yamamoto causality procedure only requires the identification of the maximum order of integration, dmax, and there is no strict requirement that all variables are to be integrated at the same order. Thus,

treating both series as I(1) guarantees methodological rigor and robustness of the empirical investigation.

Table 3. VAR Model Lag Length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-82.71384	NA	0.683111	5.294615	5.386224	5.324981
1	-63.13311	35.49008	0.258249	4.320819	4.595645*	4.411916
2	-57.31698	9.814717*	0.231476*	4.207311*	4.665354	4.359139*
3	-54.04794	5.107869	0.244538	4.252996	4.894256	4.465556

Source: Created by the author

Before performing the Toda-Yamamoto causality test, the appropriate lag length is determined. According to Table 3, the appropriate lag length (k) is 2.

Toda-Yamamoto Causality Test

The Toda and Yamamoto (1995) procedure is a technique which allows for series with different integration orders and for testing for causality in levels. As a result, the current approach leads to more reliable results since that it does not cause loss of information in the series. The lag length is determined in the first step, which is then followed by estimating a augmented VAR model by adding the maximum integration order of the series to the determined lag length to the maximum lag length. At the final stage, the Modified Wald (MWald) statistic is calculated by imposing a null in the lags that correspond to the maximum integration order and the test for causality is a result (İzgi, 2021, p. 8).

Table 4 shows the Granger-causality status of the variables using the Toda-Yamamoto causality test. VAR models were then estimated for the system of equations with k=2, dmax=1 and the causal links of the variables were tested. In the Toda-Yamamoto causality setting, one should clearly differentiate between the lag length k and the augmented lag length k + dmax. The optimal lag length in the present study was found to be k = 2 according to the Akaike Information Criterion. Since The maximum integration order of the variables was found to be dmax = 1, the VAR model was computed for (k + dmax) = 3 lags.

According to the Toda–Yamamoto procedure, the Modified Wald (MWald) test was conducted on the first k lagged coefficients (i.e., the first two lags), and the extra lag was added in the model in order to guarantee the validity of the asymptotic distribution of the test statistics.

Table 4. Toda-Yamamoto Test Results

Dependent Variable	MWald	k	Probability Value	Direction of Causality	Result
Balance	0,878221	3	0,64461	NEO ➡ Balance	There is no causal relationship between the net error and omission

					item and the trade balance.
NEO	5,488069	3	0,06431	Balance ➡ NEO	There is a one-way partial weak causality relationship from the foreign trade balance to the net error and omission item.

Source: Created by the author

Note: The VAR model is estimated with (k + dmax) = 3 lags, while MWald statistics are computed based on the first k = 2 lags.

The findings give weak (marginal) evidence of a unidirectional causality from the foreign trade balance to the net errors and omission (NEO) item at the 10% significance level (p = 0.064). But, it must be emphasized that this result is not very strong and it is probable that it changes depending on the type of data and specification of the model used, so it should be taken with a grain of salt.

Results and Conclusion

The results of this study reveal that the causal relationship between the Trade Balance and the Net Error and Omission (NEO) item in Turkiye is unidirectional, from the trade balance to the NEO item. Conversely, no statistically significant causal relationship was found from the NEO item to the foreign trade balance. This result indicates that the NEO acts as an item that responds to foreign balance dynamics rather than being an active factor determining the foreign trade balance.

This finding is consistent with studies that largely treat the NEO item as reflecting measurement errors, delayed records, and inconsistencies in foreign trade transactions (Eğilmez, 2012; Çıplak, 2005). In these approaches, NEO is treated as a statistical balancing item that arises following disruptions to foreign trade or current account balance. The causality relationship identified in this study, from the foreign trade balance to NEO, empirically supports this interpretation.

The literature shows that fluctuations in the trade balance or current account, particularly during periods of crisis and uncertainty, are associated with increases in the NEO item. In this context, the results of this study are largely consistent with empirical findings (Ferretti & Razin, 1999; Blomberg et al., 2004; Akbaş et al., 2014; Raza & Zoega, 2019; Keşap & Sandalcılar, 2021; Kohler, 2022), the results of this study are largely consistent.

On the other hand, the findings of this study are also consistent with studies that fail to detect causality from the NEO to the Balance (Çıplak, 2005; Eğilmez, 2012; Keşap & Sandalcılar, 2021). This situation indicates that NEO should be evaluated not as a tool for policymakers to steer the foreign balance, but rather as a result of irregularities in foreign trade and capital movements. Therefore, this study presents findings that support the literature arguing that the NEO item should be treated as a result variable rather than a cause variable.

In conclusion, the findings of this study emphasise the decisive role of the foreign trade balance in the NEO item

and reveal that NEO is an indicator sensitive to foreign balance dynamics in the Turkish economy. In this respect, the study produces results consistent with the literature that treats NEO as a dependent balancing item and provides a complementary contribution to existing studies in terms of methodology.

Beyond the statistical interpretation of the results, the one-way causality identified between the trade balance and the Net Error and Omission (NEO) item can be explained by various fundamental economic mechanisms. In particular, fluctuations in the trade balance—especially persistent trade deficits—tend to lead to inconsistencies between recorded and actual cross-border transactions. Such discrepancies can result from timing differences when trades are recorded, underdeclaration or mispricing of imports and exports, and from unrecorded or undisclosed capital flows relating to trade finance. As a result, these types of discrepancies are not reported straightaway as errors and omissions in the capital and financial account, but are subsequently appearing as the balancing item in the Balance of Payments. This mechanism is also relevant in the case of the Turkish economy where some structural peculiarities such as high import dependency, exchange rate volatility, vulnerability to external shocks may exaggerate the differences between actual and registered flows of capital. Ultimately, a growing trade deficit or volatile trade patterns may cause the magnitude of statistical discrepancy to increase, and hence to active movements in the NEO item. In this respect, instead of the foreign balance being "determined" by NEO as a "stand-alone" consideration, NEO is to be regarded as a countervailing variable which is reflective of the cumulative impact of measurement gaps, invisible financial flows, and other structural imbalances in the foreign trade dynamics.

The conclusions of this paper has several relevant policy implications. First, as the Net Errors and Omissions (NEO) item seems to respond to trade balance imbalances rather than cause them, policy efforts should focus on addressing the structural causes of trade deficits, namely by reducing import dependence for energy and intermediate goods and by raising export potential. Second, the fact that NEO is affected by differences in what is recorded and what goes unrecorded indicates the need for the enhancement of the quality, transparency, and coordination of balance-of-payments data. Improving data collection methodologies, institution-building, and the use of mirror statistics and checking mechanisms could contribute to mitigate measurement errors and enhance reliability. Third, because exchange rate fluctuations and external shocks may increase discrepancies, macroeconomic stability and predictable exchange rate policies could indirectly help to reduce the fluctuations of the NEO component. Finally, given that NEOs may in part capture unrecorded short-term capital flows, policy implications should also include enhancing monitoring frameworks of capital flows and financial transactions so as to improve financial transparency and the consistency of external sector statistics.

This study have limitations when evaluating the findings of this study. First, the analysis is the two-variable setting considering the causality relation between NEO item and the foreign trade balance. While this approach offers the advantage of clearly revealing the direct causal relationship between the variables, excluding potential

mediating or control variables, such as the exchange rate, capital movements, financial openness, and economic uncertainty, from the model may limit the scope of the results.

Second, the data used in the study are annual. While annual data allow for the analysis of long-term trends, they may make it difficult to fully capture the dynamic effects of short-term shocks and sudden capital movements. As a result, the influence of fluctuations in the NEO item may have been somewhat reduced, notably during crises.

Third, by its nature, the NEO item may contain measurement errors, unrecorded transactions, and statistical inconsistencies. Therefore, the uncertainties inherent in NEO data require caution in interpreting empirical results. Although the Toda–Yamamoto method yield results that are robust to integration orders and structural breaks, researchers cannot eliminate structural problems arising from data quality.

REFERENCES

Akbaş, Y. E., Şentürk, M., & Sancar, C. (2014). The relationship between capital flows and current deficit: evidence from Turkey. *Indian Journal of Finance*, *8*(11), 7–22. https://doi.org/10.17010/ijf/2014/v8i11/71693

Akçay, Ü., & Güngen, A. R. (2019). *The making of Turkey's 2018–2019 economic crisis* (IPE Working Paper No. 120). Institute for International Political Economy (IPE). https://www.ipe-berlin.org/fileadmin/institut-ipe/Dokumente/Working_Papers/ipe_working_paper_120.pdf

Aydın, M. F., Başkaya, Y. S., & Demiroğlu, U. (2015). Türkiye'de ihracatın ithalatı karşılama oranı üzerine ampirik bir analiz. *Iktisat Isletme ve Finans*, *30*(354), 1-10. https://www.tcmb.gov.tr/wps/wcm/connect/74adb1f9-d0e0-443b-af64-dfa2a74bd9a1/EN1408eng.pdf?CACHEID=ROOTWORKSPACE-74adb1f9-d0e0-443b-af64-dfa2a74bd9a1-m3fw5jS&MOD=AJPERES

Blomberg, S. B., Hess, G. D., & Orphanides, A. (2004). The macroeconomic consequences of terrorism. *Journal of Monetary Economics, 51*(5), 1007–1032. https://doi.org/10.1016/j.jmoneco.2004.04.001

Cerutti, E., Claessens, S., & Rose, A. K. (2017). *How important is the global financial cycle? Evidence from capital flows* (No. w23699). National Bureau of Economic Research, https://www.bis.org/publ/work661.pdf

Collin, M. (2019). Illicit financial flows: concepts, measurement, and evidence. *World Bank Research Observer*, 35(1), 44–86. https://documents1.worldbank.org/curated/en/409341624542914243/pdf/Illicit-Financial-Flows-Concepts-Measurement-and-Evidence.pdf

Cuddington, J. T. (1986). *Capital flight: Estimates, issues, and explanations* (Vol. 58). Princeton, NJ: International Finance Section, Department of Economics, Princeton University, http://ies.princeton.edu/pdf/S58.pdf

Çakal, E. (2019). Türkiye'de cari açığın sürdürülebilirliği: ihracat ve ithalat arasındaki ilişkinin ekonometrik bir analizi (2002-2016), *Aydın Adnan Menderes Üniversitesi Sosyal Bilimler Enstitüsü İktisat Anabilim Dalı Yüksek Lisans Tezi*, Aydın.

Çakmaklı, B. M. (2025). Inflation, exchange rate and foreign trade: Long and short run relationships in the Turkish economy. *InTraders International Trade Academic Journal*, 8(1), 1–19. https://doi.org/10.55065/intraders.1660803

Çıplak, U. (2005). *Ödemeler dengesinde "Net Hata ve Noksan" kalemi üzerine bir değerlendirme.* Türkiye Cumhuriyet Merkez Bankası. https://www.tcmb.gov.tr/wps/wcm/connect/01c7bdcc-a979-4773-a4d4-3b68b7be530b/Net%2BHata%2Bve%2BNoksan.pdf?MOD=AJPERES

Demir, M. A. (2020). Türkiye'nin İhracat ve İthalat Kompozisyonunun Dış Ticaret Dengesi Üzerine Etkisi: Ab-15 Ülkeleri İçin İki Yönlü Panel Analizi. *Balıkesir Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 23(44), 887-909, https://doi.org/10.31795/baunsobed.731693

Ding, L. S., & Tang, T. C. (2017) 'Net Errors and Omissions' of balance of payments and its sustainability: a survey of literature, *Economics Bulletin*, 37(4), 2753-2766.

Ding, L. S., & Tang, T. C. (2019). Sustainability of 'Net Errors and Omissions' of balance of payments – with global results. *Labuan Bulletin of International Business and Finance*, 17(2), 1–7. https://doi.org/10.51200/lbibf.v17i2.2535

Eğilmez, M. (2012). *Net Hata ve Noksan*. https://www.mahfiegilmez.com/2012/05/net-hata-ve-noksan.html

Eğilmez, M. (2013). *Net Hata ve Noksan'ın Açıklanması Gerekir*. https://www.mahfiegilmez.com/2013/12/net-hata-ve-noksann-acklanmas-gerekir.html

Emeç, A. S., Özdemir, D., & Kaplan, F. (2023). Net hata ve noksan kalemi ile reel efektif döviz kur endeksi arasındaki ilişki: Türkiye üzerine bir inceleme. *İzmir İktisat Dergisi*, 38(3), 670-685. https://doi.org/10.24988/ije.1167345

Ferretti, G. M. M., & Razin, A. (1999). Current account deficits and capital flows in East Asia and Latin America: are the early nineties different from the early eighties? In *Changes in Exchange Rates in Rapidly Developing Countries: Theory, Practice, and Policy Issues* (p. 57–108). University of Chicago Press.

Global Financial Integrity (GFI). (2019). *Illicit financial flows to and from 148 developing countries: 2006–2015* (GFI Report). Global Financial Integrity. https://gfintegrity.org/wp-content/uploads/2019/01/IFF-Report-2019_11.18.19.pdf

IMF — Committee on Balance of Payments Statistics (BOPCOM). (2019). *Analysis of net errors and omissions* (BOPCOM—19/14). International Monetary Fund. https://www.imf.org/external/pubs/ft/bop/2019/pdf/19-14.pdf

İzgi, F. (2021). *Türkiye'de enflasyon ve dış ticaret ilişkisi: nedensellik testleri, Uluslararası Lisansüstü Çalışmalar Kongresi (IGSCONG'21)*, 25-28 Haziran, Online Sunum, Erişim adresi: https://scholar.google.com/citations?view_op=view_citation&hl=tr&user=no3IlkUAAAAJ&citation_for_view=no3IlkUAAAAJ:YsMSGLbcyi4C

Kar, D., & Freitas, S. (2012). *Illicit financial flows from Developing Countries: 2001-2010*. Washington, DC: Global Financial Integrity, https://transparency.org.kw.au-ti.org/upload/books/228.pdf

Kaya, A. I., & Çiçekçi, C. (2023). Structural transformation and sources of growth in Turkey, *WIDER Working Paper*, No. 2023/71, ISBN 978-92-9267-379-6, The United Nations University World Institute for Development Economics Research (UNU-WIDER), Helsinki, https://doi.org/10.35188/UNU-WIDER/2023/379-6

Keşap, D., & Sandalcılar, A. R. (2021). Net hata ve noksan hesabı belirleyicilerinin analizi: Türkiye örneği. *Uluslararası İktisadi ve İdari İncelemeler Dergisi*, (32), 149-168. https://doi.org/10.18092/ulikidince.934498

Kohler, K. (2022). Capital flows and geographically uneven economic dynamics: A monetary perspective. *Environment and Planning A: Economy and Space*, *54*(8), 1510-1531. https://doi.org/10.1177/0308518X221120823

Kubelec, C. & Sa, F. G., (2010). The geographical composition of national external balance sheets: 1980-2005, *Bank of England Working Paper* No. 384, http://dx.doi.org/10.2139/ssrn.1577143

Mensah, A.C. & Okyere, E. (2020). Causality analysis on export and economic growth nexus in Ghana. *Open Journal of Statistics*, 10, 872–888. https://doi.org/10.4236/ojs.2020.105051

OECD (2021), OECD economic surveys: Turkey 2021, *OECD Publishing*, Paris, https://doi.org/10.1787/2cd09ab1-en

Oğuz, Y. A. (2024). Türkiye'deki son beş yıllık dış ticaretin ülke gruplarına göre incelenmesi. *Scientific And Academic Research (ISSN: 2980-308X)*, *3*(2), 281–290. https://e-scar.com/index.php/pub/article/view/37

Önen, M. A. C., & Meral, Y. (2022). Dollarization's effects in Turkey economy. *InTraders International Trade Academic Journal*, 4(2), 72–106. https://doi.org/10.55065/intraders.1058509

Raza, H. & Zoega, G. (2019). From a capital account surplus to a current account deficit. In: Aliber, R., Zoega, G. (eds) *The 2008 Global Financial Crisis in Retrospect*. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-12395-6_10

Siranova, M., & Tiruneh, M. W. (2018). Exploding net errors and omissions as a capital flight phenomenon: the case of Slovakia. *Applied Economics*, *50*(16), 1866–1884. https://doi.org/10.1080/00036846.2017.1380288

Siranova, M., Tiruneh, M. W., & Fisera, B. (2021). Creating the illicit capital flows network in Europe–do the net errors and omissions follow an economic pattern?. *International Review of Economics & Finance*, *71*, 955-973. https://doi.org/10.1016/j.iref.2020.10.020

Siranova, M. (2024). Statistical omissions as the stabilizing factor of net foreign assets in EU countries. *International Economics*, 178, 100485. https://doi.org/10.1016/j.inteco.2024.100485

Şahin, S. (2022). Net hata ve noksan hesabına bakış: seçilmiş ülkelere yönelik analiz (1980-2018). *İktisat Politikası Araştırmaları Dergisi - Journal of Economic Policy Researches*, 9(1), 103-120. https://doi.org/10.26650/JEPR1020460

TCMB. (2016), *Ödemeler dengesi ve uluslararası yatırım pozisyonu raporu, 2016-IV*. Türkiye Cumhuriyet Merkez Bankası, https://tcmb.gov.tr/wps/wcm/connect/3941a65e-d6f1-473a-b5a9-78a520a79580/ODRapor_20164.pdf?MOD=AJPERES&CACHEID=ROOTWORKSPACE-3941a65e-d6f1-473a-b5a9-78a520a79580-m5lXFs4

Temiz, D. (2009). Gümrük birliği ile birlikte Türkiye'nin dış ticaretinde yapısal değişimler oldu mu?. *Ankara Avrupa Çalışmaları Dergisi*, *8*(1), 115-138, https://doi.org/10.1501/Avraras_0000000064

TUIK (2025). *Dış Ticaret İstatistikleri Aralık 2024*, https://data.tuik.gov.tr/Bulten/Index?p=D%C4%B1%C5%9F-Ticaret-%C4%B0statistikleri-Aral%C4%B1k-2024-53538&dil=1

Tunçsiper, B., & Rençber, E. Z. (2017). Dış ticaret ve ekonomik büyüme arasındaki nedensellik ilişkisi: Türkiye örneği. *International Journal of Social Sciences and Education Research*, *3*(2), 619–630. https://doi.org/10.24289/ijsser.270501

Yılmaz, E. G., & Kahveci, Ş. (2024). Does the misuse of net errors and omissions arise from a corruption culture?, *Journal of International Studies*, 17(4), 150-162. https://doi.org/10.14254/2071-8330.2024/17-4/9

InTraders International Trade Academic Journal

e-ISSN: 2667-4408 **www.intraders.org**

Volume: 9
Issue : 1
Research Article

Received: February 20, 2026
Revision: March 31, 2026
Accepted: May 20, 2026
DOI: https://www.doi.org/10.55065/intraders.1905139

Forecasting Turkish Exports: A Comparative Study of Statistical, Machine Learning, and Deep Learning Methods

Ümit YILMAZ[12], Fehime GÜNBEGİ[3]

Abstract

The purpose of this study is to identify the most accurate forecasting approach for Turkish monthly merchandise exports by rigorously comparing statistical, machine learning, and deep learning methods on a low-frequency macroeconomic series characterized by structural breaks and regime changes. Regarding methodology, eight models are evaluated, SARIMAX, Prophet, Hybrid-S (SARIMAX+CatBoost), Hybrid-P (Prophet+CatBoost), XGBoost, CatBoost, Gated Recurrent Unit (GRU), and Neural Basis Expansion Analysis for Time Series (N-BEATS), applied to monthly Turkish export data spanning January 2002 to December 2025 (288 observations), evaluated over an 83-month walk-forward test period (February 2019–December 2025), with Brent crude oil price, real effective exchange rate, and industrial production index as exogenous variables. Walk-forward expanding-window validation eliminates look-ahead bias, hyperparameters are optimized via Optuna with 50 trials, and statistical significance is assessed using Diebold-Mariano tests. The findings reveal that the SARIMAX+CatBoost hybrid achieves the highest predictive accuracy (R^2 = 0.857, MAPE = 5.67%), marginally outperforming standalone SARIMAX (R^2 = 0.853, MAPE = 5.72%), while deep learning methods (GRU, N-BEATS) perform substantially below all other models (R^2 = 0.44 and 0.39, respectively), consistent with the literature on neural networks applied to low-frequency, small-sample macroeconomic series. In terms of contribution, this study presents the first unified eight-model benchmark for Turkish export forecasting under a strictly leakage-free walk-forward validation protocol, introduces two novel hybrid architectures validated across multiple structural regimes including the COVID-19 shock, and empirically confirms the data-regime hypothesis: statistical and hybrid methods dominate in low-frequency, small-sample, structurally unstable macroeconomic environments.

Keywords: *Export forecasting, machine learning, Türkiye*

JEL Codes: *C22, C45, C53*

There is no conflict of interest.

[1] Corresponding Author: Ümit Yılmaz, umit.yilmaz@btu.edu.tr
[2] Current Affiliation: Instructor Dr., Bursa Technical University, E-Mail: umit.yilmaz@btu.edu.tr, OI: 0000-0003-4268-8598
Previous Affiliation: Asst. Prof. Dr., Balıkesir University, E-Mail: umityilmaz@balikesir.edu.tr, OI: 0000-0003-4268-8598
Contribution rates to the study 50 %.
[3] Asst. Prof. Dr., Balıkesir University, E-Mail: fehimegunbegi@balikesir.edu.tr, OI: 0000-0003-1410-4452 Contribution rates to the study 50 %.

Cite As: Yılmaz, Ü., & Günbegi, F. (2026). Forecasting Turkish exports: A comparative study of statistical, machine learning, and deep learning methods. *InTraders International Trade Academic Journal,* 9(1), 175–196. https://doi.org/10.55065/intraders.1905139

INTRODUCTION

For developing countries, exports are a significant economic activity that supports increased production, creates employment, and generates foreign exchange earnings. Analyzing the determinants of export performance is therefore important for both academic research and economic policy formulation.

The classic export function is modeled within the framework of two approaches in economic literature. The first model is a basic export-function model established by Goldstein and Khan (1985) and Senhadji and Montenegro (1999). The second model refers to an approach defined as extended export functions, which incorporates variables such as production capacity, energy prices, cost factors, and competitiveness, in addition to exports, foreign income, and real exchange rate variables. Within this framework, Türkiye presents a particularly instructive case: a large emerging market that has undergone rapid export growth alongside recurring macroeconomic instability, making it an ideal setting to test the explanatory power of both extended export functions and modern forecasting methods.

International trade constitutes one of the principal engines of economic growth. For an emerging market economy such as Türkiye, exports serve as a primary driver of gross domestic product expansion, foreign exchange accumulation, and employment creation. Since the structural reforms of the early 2000s, Turkish merchandise exports have grown from approximately USD 36 billion in 2002 to over USD 255 billion in 2023, reflecting a sustained integration into global value chains. The breadth of this export expansion is further documented by Kavacık (2023), who employs the Revealed Symmetric Comparative Advantage Index across 99 product chapters to show that Türkiye's number of competitive export categories increased from 37 in 2001 to 45 in 2021, with newly emerged advantages in high-value sectors including vehicles and aluminium, a structural upgrading that underscores the dynamic export environment the present forecasting models must capture. This expansion has not, however, been monotonic: Türkiye’s export trajectory has been punctuated by multiple macroeconomic shocks, including the 2008–2009 global financial crisis, the 2018 currency crisis that triggered a sharp depreciation of the Turkish lira, and the COVID-19 pandemic that caused an abrupt contraction in global demand in early 2020. The fiscal dimension of this instability is quantified by Göze Kaya and Durgun Kaygısız (2023), who demonstrate, via Johansen cointegration, that budget deficits and the money supply are cointegrated with inflation in Türkiye over 2003–2023, with a 1% increase in the budget deficit raising inflation by 0.06%. This finding confirms the cost-push and demand-side pressures operating on the macroeconomic environment within which the present export series is embedded. Accurately forecasting this volatile yet economically vital series requires methods capable of handling structural breaks, regime changes, and nonlinear dynamics simultaneously, a challenge that has motivated three successive generations of forecasting approaches.

The forecasting literature has evolved through three broad methodological generations. The first generation relied on classical time-series models, primarily autoregressive integrated moving average (ARIMA) variants and their

seasonal extensions (SARIMA, SARIMAX), which exploit temporal autocorrelation and accommodate exogenous regressors within a parametric framework (Box et al., 2016). Applied to Turkish trade, time-series approaches have a substantial empirical base: Iossifov and Fei (2019)'s working paper documented a structural break in the Real Effective Exchange Rate (REER) elasticity of Turkish real exports around 2008, finding that the long-run relationship between the exchange rate and export volumes shifted sign after the global financial crisis, evidence of regime-dependent dynamics directly relevant to the present modeling framework. Unal and Karamelikli (2026), using monthly bilateral trade data between Türkiye and Germany from 2002 to 2021, showed that nonlinear autoregressive exogenous (NARX) neural networks outperform traditional ARIMA models on disaggregated commodity sections, while also finding that forecast performance varies substantially across sectors, an observation motivating the aggregate-level analysis conducted here. More recently, Çakmaklı (2025) examines the long- and short-run relationships between the exchange rate, exports, imports, and GDP per capita in the Turkish economy over 1994–2023 using Johansen cointegration and VECM, finding no significant long-run cointegration between the exchange rate and exports, a result attributed to Türkiye's dependence on global demand conditions and its import-driven export structure, which further underscores the structural complexity motivating the present forecasting framework. The second generation introduced machine learning (ML) approaches, including gradient-boosted trees, random forests, and support vector regression, that capture nonlinear relationships among predictors without imposing parametric constraints. In the context of Turkish trade forecasting, Gulzar et al. (2024) applied artificial neural networks, logistic regression, and support vector regression to predict Türkiye's high-technology exports using World Bank data for 2007–2023, finding that ANN achieved the highest accuracy among the three approaches, a result that underscores the potential of ML methods for Turkish trade series while leaving open the question of which architecture performs best on aggregate monthly merchandise exports under a leakage-free walk-forward protocol. The third generation encompasses deep learning (DL) models, such as long short-term memory (LSTM) networks, GRU, and purpose-built architectures like N-BEATS, designed to learn complex temporal dynamics directly from data. Despite their theoretical capacity, DL models have shown mixed results on short macroeconomic series characterized by structural instability (Hewamalage et al., 2021).

However, the empirical record on which generation performs best is far from settled. The M4 forecasting competition (Makridakis et al., 2020), which evaluated 61 methods across 100,000 time series, found that pure ML methods performed poorly relative to statistical benchmarks on monthly macroeconomic data, while the winning submission employed a statistical–ML hybrid that achieved approximately 9.4% improvement over the combination benchmark. The M5 competition (Makridakis et al., 2022), conducted on daily retail sales data with over 42,000 series, produced a more favorable assessment of ML methods, illustrating that relative performance is strongly conditional on data frequency and sample size. A growing strand of research, therefore, advocates

combining the structural interpretability of statistical methods with the nonlinear correction capacity of ML algorithms (Petropoulos et al., 2022).

Despite the growing methodological literature, three gaps remain. First, no existing study applies a unified eight-model comparison, spanning statistical, ML, DL, and hybrid architectures, to Turkish export data under a strictly leakage-free walk-forward validation protocol. Second, the two-stage hybrid residual correction approach has not been evaluated on an emerging market export series subject to multiple structural breaks. Third, the relative performance of modern DL architectures (GRU, N-BEATS) against classical alternatives has not been systematically assessed for Türkiye. This paper addresses all three gaps by conducting a rigorous, methodologically unified comparison of eight forecasting approaches on monthly Turkish exports from January 2002 to December 2025.

This study aims to examine the key determinants of exports within the framework of an extended export function. Consistent with the demand-side specification of Goldstein and Khan (1985), the Real Effective Exchange Rate (REER) is included to capture price competitiveness; an appreciation of the REER implies a deterioration in Türkiye's export competitiveness and is expected to exert a negative effect on export volumes. Following the supply-side extensions in the literature, the Industrial Production Index (IPI) is included as a proxy for domestic production capacity and exportable goods volume. Brent crude oil price is incorporated to capture cost-push pressures, global demand conditions, and terms-of-trade effects, consistent with practice in studies on energy-importing emerging markets. Together, these three variables operationalize the extended export function framework, encompassing both export demand factors (REER, Brent) and export supply factors (IPI).

The study is expected to contribute to understanding export dynamics and providing guiding findings for policymakers.

Building on the three research gaps identified above, this study tests the following hypotheses:

H1: Statistical and hybrid models achieve higher predictive accuracy than pure machine learning and deep learning models when applied to low-frequency, small-sample, and structurally unstable macroeconomic export series.

H2: Two-stage hybrid residual correction (Hybrid-S and Hybrid-P) yields higher predictive accuracy than their respective statistical base models (SARIMAX and Prophet).

H3: Deep learning architectures (GRU and N-BEATS) underperform relative to statistical and hybrid alternatives in the presence of structural breaks and limited training observations.

The remainder of this paper is organized as follows. Section 2 presents related works. Section 3 describes the dataset, preprocessing, model specifications, training procedure, and evaluation metrics. Section 4 presents

empirical results. Section 5 provides a broader discussion. Section 6 concludes.

RELATED WORKS

Export forecasting has attracted a broad empirical literature spanning classical econometric methods, machine learning approaches, and studies focused specifically on Türkiye's trade dynamics.

A substantial body of research applies classical time-series and econometric methods to export forecasting across different countries and periods. Wong et al. (2010) examine Taiwan's export performance using ARIMA and Vector Autoregressive Moving Average (VARMA) models, while Lehmann (2021) applies an Autoregressive Distributed Lag (ADL) framework to EU countries over 1996–2016. Ghauri et al. (2020) employ Box-Jenkins and ARIMA models for Pakistan, and Rahmaddi and Ichihashi (2012) analyze Indonesian export dynamics over 1971–2007. Kumar (2009) estimates China's export demand function using the Johansen cointegration method. Harb (2007) applies Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS) estimators to trade flows between Arab countries and the Eurozone, and Piñeres and Cantavella-Jordá (2010) examine the short-run effects of currency devaluation on Latin American exports using pooled time-series estimations. Koç Yurtkur and Tay Bayramoğlu (2012) analyze export determinants across emerging market economies for 1994–2009 using a panel data approach.

More recent studies have introduced machine learning and hybrid approaches to capture nonlinear export dynamics. Dave et al. (2021) combine ARIMA with an LSTM neural network to forecast Indonesian exports, demonstrating the gains achievable by augmenting classical models with deep learning components. Yuan (2017) applies Particle Swarm Optimization and the Group Method of Data Handling (GMDH) to import and export forecasting in the Shenzhen area. Avşar and Ecemiş (2023) compare a range of ML methods, including linear regression, Gaussian Process Regression, and Support Vector Regression, applied to Türkiye's trade flows over 1969–2022, and find that nonparametric approaches offer competitive accuracy at longer horizons.

A separate strand of the literature focuses specifically on Türkiye's export dynamics. Koççat (2008) investigates the linkages between exports, exchange rates, and economic growth using Johansen cointegration. Vergil (2010) tests the home market effect in Turkish exports using ARDL-based gravity equations across 42 partner countries. Altintaş et al. (2011) examine the long- and short-run relationships between Turkish exports, foreign income, exchange rates, and relative prices over 1993–2009 using multivariate cointegration and ECM. Alakbarov et al. (2017) estimate Türkiye's export demand function for 2001–2013.

Taken together, this literature establishes three observations that motivate the present study. First, classical time-series and econometric methods remain the dominant approach in export forecasting but are limited in their ability to capture nonlinear dynamics and structural breaks. Second, ML and hybrid methods have shown promise but have not been systematically benchmarked against one another on Turkish aggregate export data under a leakage-

free validation protocol. Third, no existing study simultaneously evaluates statistical, ML, DL, and hybrid architectures on a single Turkish export series, leaving open the question of which modeling paradigm performs best in this structurally complex environment.

METHODOLOGY

A comprehensive flowchart of the full methodology pipeline is provided in Figure 1.

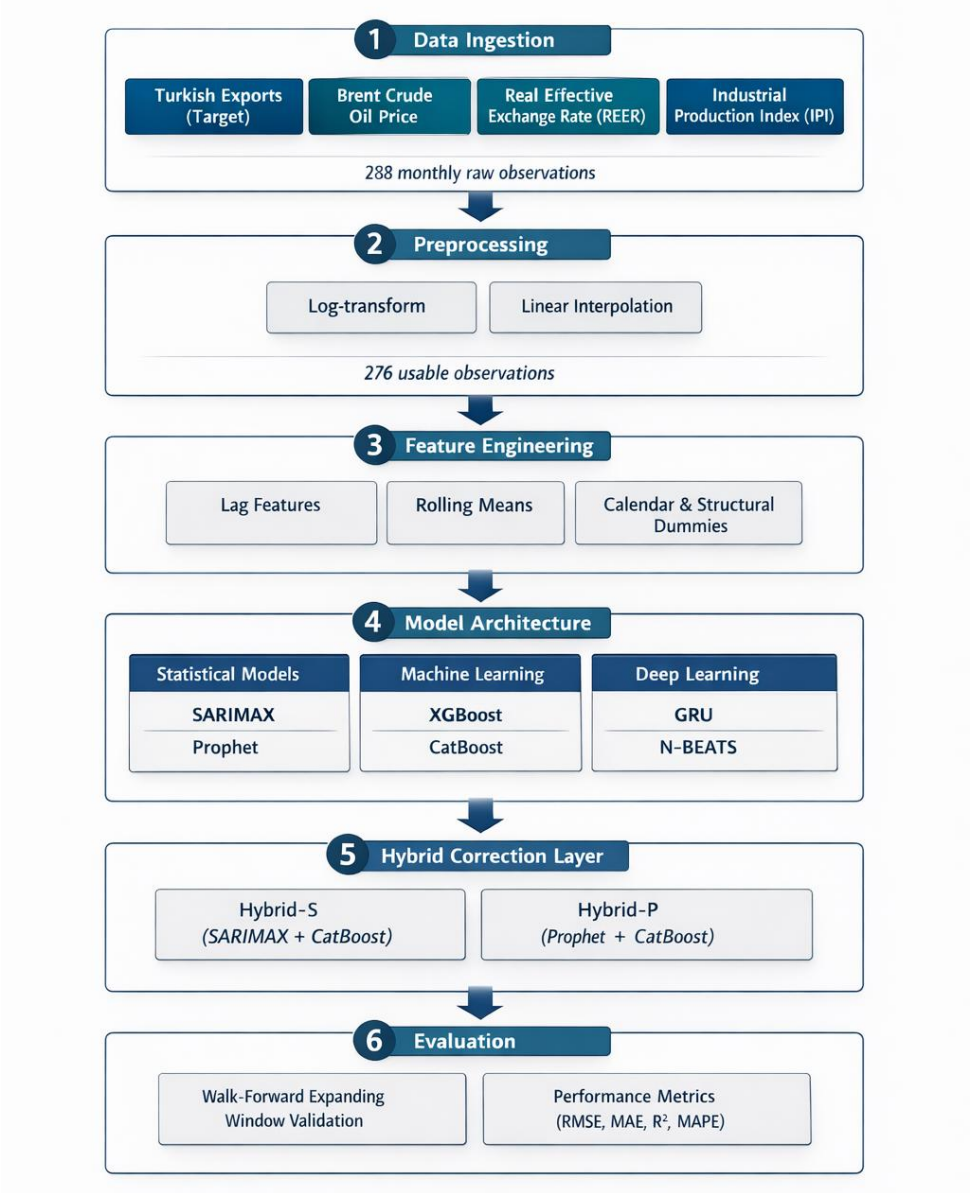


Figure 1: Complete methodology flowchart

Source: Created by the author.

Dataset and Preprocessing

The primary dataset consists of 288 monthly observations on Turkish merchandise exports (in thousands of USD) spanning January 2002 to December 2025, sourced from the Turkish Statistical Institute (TÜİK) and the Turkish Exporters Assembly (TİM). Four macroeconomic variables serve as exogenous regressors:

- Exports (TİM, 2026).
- Brent Crude Oil Price (USD/barrel): serves as a cost-push factor and a proxy for global demand conditions (FRED, 2026).
- Real Effective Exchange Rate (REER): captures price competitiveness; an appreciation implies a deterioration in Türkiye's export competitiveness (TCMB, 2026).
- Industrial Production Index (IPI): captures domestic supply capacity and serves as a leading indicator of exportable goods volume (TÜİK, 2026).

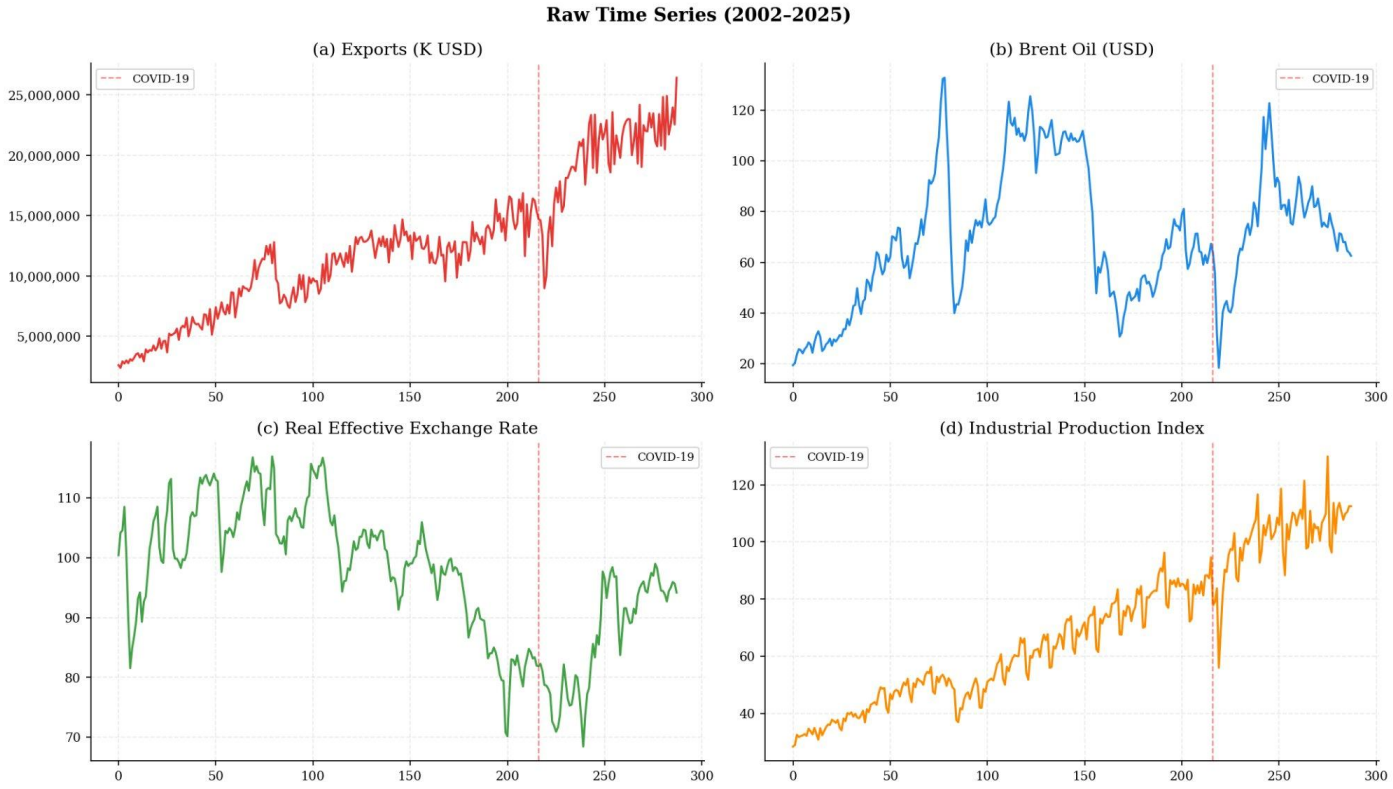


Figure 2: Raw time series of Turkish exports, Brent oil price, real effective exchange rate, and industrial production index (2002–2025).

Source: Created by the author.

Figure 2 presents the raw time series of all four variables over the full sample period, with the COVID-19 onset (March 2020) highlighted by a vertical reference line. Missing values are imputed via linear interpolation. All four series are log-transformed (log1p) prior to modeling to stabilize variance and approximate stationarity in growth rates. For ML and DL models, engineered features include: cyclical month encoding (sine/cosine), a normalised year trend signal, lag features at 1, 2, 3, 6, and 12 months, 3- and 12-month rolling averages of the lagged series, a COVID-19 structural break dummy (March–December 2020), and a post-COVID recovery indicator (from January 2021). All features are constructed in a leakage-free manner, ensuring that only

information available at forecast time is used.

After applying lag features (maximum lag: 12 months), 276 observations are usable for modeling; the December 2025 IPI value, unavailable at the time of writing, is imputed via linear interpolation. The sample is divided into an initial training window of 70% (193 months, Jan 2002–Jan 2019) and a test period of 30% (83 months, Feb 2019–Dec 2025), ensuring the test period spans both the COVID-19 shock and the post-pandemic recovery.

Methods

Table 1 provides a consolidated overview of the input features used by each model. A key distinction exists between statistical and non-statistical approaches: SARIMAX and Prophet encode temporal autocorrelation through their internal model structures and therefore require only the five exogenous regressors as supplementary inputs. By contrast, XGBoost, CatBoost, GRU, and N-BEATS lack built-in memory and rely on engineered lag features, rolling means, and calendar encodings, yielding a 15-dimensional feature vector. The hybrid correctors (Hybrid-S and Hybrid-P) operate on a distinct input domain, receiving only lagged residuals from their respective base models.

Table 1: Model Input Feature Summary

Model	Category	Input Features	# Feat.
SARIMAX	Statistical	log_exports + 5 exogenous: log_oil, log_REER, log_IPI, covid_dummy, post_covid_dummy	5 exog
Prophet	Statistical	log_exports as y + same 5 regressors: log_oil, log_REER, log_IPI, covid_dummy, post_covid_dummy	5 exog
XGBoost	ML	15 features: log_oil, log_REER, log_IPI, month_sin, month_cos, year_norm, lag_1/2/3/6/12, MA-3, MA-12, covid_dummy, post_covid_dummy	15
CatBoost	ML	Identical 15-feature vector as XGBoost	15
GRU	DL	Sliding window (w=12–24) of the same 15-feature vector as XGBoost/CatBoost	15 × w
N-BEATS	DL	Lookback window of log_exports (w=12–24) + 15-feature exogenous vector via projection layer	15 + w
Hybrid-S/P	Hybrid	6 residual-lag features from base model: $r_{t-1}, r_{t-2}, r_{t-3}, r_{t-6}, r_{t-12}, MA3_{t-1}$	6

Source: Created by the author.

SARIMAX

The Seasonal Autoregressive Integrated Moving Average with eXogenous variables (SARIMAX) method is used in time series analysis. The model is an advanced econometric method capable of analyzing trends, external shocks, and seasonal fluctuations. Moreover, this method is widely used in forecasting macroeconomic variables such as energy demand, inflation, and exports (Box et al., 2016).

The SARIMAX model is specified as SARIMAX(p, d, q)(P, D, Q)$_{12}$, as given in Equation 1.

$$\Phi_P(B^{12})\phi_p(B)(1-B)^d(1-B^{12})^D y_t = \Theta_Q(B^{12})\theta_q(B)\varepsilon_t + \beta' x_t \quad (1)$$

where B is the backshift operator; y_t is the natural logarithm of Turkish merchandise exports at month t, log-transformed to stabilise variance and render multiplicative seasonality additive; $x_t =$

$[log\_oil_t, \log\_REER_t, \log\_IPI_t, covid_t, post\_covid_t]'$ is the vector of five exogenous regressors at time t; β is the corresponding coefficient vector capturing the partial effects of each regressor on log-exports, holding the autoregressive dynamics constant; and $\varepsilon_t \sim N(0, \sigma^2)$ is a white noise disturbance.

The non-seasonal operators $\phi_p(B)$ and $\theta_q(B)$ govern short-run autocorrelation and moving-average dynamics, respectively. Their seasonal counterparts, $\Phi_P(B^{12})$ and $\Theta_Q(B^{12})$, operate at the 12-month lag, capturing the strong intra-year periodicity evident in Turkish export data, which is driven by agricultural cycles, tourism-linked manufacturing demand, and automotive sector production schedules. The differencing operators $(1-B)^d$ and $(1-B^{12})^D$ render the series stationary in the non-seasonal and seasonal dimensions, respectively; for the present series, d = 1 (first difference to remove the stochastic trend) and D = 1 (seasonal difference to eliminate the seasonal unit root) are selected by the Augmented Dickey-Fuller (ADF) unit root test.

Model orders $(p,d,q)(P,D,Q)_{12}$ are selected by minimizing the Akaike Information Criterion (AIC) using the pmdarima auto_arima procedure with stepwise search over $p,q \in \{0,1,2,3\}$ and $P,Q \in \{0,1,2\}$. AIC is preferred over BIC in this context because it penalizes model complexity less severely, reducing the risk of underfitting in a series with rich seasonal and structural dynamics. The stepwise search evaluates candidate models in decreasing order of complexity, halting when no further reduction in AIC is achievable, thereby substantially reducing the computational cost relative to exhaustive grid search.

SARIMAX is well-suited to the present application for three reasons. First, its explicit seasonal operators directly capture the 12-month periodicity of Turkish exports, eliminating the need for manual seasonal dummy variables. Second, the exogenous regressor vector x_t allows the structural break dummies ($covid_t$, $post\_covid_t$) to enter the model as level-shift interventions with estimated coefficients, providing an interpretable quantification of the COVID-19 shock and recovery magnitude. Third, the parsimonious parametric structure, typically requiring fewer than ten free parameters, is well-identified given the 193-observation training window, a condition under which data-hungry alternatives such as deep learning architectures are known to underfit.

Prophet

The Prophet method is an additive modeling approach that decomposes structural components such as seasonality, exogenous effects, and trends. The method is widely used in financial and econometric series because it provides flexible and robust forecasts even on datasets containing outliers, missing observations, and seasonal fluctuations (Taylor & Letham, 2018).

Prophet is an additive decomposition model, as defined in Equation 2 (Taylor & Letham, 2018):

$$y(t) = g(t) + s(t) + h(t) + \epsilon_t \quad (2)$$

where $g(t)$ is a piecewise-linear trend with automatic changepoint detection, $s(t)$ captures Fourier-series seasonality, and $h(t)$ accommodates user-specified events. Exogenous regressors are included as linear additive terms. Yearly seasonality is enabled, and all five regressors are added as additional regressors. The changepoint prior scale is set to 0.05.

XGBoost

eXtreme Gradient Boosting (XGBoost) is an advanced ML-based prediction algorithm that achieves accurate predictions by optimizing a gradient boosting ensemble of decision trees. The model is used in areas such as financial risk analysis, time series prediction, and economic forecasting. The method has gained prominence in modern data science and econometrics literature owing to its combination of predictive accuracy and computational efficiency (Chen & Guestrin, 2016).

XGBoost minimizes a regularized objective over an ensemble of decision trees, as given in Equations 3 and 4 (Shangguan, 2025):

$$L(\varphi) = \sum_{i=1}^{n} l(y_i, \hat{y}_i) + \sum_{k=1}^{K} \Omega(f_k) \tag{3}$$

$$\Omega(f_k) = \gamma T + 0.5\lambda \|w\|^2 \tag{4}$$

where $l(y_i, \hat{y}_i)$ is a differentiable convex loss function measuring the difference between the prediction $\hat{y}_i$ and the true value y_i, and $\Omega(f_k)$ is the regularization term defined in Equation 4, where γ is the minimum loss reduction required to make a leaf split, T is the number of leaves, λ is the L2 regularization coefficient, and w is the vector of leaf weights. Hyperparameters are optimized via the Tree-structured Parzen Estimator (TPE), a Bayesian optimization algorithm, using Optuna (Akiba et al., 2019), with 50 trials conducted on a held-out 20% validation slice of the initial training window.

CatBoost

CatBoost (**Cat**egorical **Boost**ing), is an ML method based on the gradient boosting algorithm, specifically designed for efficiently handling categorical variables. This method stands out for its ability to incorporate categorical data without additional preprocessing, its mitigation of the overfitting problem through its ordered boosting approach, and its capacity to deliver high predictive performance even on small datasets. It is widely used in fields such as economics and finance (Prokhorenkova et al., 2018).

CatBoost introduces ordered boosting and symmetric oblivious trees to reduce prediction shift—the bias arising when the same training examples are used to compute both the gradient and the model update (Prokhorenkova et al., 2018). This property is particularly beneficial for small-to-medium datasets, reducing overfitting.

Hyperparameters are optimized via Optuna TPE with 50 trials.

GRU

GRU is a DL method. Specifically developed for modeling datasets with time dependencies. The model learns long-term dependencies and produces more stable predictions by mitigating the vanishing gradient problem inherent in traditional Recurrent Neural Networks (RNN). The method used in areas such as demand forecasting, financial time series, and macroeconomic variable prediction (Cho et al., 2014).

The GRU controls information flow through reset and update gates, as defined in Equations 5 through 8 (Gu et al., 2026):

$$z_t = \sigma(W_z x_t + U_z h_{t-1} + b_z)\ (update\ gate) \tag{5}$$

$$r_t = \sigma(W_r x_t + U_r h_{t-1} + b_r)\ (reset\ gate) \tag{6}$$

$$\tilde{h}_t = \tan(W_h x_t + U_h(r_t \odot h_{t-1}) + b_h) \tag{7}$$

$$h_t = (1 - z_t) \odot h_{t-1} + z_t \odot \tilde{h}_t \tag{8}$$

where σ is the sigmoid activation function, $\tan h$ is the hyperbolic tangent, and $\odot$ denotes element-wise multiplication.

The GRU is implemented in PyTorch with AdamW optimizer, cosine annealing scheduling, Huber loss (δ=1.0), gradient clipping, and early stopping. Architecture hyperparameters are optimized via Optuna TPE with 50 trials.

N-BEATS

N-BEATS is a DL-based time series forecasting model. N-BEATS can decompose structural patterns within data using layered blocks without requiring any prior assumptions. It is widely used in forecasting financial variables, energy demand, and economic indicators. In modern time series analysis, N-BEATS is considered a significant DL approach (Oreshkin et al., 2019).

N-BEATS decomposes forecasts via a stack of trend, seasonality, and generic blocks, each producing a backcast and forecast, as given in Equations 9 and 10 (Oreshkin et al., 2019):

$$\mathbf{x}_\ell = \mathbf{x}_{\ell-1} - \hat{\mathbf{x}}_{\ell-1} \tag{9}$$

$$\hat{\boldsymbol{y}} = \sum_{\ell} \hat{\boldsymbol{y}}_\ell \tag{10}$$

Trend blocks project onto a polynomial basis; seasonality blocks project onto a Fourier basis. Exogenous

regressors are integrated via a dedicated projection layer. Hyperparameters are optimized via Optuna TPE with 50 trials.

Hybrid-S (SARIMAX + CatBoost)

Hybrid-S is a hybrid approach for modeling both linear and nonlinear relationships in time series. The method integrates the strengths of time series models and ML algorithms within a unified framework. The SARIMAX model captures the linear structure of the series as a function of seasonality, trend, and exogenous variables. In contrast, the residual components are remodeled with the CatBoost algorithm to capture nonlinear patterns. Through this approach, the ML component captures complex data relationships that classical econometric models cannot explain, thereby increasing prediction accuracy.

Hybrid-S combines the SARIMAX base model with a CatBoost residual corrector. In the first stage, SARIMAX is fitted on the full in-sample window and its in-sample residuals, defined in Equation 11, are computed:

$$r_t = y_t - \hat{y}_t^{SARIMAX} \tag{11}$$

In the second stage, a CatBoost model is trained to predict these residuals, defined in Equation 12:

$$\hat{y}_t^{Hybrid-S} = \hat{y}_t^{SARIMAX} + f_{cat}(r_{t-1}, r_{t-2}, r_{t-3}, r_{t-6}, r_{t-12}, MA3_{t-1}) \tag{12}$$

During walk-forward validation, the residual history is updated at each step with the true forecast error, ensuring the corrector always operates on genuinely out-of-sample residuals. CatBoost hyperparameters are optimized via Optuna TPE with 50 trials.

Hybrid-P (Prophet + CatBoost)

Hybrid-P combines Prophet with a CatBoost residual corrector to model both nonlinear data relationships and structural time series components. It combined statistical modeling with ML techniques. Hybrid models have consistently demonstrated superior performance in financial and economic time series, making such approaches increasingly prevalent in the modern forecasting literature.

Hybrid-P is architecturally identical to Hybrid-S but substitutes Prophet as the base model, as given in Equation 13:

$$\hat{y}_t^{Hybrid-P} = \hat{y}_t^{Prophet} + f_{cat}(r_{t-1}, r_{t-2}, r_{t-3}, r_{t-6}, r_{t-12}, MA3_{t-1}) \tag{13}$$

Comparing Hybrid-P with Hybrid-S allows us to isolate the base model's contribution to overall hybrid performance while holding the correction mechanism constant.

Model Training Procedure

All models are evaluated under walk-forward expanding-window validation. Beginning with an initial 70% training window, each model produces a one-step-ahead forecast; the training window expands by one observation, and the model is retrained before the next forecast. This procedure produces 83 genuine out-of-sample predictions. Hyperparameter optimization for ML and DL models is performed once on the initial training window, using a held-out 20% validation slice with time-ordered splitting to prevent data leakage.

Evaluation Metrics

Four metrics are used to evaluate point forecast accuracy.

Root Mean Squared Error (RMSE) (Equation 14) penalizes large errors quadratically and is expressed in USD to preserve interpretability in the original scale:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \tag{14}$$

Mean Absolute Error (MAE) (Equation 15) applies a linear penalty and is less sensitive to outliers than RMSE:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i| \tag{15}$$

Coefficient of Determination (R^2) (Equation 16) measures the proportion of variance explained; a value of zero indicates performance equivalent to a naïve mean forecast:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{16}$$

Mean Absolute Percentage Error (MAPE) (Equation 17) is scale-free and facilitates cross-period and cross-study comparison:

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\frac{|y_i - \hat{y}_i|}{|y_i|} \tag{17}$$

Statistical significance of pairwise performance differences is assessed with the Diebold-Mariano test (Diebold & Mariano, 1995), using squared-error loss differentials with heteroscedasticity- and autocorrelation-consistent standard errors. Hybrid-S serves as the reference model for all pairwise comparisons.

RESULTS

Table 2 presents the walk-forward validation performance of all eight models over the 83-month test period from February 2019 to December 2025. Models are ranked in descending order of R^2. The evaluation window encompasses multiple structural regimes: the pre-COVID expansion (February 2019–February 2020), the acute COVID-19 contraction (March–December 2020), the sharp V-shaped recovery (2021), and the elevated but volatile export plateau driven by global inflationary pressures and Türkiye's exchange rate depreciation (2022–2025).

Table 2: Walk-Forward Validation Results — Test Period (2019–2025)

Model	Category	RMSE (USD)	MAE (USD)	R^2	MAPE (%)
Hybrid-S	Hybrid	1,387,621	1,045,676	0.8566	5.67%
SARIMAX	Statistical	1,403,969	1,061,353	0.8532	5.72%
Hybrid-P	Hybrid	1,499,204	1,176,326	0.8326	6.25%
Prophet	Statistical	1,527,050	1,201,225	0.8263	6.35%
CatBoost	ML	1,541,215	1,203,852	0.8230	6.59%
XGBoost	ML	1,568,495	1,235,916	0.8167	6.69%
GRU	DL	2,743,094	2,289,865	0.4394	11.95%
N-BEATS	DL	2,861,628	2,285,606	0.3899	12.22%

Source: Created by the author.

The results reveal a clear and statistically grounded performance hierarchy across all four evaluation metrics. Statistical and hybrid models uniformly outperform both pure ML and DL approaches, with the performance gap between the top tier (Hybrid-S, SARIMAX, Hybrid-P) and the DL tier (GRU, N-BEATS) being both large in magnitude and consistent across all metrics. RMSE for Hybrid-S is 1,387,621 USD, while GRU and N-BEATS produce RMSE values of 2,743,094 and 2,861,628 USD, respectively, a nearly two-fold difference that reflects a systematic inability of DL models to track the export series across the full test window.

Hybrid-S (SARIMAX + CatBoost) achieves the highest overall accuracy, with $R^2 = 0.857$ and MAPE = 5.67%. The companion hybrid, Hybrid-P (Prophet+CatBoost), ranks third overall with $R^2 = 0.833$ and MAPE = 6.25%. The consistent improvement of both hybrid models over their respective base models, SARIMAX improving from $R^2 = 0.853$ to 0.857, and Prophet from $R^2 = 0.826$ to 0.833, confirms that the CatBoost residual corrector captures systematic nonlinearity that the base statistical models leave unexplained, regardless of which base model is employed.

Among standalone models, SARIMAX ranks second overall with $R^2 = 0.853$, MAPE = 5.72%, RMSE = 1,403,969 USD, and MAE = 1,061,353 USD. The Diebold-Mariano test p-value of 0.089 for the SARIMAX–Hybrid-S comparison indicates the null hypothesis of equal predictive accuracy cannot be rejected at the 5% level, suggesting that the practical decision between SARIMAX and Hybrid-S may be governed by considerations of computational simplicity rather than statistical dominance alone. Prophet ranks fourth ($R^2 = 0.826$, MAPE = 6.35%).

The two pure ML models occupy the middle tier. CatBoost (R^2 = 0.823, MAPE = 6.59%) marginally but consistently outperforms XGBoost (R^2 = 0.817, MAPE = 6.69%) across all four metrics. Both ML models achieve R^2 above 0.81, validating the feature engineering pipeline.

GRU and N-BEATS exhibit substantially inferior performance across all metrics. GRU achieves R^2 = 0.439, MAPE = 11.95%, RMSE = 2,743,094 USD; N-BEATS achieves R^2 = 0.390, MAPE = 12.22%, RMSE = 2,861,628 USD. The practical magnitude of the shortfall is substantial: GRU's RMSE exceeds Hybrid-S's by approximately USD 1.36 billion per month. Diebold-Mariano tests confirm that Hybrid-S is statistically significantly more accurate than GRU ($p < 0.001$) and N-BEATS ($p < 0.001$) at the 1% level, and also superior to Prophet ($p = 0.031$) at the 5% level.

Visual inspection of Figure 3 corroborates the quantitative metrics. Hybrid-S and SARIMAX closely track the actual export trajectory across all sub-periods, correctly capturing the sharp COVID-19 contraction and the steep V-shaped recovery. Hybrid-P and Prophet reproduce the broad trend but show greater local deviation around the 2022–2023 exchange-rate-driven export spike. GRU and N-BEATS exhibit qualitatively different failure modes: both models systematically underpredict the post-2021 export expansion, producing forecasts anchored at the pre-pandemic level.

Figure 4 makes the bimodal ranking structure immediately apparent: the top six models cluster tightly in R^2 space between 0.817 and 0.857, while GRU and N-BEATS fall below by approximately 0.38 R^2 units. Figure 5 reveals that Hybrid-S and SARIMAX exhibit the narrowest interquartile ranges and median errors close to zero, confirming the absence of systematic bias. The DL models exhibit pronounced left skew in the error distribution, with long negative tails reflecting systematic underprediction concentrated during the 2021–2023 recovery phase.

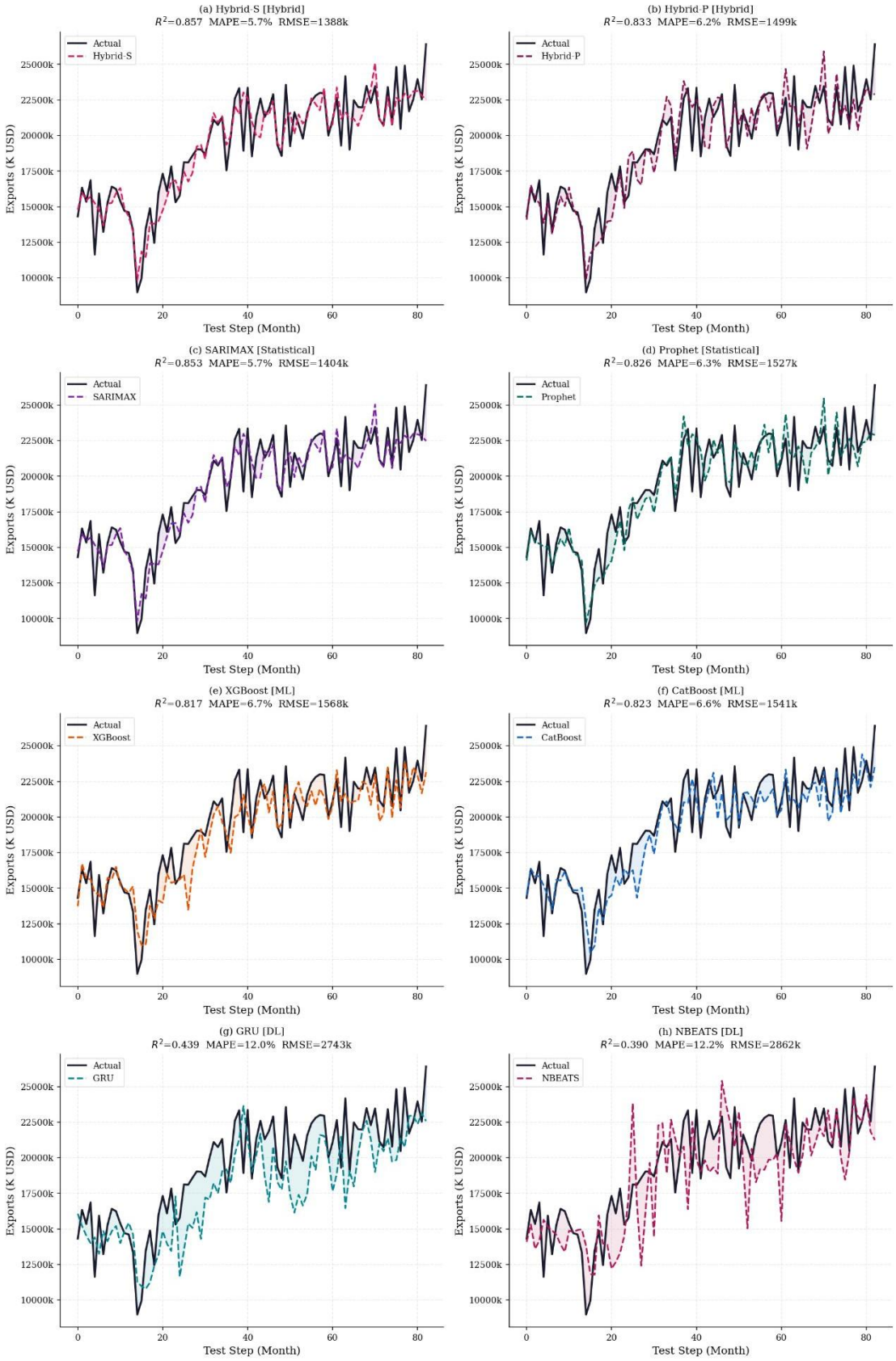


Figure 3: Walk-forward forecast trajectories for all eight models over the 83-month test period (2019–2025).

Source: Created by the author.

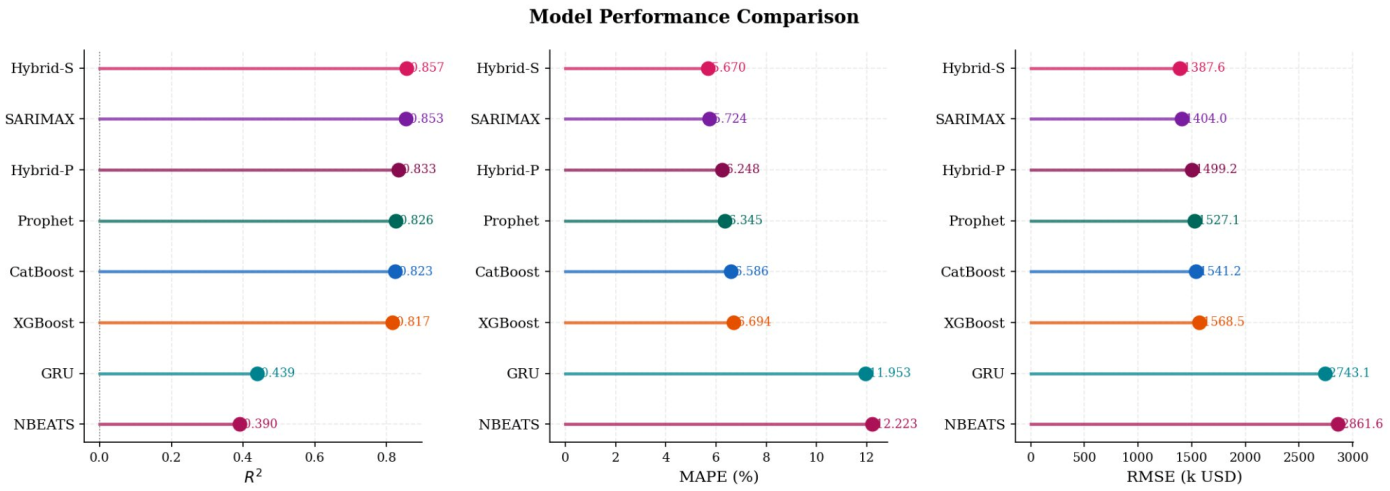


Figure 4: Lollipop charts comparing model performance across R^2 (left), MAPE (%) (center), and RMSE in thousands of USD (right).

Source: Created by the author.

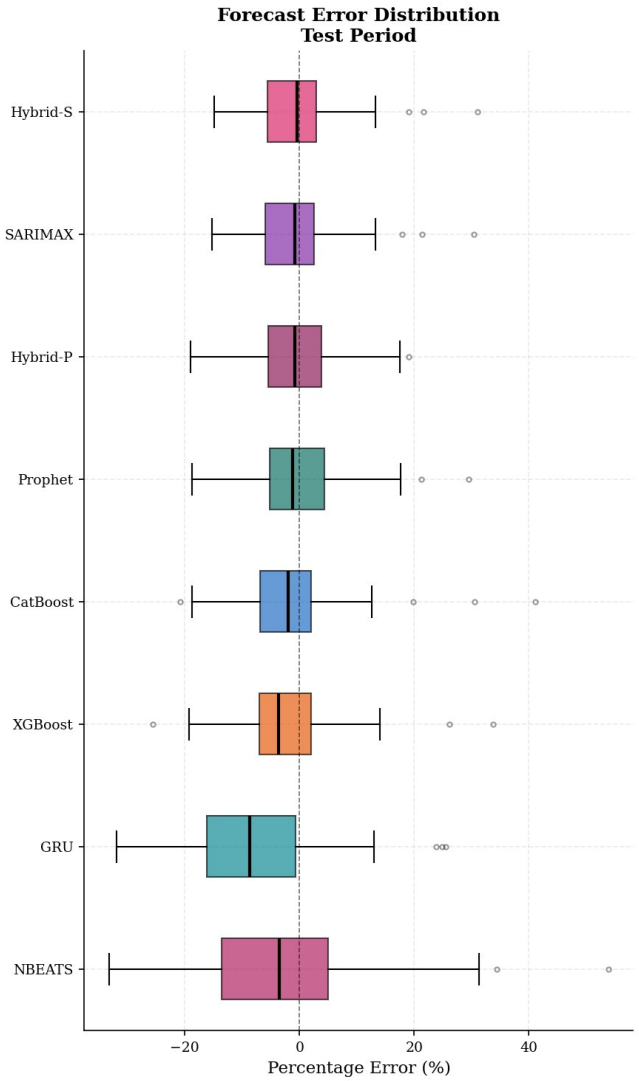


Figure 5: Horizontal box plots of the percentage forecast error distribution for each model over the test period.

Source: Created by the author.

DISCUSSION

The results of this study admit coherent and internally consistent interpretation. The consistent outperformance of Hybrid-S and Hybrid-P over their respective base models provides direct empirical support for the complementarity hypothesis advanced by Bates and Granger (1969). SARIMAX and Prophet each capture the dominant linear structures of the series, namely trend, seasonal periodicity, and the level shifts induced by the 2018 currency crisis and the COVID-19 pandemic, through their parametric equations and explicitly specified dummy variables. The CatBoost residual corrector then extracts the systematic nonlinear component that remains in the base-model errors. Crucially, this improvement is observed for both statistical base models and to comparable magnitudes (ΔMAPE of approximately 0.6 percentage points), confirming that the hybrid benefit is model-agnostic. The modest absolute magnitude of the improvement ($\Delta R^2 = 0.004$ for Hybrid-S over SARIMAX) further indicates that the dominant structural features of Turkish export dynamics are already well captured by the linear model.

The underperformance of GRU and N-BEATS reflects a well-documented empirical regularity: DL architectures require large datasets to realize their representational capacity advantage. With 276 usable observations, the present dataset falls substantially below the threshold at which gradient-based optimization of networks with tens of thousands of parameters converges reliably (Makridakis et al., 2020). The walk-forward protocol exacerbates this challenge: at each of the 83 test steps, the DL model is retrained from random initialization on a window of only 193 observations. The COVID-19 structural break compounds the difficulty: statistical models accommodate the March 2020 shock through an explicitly specified dummy variable; gradient-boosted tree models propagate the shock through the lag feature vector within one to twelve months; DL models must infer the regime shift entirely from gradient updates with only a handful of post-break observations, a task inherently ill-conditioned given the network architecture's degrees of freedom. The systematic underprediction of the post-2021 recovery phase is particularly illustrative in this regard. The V-shaped rebound in Turkish exports during 2021–2023 was driven by a confluence of factors: the global demand surge following pandemic-era supply chain normalization, the sharp depreciation of the Turkish lira which boosted export competitiveness, and elevated commodity prices. These were structurally novel conditions with no close historical analogue in the 2002–2019 training window. Statistical models handled this regime shift through their explicitly parameterized dummy variables and REER coefficient, while gradient-boosted models captured it through lag features within a short propagation window. DL models, however, lacked sufficient post-break observations to update their internal representations, resulting in forecasts anchored at pre-pandemic export levels throughout the recovery phase.

The performance hierarchy documented here is consistent with the M4 competition (Makridakis et al., 2020), where pure ML methods performed below expectations on monthly macroeconomic data and the winning statistical–ML hybrid (ES-RNN) achieved approximately 9.4% improvement over the combination benchmark,

a result strikingly analogous to the present finding. By contrast, the M5 competition (Makridakis et al., 2022), which focused on daily retail sales with over 42,000 series, showed gradient-boosted methods to be dominant. This reversal illustrates the data-regime hypothesis: statistical and hybrid methods dominate in the low-frequency, small-sample, structurally unstable regime; pure ML and DL methods gain advantage only when training data is abundant, high-frequency, and structurally stable.

CONCLUSION

This study presents a comprehensive benchmarking exercise comparing eight forecasting models trained on monthly Turkish export data spanning 2002–2025, evaluated over an 83-month walk-forward test period (February 2019–December 2025). The central finding is that the SARIMAX+CatBoost hybrid model achieves the highest predictive accuracy ($R^2 = 0.857$, MAPE = 5.67%), followed closely by standalone SARIMAX ($R^2 = 0.853$) and the Prophet+CatBoost hybrid ($R^2 = 0.833$). ML models deliver competitive performance ($R^2 \approx 0.82$) that substantially exceeds DL alternatives. GRU and N-BEATS achieve R^2 values of 0.44 and 0.39, respectively, confirming that DL is poorly suited to the low-frequency, small-sample, structurally unstable environment of macroeconomic export data.

For policy institutions and trade ministries requiring monthly export forecasts, Hybrid-S offers a practical operational solution: the SARIMAX base model provides interpretable coefficient estimates for policy communication. At the same time, the CatBoost correction layer captures residual nonlinearity without requiring GPU infrastructure or large training data. The model's robustness across the COVID-19 shock further supports its operational deployment.

Several limitations should be acknowledged. First, this study considers only one-step-ahead forecasting; performance across multi-step horizons may yield a different cross-model ranking. Second, the evaluation assumes that all exogenous regressors are available at forecast time, which may not be held in practice, given publication lags of 4 to 8 weeks for IPI and REER. Third, hyperparameter optimization for ML and DL models is conducted once on the initial in-sample window; adaptive re-optimization could improve DL performance, albeit at substantially higher computational cost. Fourth, this study considers a single aggregate merchandise export series; disaggregation to the sectoral level may reveal heterogeneous model performance.

Future research should extend this framework in four directions: evaluation across multi-step forecast horizons (h = 3, 6, 12 months); disaggregation to sectoral export series (automotive, textile, chemical, and agri-food); incorporation of additional high-frequency exogenous indicators such as shipping cost indices (Baltic Dry Index) and trading-partner industrial production; and assessment of pretrained foundation time-series models (TimeGPT, Moirai, Chronos) that leverage transfer learning from large heterogeneous series collections and may circumvent the small-sample constraint that limits DL performance in the present application.

REFERENCES

Akiba, T., Sano, S., Yanase, T., Ohta, T., & Koyama, M. (2019). *Optuna: A Next-generation Hyperparameter Optimization Framework* Proceedings of the 25th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining, Anchorage, AK, USA. https://doi.org/10.1145/3292500.3330701

Alakbarov, N., Gündüz, M., & Özkaya, M. H. (2017). Türkiye'nin İhracat Talebi Fonksiyonunun Farklı Ülke Gruplarına Göre Eşbütünleşme Analizi. *Dokuz Eylül Üniversitesi İktisadi İdari Bilimler Fakültesi Dergisi*, *32*(2), 369–395. https://doi.org/10.24988/deuiibf.2017322662

Altintaş, H., Cetin, R., & Öz, B. (2011). The Impact of Exchange Rate Volatility on Turkish Exports: 1993-2009. *South East European Journal of Economics and Business*, *6*(2), 71–81. https://doi.org/10.2478/v10033-011-0017-8

Avşar, İ. İ., & Ecemiş, O. (2023). Türkiye'nin İthalat ve İhracatının Veri Madenciliği Yöntemleriyle Tahmini. *Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, *6*(3), 1890–1907. https://doi.org/10.47495/okufbed.1220874

Bates, J. M., & Granger, C. W. J. (1969). The Combination of Forecasts. *OR*, *20*(4), 451–468. https://doi.org/10.2307/3008764

Box, G. E. P., Jenkins, G. M., Reinsel, G. C., & Ljung, G. M. (2016). *Time series analysis: Forecasting and control*. John Wiley & Sons. https://www.wiley.com/en-us/Time+Series+Analysis%3A+Forecasting+and+Control%2C+5th+Edition-p-9781118675021

Chen, T., & Guestrin, C. (2016). *XGBoost: A Scalable Tree Boosting System* Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, San Francisco, California, USA. https://doi.org/10.1145/2939672.2939785

Cho, K., van Merriënboer, B., Bahdanau, D., & Bengio, Y. (2014). *On the Properties of Neural Machine Translation: Encoder–Decoder Approaches* Proceedings of SSST-8, Eighth Workshop on Syntax, Semantics and Structure in Statistical Translation, Doha, Qatar. https://doi.org/10.3115/v1/W14-4012

Çakmaklı, B. M. (2025). Inflation, Exchange Rate and Foreign Trade: Long And Short Run Relationships In The Turkish Economy. *InTraders International Trade Academic Journal*, *8*(1), 1–19. https://doi.org/10.55065/intraders.1660803

Dave, E., Leonardo, A., Jeanice, M., & Hanafiah, N. (2021). Forecasting Indonesia Exports using a Hybrid Model ARIMA-LSTM. *Procedia Computer Science*, *179*, 480–487. https://doi.org/10.1016/j.procs.2021.01.031

Diebold, F. X., & Mariano, R. S. (1995). Comparing Predictive Accuracy. *Journal of Business & Economic Statistics*, *13*(3), 253–263. https://doi.org/10.2307/1392185

FRED. (2026). *Crude Oil Prices: Brent - Europe (DCOILBRENTEU)*. Federal Reserve Bank of St. Louis. Retrieved 27.01.2026 from https://fred.stlouisfed.org/series/DCOILBRENTEU

Ghauri, S. P., Ahmed, R. R., Streimikiene, D., & Streimikis, J. (2020). Forecasting exports and imports by using autoregressive (AR) with seasonal dummies and Box-Jenkins approaches: A case of Pakistan. *Engineering economics*, *31*(3), 291–301. https://doi.org/10.5755/j01.ee.31.3.25323

Goldstein, M., & Khan, M. (1985). Income and price effects in foreign trade. In R. W. Jones & P. B. Kenen (Eds.), *Handbook of International Economics* (Vol. 2, pp. 1041–1105). Elsevier. https://doi.org/10.1016/S1573-4404(85)02011-1

Göze Kaya, D., & Durgun Kaygısız, A. (2023). Türkiye'de Bütçe Dengesi ve Enflasyon İlişkisi: Son 20 Yılın Ampirik Analizi [The Relationship Between Budget Balance And Inflation in Turkey: An Empirical Analysis of The Last 20 Years]. *InTraders International Trade Academic Journal*, *6*(2), 201–222.

https://doi.org/10.55065/intraders.1395563

Gu, K., Cao, L., Cao, J., Li, M., Chen, H., Wang, Z., Liu, S., & Zhang, K. (2026). A hybrid SVMD-RIME-TCN-BiGRU model for wind power prediction. *Energy Informatics*, *9*(1), 8. https://doi.org/10.1186/s42162-026-00630-z

Gulzar, Y., Oral, C., Kayakus, M., Erdogan, D., Unal, Z., Eksili, N., & Caylak, P. C. (2024). Predicting High Technology Exports of Countries for Sustainable Economic Growth by Using Machine Learning Techniques: The Case of Turkey. *Sustainability*, *16*(13), 5601. https://doi.org/10.3390/su16135601

Harb, N. (2007). Trade between Euro zone and Arab countries: a panel study. *Applied Economics*, *39*(16), 2099–2107. https://doi.org/10.1080/00036840600722307

Hewamalage, H., Bergmeir, C., & Bandara, K. (2021). Recurrent Neural Networks for Time Series Forecasting: Current status and future directions. *International Journal of Forecasting*, *37*(1), 388–427. https://doi.org/10.1016/j.ijforecast.2020.06.008

Iossifov, P., & Fei, X. (2019). Real Effective Exchange Rate and Trade Balance Adjustment. *IMF Working Papers*, *19*(131), 1. https://doi.org/10.5089/9781498312738.001

Kavacık, M. (2023). What did Türkiye do in terms of export competitiveness after 2000? *InTraders International Trade Academic Journal*, *6*(2), 119–149. https://doi.org/10.55065/intraders.1390704

Koç Yurtkur, A., & Tay Bayramoğlu, A. (2012). Gelişmekte Olan Piyasa Ekonomilerinde İhracatın Dinamikleri. *Yönetim ve Ekonomi Dergisi*, *19*(1), 19–33. https://izlik.org/JA34PY52LN

Koççat, H. (2008). Exchange rates, exports and economic growth in Turkey: evidence from Johansen cointegration tests. *Journal of Economic & Management Perspectives*, *2*(1), 5. https://www.proquest.com/docview/228313408/fulltextPDF/DFAEEEDCF9BA4F82PQ/

Kumar, S. (2009). An empirical evaluation of export demand in China. *Journal of Chinese Economic and Foreign Trade Studies*, *2*(2), 100–109. https://doi.org/10.1108/17544400910966077

Lehmann, R. (2021). Forecasting exports across Europe: What are the superior survey indicators? *Empirical Economics*, *60*(5), 2429–2453. https://doi.org/10.1007/s00181-020-01838-y

Makridakis, S., Spiliotis, E., & Assimakopoulos, V. (2020). The M4 Competition: 100,000 time series and 61 forecasting methods. *International Journal of Forecasting*, *36*(1), 54–74. https://doi.org/10.1016/j.ijforecast.2019.04.014

Makridakis, S., Spiliotis, E., & Assimakopoulos, V. (2022). M5 accuracy competition: Results, findings, and conclusions. *International Journal of Forecasting*, *38*(4), 1346–1364. https://doi.org/10.1016/j.ijforecast.2021.11.013

Oreshkin, B. N., Carpov, D., Chapados, N., & Bengio, Y. (2019). N-BEATS: Neural basis expansion analysis for interpretable time series forecasting. *ArXiv*, *abs/1905.10437*. https://doi.org/10.48550/arXiv.1905.10437

Petropoulos, F., Apiletti, D., Assimakopoulos, V., Babai, M. Z., Barrow, D. K., Ben Taieb, S., Bergmeir, C., Bessa, R. J., Bijak, J., Boylan, J. E., Browell, J., Carnevale, C., Castle, J. L., Cirillo, P., Clements, M. P., Cordeiro, C., Cyrino Oliveira, F. L., De Baets, S., Dokumentov, A.,…Ziel, F. (2022). Forecasting: theory and practice. *International Journal of Forecasting*, *38*(3), 705–871. https://doi.org/10.1016/j.ijforecast.2021.11.001

Piñeres, S. A. G. d., & Cantavella-Jordá, M. (2010). Short-run effects of devaluation: a disaggregated analysis of Latin American exports. *Applied Economics*, *42*(2), 133–142. https://doi.org/10.1080/00036840701579259

Prokhorenkova, L., Gusev, G., Vorobev, A., Dorogush, A. V., & Gulin, A. (2018). *CatBoost: unbiased boosting*

with categorical features 32nd Conference on Neural Information Processing Systems (NeurIPS 2018), Montréal, Canada. https://papers.nips.cc/paper_files/paper/2018/file/14491b756b3a51daac41c24863285549-Paper.pdf

Rahmaddi, R., & Ichihashi, M. (2012). How Do Foreign and Domestic Demand Affect Exports Performance? An Econometric Investigation of Indonesia's Exports. *Modern Economy*, *3*(1), 32–42. https://doi.org/10.4236/me.2012.31005

Senhadji, A. S., & Montenegro, C. E. (1999). Time Series Analysis of Export Demand Equations: A Cross-Country Analysis. *IMF staff papers*, *46*(3), 259–273. https://doi.org/10.2307/3867643

Shangguan, Z. (2025). An Explainable Machine-Learning Framework Based on XGBoost–SHAP and Big Data for Revealing the Socioeconomic Drivers of Population Urbanization in China. *Systems*, *13*(8), 679. https://doi.org/10.3390/systems13080679

Taylor, S. J., & Letham, B. (2018). Forecasting at Scale. *The American Statistician*, *72*(1), 37–45. https://doi.org/10.1080/00031305.2017.1380080

TCMB. (2026, 2026/01/27). *Reel Kesim Güven Endeksi (RKGE) – BIE_RKUFEY Serisi*. Türkiye Cumhuriyet Merkez Bankası (TCMB). Retrieved 27.01.2026 from https://evds3.tcmb.gov.tr/tumSeriler/2504/bie_rkufey

TİM. (2026). *İhracat Rakamları*. Türkiye İhracatçılar Meclisi (TİM). Retrieved 27.01.2026 from https://tim.org.tr/tr/ihracat-rakamlari

TÜİK. (2026, 2026/01/27). *Basın Bülteni No: 58192*. Türkiye İstatistik Kurumu (TÜİK). https://veriportali.tuik.gov.tr/tr/press/58192

Unal, Seyma N., & Karamelikli, H. (2026). A Comparative Forecasting Framework for Turkey–Germany Trade: Evidence From Time Series and Artificial Neural Networks Models. *Journal of Forecasting*, *45*(3), 1177–1187. https://doi.org/10.1002/for.70084

Vergil, H. (2010). Türkiye ticaretinde ulusal pazar etkisi. *İktisat İşletme ve Finans 25*(286), 35–59. https://doi.org/10.3848/iif.2010.286.2416

Wong, H.-L., Tu, Y.-H., & Wang, C.-C. (2010). Application of fuzzy time series models for forecasting the amount of Taiwan export. *Expert Systems with Applications*, *37*(2), 1465–1470. https://doi.org/10.1016/j.eswa.2009.06.106

Yuan, Y. (2017). Forecasting method for import and export trade on the basis of GMDH network model. *Journal of Discrete Mathematical Sciences and Cryptography*, *20*(4), 755–766. https://doi.org/10.1080/09720529.2017.1358859

InTraders Academic Platform

https://www.intraders.org

Autumn Conferences

https://www.intraders.org/october/

Spring Conferences

https://www.intraders.org/may/

Academic Journal

https://dergipark.org.tr/en/pub/intraders

Conference Alerts

https://www.conferencealertsintraders.com

InTraders International Trade Academic Journal

Volume 9, Issue 1, July 2026

e-ISSN-2667-4408

www.intraders.org