Araştırma Makalesi

An Integrated Analysis of Labor-Environment Interactions Using Econometric Inference and Multi Criteria Decision Making Frameworks

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Abstract: Global climate commitments have direct implications for labour markets. This makes it necessary to consider the link between labour and the environment within a broader systemic setting. Labour indicators and carbon emissions reflect different aspects of the same processes. For this reason, environmental variables can no longer be set aside in labour market analysis. The study focuses on Turkey and groups labour market indicators into two categories: Production-side and socioeconomic conditions. It then examines how these indicators relate to per capita carbon emissions. The analysis draws on cointegration, causality and multi-criteria-decision-making approaches. The empirical work covers the period from 1990 to 2023. Several econometric tests are applied, including the ADF unit root test, the KPSS stationarity test, the Zivot-Andrews unit root test with structural breaks, the Gregory-Hansen cointegration test with structural breaks and the Toda-Yamamoto

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causality test. In addition, MEREC and ARIE are used within the multi-criteria-decision-making framework. The results are checked through the LOO procedure and sensitivity analyses. The findings show a stronger link between carbon emissions and indicators classified under the production side than those grouped under socioeconomic conditions. In the case of Turkey, carbon emissions per capita, gross domestic product per capita and labour productivity stand out as the most influential criteria. These results indicate that employment policies in Turkey cannot be designed separately from environmental sustainability goals.

Keywords: Labour, environment, carbon emissions, econometric analysis, decision analysis.

Emek-Çevre Etkileşimlerinin Ekonometrik İnferans ve Çok Boyutlu Sayısal Karar Çerçeveleriyle Bütüncül İncelenmesi

Öz: Küresel iklim taahhütlerinin işgücü piyasaları üzerindeki etkileri emek ve çevre ilişkisinin sistemik bir çerçevede ele alınmasını gerektirmektedir. Bu bağlamda, emek göstergeleri ve karbon emisyonlarının aynı süreçlerin farklı yansımaları olduğunun anlaşılması emek piyasası analizlerinde çevresel göstergelerin artık göz ardı edilemez hale geldiğini ortaya koymaktadır. Bu çalışma Türkiye'de işgücü piyasası göstergelerini emek-üretim ve emek-sosyal olarak sınıflandırarak bu göstergeler ile kişi başı karbon emisyonları arasındaki ilişkiyi eşbütünleşme, nedensellik ve çok kriterli karar verme çerçeveleriyle incelemektedir. Çalışmada uygulamaya alınan analizler 1990-2023 dönemini kapsamaktadır. Bu dönem özelinde sırasıyla ADF birim kök testi, KPSS durağanlık sınaması, Zivot Andrews yapısal kırılmalı birim kök testi, Gregory Hansen yapısal kırılmalı eşbütünleşme testi, Toda Yamamoto nedensellik testi ekonometrik çerçevede uygulanmıştır. Çok Kriterli Karar Verme modelleri olarak ise MEREC ve ARIE kullanılmıştır. Elde edilen sonuçlar LOO prosedürü ve duyarlılık analizleriyle sınanmıştır. Çalışmada emek-üretim olarak sınıflandırılan göstergelerin emek-sosyal olarak sınıflandırılan göstergelere kıyasla karbon emisyonları ile daha etkin bir ilişki içerisinde olduğu ve Türkiye özelinde bu konuda kişi başına karbon emisyonlarının, kişi başına gelirin ve emek verimliliğinin baskın kriterler olduğu bulguları elde edilmiştir. Sonuçlar, Türkiye'de istihdam politikalarının çevresel sürdürülebilirlik hedeflerinden bağımsız tasarlanamayacağını göstermektedir.

Anahtar Kelimeler: Emek, çevre, karbon emisyonları, ekonometrik analiz, karar analizi.

Introduction

The relationship between economic activity, labour indicators and environmental conditions has drawn growing attention in recent years. Changes in labour demand during periods of economic growth often move alongside shifts in environmental indicators. This pattern suggests that the two do not evolve in isolation and are better considered together. Transformations in production structures, patterns of energy use and technological change shape this interaction. Sectors also differ in their sensitivity to environmental issues. These factors point to multiple channels through which labour markets connect with environmental conditions, sometimes directly, sometimes through indirect links. In the case of Turkey, structural features of the economy add further complexity. Labour market indicators and environmental variables do not follow a single pattern. Growth targets, the sectoral composition of employment and the weight of carbon intensive industries all play a role. Taken together, these elements make it difficult to rely on simple or single channel explanations. A broader analytical frame is therefore needed. Such an approach should account for changes over time and consider the relative importance of different indicators within the system.

Unemployment has long remained a central socioeconomic issue within the history of capitalism. It has been addressed from different angles and at varying depths, yet it continues to shape economic debates today (Gün, 2016: 1286). In the context of the green transition, it takes on a new and more pressing dimension. Discussions on limiting greenhouse gas emissions often rely on short term evaluations. Under such conditions, existing economic models tend to leave out sensitive issues such as unemployment, especially in the short run (Babiker & Eckaus, 2007: 600-601). Wang and Li (2021: 760) draw attention to the complex and uneven nature of human factors in shaping carbon emissions. Ignoring labour markets in the design of climate policies creates more than a technical gap. It also carries social and political implications. This gap becomes particularly visible along the labour-environment nexus.

The neoliberal view of social policy treats unemployment as a personal issue. It links the problem to a lack of market relevant skills. In this line of thought, the remedy lies in education and investment in human capital, with the expectation that individuals adjust themselves to market conditions. This approach rests on three core assumptions. It reduces unemployment to individual shortcomings. It treats the social structure as given. It also frames education as a tool that secures outcomes (Akpınar, 2018: 788, 795-796). A different picture emerges once environmental indicators such as carbon emissions and ecological footprint are taken into account. Labour markets are shaped not only by individual skills but also by the environmental costs of economic activity. This broadens the way unemployment is understood. It points to a structural issue tied to production patterns, energy use and environmental pressures. Under these conditions, policy cannot remain limited to individual level solutions. A wider approach is needed, one that also considers environmental sustainability. These considerations form the background that led to this research.

The focus is on Turkey. Carbon emissions per capita are examined alongside key labour indicators such as unemployment, productivity, and employment. The analysis brings together econometric inference and multi-criteria decision frameworks to capture their joint performance. The first step looks at the link between carbon emissions and labour dynamics on the production side, as well as socioeconomic conditions. Augmented Dickey Fuller (ADF) (Dickey & Fuller, 1979) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) (Kwiatkowski et al., 1992) tests are used to check stationarity. Structural breaks are examined with the Zivot-Andrews (ZA) (Zivot & Andrews, 1992). Long-run relations are explored through the Gregory-Hansen cointegration test (Gregory & Hansen, 1996). Causality is assessed with the Toda-Yamamoto (Toda & Yamamoto, 1995) approach. Series that display at least one causal link are then carried into the multi-criteria stage. These series are treated as criteria. Weights are obtained through MEthod based on the Removal Effects of Criteria (MEREC) (Keshavarz-Ghorabaee et al., 2021). Ranking is carried out with Adaptive Ranking with Ideal Evaluation (ARIE) (Fauzi et al., 2025). The results are checked with the Leave-One-Out (LOO) procedure and scenario analyses. The analysis is guided by three main research questions:

1. Is there a long-run relationship between carbon emissions and labour indicators in Turkey, covering both production side dynamics and socioeconomic conditions? Does this relationship carry statistical significance and a causal direction?

2. How important are these indicators in relation to carbon emissions in the case of Turkey? Which of them take a leading role in the evaluation?

3. If these indicators are treated as criteria, which years stand out as the most efficient in balancing environmental outcomes and income over the period under study?

These questions aim to shed light on labour-environment interactions within the context of Turkey's labour dynamics. They draw on the view that economic growth, employment policies and environmental sustainability are closely linked. For this reason, policy analysis calls for a multidimensional approach.

Another point that shaped the research design emerged from a close reading of Liu and Feng (2022: 52029). The authors report that unemployment is associated with higher carbon emissions in the Middle East, while the pattern turns negative in regions such as Europe and the Asia-Pacific. In the social sciences, many theoretical frameworks are developed in core economies. This often leads to research agendas in semi peripheral countries like Turkey being framed through approaches that do not fully align with local conditions (Cam & Yıldırım, 2025: 32). It also suggests that the questions asked and the issues given priority can vary across countries. The analysis first tests whether a link exists between carbon emissions and labour indicators. It then examines the long run connection between carbon emissions and unemployment through empirical evidence. At the same time, it brings together econometric inference and multi-criteria decision-making (MCDM) techniques within a single framework. Focusing on Turkey, an economy that faces both climate commitments and structural unemployment, helps bring out country specific dynamics. The results also offer a reference point for comparisons with similar economies. In a country where unemployment has long been a persistent issue, policy responses require careful and timely revision (Şahin & Yıldırım, 2015: 136). The paper proceeds with a review of the relevant literature and a discussion of the analytical background. This is followed by a presentation of the data and methodology. The findings are then reported and discussed. The final section offers policy implications and directions for future research.

Literature

The literature review begins with studies that explore the link between labour and the environment. Wei et al. (2018) stress the importance of demographic trends, noting their close connection with pressures on natural resources and ecological systems. Luo et al. (2025) discuss labour as a key factor in shaping firm competitiveness and the allocation of macroeconomic resources. They also underline how rising carbon risk influences patterns of labour allocation within firms. Zhang et al. (2018) report a negative and non-linear relationship between environmental pollution and labour supply. They add that the strength of this relationship varies with the level of economic development. Wang and Jiang (2020) focus on developing countries. These economies contribute both to global carbon emissions and to economic growth. At the same time, tensions between growth and emissions create serious challenges for sustainable development and make global mitigation targets harder to achieve.

Feng et al. (2024) link cross country differences in unemployment to gaps in skill based productivity. These differences also shape how economies move away from carbon intensive sectors toward cleaner technologies. Such shifts are closely tied to changes in employment structures and environmental outcomes. Xin et al.

(2023) report a long-run increase in carbon emissions associated with unemployment. Olofsson and Lundmark (2025) take a structural view of labour supply in green industries shaped by contemporary globalization. They also note that policy responses differ across contexts and often depend on employers. The uneven effects of climate policies on labour point to the need for analyses that consider regional and sectoral dynamics. With this in mind, Turkey is selected as the empirical setting.

The selection and grouping of variables in the labour-environment nexus draws on existing studies. Wei et al. (2018) serve as a key reference point. They stress the importance of population characteristics in emission scenario analysis, especially in the context of climate change. Yaman (2026) links changes in environmental performance in Turkey to shifting global dynamics, policy developments, growth in renewable capacity and rising investment in technology. Demir (2025) describes Turkey as part of the Mediterranean basin, a region highly vulnerable to climate change and notes that the country is directly exposed to these transformations. Steps taken toward the 2053 net zero target reflect technical progress. At the same time, they bring attention to issues of social justice and the need for a fair transition. Atik et al. (2026) underline the importance of economic growth for welfare. They also note that growth driven by industrial production is associated with environmental degradation and climate change. Memiş and Aydın (2023) identify climate change as a major global challenge and report a positive link between carbon emissions and economic growth. Bucak (2021) highlights the role of renewable energy and points to a chain of relations connecting human development, economic complexity and carbon emissions. Studies focused on Turkey reach similar conclusions. Doksanyedi and Meçik (2024) find one way causality running from employment to carbon emissions, with stronger effects in energy intensive sectors. Murat and Şengül (2024) draw attention to the negative effects of climate change on growth and employment and suggest the expansion of green jobs as a response. Akyazı and Korkmaz (2024) link human development, carbon emissions and energy consumption to the emergence of a green economy. Kapçak (2023) reports that unemployment, inflation and perceived corruption increase the ecological footprint in Turkey. Sancar and Polat (2021) find bidirectional links between health expenditures, economic growth and carbon emissions and call for integrated policy approaches. Taken together, these studies point to a dynamic interaction between environmental quality, economic growth, employment, energy use and social indicators.

Existing work approaches the topic through different sets of variables and viewpoints. Yu et al. (2023) link population ageing to shifts in labour structure. These shifts affect industrial adjustment and leave a lasting imprint on carbon emissions. Drawing on this line of research, the analysis uses a set of core indicators. These include carbon emissions per capita, GDP per capita, total labour force, life expectancy, productivity measured as output per hour worked and unemployment. The variables are then grouped to reflect their underlying characteristics. GDP per capita, total labour force and productivity are treated under the production side. Life expectancy and unemployment are considered within socioeconomic conditions. Across the literature, the link between unemployment and carbon emissions varies by country and region. At the same time, studies that evaluate these indicators together through MCDM remain limited. This study brings time series analysis, causality testing and MCDM into a single framework. It offers a combined assessment of unemployment and carbon emissions and seeks to address this gap in the literature.

Data and Methodology

The analysis begins with the econometric link between carbon emissions and labour indicators. All variables are examined over a common period from 1990 to 2023. This span captures a wide range of developments in Türkiye at both macro and micro levels. Several key events mark this period. The 5 April Decisions stand as one of the early turning points (Gaytancıoğlu, 2010). They are followed by the Asian financial crisis of 1997 (Sungur, 1999) and the Russian crisis of 1998 (Saleem, 2009). The 1999 earthquake appears as an unexpected shock with distinct economic effects (Aktürk & Albeni, 2002). The domestic economic crisis also forms a major part of this timeline (Kazgan, 2021; Pamuk, 2021). The global financial crisis of 2008 had wide-reaching consequences (Drezner & McNamara, 2013). More recent developments include the financial contagion effects observed in 2018 (Ateş, 2026; Ergün, 2024a). A summary of the data used in the analysis is provided in the following table.

Table 1. Information on the Dataset (Time Series Analysis)

Series	Abbrev.	Source
Carbon emissions per capita	co	Global Carbon Budget (2025)
GDP per capita	gdp	World Bank (2025a)
Total labor force	lbr	World Bank (2025a)
Life expectancy	$life$	Human Mortality Database (2025)
Productivity: Output per hour worked	$prod$	Penn World Table (2025)
Unemployment	$uemp$	FRED (2025)

Source: Table by the author.

The variables listed in Table 1 include large-scale series. A logarithmic transformation is applied to stabilize variance. After this step, each series is marked with the prefix ln. Methodological constraints related to the number of variables lead to a two model setup. The series are divided into a production side model (Equation 1) and a socioeconomic conditions model (Equation 2). This grouping follows the structure suggested in earlier studies (see Azam & Adeleye, 2024; Cui et al., 2022; Fitzgerald et al., 2018; Liddle & Parker, 2024; Liu & Feng, 2022; Wang & Li, 2021; Wang et al., 2023; Wei et al., 2018). The hypotheses tested in the study are stated as follows:

H_{01} : There is no long-run cointegration relationship between carbon emissions and GDP, total labour force and labour productivity, taking structural breaks into account.

H_{11} : There is a long-run cointegration relationship carbon emissions and GDP, total labour force and labour productivity, taking structural breaks into account.

H_{02} : There is no long-run cointegration relationship between carbon emissions and life expectancy and unemployment, taking structural breaks into account.

H_{12} : There is a long-run cointegration relationship between carbon emissions and life expectancy and unemployment, taking structural breaks into account.

The models estimated in line with these hypotheses are given in Equation 1 and Equation 2.

$$lnco_t = \beta_0 + \beta_1 lngdp_t + \beta_2 lnlbr_t + \beta_3 lnprod_t + \varepsilon_t \quad 1)$$

$$lnco_t = \beta_0 + \beta_1 lnlife_t + \beta_2 lnuemp_t + \varepsilon_t \quad 2)$$

In Equation 1, $lnco$ is specified as the dependent variable and ε_t represents the error term. The relation between Y_t and Y_{t-1} helps capture the time path of the series. A series is treated as stationary when its mean and variance remain stable over time. If a unit root is present, standard regression results may become misleading and spurious relationships may appear (Aktaş, 2009: 37-38; Dikmen, 2018: 310). Stationarity is examined through unit root tests. A series without a unit root is considered stationary. If a unit root exists, the series is non-stationary (Ergün, 2024b: 326). The analysis employs the ADF, KPSS and ZA unit root tests. Among these, the ADF test is widely used in time series analysis (Nieh & Yau, 2004: 176). The notation for the model with a constant and a trend is given in Equation 3.

$$\Delta Y_t = \alpha + \gamma t + \beta y_{t-1} + \sum_{i=1}^{p} \delta \Delta y_{t-i} + u_t \qquad 3)$$

The hypotheses for the ADF unit root test are stated as $H_0 : \beta = 0$ and $H_1 : \beta < 0$. Kwiatkowski et al. (1992) develop the KPSS stationarity test using the Lagrange Multiplier (LM) statistic. In this framework, the null assumes stationarity, while the alternative points to non-stationarity. The KPSS approach is often used alongside unit root tests, as the two provide complementary evidence (Yavuz, 2004: 241).

$$LM = \sum_{i=1}^{T} S_t^2 / \sigma_\varepsilon^2 \qquad 4)$$

Equation 4 presents the LM statistic used in the KPSS test. The KPSS is a right-tailed test with the hypotheses stated as $H_0 : \sigma_\varepsilon^2 = 0$ and $H_1 : \sigma_\varepsilon^2 > 0$ (Bozkurt & Altıner, 2018: 172; Özdemir, 2022: 270). Ignoring structural breaks in econometric analysis can distort results and lead to systematic bias. For this reason, a range of unit root tests with structural breaks has been developed in the literature. Among these, the ZA unit root test is applied in this study. It builds on a critique of the exogenous break assumption introduced by Perron (1989). The ZA approach allows for an estimated break in the trend function under the alternative hypothesis (Tıraşoğlu-Yıldırım, 2014: 73). The specification that allows for breaks in both the intercept and the trend is given below.

$$y_t = \hat{\mu}^C + \hat{\alpha}^C y_{t-1} + \hat{\beta}^C t + \hat{\theta}^C DU_t(\hat{\lambda}) + \hat{\gamma}^C DT_t^*(\hat{\lambda}) + \sum_{j=1}^{k} \hat{c}_j^C \Delta y_{t-j} + \hat{e}_t \qquad 5)$$

In Equation 5 λ denotes the break point. DU_t captures a shift in the intercept, and DT_t^* reflects a change in the slope. Within the ZA framework, the presence of a unit root is assessed through the coefficient of y_{t-1}. Its statistical significance provides the basis for the test. If the absolute value of the t-statistic exceeds the ZA critical values, the null of a unit root with structural breaks is rejected (Yavuz, 2006: 166; Yılancı, 2009: 328). Given the use of a unit root test with structural breaks, the analysis of relationships between variables also relies on methods that allow for such breaks. In this context, the Gregory-Hansen cointegration test is employed. This test was introduced by Gregory and Hansen (1996), and its notation is provided below (Tıraşoğlu & Yıldırım, 2012: 114).

$$y_{1t} = \mu_1 + \mu_2\varphi_{t\tau} + \alpha_1^T y_{2t} + \alpha_2^T y_{2t}\varphi_{t\tau} + e_t \quad t = 1, \ldots, n \qquad 6)$$

Equation 6 specifies the model for a regime shift. In this setup, α_1 represents the slope before the break, while α_2 captures the change that occurs after the break (Gregory & Hansen, 1996: 103). The notation for the Phillips test statistics and the ADF test statistic is given in Equation 7.

$$Z_\alpha^* = \underset{\tau \in T}{inf} Z_a(\tau) \quad , \qquad Z_t^* = \underset{\tau \in T}{inf} Z_t(\tau) \quad , \qquad ADF^* \underset{\tau \in T}{inf} ADF(\tau) \qquad 7)$$

In the Gregory and Hansen (1996) cointegration test, the selected test statistics are compared with their critical values. This comparison allows an assessment of whether a cointegration relationship exists in the presence of a structural break. To examine causal links between the variables, the Toda-Yamamoto causality test is applied. Studies that combine the Gregory-Hansen cointegration test with the Toda-Yamamoto approach can also be found in the literature (see Aydınbaş & Ünlüoğlu, 2022; Beşel & Savaşan, 2014; Polat & Ergun, 2018; Şahin & Durmuş, 2019). The application of the Toda-Yamamoto test requires that the maximum order of integration, denoted as, d_{max} does not exceed the selected lag length k in the model. The test is carried out based on the augmented specification $k + d_{max}$ (Toda & Yamamoto, 1995: 230). An example of the test in a two variable system with lags is provided in Equations 8 and 9 (Alimi & Ofonyelu, 2013: 131).

$$X_t = \omega + \sum_{i=1}^{m} \theta_i X_{t-i} + \sum_{i=m+1}^{m+dmax} \theta_i X_{t-i} + \sum_{i=1}^{m} \theta_i Y_{t-i} + \sum_{i=m+1}^{m+dmax} \theta_i Y_{t-i} + v_1 \qquad 8)$$

$$Y_t = \psi + \sum_{i=1}^{m} \varnothing_i Y_{t-i} + \sum_{i=m+1}^{m+dmax} \varnothing_i Y_{t-i} + \sum_{i=1}^{m} \beta_i X_{t-i} + \sum_{i=m+1}^{m+dmax} \beta_i X_{t-i} + v_2 \qquad 9)$$

Equations 8 and 9 define m as the optimal lag length, while d_{max} denotes the maximum order of integration in the system. The error terms in the models are represented by v_1 and v_2. The null states that X does not cause Y whereas the alternative allows for a causal link (Koca & Yıldırım, 2021: 455). Based on this framework, Toda and Yamamoto (1995: 233) show that the Wald test in a VAR model of order $k + (d_{max})$ follows a chi-square distribution. The analysis then proceeds with MCDM methods.

Table 2. Information on the Dataset (MCDM)

Criteria	Opt. - MEREC	Opt. - ARIE	Literature
co	C	T	Kekül (2025), Senir and Atlı (2025), Republic of Türkiye Updated First Nationally Determined Contribution (2023)
gdp	B	T	Örtlek (2026), Demir (2026), Presidency of Strategy and Budget Presidency of The Republic of Türkiye (2025)
lbr	B	B	Ordu and Tekman (2025), Eker et al. (2013)
$life$	B	B	Ritmak et al. (2023), Arıkan-Kargı (2025)
$prod$	B	B	Fernald et al (2021), Asher et al. (2021)
$uemp$	C	C	Birol (2024), Arslan (2023)

The table includes all criteria. In the implementation stage, only variables with at least one causal link are retained. C denotes cost criteria, B refers to benefit criteria and T indicates target criteria. No logarithmic transformation is applied, as MCDM methods rely on their own normalization procedures.
Source: Table by the author.

The optimization directions for the criteria in Table 2 are set based on the literature for benefit and cost categories. For target criteria, official reports are used as reference. For the co criterion, the target follows the 2053 strategy with a 41% reduction goal. For gdp, the target is aligned with the Medium Term Programme (MTP)-2028. In the Medium Term Programme of Turkey, the heading Main Economic Indicators sets a per capita GDP target of 20,987 USD for 2028 (Presidency of Strategy and Budget Presidency of The Republic of Turkey, 2025: 49). Based on this, the target value used in the normalization of the gdp criterion is taken as 20,987 USD. Turkey's first Nationally Determined Contribution under the Paris Agreement was published in 2012. In 2023, the country declared a 41 percent reduction relative to the 2012 baseline scenario (Bahçekapılı, 2025: 347; Economic

Development Foundation, 2025). Accordingly, the value of 4.7694 for 2012 is reduced by 41 percent. The resulting value of 2.8139 is used as the target for the co criterion in the normalization procedure. In this study, target values for gdp and co were taken from official reports and set at 20,987 USD and 2.8139, respectively. These values were entered manually into the INNOVRANK interface provided by Fauzi et al. (2025), and the ARIE procedure was carried out accordingly. No additional calculations were applied, except for a 41% reduction in Turkey's co value in 2012. This reflects the practical and flexible structure of the ARIE method. The normalized values and target values are also reported in the Appendix-A. The MEREC method is used to determine the weights of the criteria. Proposed by Keshavarz-Ghorabaee et al. (2021), MEREC calculates the objective weights of criteria. Unlike other methods, it considers the impact of each criterion on alternative performance as a weighting measure. The main advantages of this method are as follows. Criterion weights are derived directly from the data set and do not depend on decision maker judgment. This reduces subjective bias. The effect of each criterion is examined by observing changes after its removal, which makes its contribution to the decision process clear. The notation of the method is provided in the Appendix-B and further details are available in the original study (see Keshavarz-Ghorabaee et al., 2021: 8-9).

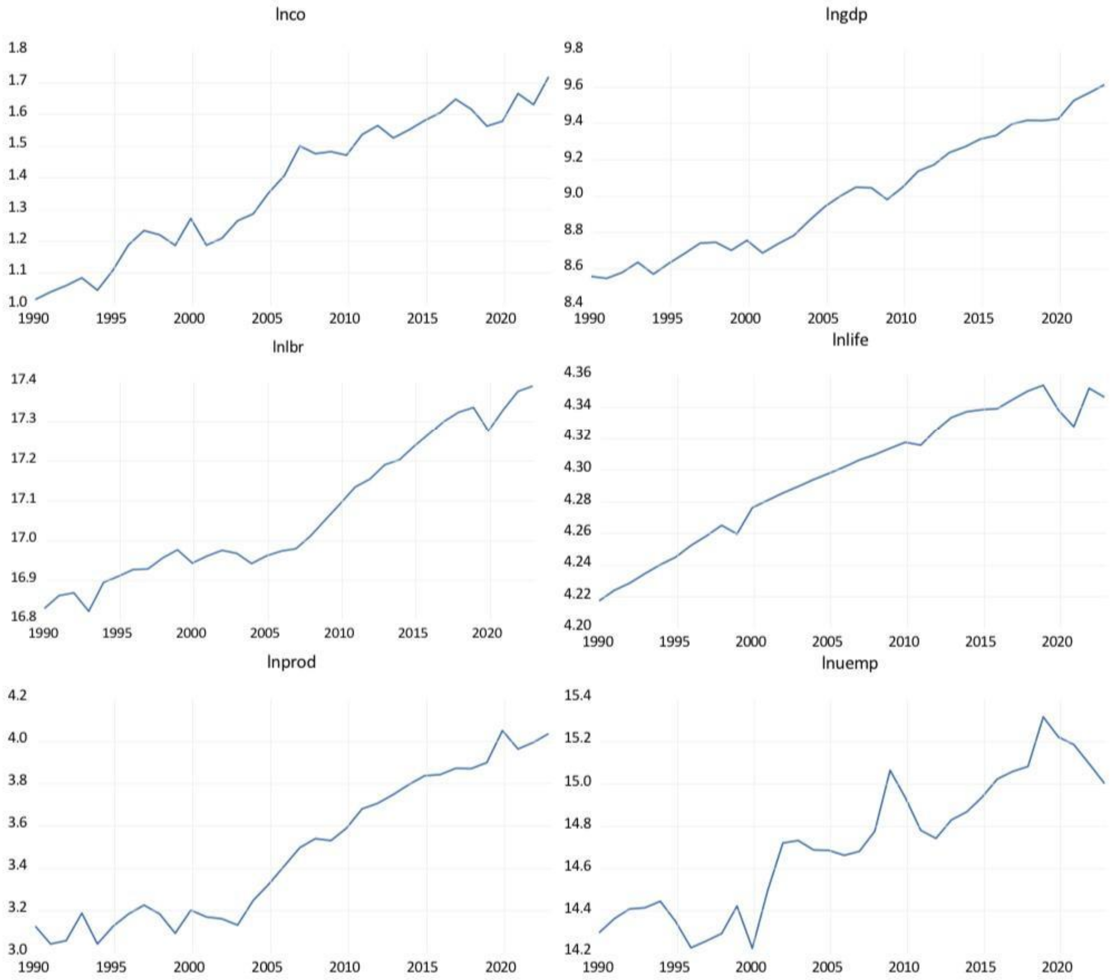
The ARIE method, introduced by Fauzi et al. (2025), is used to rank the alternatives. It extends standard normalization approaches by including a target-oriented structure alongside benefit and cost criteria. The method relies on a scoring function with two parameters. The sensitivity parameter γ controls the effect of deviations. The balance coefficient κ regulates the trade-off between closeness to the ideal and distance from the anti-ideal. The ARIE method uses a target based normalization structure that goes beyond benefit and cost criteria. It allows each criterion to be evaluated with a reference point based on expert judgment, regulatory standards, historical averages, or strategic targets. This provides flexibility in the analysis. As a relatively recent method, ARIE also supports applications that align with current data sets and policy goals. The notation of the method is given in the Appendix-C and further details can be found in the original study (see Fauzi et al., 2021: 5-8).

Sensitivity checks rely on two procedures. The MEREC method uses a LOO approach. The ARIE method relies on scenario analysis. In the LOO, each criterion is removed in turn. The MEREC method is then run again with the remaining criteria, and the weights are recalculated. This allows a direct view of how each criterion affects the others. In the scenario analysis, each criterion weight is increased and decreased by 10 percent. The total weight remains equal to 1. The remaining weights are adjusted proportionally. After each change, alternative scores are recalculated and shifts in ranking are examined. The LOO procedure appears frequently in regression models and MCDM studies (Gramatica et al., 2007; Kizielewicz & Baczkiewicz, 2025; Wang et al., 2025). Scenario analysis with 10 percent changes is also widely used as a robustness check (Qaradaghi & Deason, 2018; Wu et al., 2021). Econometric analyses are carried out using EViews 11.0 and STATA 15.0. MEREC calculations and its sensitivity checks are handled in Microsoft Excel 16.0. The ARIE method and its scenario analysis are implemented through the INNOVRANK. The next section presents the empirical findings based on these methods and discusses the results in detail.

Findings

The analysis begins with the econometric relationship between carbon emissions and labor indicators. The time path of the series is presented in Figure 1.

Figure 1. Temporal Trajectories of the Series



Source: Obtained as an output from the EViews.

Figure 1 shows a general upward trend in most series over the long run. Unemployment follows a more volatile path and shows a slight decline in recent years. Descriptive statistics for the series are given in Table 3.

Table 3. Descriptive Stats

	Mean	Median	Skewness	Kurtosis	Jarque-Bera	Probability
lnco	1.3769	1.4369	0.2162	1.6413	2.8525	1.5431
lngdp	9.0001	8.9873	0.2583	1.7272	2.6729	0.2627
lnlbr	17.0676	16.9767	0.4523	1.7900	3.2335	0.1985
lnlife	4.2966	4.3036	-0.3776	1.8935	2.5426	0.2804
lnprod	3.4787	3.4511	0.2430	1.5148	3.4594	0.1773
lnuemp	14.7106	14.7231	0.0408	1.8557	1.8644	0.3936

Source: Obtained as an output from the EViews.

The mean and median values are close across all variables. This suggests that extreme values do not play a strong role in the series. In the literature, skewness is expected to fall between -1 and +1. Kurtosis is expected to lie between -2 and +2 (Uysal & Kılıç, 2022: 223). The results in Table 2 largely meet these ranges. Under the normality assumption, the Jarque-Bera statistic should be below five. The probability value should exceed 0.05. A probability above 0.05 indicates normally distributed errors (Dereli, 2014: 257; Teyyare, 2018: 130; Uçan & Saraç, 2020: 700-701). In this study, all probability values from the Jarque-Bera test are above the 5 percent level. This does not contradict the normality assumption. Overall, the data show a stable structure and appear suitable for analysis. Before moving to unit root tests, regression results are reported to guide model selection.

Table 4. Model Decision Results for Constant and Trend

M	*lnco*	*lngdp*	*lnlbr*	*lnlife*	*lnprod*	*lnuemp*
Constant	1.0281 [0.0000]	8.4529 [0.0000]	16.7879 [0.0000]	4.2290 [0.0000]	2.9282 [0.0000]	14.2239 [0.0000]
Trend	0.0211 [0.0000]	0.0331 [0.0000]	0.0169 [0.0000]	0.0040 [0.0000]	0.0333 [0.0000]	0.0295 [0.0000]

The values in this table represent the coefficients of the regression model. The figures in parentheses indicate the corresponding probabilities.

Source: Obtained as an output from the EViews.

The results show that both the constant and trend specifications are statistically significant for all variables. The analysis therefore proceeds with models that include both a constant and a trend.

Table 5. Results of ADF, KPSS and ZA

T	$lnco$	$lngdp$	$lnlbr$	$lnlife$	$lnprod$	$lnuemp$
ADF	-2.8562	-2.5300	-1.6202	-1.8845	-2.9006	-2.6704
KPSS	0.1215**	0.1772	0.1647	0.1872	0.1455**	0.0736
ZA	-4.4362 [2006]	-4.1388 [1999]	-3.5834 [2003]	-4.3974 [2016]	-4.7648 [2005]	-4.9834 [2001]
T	$\Delta lnco$	$\Delta lngdp$	$\Delta lnlbr$	$\Delta lnlife$	$\Delta lnprod$	$\Delta lnuemp$
ADF	-5.2741**	-3.8786**	-4.5389**	-5.0528**	-5.9408**	-5.2435**
KPSS	0.1389**	0.2892**	0.1650**	0.3772**	0.2010**	0.1849**
ZA	-6.5941**	-6.1404**	-6.8789**	-6.9062**	-8.8956**	-5.6604**

The symbol Δ denotes the first difference of the series. For the ADF test, critical values follow MacKinnon (1996). At the level form, the values are -4.26, -3,55 and -3,20 for the 1%, 5%, and 10% significance levels. For the first difference, the values are -2.63, -1.95 and -1.61. For the KPSS test, critical values are based on Kwiatkowski et al. (1992). At the level form, they are 0.216, 0.146, and 0.119. For the first difference, they are 0.739, 0.463, and 0.347. The Newey-West bandwidth is used in the KPSS test. In the ADF test, a user-specified lag length of 0 is selected following Dikmen (2018). The reported statistics refer to the t-statistic (τ) for the ADF test, the LM statistic for the KPSS test, and the t-statistic for the ZA test. In the ZA test, values in brackets indicate the break dates. The lag length is set to one. The critical values for the ZA test at the level form are -5.57, -5.08 and -4.82. For the first difference, they are -5.34, -4.93 and -4.58. ** indicates significance at the 5% level.

Source: Obtained as an output from the EViews.

In time series analysis, taking first differences removes the constant and trend components (Dikmen, 2018: 321). This is taken into account during the differencing process. The unit root test results show that, under the ADF test, the t-statistics (τ) for all series are smaller in absolute value than the critical values at the 5% level. The null hypothesis is therefore retained, and the series are treated as having a unit root. The KPSS test yields a different pattern. Except for $lnco$ and $lnprod$, the LM statistics fall below the asymptotic critical values at the 5% level. For these series, the null of stationarity is rejected. The contrast between ADF and KPSS results is notable. Figure 1 also suggests the presence of structural breaks. For this reason, the ZA test is applied. Under the ZA test, the t-statistics at level form remain below the critical values. The null hypothesis is retained. Once first differences are taken, the series become stationary with structural breaks. For the differenced series, the null is rejected and the alternative is accepted (Göksu & Balkı, 2023: 50-52). The estimated break dates are 2006 for $lnco$, 1999 for $lngdp$, 2003 for $lnlbr$, 2016 for $lnlife$, 2005 for $lnprod$ and 2001 for $lnuemp$. These results point to the presence of structural breaks in all series.

Overall, the series are non-stationary at levels when structural breaks are considered. They become stationary after first differencing. Long-run relationships are examined using the Gregory-Hansen cointegration test with structural breaks. Results for both models are reported in Table 6.

Table 6. Results of Gregory-Hansen Structural Break Cointegration Tests

T	Test-Stat	Date	Asymptotic Critical Values		
			1%	5%	10%
For Equation 1					
ADF	-7.01	2007	-6.89	-6.32	-6.16
Zt	-7.01	2007	-6.89	-6.32	-6.16
Za	-41.98	2007	-90.84	-78.87	-72.75
For Equation 2					
ADF	-5.90	2005	-6.45	-5.96	-5.72
Zt	-5.99	2005	-6.45	-5.96	-5.72
Za	-35.66	2005	-79.65	-68.43	-63.10

For Equation 1 and 2, the lag length is set to 1 based on VAR analysis and the Schwarz criterion (SC). For the Gregory-Hansen test, breakpoints follow the regime shift with trend specification and the Bayesian criterion is used.
Source: Obtained as an output from the STATA.

Table 6 shows a strong cointegration relationship among the variables in Equation 1 under structural breaks. For Equation 2, the relationship is weaker compared to the first model. The break years differ across models. For Equation 1, the shift appears in 2007. For Equation 2, it appears in 2005. This points to changes in the long-run structure over time and suggests that parameters vary across regimes. Table 6 shows a strong cointegration relationship among the variables in Equation 1 under structural breaks. For Equation 2, the relationship is weaker compared to the first model. The break years differ across models. For Equation 1, the shift appears in 2007. For Equation 2, it appears in 2005. This points to changes in the long-run structure over time and suggests that parameters vary across regimes. The results in Table 6 indicate that the second model, which includes unemployment and life expectancy, provides weaker evidence of cointegration. The absolute values of the ADF and Zt statistics (-5.90 and -5.99) are lower than those of the first model and remain below the 1% critical values. At the 5% level, these statistics are close to the critical thresholds. In contrast, the first model exceeds even the 1% critical values, indicating a stronger long-run relationship. The results of the Toda-Yamamoto causality test are reported below for each model separately.

Table 7. Findings from the Toda-Yamamoto Causality Test

Direction	Prob.	Hyp.	Direction	Prob.	Hyp.
$lngdp \rightarrow lnco$	0.0265	H_A	$lnlife \rightarrow lnco$	0.2477	H_0
$lnlbr \rightarrow lnco$	0.0097	H_A	$lnuemp \rightarrow lnco$	0.1770	H_0
$lnprod \rightarrow lnco$	0.1209	H_0	$lnco \rightarrow lnlife$	0.0106	H_A
$lnco \rightarrow lngdp$	0.8133	H_0	$lnuemp \rightarrow lnlife$	0.5594	H_0
$lnlbr \rightarrow lngdp$	0.6832	H_0	$lnco \rightarrow lnuemp$	0.9424	H_0
$lnprod \rightarrow lngdp$	0.8835	H_0	$lnlife \rightarrow lnuemp$	0.6610	H_0
$lnco \rightarrow lnlbr$	0.3471	H_0			
$lngdp \rightarrow lnlbr$	0.0851	H_0			
$lnprod \rightarrow lnlbr$	0.0000	H_A			
$lnco \rightarrow lnprod$	0.7852	H_0			
$lngdp \rightarrow lnprod$	0.1655	H_0			
$lnlbr \rightarrow lnprod$	0.0834	H_0			

Hyp. denotes the accepted hypothesis. For Equation 1, $k + d_{max} = 3$. For Equation 2 $k + d_{max} = 2$. Since the results need to be compared with the chi-square critical values at k degrees, Excel is used alongside EViews.

Source: Obtained as an output from the EViews and Excel.

The Toda-Yamamoto causality test is also checked with diagnostic tests. For Equation 1, the Doornik-Hansen normality test yields a probability of 0.0778. The LM test for autocorrelation gives 0.9480. The probability for heteroskedasticity is 0.3400. For Equation 2, the Doornik-Hansen probability is 0.3041. The LM autocorrelation test gives 0.7820. The heteroskedasticity probability is 0.2073. All probability values exceed 0.05. This indicates no diagnostic problems in the Toda-Yamamoto causality results for either model. The causality analysis identifies one way links from $lngdp$ to $lnco$, from $lnlbr$ to $lnco$, and from $lnprod$ to $lnlbr$. For Equation 2, there is also a one way link from $lnco$ to $lnlife$. Based on these results, the variables with at least one causal connection are selected. These are carbon emissions per capita, GDP per capita, total labor force, productivity (measured as output per hour worked) and life expectancy. The unemployment variable is also examined within a robustness analysis and the results are presented in the Appendix-D. Its low weight (0.0262) indicates a limited role, and the rankings remain largely unchanged. The exclusion of the unemployment variable is guided by the existing literature. Vardopoulos and Konstantinou (2017: 100, 109) report a correlation between unemployment and carbon emissions, yet this relationship does not indicate a stable or conclusive link. Evidence also shows that socio-economic variables do not always yield statistically significant effects on environmental indicators (Adesina and Mwamba, 2019: 155;

Lebe and Akbaş, 2025: 627, 632-635). Pickson et al. (2024: 1) note that these relationships vary across income groups. In this study, the unemployment variable is not included in the MCDM analysis due to the results of the time series causality analysis. For the period 1990-2023, no statistically significant or directional relationship is identified between unemployment and carbon emissions. The selection of variables therefore follows a criterion based on explanatory relevance and internal consistency. Variables that are not supported by causality results are not carried into the MCDM framework. At the same time, excluding unemployment does not imply that it has no influence on carbon emissions. The decision reflects the need to maintain consistency between the methods employed and the period under examination. These variables are used as criteria in the MCDM analysis. Annual alternatives are ranked over the period 1990-2023. The findings from the MEREC method are reported in Table 8.

Table 8. Results of MEREC

	wco	$wgdp$	$wlbr$	$wlife$	$wprod$
Weights	0.2421	0.2851	0.1505	0.0488	0.2733

x≈round(x,4). The symbol w denotes the weight of the corresponding criterion.
Source: Table by the author.

The MEREC results in Table 8 show clear differences in the relative influence of the criteria on the decision problem. gdp has the highest weight at 0.2851. It is followed by $prod$ with 0.2733 and co with 0.2421. The lbr has a moderate weight of 0.1505. $life$ has the lowest weight at 0.0488. After determining the weights, the alternatives defined by years are ranked using the ARIE method. The results are presented in Table 9.

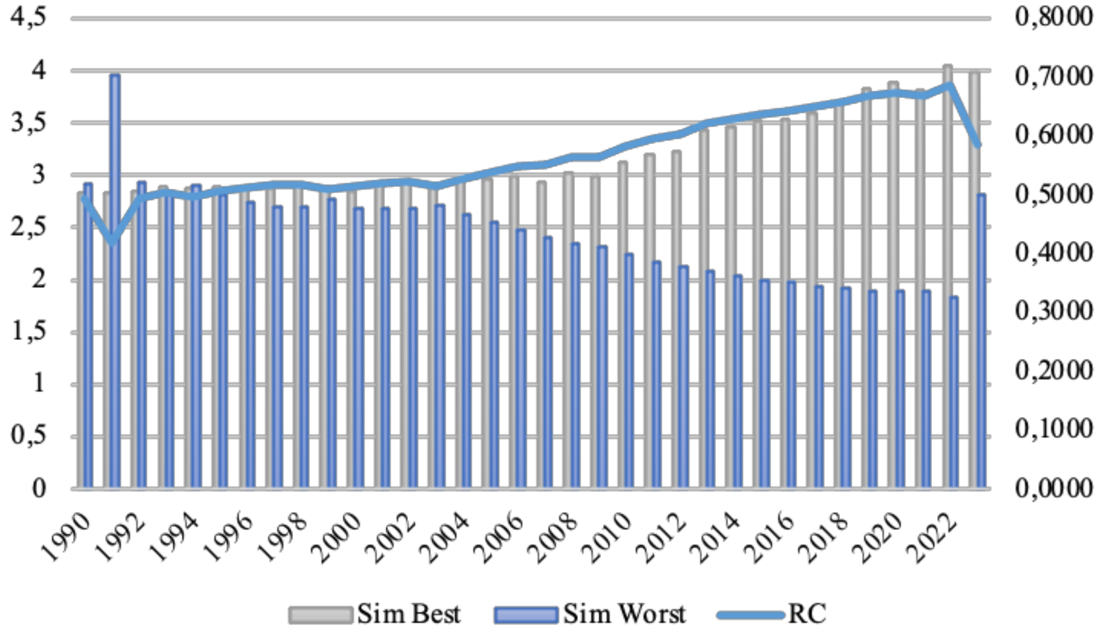
Table 9. Results of ARIE

A	RC	A	RC	A	RC	A	RC
1990	0.4931	1999	0.5103	2008	0.5627	2017	0.6493
1991	0.4175	2000	0.5152	2009	0.5630	2018	0.6583
1992	0.4929	2001	0.5200	2010	0.5820	2019	0.6687
1993	0.5030	2022	0.5221	2011	0.5956	2020	0.6729
1994	0.4973	2003	0.5149	2012	0.6018	2021	0.6678
1995	0.5068	2004	0.5282	2013	0.6223	2022	0.6875
1996	0.5120	2005	0.5375	2014	0.6290	2023	0.5856
1997	0.5163	2006	0.5471	2015	0.6380		
1998	0.5181	2007	0.5498	2016	0.6413		

x≈round(x,4). A denotes the alternatives and RC refers to compute relative closeness and ranking.
Source: Obtained as an output from the INNOVRANK.

The ARIE results in Table 9 show that $\boldsymbol{RC}$ values follow a general upward trend over the long run. This pattern is interrupted by periodic fluctuations. $\boldsymbol{RC}$ starts at 0.4931 in 1990. It drops to 0.4175 in 1991. In the following years, the series recovers gradually and records modest and relatively stable increases during the second half of the 1990s. From the early 2000s onward, the upward movement becomes more pronounced. After 2004, the pace of increase accelerates. During the 2010s, the index moves steadily upward. After 2010, $\boldsymbol{RC}$ values rise above 0.58 and maintain a consistent increase. The series reaches its peak at 0.6875 in 2022. In 2023, it falls to 0.5856 and shows a decline. Figure 2 presents the time path evolution of the computed relative closeness and ranking values across the analysis period.

Figure 2. Time-Path Graphs of the RC Results with Sim Best and Sim Worst



Source: Created by the author based on the findings obtained from INNOVRANK

The ARIE results indicate that the rise in RC values is driven by simultaneous changes in Sim Best and Sim Worst. From the mid-2000s onward, Sim Best shows a clear upward pattern. At the same time, Sim Worst declines steadily. In line with the targets set by Türkiye, reference values of 20,987 USD for

gdp and 2.8139 for co are defined in the model. These targets are directly included in the normalization stage. The analysis compares each alternative in terms of its distance to these values and its deviation from the anti-ideal. The results show higher Sim Best values and lower Sim Worst values. This pattern indicates a closer alignment with the targets and a greater distance from the anti-ideal. The increase in RC reflects both effects together. Closeness to the ideal improves, and distance from the anti-ideal also grows. In 2023, RC declines. Sim Best remains high, but Sim Worst increases sharply. This suggests that, despite staying close to target values in some criteria, the alternatives move closer to the anti-ideal in others. As a result, overall performance weakens. Within the robustness analysis, unemployment is included and the MEREC and ARIE methods are applied again. The weight of this criterion is the lowest at 0.0262. The rankings remain largely stable, with only minor changes between 2019 and 2021. These results are reported in the Appendix-D. They support the decision to exclude unemployment from the main model on methodological and numerical grounds. The results of the LOO procedure applied to the MEREC method are reported in Table 10.

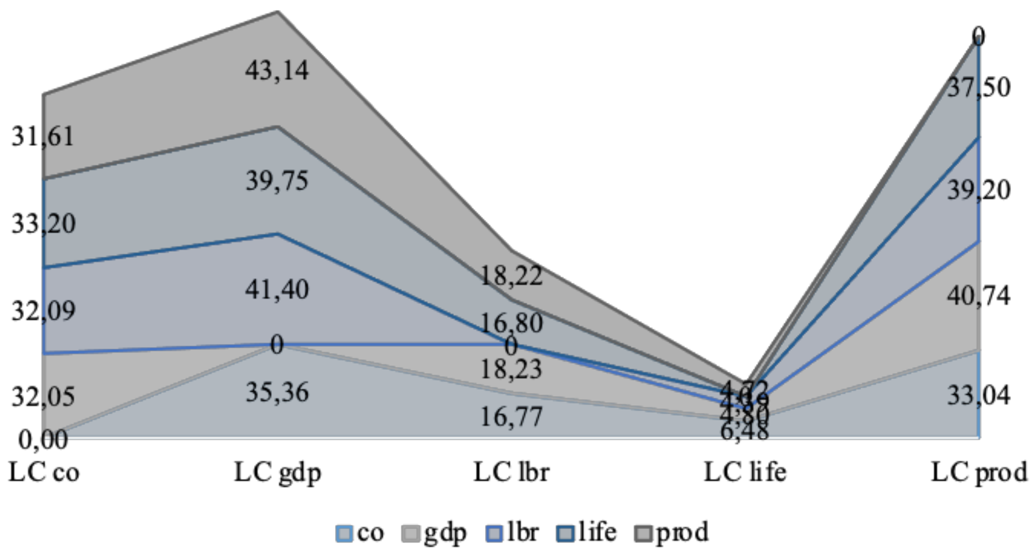
Table 10. LOO Procedure Results

LC	co	gdp	lbr	$life$	$prod$
co		0.3766	0.1988	0.0650	0.3597
gdp	0.3277		0.2128	0.0682	0.3912
lbr	0.2827	0.3372		0.0570	0.3231
$life$	0.2578	0.2989	0.1571		0.2862
$prod$	0.3221	0.4014	0.2095	0.0671	

x≈round(x,4). The symbol LC denotes the leave-one-out criterion.
Source: Table by the author

Percentage changes relative to the original weights were also calculated to facilitate the interpretation of the findings presented in Figure 3.

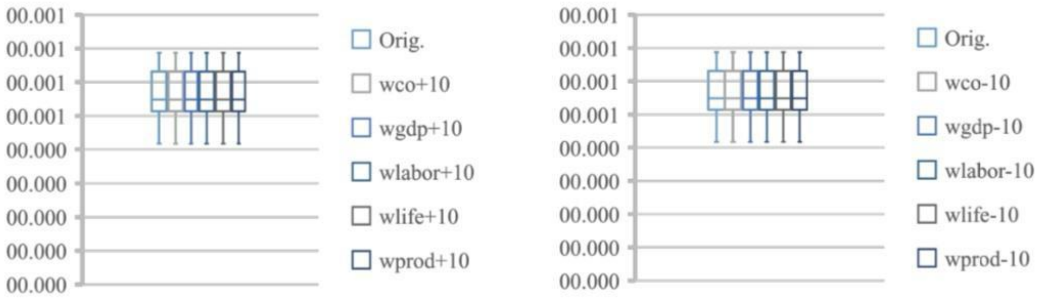
Figure 3. Percentage Change the LOO Procedure



Source: Created by the author based on the findings obtained from INNOVRANK

The percentage changes from the LOO procedure show how each criterion affects the system. When co is removed, all other criteria increase by roughly 31-33%. The pattern is similar across variables. This suggests a balancing role within the system. Removing gdp produces the largest deviations. The increases exceed 41% for both $prod$ and $labor$. This points to a central role for gdp in the model. When lbr is excluded, the changes remain more limited. The increases fall between 16% and 18%. This indicates a moderate influence. Excluding $life$ leads to the smallest changes. The increases stay within the 4-6% range across all criteria. When $prod$ is removed, the remaining criteria rise by about 33-40%. This again signals a strong influence. The results of the scenario analysis are presented in the figure below.

Figure 4. Scenario Analyses Variation Ranges



Source: Created by the author based on the findings obtained from INNOVRANK

The results of the scenario analysis are presented in Figure 4. A 10% increase and decrease is applied to each criterion weight. Despite these changes, the ranking of alternatives remains largely unchanged. This indicates a stable structure and strong robustness to weight variations. The findings are examined in greater detail in the next section, with both conceptual and empirical aspects discussed in a comparative manner.

Discussion

The discussion centers on how carbon emissions relate to labor dynamics across production and socioeconomic dimensions. The overall pattern suggests that changes in emissions are closely tied to production activity and economic scale. The distributional features observed in the data can be linked to Turkey's growth trajectory, particularly the expansion that followed the early 2000s (Credit Agricole Group, n.d.; OECD, 2025; Sungur, 2015: 247-252; World Bank, 2025). At the same time, periods of instability leave visible marks on the series, which is consistent with the fluctuations documented in earlier work (Haydaroğlu & Çırak, 2024: 658; Kazgan, 2021: 250-251). The break dates identified in the analysis correspond to well-known turning points in the Turkish economy. The mid-2000s stand out as a period shaped by structural adjustments, shifts in external balances and changes in productivity dynamics (Kazgan, 2021: 249; Yalçın, 2010: 200). Demographic change also plays a role in shaping long-term patterns, particularly through gradual shifts in life expectancy (Tekin & Kara, 2018: 222-223). Earlier crisis periods, especially around the turn of the century, appear in the data through breaks in income and labor-related indicators (Pamuk, 2021: 278, 282-283). According to Kazgan (2021: 249), the manufacturing sector sustains itself between 1998 and 2003 by raising labor productivity rather than employment. This pattern is described as a resource effect of unemployment. Taken together, these elements point to an economy where structural transformations, rather than short-term fluctuations, shape the relationship between labor and emissions. The cointegration and causality findings reinforce this interpretation.

Production related variables display a more direct and stable connection with emissions. GDP per capita, labor and productivity emerge as central components of this relationship. In contrast, life expectancy and unemployment operate through less direct channels. Their links with emissions appear weaker and more dispersed over time. This difference suggests that emission patterns in Turkey are closely tied to the scale and structure of production, as well as to energy use embedded in economic activity. Similar arguments are raised in studies that connect emissions to structural and institutional conditions (Pelit and Avşar, 2025: 1, 13; Liddle and Parker, 2024: 7). These patterns carry over into the multi criteria analysis. The variables selected through causality testing form a coherent set for the MCDM framework. The MEREC results assign comparable importance to carbon emissions, GDP per capita and productivity. This outcome underlines the role of growth related factors in shaping the interaction between labor and the environment. Earlier studies report similar links between economic expansion and environmental pressure (Külünk, 2018; Özdemir & Koç, 2020; Öztürk & Saygın, 2020).The ARIE rankings highlight a distinct period of relatively strong performance between 2019 and 2022. This phase coincides with improvements in income and productivity alongside a more contained increase in emissions. The temporary nature of this pattern should be noted. Global evidence points to a short lived decline in emissions during the pandemic period (Ray et al., 2022: 1; Sikarwar et al., 2021: 1, 6). Turkey's growth performance during the same period, supported by domestic demand, also shapes the observed ranking outcomes (IMF, 2021). The reversal in 2023 suggests that earlier gains do not fully persist once these conditions change. The role of unemployment is also checked through a robustness exercise reported in the Appendix-D. Its low weight (0.0262) and the absence of notable changes in rankings indicate a limited contribution to the overall results.

Results and Policy Recommendations

There is a complex relationship among economic growth, employment and environmental sustainability. It involves multiple dimensions and mutual interactions. A comprehensive view of these links helps clarify the policy implications of the empirical results. In Turkey, industrialization, population growth and global economic processes shape environmental quality. Examining the drivers of environmental change remains an important research task.

The results indicate that economic growth and labor expansion in Turkey are associated with higher carbon emissions per capita. Growth oriented policies need to account for environmental costs and align with green transformation goals. Energy efficiency in industry and production should be strengthened. The use of renewable energy needs wider adoption. The shift toward low carbon technologies also requires stronger support. Causality from carbon emissions to life expectancy highlights the link between environmental quality and public health. Policies that reduce air pollution and carbon emissions deserve greater emphasis. The causality from productivity to labor suggests that gains in efficiency shape employment structures. This brings education and technology oriented policies to the forefront, especially those that support a skilled workforce. The MCDM results point to GDP per capita as the most influential criterion in the labor-environment decision framework in Turkey. Productivity and carbon emissions follow. This pattern underlines the need to consider growth and productivity together with their environmental effects. Policy design should align economic expansion with environmental sustainability. Efforts to reduce carbon intensity in production technologies remain a key priority.

Considering the econometric findings together with the MCDM results provides a clearer interpretation of the overall picture. Production related variables stand out in both causality and cointegration analyses, and they also receive higher weights in the MCDM results. This points to a consistent pattern across the findings. Emission dynamics in Turkey appear closely linked to production, productivity and income, whereas socioeconomic variables follow a more indirect path. At the same time, the joint use of these methods requires careful interpretation. Econometric analysis reflects causal structure, while MCDM focuses on relative importance and ranking. The results therefore depend on the chosen framework. In this sense, rankings should be read as relative outcomes shaped by the selected criteria, weighting scheme and model assumptions, rather than as absolute performance measures.

This study differs from Keklik and Dursun (2025) in both its findings and its scope, as it does not include urbanization. It shows closer alignment with the results reported by Öztürk and Saygın (2020). Some limitations remain. The analysis focuses on a specific period and a limited set of macroeconomic variables. Other factors that shape environmental quality, such as institutional structure, energy policies and technological change, are not included. The causality analysis identifies directional links between variables. It does not provide detailed insight into the magnitude or deeper structure of these relationships. The MEREC method offers an objective way to assign weights, yet the results depend on the data set and the selected criteria. The findings are specific to Turkey. Their relevance for other countries or time periods may therefore be limited. In this study, criteria are selected based on causality relationships among the variables. Only those with at least one causal link are included in the MCDM analysis. Unemployment is excluded since no significant relationship is found in the causality tests. At the same time, leaving out a potentially relevant variable such as unemployment is considered a limitation of the study. Future research could further integrate econometric findings with MCDM procedures, particularly in the stages of criterion selection and weighting. The role of unemployment may also be revisited under alternative model settings, given its sensitivity to specification and time period. Extending the framework with additional variables such as renewable energy use, energy consumption patterns, technological change and institutional factors would provide a broader view of labor-environment relationships.

Geniş Özet

Bu çalışmada Türkiye'de emek piyasası dinamikleri ile çevresel göstergeler arasındaki karşılıklı etkileşimlerin bütüncül biçimde analiz edilmesi amaçlanmaktadır. Ekonomik büyüme, istihdam, karbon emisyonları ve üretkenlik gibi temel göstergeler genellikle birbirinden bağımsız alanlara aitmiş gibi ele alınmakla birlikte özellikle son yıllarda sürdürülebilir kalkınma tartışmalarının merkezine yerleşen çevresel baskılar emek piyasasının da çevresel maliyetlerden etkilendiğini göstermektedir. Üretim yapısındaki dönüşümler, enerji tüketim kalıpları, teknolojik yenilikler ve sektörlerin farklı çevresel duyarlılık düzeyleri işgücü piyasası göstergelerinin çevresel faktörlerle hem doğrudan hem de dolaylı biçimde bağlantılı olabileceğine işaret etmektedir. Türkiye'nin yapısal özellikleri dikkate alındığında bu göstergeler arasındaki ilişkinin çok boyutlu bir analitik çerçeve gerektirdiği değerlendirilmektedir. Bu motivasyonla çalışma iki yöntemsel bileşen üzerine inşa edilmiştir. İlk aşamada karbon emisyonları ile emeğin, üretim ve sosyo-ekonomik dinamikleri arasında uzun dönemli ve nedensel ilişkilerin olup olmadığı zaman serileri analizleri ile incelenmiştir. Birim kök testleri her iki modelde de serinin kalıcı şoklar içerdiğini göstermiştir. Tahmin edilen kırılma tarihleri kişi başı karbon emisyonları için 2006, kişi başı GSYH için 1999, işgücü için 2003, yaşam beklentisi için 2016, emek verimliliği için 2005 ve işsizlik için 2001 olarak belirlenmiştir.

Karbon emisyonları, kişi başı gelir, toplam işgücü ve verimlilik değişkenlerinde hafif sağa çarpıklık dikkat çekmektedir. Basıklık açısından ise seriler daha yayvan bir yapı göstermektedir. Bu sağa çarpık görünüm Türkiye'nin uzun dönemli büyüme dinamikleriyle uyumludur. Özellikle 2000'li yıllardan sonra ekonomik genişleme, sanayileşme ve üretim artışı daha belirgin hale gelmiştir. 2001 krizi sonrasında sanayi ve hizmet sektörlerinde art arda büyüme dönemleri yaşanmıştır. 2000'li yılların ortasından itibaren uygulanan politikalar ve reformlar ekonomik yapıyı görece ve nicel açıdan güçlendirmiştir. Bu süreçte gelir düzeyi yükselmiş ve kişi başına düşen gelir artmıştır. Zaman içinde serilerin daha yüksek değerlere doğru yoğunlaşması dağılımın sağ kuyruğunun uzamasına yol açmıştır. Serilerin yayvan dağılım özellikleri ekonomik dalgalanmalar ve kriz dönemleriyle ilişkilendirilebilir. Geleneksel birim kök testleri düzey değerlerinde birim kök içeren serilerin durağan olmadığını göstermektedir. Bu tür serilerde ortaya çıkan şokların etkileri kalıcı nitelik taşımaktadır. Demografik yapıdaki değişim de dikkat çekmektedir. Özellikle ileri yaş grubunun toplam nüfus içindeki payı zamanla artmıştır. Bu durum yaşam beklentisi göstergelerinde gözlenen değişimlerle örtüşmektedir. Ekonomik kriz dönemleri, gelir ve işgücü göstergelerinde belirgin kırılmalar yaratmıştır. Bu süreçte üretim yapısında dönüşüm yaşanmıştır. Bazı sektörler istihdamı artırmak yerine verimlilik artışı yoluyla ayakta kalmaya çalışmıştır. Verimlilikte gözlenen değişimler, döviz kuru hareketleri ve büyüme hızındaki yavaşlamalarla birlikte değerlendirilmektedir. Aynı dönemde dış açıkların genişlemesi ve kârlılık oranlarının gerilemesi de dikkat çekmektedir. Genel olarak bulgular, ekonomik gelişmelerle uyumlu bir görünüm sunmaktadır. Eşbütünleşme ve nedensellik sonuçları dikkate alındığında da benzer bir eğilim görülmektedir.

Makroekonomik verilerin analiz edilmesi ekonomik politikaların değerlendirilmesinde temel bir yaklaşım olarak kullanılmaktadır. Son yıllarda iklim olaylarının daha sık hale gelmesiyle birlikte ekonomik büyüme, nüfus yapısı ve işsizlik gibi göstergelerde de değişimler yaşanmıştır. Yeşil ve temiz enerji kullanımının artması karbon emisyonlarının azalmasıyla birlikte istihdam yapısında da dönüşümler yaratmaktadır. Bu süreçte sektörler içinde ve arasında yapısal değişimler ortaya çıkmaktadır. Elde edilen bulgular, üretim odaklı değişkenlerin sosyoekonomik değişkenlere kıyasla daha güçlü bir uzun dönem ilişkisi sergilediğini göstermektedir. Bu durum karbon emisyonlarının üretim faaliyetleri, enerji kullanımı ve ekonomik büyüme ile doğrudan bağlantılı olmasından kaynaklanmaktadır. Kişi başı gelir, işgücü ve verimlilik emisyonların temel belirleyicileri olarak öne çıkmaktadır. Buna karşılık yaşam beklentisi ve işsizlik gibi değişkenler daha dolaylı etkiler üzerinden ilişki kurmaktadır. Bu nedenle uzun dönem ilişkileri daha zayıf görünmektedir. Türkiye ekonomisinin üretim ve enerji yoğun yapısı bu sonucu desteklemektedir. Analizler, üretim tarafında ve sosyoekonomik göstergelerde farklı dönemlerde yapısal değişimlerin yaşandığını göstermektedir. Bu değişimler ekonomik yapıdaki dönüşümler ve kriz süreçleriyle ilişkilendirilmektedir. Nedensellik bulguları işgücü piyasası ile karbon emisyonları arasında yapısal bir bağ olduğunu ortaya koymaktadır. Bu durum, istihdam ve çevre politikalarının birlikte ele alınması gerektiğini göstermektedir. Karbon emisyonları yalnızca teknik bir gösterge değildir. Ekonomik yapı, kurumsal kapasite ve sürdürülebilirlik politikaları ile birlikte değerlendirilmesi gereken çok boyutlu bir yapıya sahiptir. Genel olarak sonuçlar, ekonomik gelişmeler ile çevresel göstergeler arasında güçlü bir etkileşim bulunduğunu ve bu ilişkinin politika tasarımında dikkate alınması gerektiğini ortaya koymaktadır.Nedensellik sonuçlarına göre en az bir nedensellik ilişkisi içeren değişkenler (karbon emisyonları, kişi başı gelir, toplam işgücü, saat başına üretim olarak ölçülen verimlilik ve yaşam beklentisi) çok kriterli karar verme analizinde kriter olarak kullanılmıştır. 1990-2023 dönemi için yıllar alternatif olarak sıralanmıştır. MEREC sonuçları, karbon emisyonları, kişi başı gelir ve verimlilik kriterlerinin birbirine yakın ve yüksek ağırlıklara sahip olduğunu göstermektedir. Bu durum Türkiye'de emek ve çevre etkileşiminin büyük ölçüde büyüme dinamikleriyle şekillendiğini göstermektedir. Bu üç kriter, üretim sürecinin temel unsurlarını ve ekonomik faaliyetlerin ölçeğini doğrudan yansıtmaktadır. ARIE sonuçları yılların performans sıralamasını ortaya koymaktadır. 2019-2022 dönemi en yüksek performansın görüldüğü dönem olarak öne çıkmaktadır. Bu durum karbon emisyonlarının daha kontrollü bir seyir izlemesiyle ilişkilidir. Analizde karbon emisyonları azaltılması gereken bir kriter olarak ele alınmıştır. Bu dönemde emisyon artış hızının sınırlı kalması ekonomik göstergelerle birlikte toplam performansı yukarı taşımıştır. Pandemi etkisi ve emisyonlardaki görece dengeli seyir de bu sonucu desteklemiştir. 2020 yılında küresel ölçekte emisyonlarda düşüş gözlenmiş, ancak bu azalmanın kalıcı olmadığı değerlendirilmiştir.

Sonuç olarak bu konuda sunulacak öneriler de bu bütünleşik ilişki dikkate alınarak tasarlanmaktadır. Ekonomik büyüme politikaları çevresel maliyetleri dikkate alacak şekilde yeşil dönüşümle uyumlu hale getirilmelidir. Sanayide enerji verimliliği artırılmalı ve yenilenebilir enerji ile düşük karbon teknolojileri daha güçlü biçimde desteklenmelidir. Hava kirliliği ve karbon emisyonlarını azaltmaya yönelik politikalar güçlendirilmeli ve çevre kalitesi ile halk sağlığı arasındaki ilişki politika tasarımında doğrudan gözetilmelidir. Verimlilik artışının istihdam yapısını şekillendirdiği dikkate alınarak nitelikli işgücünü geliştiren eğitim ve teknoloji odaklı politikalar önceliklendirilmelidir.

Beyanlar

Katkı Oranı Beyanı

Bu çalışmanın tüm süreçlerine yazar tek başına katkıda bulunmuştur.

Çıkar Çatışması Beyanı

Bu çalışma kapsamında yazar herhangi bir kişi, kurum, kuruluş veya finansal kaynakla çıkar ilişkisine sahip değildir. Araştırmanın planlanması, yürütülmesi, veri toplama süreçleri, analizlerin gerçekleştirilmesi ve sonuçların raporlanması aşamalarında çalışmanın bütünlüğünü etkileyebilecek nitelikte herhangi bir ticari, mali, kurumsal veya kişisel çıkar çatışması bulunmamaktadır. Yazar, araştırmanın tüm aşamalarında bilimsel etik ilkelere uygun şekilde hareket etmiş olup çalışmanın ortaya koyduğu bulguların nesnel, bağımsız ve şeffaf bir şekilde değerlendirilmesini sağlayacak gerekli akademik sorumluluğu yerine getirmiştir. Çalışmada kullanılan veriler, yöntemler ve sonuçlar üzerinde dışarıdan herhangi bir baskı, yönlendirme veya çıkar temelli müdahale söz konusu değildir. Ayrıca, araştırmanın hazırlanması veya yayımlanma sürecinde herhangi bir fon sağlayıcı kurumdan maddi destek alınmamıştır. Çalışmanın şekillenmesine veya sonuçların yorumlanmasına doğrudan ya da dolaylı katkı sunarak çıkar çatışması oluşturacak üçüncü taraf bir yapı bulunmamaktadır. Yazar bu çalışmanın tamamen akademik amaçla üretildiğini ve sonuçların yalnızca bilimsel çerçevede değerlendirilmesi gerektiğini beyan eder.

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Appendices

Appendix A. Values Used in Normalization Calculations in MCDM Methods

	co	gdp	lbr	$life$	$prod$
Minimum	2.7594	5134.41	20211005	67.8348	20.8916
Maximum	5.5797	14932.88	35554975	77.7370	57.2195
Target	2.8139	20987.00	-	-	-

Source: Table by the author, Economic Development Foundation (2025) and Presidency of Strategy and Budget Presidency of The Republic of Turkey (2025)

Appendix B. Procedure of the MEREC

No	Notations	Flowchart
1	$n^x_{ij} = \begin{cases} \frac{\min_k x_{kj}}{x_{ij}} & if\ j \in \mathcal{B} \\ \frac{x_{ij}}{\max_k x_{kj}} & if\ j \in C \end{cases}$	Normalize the decision matrix
2	$S_i = ln\left(1 + \left(\frac{1}{m}\sum_j \lvert ln(n^x_{ij})\rvert\right)\right)$	Calculate the overall performance of the alternatives
3	$S'_{ij} = ln\left(1 + \left(\frac{1}{m}\sum_{k,k\neq j} \lvert ln(n^x_{ik})\rvert\right)\right)$	Calculate the performance of the alternatives by removing each criterion
4	$E_j = \sum_i \lvert S'_{ij} - S_i \rvert$	Compute the summation of absolute deviations
5	$w_j = \frac{E_j}{\sum_k E_k}$	Determine the final weights of the criteria

At the start of the method, the decision matrix is assumed to be ready. Denoted as n^x_{ij}, $\mathcal{B}$ *represents benefit criteria and* C *represents cost criteria. The total absolute deviations are calculated to represent the removal effect of criterion* E_j. w_j *denotes the weight of the* j*th criterion and is calculated.*

Source: Keshavarz-Ghorabaee et al. (2021).

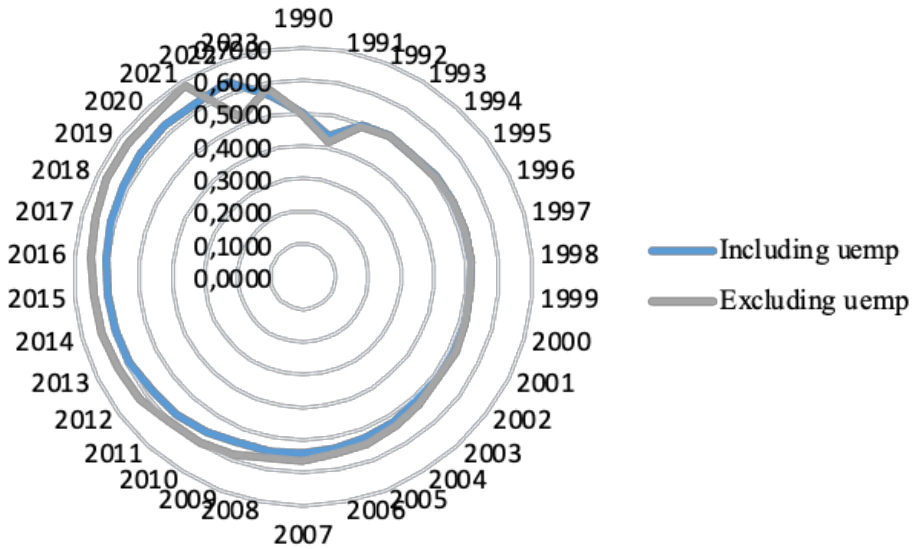
Appendix C. Procedure of the ARIE

No	Notations	Flowchart
1	$r_{ij} = \frac{x_{ij}}{x_j^{max}}$ $r_{ij} = \frac{x_j^{min}}{x_{ij}}$ $r_{ij} = 1 - \frac{\lvert x_{ij} - x_j^T \rvert}{max(\lvert x_j^{max} - x_j^T \rvert, \lvert x_j^{min} - x_j^T \rvert)}$	Normalized the decision matrix
2	$v_{ij} = w_j . r_{ij}$ $v_j^{max} = \underset{i}{max} v_{ij}, v_j^{min} = \underset{i}{min} v_{ij}$	Weighted normalized decision matrix
3	$Sim_i^{best} = \sum_{j=1}^{n} \left(\frac{v_{ij}}{v_j^{max}} \right)^{\gamma}$ $Sim_i^{worst} = \sum_{j=1}^{n} \left(\frac{v_j^{min}}{v_{ij}} \right)^{\gamma}$	Similarity to ideal and anti-ideal
4	$RC_i = \frac{\kappa . Sim_i^{best}}{\kappa . Sim_i^{best} + (1 - \kappa) . Sim_i^{worst}}$	Relative closeness and ranking

At the start of the method, the decision matrix is assumed to be ready. ARIE supports benefit cost and target-based normalization. In the target approach, x_j^T *denotes the reference value set for each criterion based on expert judgment, averages or policy targets. The values of* x_j^T *are derived from official policy targets and included directly in the normalization process.* w_j *denotes the weight of criterion* j*. The weighted normalized value* v_{ij} *is obtained by multiplying the normalized value* r_{ij} *by its corresponding weight, where the weights sum to one. a balance parameter* $\kappa \in [0, 1]$ *is introduced to control the trade-off between closeness to the ideal and distance from it.*
Source: Fauzi et al. (2025).

Appendix D. Application of MEREC and ARIE with the Inclusion of the Unemployment Criterion and Visual Comparison of Model Results

A	RC	A	RC	A	RC	A	RC
1990	0.4989	1999	0.5106	2008	0.5460	2017	0.6081
1991	0.4387	2000	0.5161	2009	0.5435	2018	0.6151
1992	0.4977	2001	0.5172	2010	0.5588	2019	0.6215
1993	0.5052	2022	0.5168	2011	0.5701	2020	0.6257
1994	0.5007	2003	0.5113	2012	0.5750	2021	0.6219
1995	0.5087	2004	0.5216	2013	0.5899	2022	0.6384
1996	0.5136	2005	0.5284	2014	0.5946	2023	0.5649
1997	0.5165	2006	0.5357	2015	0.6007		
1998	0.5175	2007	0.5373	2016	0.6024		



x≈round(x,4). A denotes the alternatives and RC refers to compute relative closeness and ranking. When unemployment is included as a criterion, the weights are as follows: wco (0.2318), wgdp (0.2790), wlabor (0.1476), wlife (0.0478) and wuemp (0.0262).

Source: Obtained as an output from the INNOVRANK and Microsoft Excel