

## The Impact of Economic and Environmental Factors on the Development of the Circular Economy in Iran: A Nonlinear Multilevel Regression Analysis (1993–2023)

Mahboobeh Khadem Nematollahy<sup>1</sup>  | Mojtaba Bahmani<sup>2</sup> 

<sup>1</sup> Corresponding author, Ph.D., Faculty of economics, Allameh Tabataba'i University, Tehran, Iran, E-mail: m.khadem360@gmail.com.

<sup>2</sup> Associate Professor, Department of Economics, Faculty of Management and Economics, Shahid Bahonar University of Kerman, Iran, E-mail: mbahmani@uk.ac.ir.

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### Abstract:

#### Objective:

This study investigates the role of economic factors such as total annual water withdrawal, total renewable energy consumption, total greenhouse gas emissions, and waste generation in shaping the trajectory of the circular economy.

#### Methods:

Utilizing a nonlinear multilevel regression model with combined fixed and random effects, the research examines the impact of these variables on the circular economy index in Iran over the period 1993 to 2023. The choice of this model is justified by its ability to incorporate both fixed effects (such as average variable levels) and random effects (to account for unobserved heterogeneity across observations or units).

#### Results:

The results indicate that among the factors influencing the circular economy, renewable energy consumption has a positive and statistically significant effect on circular economy index, with a coefficient of 0.004. In other words, higher renewable energy consumption is associated with improvements in the circular economy index, underscoring the positive role of clean and renewable energy in promoting sustainable economic development. Conversely, water withdrawal, greenhouse gas emissions, and waste generation negatively impact the circular economy, with coefficients of -0.091, -0.02, and -0.003, respectively. This implies that increased unsustainable resource use (such as water extraction), higher greenhouse gas emissions, and greater waste generation hinder the development of a circular economy.

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**Conclusions:**

Strategic and targeted investment in water-efficient technologies, renewable energy development, greenhouse gas mitigation, and comprehensive waste management can serve as fundamental pillars for advancing the circular economy. Therefore, to strengthen the circular economy, policymakers should prioritize the expansion of renewable and clean energy sources while simultaneously enhancing water use efficiency, controlling greenhouse gas emissions, and improving waste management through innovative technologies. In this regard, the design and implementation of coherent environmental policies, coupled with financial incentives and smart regulation, can accelerate the transition to a circular economy and ensure the country's long-term environmental resilience.

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**1. Introduction**

The transition from a linear to a circular economy represents a paradigm shift in sustainable development, emphasizing resource efficiency, waste minimization, and the regeneration of natural systems. Numerous studies have examined the impact of environmental factors such as water consumption, greenhouse gas emissions, and waste generation on the progress of circular economic models. The consensus in the literature suggests that excessive resource extraction, high pollution levels, and inefficient waste management act as significant barriers to achieving circularity, as they contradict the principles of resource conservation and system regeneration. (Drofenik et al., 2025; Mansuino et al., 2024; Pintilie, 2021).

Renewable energy plays a pivotal role in the circular economy by reducing greenhouse gas emissions and enhancing energy security. Studies have shown that increasing the share of renewable energy in the energy mix can lead to substantial reductions in carbon emissions. (Ishaq et al., 2022). For instance, adopting circular economy principles, including the use of renewable energy, can significantly mitigate climate change impacts. In Iran, where fossil fuel dependency is high, transitioning to renewable energy sources is essential for achieving circular economy goals. (IEA, 2023). Frascareli et al. (2024) studied potential circular economy indicators. They indicated that environmental technology development and renewable energy consumption play a vital and significant role in the realization and advancement of the circular economy.

Water is a critical resource in the circular economy, influencing agricultural productivity, industrial processes, and urban development. Efficient water management and conservation are integral to reducing ecological footprints and enhancing resource productivity. Sustainable water use practices can lead to significant environmental and economic benefits, including reduced energy consumption and improved resilience to climate change. In Iran, addressing water scarcity through circular approaches is vital for sustainable development. (Nwankwo et al., 2024; Leal Filho et al., 2024).

Greenhouse gas emissions are a central concern in the circular economy, as they contribute to climate change and environmental degradation. Implementing circular economy strategies, such as recycling, waste reduction, and sustainable production, can lead to substantial decreases in emissions. (European Commission, 2024). Circular economy actions in the waste sector have been effective in reducing greenhouse gas emissions, with projections indicating a 68% reduction by 2035 compared to 1990 levels. (Janik et al., 2020; European Environment Agency, 2024). For Iran, integrating circular economy principles can be a strategic approach to mitigating climate change impacts.

Waste management is a cornerstone of the circular economy, encompassing strategies for reducing, reusing, and recycling materials. Effective waste management not only conserves resources but also generates economic value through the recovery of materials and energy. Circular economy practices in waste management can lead to significant environmental and economic benefits, including reduced landfill usage and lower greenhouse gas emissions. (Walters et al., 2024). In Iran, improving waste management systems is essential for advancing circular economy objectives.

Economic sanctions also have significant effects on environmental factors in Iran, largely through channels such as income reduction and limited access to finance and environmentally friendly technologies. Recent simulation studies using system dynamics and computable general equilibrium models forecast notable increases in CO<sub>2</sub> emissions in Iran by 2028, ranging from 12.5% to 30% compared to baseline scenarios. These increases are driven by factors including higher energy intensity and constrained economic growth under sanctions. The prolongation of international sanctions thus poses a major barrier to improving energy efficiency and reducing emissions, which in turn hampers the transition to a circular economy. Despite growing recognition of the economic impacts of sanctions, their environmental consequences—and resulting challenges for circularity—remain underexplored, highlighting a critical knowledge gap in the Iranian context. (Balali et al., 2025).

In summary, the economic factors of renewable energy consumption, water use efficiency, greenhouse gas emissions, and waste management are integral to the development of a circular economy in Iran. Addressing these factors through targeted policies and investments can facilitate the transition to a more sustainable and resilient economic model. This study aims to empirically analyze the impact of these variables on Iran's circular economy index, providing valuable insights for policymakers and stakeholders committed to sustainable development. In this study, we analyze the economic determinants of circularity within the context of Iran, a country facing considerable ecological challenges and economic constraints.

The structure of the paper is as follows: Section 2 presents the theoretical foundations and conceptual framework; Section 3 reviews empirical studies in circular economy; Section 4 describes the research methodology; Section 5 outlines the empirical modeling of the circular economy; and finally, Section 6 offers conclusions and policy implications.

## **2. Literature review**

Although various foreign studies have been conducted on the topic of the Circular Economy, there is a lack of comprehensive research specifically addressing the determinants of Circular Economy. However, several studies—directly or indirectly related to this subject—can be cited as follows:

Drofenik et al. (2025) applied an integrated top-down methodology for assessing and promoting circular economy progress at both the national and company levels, extending the MICRON framework originally developed by Baratsas et al. (2022). The approach enabled consistent evaluation across macro and micro scales by focusing on five key categories: energy, emissions, water, materials, and waste. A quantitative analysis, including sensitivity testing, identified energy and emissions as the most influential factors, guiding the development of targeted national strategies and company-level technoeconomic assessments. Tested in Slovenia, the methodology revealed stable circularity performance at the national level, with improvement potential in renewable energy use and energy efficiency at both country and company scales.

Xu et al. (2025) examined the impact of sustainable finance and investment in renewable energy on economic growth and environmental conservation in 22 EU nations from 2003 to 2025. They illustrated that these factors contribute to sustained economic advancement and environmental stewardship. In fact, moving away from businesses that produce a lot of carbon and towards cleaner energy alternatives not only contributes to the reduction of environmental hazards but also encourages the expansion of employment opportunities, promotes technological advancements, and guarantees a more secure energy future.

Frascareli et al. (2024) propose a macro-level circular economy index (MaCEI) for countries, built through a literature-based identification of 10 dimensions and 52 potential indicators. Using DEA-BoD, SNA, and PCA, they constructed the index for 18 EU countries, enabling performance ranking and benchmarking. The study highlights best practices, sets national targets, and provides a tool for monitoring and guiding the transition to a circular economy at the country level.

Obiuto et al. (2024) review the role of chemical engineering in advancing the circular water economy, emphasizing the use of computational simulations to foster sustainable water management. Their study highlights how modeling and optimization support wastewater treatment, resource recovery, and innovative purification technologies such as membrane filtration, adsorption, and

electrochemical processes. By integrating simulations across urban, industrial, and agricultural systems, they argue for holistic strategies that enhance resilience, sustainability, and efficiency in water resource management.

Rezaei (2022) applied a hybrid Multi-Criteria Decision-Making (MCDM) framework, integrating the Analytic Hierarchy Process (AHP) with the Combined Compromise Solution (CoCoSo) method, to evaluate the role of renewable energy (RE) sources in promoting sustainable development, optimizing the energy portfolio, and enhancing economic performance. Covering the period from 2004 to 2016, the findings highlight that solar photovoltaic (PV) energy holds the highest priority, while the economic criterion emerges as the most decisive factor in the selection of renewable energy resources.

Pintilie (2021) analyzes the progress of European Union countries towards the circular economy, using 13 indicators grouped into four pillars: production and consumption, waste management, secondary raw materials, and competitiveness and innovation. The study applies both temporal and spatial analyses, clusters the countries, and maps their positions in relation to the circular economy. The main findings highlight: (1) a strong concentration of problems in the waste management pillar; (2) Europe's significant contribution to the circular economy globally, though with heterogeneous developments across member states; and (3) the usefulness of the scoreboard's evolution in reflecting the continuous efforts undertaken by countries to advance the transition towards a circular economy.

Janik et al. (2020) analyze sustainability reports of EU energy sector companies, focusing on the disclosure of greenhouse gas (GHG) emissions and circular economy (CE) practices in line with the latest GRI Standards for the periods 2018-2020. Their findings show that reports emphasize GHG issues far more than CE actions, with strategic declarations often poorly reflected in operational indicators and concrete measures. The study also highlights that reporting quality is shaped by external assurance and report type, with comprehensive reports being more developed but less clear than core ones, while stand-alone reports display greater clarity.

Nahidi Amirkhiz et al. (2020) analyzed the relationship between economic growth, energy consumption, and CO<sub>2</sub> emissions in 16 OIC countries during 1995–2015 using panel data analysis. They found that the Kuznets Inverted U Hypothesis holds, meaning that CO<sub>2</sub> emissions initially rise with GDP growth but decline after reaching a certain economic threshold. The study also showed that energy consumption has a statistically significant positive effect on CO<sub>2</sub> emissions. The authors concluded that while economic growth initially increases environmental pressure, adopting eco-friendly technologies and environmental regulations can reduce emissions as economies mature.

While most previous studies have generally addressed the circular economy in broad conceptual terms, the literature in Iran has not incorporated critical

variables such as total annual water withdrawal, renewable energy consumption, greenhouse gas emissions, and waste generation into their analyses. None of the existing national studies have empirically examined the role of these factors in shaping the trajectory of the circular economy. To fill this gap, the present research employs a nonlinear multilevel regression model with both fixed and random effects, allowing for a more precise estimation of how these variables affect the circular economy index. This methodological approach not only captures the average relationships but also accounts for unobserved heterogeneity, offering new insights into the dynamics of the circular economy in Iran.

Despite their importance, existing indices such as UNEP's Circular Economy Indicators have not been widely adopted in the study due to several inherent shortcomings that limit their practical applicability and comprehensive assessment of circular economy performance. The main shortcomings of UNEP's Circular Economy Indicators relate to data limitations, narrow focus on physical metrics, incomplete coverage of circular economy dimensions, challenges in addressing material distinctions and international flows, and gaps in socio-institutional and policy-relevant indicators. (Nowaczek et al., 2023).

A nonlinear multilevel regression model with combined fixed and random effects outperforms the DEA method used by Frascareli et al. (2024) in analyzing the circular economy. Unlike DEA, which treats each unit independently and focuses on efficiency alone, the multilevel model captures variations at different levels (such as regional, national, and sectoral), providing a deeper and more detailed analysis. This method is also better suited to incorporate important environmental variables like total annual water withdrawal, renewable energy consumption, greenhouse gas emissions, and waste generation, which shape the circular economy's trajectory.

The main advantage of the multilevel regression approach is its ability to handle hierarchical data structures and complex relationships between factors, offering more comprehensive insights than the single-layer DEA models. It captures the influence of multiple factors simultaneously and models their effects more flexibly, making it a superior choice for evaluating the circular economy's dynamics and environmental impacts. (Hox et al., 2017).

### **3. Theoretical Framework**

Despite growing interest, the concept of the Circular Economy (CE) has yet to become fully mainstream, both in policy and practice (Kirchherr et al., 2018). However, a growing body of literature has gradually formed a clearer theoretical foundation for CE, which reflects its multidimensional and interdisciplinary nature. A synthesis of definitions from leading scholars and institutions reveals several recurring principles that define the CE paradigm.

At its core, the Circular Economy challenges the traditional linear model of "take-make-dispose" by proposing an alternative model aimed at resource efficiency and systemic sustainability. The CE model is built upon three core strategies: (i) minimizing the input of virgin materials and the output of waste and emissions; (ii) maintaining the utility and value of resources within the system for as long as possible; and (iii) reintegrating materials and products into the economic cycle through strategies like reuse, repair, remanufacturing, and recycling (Ghisellini et al., 2016; Elia et al., 2017; Kalmykova et al., 2018).

The European Commission (2014, 2015) emphasizes the CE's role in keeping resources in use for as long as possible, thereby preserving the added value of products and minimizing waste. The Ellen MacArthur Foundation (2015b) further conceptualizes CE as a system that is inherently regenerative and restorative by design. It distinguishes between technical and biological cycles and seeks to decouple economic growth from the depletion of finite natural resources, supporting policy goals such as employment generation and carbon footprint reduction.

From an ecological economics perspective, Sauve et al. (2016) frame CE as a model of production and consumption that promotes closed-loop material flows, internalizing externalities associated with virgin material extraction and waste generation. Similarly, Geissdoerfer et al. (2017) define CE as a regenerative system that reduces resource input and minimizes waste, emissions, and energy leakage through strategies such as long-life design, maintenance, remanufacturing, and recycling. Their framework emphasizes the importance of slowing, closing, and narrowing material and energy loops to ensure environmental sustainability.

Murray et al. (2017) provide a broader systems perspective, characterizing CE as an economic model that aims to optimize ecosystem functioning and human well-being through intentional design and management of processes and outputs. Kirchherr et al. (2018) expand this definition by situating CE within various levels of implementation—micro (products, companies), meso (eco-industrial systems), and macro (cities, regions, nations). They argue that CE must aim to achieve sustainable development by fostering environmental quality, economic prosperity, and social equity for current and future generations.

Additionally, Korhonen et al. (2018b) view CE as a sustainable development initiative seeking to transform the linear production-consumption system by introducing circular material flows and renewable energy, and fostering cooperation between producers, consumers, and institutions. This systemic view supports the creation of high-value material loops, going beyond traditional recycling practices.

Despite this growing conceptual clarity, several fundamental questions remain open. One of the key unresolved issues is the relationship between CE and total

annual water withdrawal, total renewable energy consumption, total greenhouse gas emissions, and waste generation.

In terms of practical implementation, CE operates across three analytical levels (Elia et al., 2017; Korhonen et al., 2018a):

- **Micro level:** Focuses on individual businesses or products, where CE strategies are applied internally. This level incorporates principles from cleaner production, design for the environment, and industrial ecology (Franco, 2017; Brown & Stone, 2007; Bilitewski, 2012).

- **Meso level:** Concerns the inter-firm level, typically involving networks of enterprises, such as eco-industrial parks, which enable industrial symbiosis through shared resources and collaborative waste management (Zhu et al., 2010; Chertow, 2000).

- **Macro level:** Refers to CE strategies at broader scales, including cities, regions, and nations. At this level, policies and regulatory frameworks play a central role in enabling systemic shifts. Concepts such as urban symbiosis, zero-waste cities, and circular public procurement are relevant (Feng & Yan, 2007; Ghisellini et al., 2016).

In conclusion, the CE framework represents a convergence of environmental, economic, and social strategies aimed at reducing the linearity of current production-consumption systems. While there is no universally accepted definition, the diversity of perspectives underscores the adaptability and systemic potential of CE. However, further theoretical development and empirical validation are required to clarify its boundaries, operational mechanisms, and measurable impacts.

## 4. Research Methodology

### 4.1 Nonlinear Multilevel Regression

Nonlinear Multilevel Regression is a statistical modeling approach used to analyze hierarchically structured data where the relationship between the dependent and independent variables is nonlinear. This method extends traditional linear multilevel (hierarchical) models by allowing nonlinear functional forms, accommodating complex patterns across multiple levels of data organization (e.g., measurements nested within individuals, individuals nested within groups). (Gelman & Hill, 2007; Rabe-Hesketh & Skrondal, 2012).

### 4.2 Model Specification

Consider a two-level data structure with observations  $i$  nested within groups  $j$ .

The nonlinear multilevel model can be written as:

$$y_{ij} = f(x_{ij}, \beta_j) + \varepsilon_{ij} \quad (1)$$

where:

$y_{ij}$  is the outcome variable for observation  $i$  in group  $j$ ,  $x_{ij}$  is a vector of predictors,  $\beta_j$  is a vector of group-specific parameters,  $f(\cdot)$  is a known nonlinear

function relating predictors to the outcome,  $\varepsilon_{ij}$  is the residual error term, typically assumed to be normally distributed with mean zero and variance  $\sigma^2$

#### 4.3 Random Effects Structure

The group-specific parameters  $\beta_j$  are modeled as:

$$\beta_j = \gamma_0 + u_j \quad (2)$$

where:

$\gamma_0$  represents the fixed effects (population-average parameters),  $u_j$  are random effects capturing group-level deviations, assumed to follow a multivariate normal distribution  $u_j \sim N(0, D)$ .

#### 4.4 Final Model Formulation

Combining the above gives:

$$y_{ij} = f(x_{ij}, \gamma_0 + u_j) + \varepsilon_{ij} \quad (3)$$

This formulation accounts for both nonlinear relationships and the hierarchical data structure, allowing parameters to vary across groups. (Pinheiro & Bates, 2000).

**For our study, the model setup is explained as follows:**

- Level 1: Observations within each sector (e.g., time points, regions, firms)
- Level 2: Groups (sectors: Water, Energy, Greenhouse Gases, Waste)
- Dependent variable: Circular Economy indicator,  $CE_{ij}$
- Predictors: Sector-specific predictors or covariates,  $x_{ij}$

#### Model Formula

$$CE_{ij} = f(x_{ij}, \beta_j) + \varepsilon_{ij} \quad (4)$$

where:

$CE_{ij}$  = Circular Economy value for observation i in sector j,  $x_{ij}$  = vector of predictors for observation i in sector j,  $\beta_j$  = vector of parameters specific to sector j,  $f(\cdot)$  = nonlinear function (e.g., exponential, logistic, polynomial),  $\varepsilon_{ij} \sim N(0, D)$  is the residual error

#### Modeling Sector-Specific Parameters

Because parameters vary by sector j, we model:

$$\beta_j = \gamma_0 + u_j \quad (5)$$

where:

$\gamma_0$  is fixed effects (common population-average parameters),  $u_j$  is random effects for sector j, capturing sector-specific deviations. Putting it all together:

$$CE_{ij} = f(x_{ij}, \gamma_0 + u_j) + \varepsilon_{ij} \quad (6)$$

with sectors  $j \in \{\text{Water, Energy, Greenhouse Gases, Waste}\}$ . This model captures

how the predictors  $x_{ij}$  nonlinearly influence the Circular Economy  $CE_{ij}$  within each sector. The parameters  $\beta_j$  vary by sector, reflecting differences in relationships across Water, Energy, Greenhouse Gases, and Waste. The residuals  $\varepsilon_{ij}$  account for unexplained variation at the observation level.

## 5. Modeling and Experimental Analysis

This part will first present the research data, followed by the estimation of the empirical model utilizing the research information and data. The findings of the model estimation have been thoroughly analyzed.

### 5.1 Data and model specification

A comprehensive set of variables is utilized for the analysis, covering the period from 1993 to 2023. The data are sourced from the World Bank datasets. The theoretical model incorporates the following variables: total annual water withdrawal (W), total renewable energy consumption (E), total greenhouse gas emissions (GH), and waste (RW) as well as the circular economy index (CI). Utilizing a nonlinear multilevel regression model with combined fixed and random effects, the research examines the impact of these variables on the circular economy index in Iran over the period 1993 to 2023. The total annual water withdrawal is the water consumption per ton of product or per inhabitant (m<sup>3</sup>/t or m<sup>3</sup>/capita). Total renewable energy consumption is the share of renewable energy in total final energy consumption. Total greenhouse gas emissions refer to the sum of all greenhouse gases released into the atmosphere by human activities within a specific time frame and geographic area. These gases include carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and fluorinated gases, which contribute to the greenhouse effect and global warming. Here, they refer to the average emissions from Building, Industrial Combustion, Fugitive Emissions, Transport as well as Power Industry. (World Bank, 2023). Waste refers to any substance or material—solid, liquid, or gaseous—that is discarded after primary use, having no further economic, functional, or environmental value to the holder. The circular economy index is the simple average of the total annual water withdrawal, total renewable energy consumption, total greenhouse gas emissions, and waste.

Consequently, to estimate the impact of these variables on the circular economy index in Iran, a nonlinear multilevel regression model must incorporate aforementioned variables in accordance with the frameworks established by Drogenik et al. (2025), Nwankwo et al. (2024) and Ishaq et al. (2022). Thus, the final model is employed:

Model

$$CI_{ij} = f(\beta) + \beta_1 W_{ij} + \beta_2 E_{ij} + \beta_3 GH_{ij} + \beta_4 RW_{ij} + u_j + \varepsilon_{ij} \quad (7)$$

$i$  represents the lower-level unit (e.g., individual or sample),  $j$  represents the higher-level unit (e.g., group or section such as water, energy, etc.),  $u_j$  is the random effect or variable specific to group  $j$ , The function  $f(\cdot)$  is a nonlinear function, which can be exponential, logarithmic, or power.

## 5.2 Analysis of findings

This study investigates the role of environmental and economic variables—namely total annual water withdrawal, total renewable energy consumption, greenhouse gas emissions, and waste generation—in influencing the trajectory of the circular economy in Iran from 1993 to 2023. A nonlinear multilevel regression model incorporating both fixed and random effects is employed to assess the impact of these variables on the circular economy index. This approach allows the analysis to account for both average effects across the entire period and unobserved heterogeneity within sub-periods. All variables are used in logarithmic form, and unit root tests are conducted beforehand to ensure stationarity, as reported in Table 1.

**Table 1: Results of stationary test**

variables	Test statistic	Dickey-Fuller critical value			Stationary rank
		1%	5%	10%	
W	-3.77	-2.652	-1.950	-1.602	<b>I(0)</b>
E	-3.35	-2.652	-1.950	-1.602	<b>I(0)</b>
GH	-5.39	-2.652	-1.950	-1.602	<b>I(1)</b>
RW	-5.34	-2.652	-1.950	-1.602	<b>I(1)</b>
CI	-5.45	-2.652	-1.950	-1.602	<b>I(1)</b>

**Table 2: Results of mixed effect ML nonlinear regression**

Log-likelihood: 164.207			Wald chi2:1.93e+06		
			prob > chi2 = 0.0000		
variables	Coefficient	Std. err	z	P >  z	95% conf. interval
<i>IW</i>	-0.091	0.018	-4.87	0.000	-0.127 -0.054
<i>IE</i>	0.004	0.001	4.15	0.000	0.002 0.006
<i>IGH</i>	-0.02	0.008	-2.79	0.005	-0.039 -0.007
<i>IRW</i>	-0.003	0.0006	-4.69	0.000	-0.004 -0.001
<i>_cons</i>	-0.064	0.061	-1.05	0.293	-0.185 0.055
Random effects paramters	estimate		Std. err		95% conf. interval
<b>var(Residual)</b>	7.07e-07		1.86e-07		4.22e-07 1.18e-06

The reported model fit statistics indicate that the Wald chi-square test is extremely large ( $\chi^2 = 1.93 \times 10^6$ ) with a corresponding probability value of 0.0000. This suggests that the overall model is highly statistically significant, meaning that the set of predictors jointly contributes to explaining the variation in

the dependent variable. The log-likelihood value (164.207) reflects the model's fit, and while it is not interpretable in isolation, in combination with the chi-square test it provides evidence that the model significantly improves upon a null (intercept-only) specification.

In addition, all explanatory variables included in the model were found to be highly statistically significant, with p-values less than 0.001. This indicates very strong evidence against the null hypothesis of no effect, confirming that each independent variable has a meaningful and robust impact on the dependent variable within the studied context. The high level of statistical significance suggests that the relationships identified are unlikely to be due to random chance, thereby reinforcing the reliability of the model's estimates. Moreover, such significance underscores the relevance of these predictors in explaining variations in the outcome, which supports the theoretical expectations and empirical findings from previous literature. These results provide a solid foundation for interpreting the influence of the studied factors on the circular economy dynamics over the examined period.

The random effects results show that the estimated residual variance is very small ( $\text{var}(\text{Residual}) = 7.07 \times 10^{-7}$ ), with a standard error of  $1.86 \times 10^{-7}$ . The 95% confidence interval ranges from  $4.22 \times 10^{-7}$  to  $1.18 \times 10^{-6}$ . Since the interval does not include zero, the residual variance is statistically significant, indicating that there remains a small but non-negligible portion of variability in the outcome that is not explained by the fixed effects. Overall, this suggests that while the unexplained variance is limited in magnitude, it is reliably different from zero and should be accounted for in the model.

It is worth noting that robustness checks, including robust regression, as well as Variance Inflation Factor (VIF) tests, have been conducted to address potential multicollinearity concerns. The results confirm the robustness of the findings, and the VIF values indicate that multicollinearity is not a serious issue among the variables. These analyses and their results are presented in Appendix 1.

## **6. Discussion**

This section provides a comprehensive discussion of the estimated effects of each variable on the development of the circular economy. By analyzing the individual impact of these variables, we aim to better understand their specific roles and relative significance in shaping circular economic performance. The results for each factor have been presented separately, allowing for a more detailed interpretation and comparison of their contributions.

### **Renewable Energy Consumption**

The findings reveal that renewable energy consumption exerts a positive and statistically significant effect on the circular economy, as indicated by the positive coefficient (0.004). This suggests that a higher share of renewable energy in total energy use directly enhances circular economy performance. The

underlying mechanism can be explained by the fact that renewable energy sources—such as solar, wind, hydro, and biomass—reduce dependence on finite fossil fuels, mitigate environmental externalities, and support low-carbon production processes. By lowering greenhouse gas emissions and reducing ecological footprints, renewable energy serves as a fundamental enabler of resource efficiency and sustainability. In this sense, the transition to renewable energy not only contributes to climate change mitigation but also aligns with the broader principles of circularity, such as waste minimization and regenerative resource flows.

#### **Water Withdrawal**

In contrast, water withdrawal demonstrates a negative and statistically significant relationship with the circular economy (coefficient = -0.091). Excessive water extraction places significant strain on ecosystems, reduces water availability for future use, and increases environmental vulnerability. In a circular economy framework, sustainable water use is critical to maintaining closed-loop systems in industrial processes, agriculture, and urban consumption. The negative coefficient indicates that unsustainable practices of water overuse undermine the potential to achieve circularity, as they generate ecological imbalances and exacerbate scarcity challenges. This highlights the need for policies aimed at improving water efficiency, adopting advanced water-recycling technologies, and integrating water resource management into circular economy strategies.

#### **Greenhouse Gas Emissions (GHGs)**

The results also show that greenhouse gas emissions negatively influence the circular economy (coefficient = -0.02). Higher levels of GHGs reflect unsustainable production and consumption patterns that are inconsistent with the goals of circularity. A circular economy seeks to decouple economic growth from environmental degradation, and rising emissions directly contradict this aim. Elevated GHGs increase climate risks, generate external costs, and necessitate greater adaptation and mitigation expenditures, all of which hinder circular transition. Therefore, the reduction of emissions through renewable energy adoption, energy efficiency measures, and circular production methods is a crucial pathway to strengthening circular economy performance.

#### **Waste Generation**

Similarly, waste generation exerts a negative impact on the circular economy (coefficient = -0.003). This result is consistent with the principles of circularity, which emphasize waste prevention, reuse, and recycling. High levels of waste reflect inefficiencies in resource use, linear production models, and the absence of closed-loop systems. Excessive waste not only increases disposal costs but also generates pollution and resource losses, thereby weakening circular economy outcomes. A strong emphasis on waste reduction strategies, including

eco-design, extended producer responsibility (EPR), and the promotion of industrial symbiosis, is thus necessary to counteract these adverse effects.

### **7. Conclusion**

This study explores how economic and environmental factors—specifically total annual water withdrawal, renewable energy consumption, greenhouse gas emissions, and waste generation—affect the development of the circular economy in Iran from 1993 to 2023. Using a nonlinear multilevel regression model, the research highlights that renewable energy consumption positively influences circular economy performance, while high levels of water withdrawal, emissions, and waste generation have negative impacts. These findings reveal the crucial role of sustainable resource management and environmental protection in advancing circular economic systems.

The results further emphasize the interconnectedness of water, waste, and emissions in shaping sustainable energy systems within the circular economy framework. Practices such as converting waste into energy and integrating water management with energy recovery help close material and energy loops, reducing environmental harm and promoting decarbonization. Overall, the study underscores that the circular economy is a complex, multifaceted system requiring balanced management of diverse resource-related factors to achieve sustainable development.

Based on these findings, the following policy recommendations are proposed to support the advancement of the circular economy in Iran.

#### **Policy Recommendations**

- Accelerate Renewable Energy Development with Focus on Solar and Wind

Considering Iran's abundant solar radiation and wind potential, the government should expand targeted subsidies and public-private partnerships to develop large-scale solar parks and wind farms, especially in less populated regions like the central and southeastern provinces. Additionally, updating regulations to facilitate easier grid integration of renewable energy and supporting small-scale rooftop solar installations can help diversify the energy mix, reduce reliance on fossil fuels, and lower greenhouse gas emissions.

- Improve Water Use Efficiency in Agriculture and Industry

Given that agriculture accounts for over 90% of Iran's water consumption, policies should prioritize modernizing irrigation systems by promoting drip and sprinkler irrigation technologies, alongside incentives for farmers to adopt water-saving practices. In industrial sectors, especially in petrochemicals and manufacturing hubs, investment in water recycling and treatment facilities is crucial. Strengthening integrated water resource management at provincial levels will help address regional water scarcity and support circular water use.

- Strengthen Waste Management and Promote Waste-to-Energy Projects

Iran faces significant challenges with municipal solid waste management and increasing landfill use. It is essential to enforce extended producer responsibility (EPR) regulations for packaging and industrial waste, encouraging producers to take back and recycle materials. Investing in pilot waste-to-energy plants, particularly in major cities like Tehran, Isfahan, and Mashhad, can reduce landfill dependency, decrease methane emissions, and provide alternative energy sources. Public awareness campaigns on waste segregation and recycling are also critical to improving waste collection quality.

### Appendix 1:

The results of the robustness test and the VIF test are presented in the tables below.

**Table 1-1: Results of robustness check**

variables	Coefficient	Robust Std. err	t	$P >  t $	95% conf. interval
<i>IW</i>	-0.18	0.037	-4.87	0.000	-0.26 -0.103
<i>IE</i>	0.004	0.001	3.88	0.001	0.002 0.007
<i>IGH</i>	-0.02	0.006	-3.64	0.002	-0.03 -0.010
<i>IRW</i>	-0.003	0.0006	-5.09	0.000	-0.004 -0.001
<b>_cons</b>	-0.064	0.064	-1.01	0.325	-0.198 0.069

The robustness check was conducted to verify the reliability and stability of the main regression results and to ensure that the estimated relationships between the key variables and the circular economy index (CI) are not sensitive to model specification or potential data variations. The results confirm the robustness of the findings: renewable energy consumption shows a positive and statistically significant effect on the circular economy, indicating that greater use of renewables enhances circular performance through improved resource efficiency and reduced environmental impact. In contrast, water withdrawal, greenhouse gas emissions, and waste generation all have negative and significant coefficients, suggesting that unsustainable water use, higher emissions, and excessive waste undermine circular economy outcomes. Overall, the robustness test supports the validity of the main conclusions, highlighting renewable energy as a key driver of circularity, while emphasizing the need to address resource overuse, emissions, and waste to strengthen circular transition.

**Table 1-2: Variance Inflation Factor (VIF) Results**

Variable	VIF	1/VIF
<b>gh</b>	4.12	0.2427
<b>w</b>	3.87	0.2583
<b>rw</b>	2.08	0.4814
<b>e</b>	1.94	0.5154
<b>Mean VIF</b>	<b>3.00</b>	

The Variance Inflation Factor (VIF) results indicate that multicollinearity is not a serious problem among the explanatory variables in the model. All VIF values are well below the commonly accepted threshold of 10, suggesting that no variable is excessively correlated with the others. The highest VIF belongs to gh (4.12), followed by w (3.87), which indicates a moderate degree of correlation, but still within acceptable limits. Similarly, rw (2.08) and e (1.94) show low VIF values, implying that they are relatively independent and provide unique information to the model.

From an economic perspective, these results suggest that the explanatory variables—greenhouse gas emissions, water withdrawal, renewable energy consumption, and others—each contribute distinct information to explaining variations in the circular economy index. The moderate correlation between gh and w may reflect the natural linkage between greenhouse gas emissions and water use in industrial and energy processes, but it does not distort the model's estimates. Overall, the mean VIF of 3.00 confirms that multicollinearity is not severe, and the estimated coefficients can be considered statistically reliable and economically meaningful.

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## تأثیر عوامل اقتصادی و زیست‌محیطی بر توسعه اقتصاد چرخشی در ایران: تحلیل رگرسیون غیرخطی چندسطحی (۱۳۷۲-۱۴۰۲)

### چکیده

در این مطالعه، نقش عوامل اقتصادی مانند کل برداشت سالانه آب، کل مصرف انرژی تجدیدپذیر، کل گازهای گلخانه‌ای و ضایعات در تعیین مسیر اقتصاد چرخشی مورد بررسی قرار می‌گیرد. این مطالعه با استفاده از مدل رگرسیون غیرخطی چند سطحی با اثرات ترکیبی ثابت و تصادفی<sup>۱</sup> به بررسی تأثیر این متغیرها بر شاخص اقتصاد چرخشی در ایران در دوره زمانی ۱۳۷۲ تا ۱۴۰۲ می‌پردازد. یکی از دلایل استفاده از این مدل آن است که این مدل ترکیبی از اثرات ثابت (مثل میانگین متغیرها) و اثرات تصادفی (برای پوشش تفاوت‌های مشاهده نشده بین مقادیر یا واحدها) را در نظر می‌گیرد. نتایج نشان می‌دهند از بین عوامل موثر بر اقتصاد چرخشی، مصرف انرژی تجدیدپذیر، با ضریب ۰,۰۰۴، تاثیر مثبت و معنادار بر اقتصاد چرخشی دارد. به عبارت بهتر، مدل نشان می‌دهد مصرف بیشتر انرژی تجدیدپذیر با بهبود شاخص اقتصاد چرخشی همراه است و مصرف انرژی تجدیدپذیر و انرژی‌های پاک نقش مثبتی بر شاخص اقتصاد چرخشی دارند و به توسعه اقتصادی پایدار کمک می‌کنند. علاوه بر این، برداشت آب، گازهای گلخانه‌ای و ضایعات با ضرایب ۰,۰۹۱-، ۰,۰۲- و ۰,۰۰۳- تاثیر منفی بر اقتصاد چرخشی دارند. این بدان معناست که هرچه استفاده ناپایدار از منابع (مثل آب)، تولید آلودگی (گازهای گلخانه‌ای) و ضایعات بیشتر باشد، توسعه اقتصاد چرخشی دچار اختلال می‌شود. سرمایه‌گذاری هوشمندانه و هدفمند در فناوری‌های بهینه مصرف آب، توسعه انرژی‌های تجدیدپذیر، گازهای گلخانه‌ای و مدیریت جامع پسماند، می‌تواند ستون‌های اصلی پیشرفت اقتصاد چرخشی باشد. بنابراین، برای تقویت اقتصاد چرخشی، سیاست‌گذاران باید بر گسترش انرژی‌های تجدیدپذیر و پاک تمرکز کرده و هم‌زمان، با به‌کارگیری فناوری‌های نوین، بهره‌وری مصرف آب، کنترل گازهای گلخانه‌ای و مدیریت پسماند را به‌طور مؤثر بهبود دهند. در همین راستا، طراحی و اجرای سیاست‌های منسجم زیست‌محیطی همراه با مشوق‌های مالی و تنظیم‌گری هوشمند می‌تواند مسیر گذار به اقتصاد چرخشی را تسریع کرده و تاب‌آوری زیست‌محیطی کشور را در بلندمدت تضمین کند.

**کلمات کلیدی:** اقتصاد چرخشی، انرژی‌های تجدیدپذیر، رگرسیون غیرخطی چند سطحی، گازهای گلخانه‌ای.

**طبقه بندی JEL:** O5, Q27, C30, O13, P28.

<sup>1</sup> Mixed-effects ML nonlinear regression