Last revised: July 2025

Iran's Sustainability Gap: An Economic Analysis

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Abstract

Iran faces a widening sustainability gap as biocapacity stagnates while the ecological footprint expands. This study investigates how external debt, economic growth, natural resource rents, and renewable energy consumption affect the national *load capacity factor*—a composite index of biocapacity relative to ecological demand.

Annual data for 1995–2023 were compiled from the World Bank and the Global Footprint Network. After verifying integration orders with Augmented Dickey–Fuller tests and selecting an optimal lag length, Johansen cointegration confirmed the presence of a long-run equilibrium relationship. Long-run coefficients were then estimated using Fully Modified Ordinary Least Squares (FMOLS). Model adequacy was evaluated with Hansen and Park cointegration tests, Jarque–Bera normality, and Ljung–Box and ARCH diagnostics.

FMOLS estimates revealed positive elasticities for external debt (0.12) and renewable energy consumption (0.11), indicating that prudent external financing and clean-energy expansion enhance Iran's load capacity factor. Conversely, economic growth (–0.96) and natural resource rents (–0.12) exhibited negative elasticities, reflecting the resource-curse effect and the economy's current position on the upward phase of the Environmental Kuznets Curve. Diagnostic tests detected no autocorrelation, heteroskedasticity, or coefficient instability.

managed sovereign borrowing and accelerated investment in renewables can improve Iran's environmental carrying capacity, provided that growth strategies become less resource-intensive and rent dependence diminishes. Policy measures should include carbon-linked fiscal rules, green load-capacity bonds, a natural-resource-rent stabilization fund, and an inflation-indexed carbon tax whose proceeds support renewable feed-in tariffs.

Keywords: Ecological Carrying Capacity, Ecological Footprint, External Debt, Natural Resource Rent, Renewable Energy Consumption, Sustainable Development, Iran

JEL classification: Q01, Q56, Q32, Q43, F34, C32

Author Summary

We set out to understand why Iran’s demand on nature keeps outstripping what its land and ecosystems can regenerate each year. Using publicly available data from 1995 to 2023, we tracked the “load-capacity factor”—the simple ratio of Iran’s ecological supply (biocapacity) to its ecological demand (ecological footprint). A value below one means the country is running an ecological deficit. We then asked how four familiar economic forces shape that ratio: foreign borrowing, overall economic growth, income from oil and other natural resources, and the share of renewables in the national energy mix.

Our analysis shows a clear double message. When external debt is channelled into long-lived green projects and when renewable energy gains even a modest foothold, Iran’s ecological balance improves. By contrast, rapid GDP growth that relies on fossil fuels, together with heavy dependence on oil and gas rents, pushes the country deeper into deficit. These findings suggest that policy makers can narrow Iran’s sustainability gap by linking new borrowing to low-carbon investments, scaling up renewables, and using resource revenues to fund environmental restoration rather than day-to-day spending. Because many resource-dependent economies face similar trade-offs, our results provide a practical roadmap for aligning financial decisions with long-term ecological health.

Introduction

The environmental sustainability gap arises when human pressure and demand on ecosystems exceed their regenerative capacity. In recent decades, the growth of global resource consumption has reached a point where this ecological deficit has seriously strained ecosystems and endangered sustainability (AL-Marshadi et al., 2025). According to international reports, humanity is currently exploiting the Earth’s resources about 80% faster than the planet can regenerate; in other words, each year we consume the equivalent of 1.8 Earths. The consequences of this situation are fully evident at a global scale: widespread deforestation, soil erosion, loss of biodiversity, and increasing atmospheric CO_2 concentration are clear examples of the excessive pressure on the Earth’s biocapacity (Global Footprint Network, 2025).

Iran, as a country with diverse climates and abundant natural resources, has faced serious environmental sustainability challenges in recent decades. Reliable international and national statistics indicate that Iran’s biocapacity is lower than the consumption and ecological pressure exerted by its population. According to data from the Global Footprint Network (GFN), in 2021, Iran’s total biocapacity was estimated at about 60.4 million global hectares, ranking 36th among the world’s countries, while its total annual ecological footprint reached 262 million global hectares, placing Iran 16th globally in this regard (Haji Hashemi et al., 2021).

According to the United Nations Development Programme (2021), Iran is among the countries with high carbon footprints and is ranked among the top ten countries in terms of carbon dioxide emissions. Industrial development, widespread urbanization—which covers about 75% of the country’s population—historical reliance on cheap fossil fuels, and insufficient incentives to improve energy efficiency have all contributed to high energy consumption and increased greenhouse gas emissions in Iran.

Alongside high fossil fuel consumption, the share of renewable energy in Iran’s energy mix remains very low. Despite the country’s considerable potential for solar and wind energy, investments in these sectors have been limited, and as of early 2025, the total installed capacity of Iran’s renewable power plants was around 1,560 megawatts. Nevertheless, the share of renewable electricity in the country’s total electricity production is only about 0.7%, which indicates the high dependence of Iran’s energy economy on fossil fuels (Tehran Times, 2025).

At present, Iran is experiencing manifestations of environmental unsustainability that also impact the country’s economic and social welfare. In recent years, recurring droughts and dust storms have affected large areas of the country, causing considerable damage to the agricultural sector. Global climate change and unsustainable management of water and soil resources have also increased the uncertainties and risks facing Iran’s environmental outlook (World Bank, 2022).

This study begins with the following central question: “How do external debt, economic growth, natural resource rents, and renewable energy consumption affect Iran’s environmental load capacity factor?” The aim of this research is to provide long-term estimates that reveal which of these variables strengthen or weaken the country’s biocapacity, thereby outlining the optimal policy path to narrow the sustainability gap.

The existing literature on sustainability has mostly focused on carbon emissions or the ecological footprint, and has rarely used the composite indicator of the load capacity factor (LCF). Additionally, the role of external debt—alongside natural resource rents and the energy transition in resource-dependent economies—has seldom been examined within a single empirical framework. The main innovation of this study is the integration of the green debt theory and the resource curse hypothesis with the LCF metric, estimated using the FMOLS method for Iran. This approach provides a more precise picture of the financial and structural channels affecting sustainability.

The structure of the paper is organized as follows: Section 2 presents the theoretical foundations and conceptual framework of the study. Section 3 reviews the related empirical literature. Section 4 introduces the research methodology, data, and FMOLS econometric model. The results of the long-term estimates and diagnostic tests are presented in Section 5. Section 6 analyzes and interprets the findings in light of the international literature. Finally, Section 7 offers conclusions, policy recommendations, and suggestions for future research.

2. Theoretical Framework

2.1. Sustainability Gap and the Load Capacity Factor

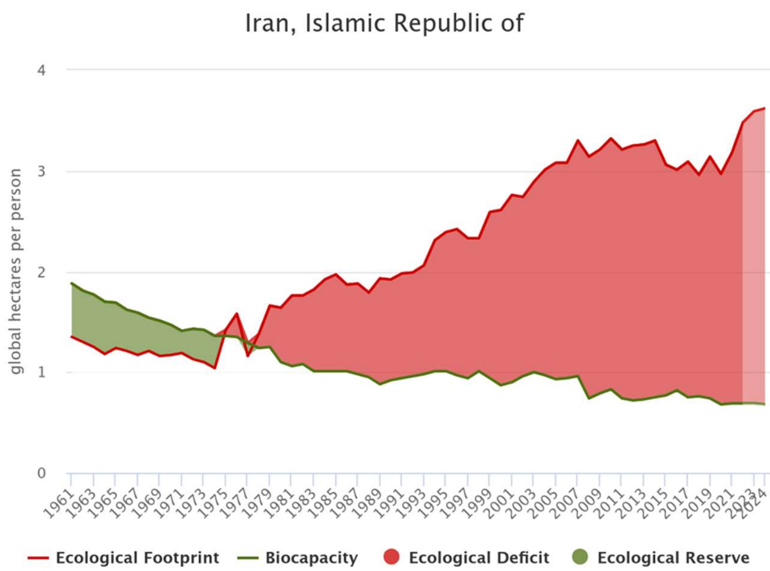
The concept of ecological carrying capacity, introduced by Wackernagel and Rees (1996), posits that long-term sustainability is achieved when a country's biocapacity at least equals its ecological footprint. The Load Capacity Factor (LCF)—the ratio of biocapacity to ecological footprint—serves as a synthetic and practical measure for assessing the pressure exerted on ecosystems (Wackernagel & Rees, 1996). LCF values below unity indicate unsustainability and the presence of an ecological deficit; in other words, resource consumption exceeds ecosystems' regenerative capacity (Arrow et al., 2012). As global resource extraction accelerates, the LCF enables policymakers to monitor both ecological supply and demand.

In Iran, a review of the historical trend of these indicators reveals that the country has consistently faced an ecological deficit, signaling a gradual intensification of the sustainability gap (Global Footprint Network, 2024). This persistent shortfall has become more pronounced due to rapid urbanization, energy-intensive development, and the impacts of climate change. Additionally, misalignments between national development policies and environmental goals have contributed to further widening the gap.

Recent dynamic input–output studies show that the combined effects of climate change and economic expansion have significantly accelerated the growth of Iran's ecological footprint, outpacing regeneration capacity (Keshavarz & Farajzadeh, 2025). Holistic management research further highlights that deficiencies in governance and insufficient cross-sectoral coordination have eroded the nation's ability to restore natural capital (Kolahi et al., 2025). Altogether, these findings suggest that bridging Iran's sustainability gap will not be feasible without comprehensive energy reforms, institutional improvements, and integrated climate risk management.

Figure 1 illustrates these historical trends in Iran's biocapacity and ecological footprint, providing a clear visual representation of the country's ecological deficit over time.

Figure 1. Trends in Ecological Footprint and Biocapacity per Capita in Iran (1961–2024)



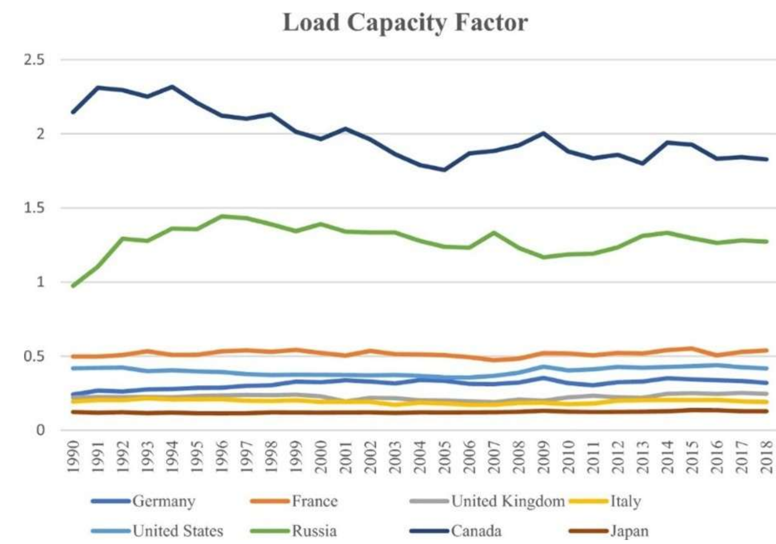
Note. This figure illustrates the per capita ecological footprint and biocapacity in Iran from 1961 to 2024. The area shaded in red represents the ecological deficit, indicating the extent to which resource consumption has exceeded the ecosystem's regenerative capacity.

Source. Global Footprint Network, National Footprint and Biocapacity Accounts (2025)

International comparisons of these indicators clarify each economy's progress toward environmental sustainability and allow for a more nuanced assessment of the strengths and weaknesses of their policy frameworks. Comparative evidence shows that systems that diversified their energy mix early, invested consistently in low-carbon technologies, and implemented broad environmental taxes have managed to stabilize—or even reverse—the downward trend in LCF over time. In contrast, economies that remain reliant on fossil fuels and lack coherent strategies for energy transition continue to face persistent ecological deficits and increasing pressure on natural resources, which ultimately undermines their long-term resilience. These experiences demonstrate that stable regulations, integrated planning, and genuine stakeholder engagement reduce investment risk and accelerate the spread of sustainable technologies. Furthermore, the sustained involvement of financial institutions and international donors has played a decisive role in supporting large-scale renewable transitions and grid modernization efforts, both in advanced and emerging economies (Mehmood et al., 2023). Recent research also indicates that green bond programs, when explicitly tied to specific emissions reduction targets, can mobilize significant private capital for clean energy infrastructure, shorten payback periods, and foster innovation. In addition, such collaborative approaches have promoted knowledge sharing and policy innovation among countries, further enhancing their adaptive capacity to address ongoing sustainability challenges (Shah et al., 2025).

Figure 2, presented below, summarizes the historical LCF trajectories for eight major economies and illustrates the impact of diverse policy strategies on ecological outcomes.

Figure 2. Comparison of Load Capacity Factor Among Selected Major Economies (1990–2018)



Note. This figure presents a comparative trend in the Load Capacity Factor (LCF) for eight major global economies (Germany, France, United Kingdom, Italy, United States, Russia, Canada, and Japan) over the period 1990 to 2018. Values above one indicate an ecological reserve, while values below one indicate an ecological deficit.

Source. Mehmood et al. (2023), data from Global Footprint Network.

2.2. External Debt and Environmental Sustainability

Within the framework of macroeconomic and public finance literature, the sustainability of public debt is primarily evaluated by comparing the cost of borrowing with the economic growth rate (Blanchard, 2019). However, in the environmental context, the allocation of external debt plays a crucial role in sustainability. Allocating external debt resources to green infrastructure and low-carbon technologies can increase biocapacity and reduce the ecological footprint; conversely, if these resources are spent on current expenditures or the import of fossil fuels, environmental pressures may intensify and sustainability will be adversely affected (Blanchard, 2019).

2.3. Economic Growth and the Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve hypothesis, proposed by Grossman and Krueger (1995), explains the relationship between economic growth and environmental quality in the form of an inverted-U. According to this hypothesis, in the early stages of economic development, GDP growth leads to increased environmental pressure and a decline in the LCF index. However, upon reaching higher levels of per capita income and surpassing a certain threshold, countries gradually move toward adopting cleaner technologies and more stringent regulations, thereby gradually decoupling economic growth from environmental degradation (Grossman & Krueger, 1995). In this context, given the Iranian economy's dependence on fossil fuels and the lack of transition beyond the aforementioned threshold, the relationship between economic growth and LCF is expected to remain negative in the studied period.

2.4. Natural Resource Rents and the Resource Curse Hypothesis

According to the "resource curse" theory (Sachs & Warner, 2001), economies dependent on primary commodity rents are typically more exposed to institutional problems, economic volatility, and slow structural transformation. Subsequent studies (Mehlum, Moene, & Torvik, 2006) have shown that dependence on natural resources can lead to a reduction in investment in natural capital and innovation, thereby resulting in a decline in environmental sustainability. In this context, increased reliance on natural resource rents is expected to have a direct negative effect on LCF.

2.5. Methodological Approach

In this study, in order to empirically examine the aforementioned relationships and control for endogeneity and autocorrelation effects that often arise in long-term analyses and cointegrated data, the Fully Modified Ordinary Least Squares (FMOLS) econometric technique is employed (Phillips & Hansen, 1990).

2.6. Summary of Conceptual Relationships

The theoretical model of this study can be summarized as follows:

$$CF = fED^{\pm},\ GDP^{-},\ NR^{-},\ EC$$

- External Debt (ED): Its effect depends on environmental orientation and the efficiency of allocation (Blanchard, 2019).
- Economic Growth (GDP): Expected to have a negative effect in the short term (Grossman & Krueger, 1995).
- Natural Resource Rents (NR): Predicted to reduce LCF (Mehlum et al., 2006).
- Renewable Energy Consumption (REC): Has a positive effect on LCF.

3. Literature Review

Numerous studies over the past decade have examined the macroeconomic factors affecting environmental sustainability, especially focusing on indicators such as the Ecological Footprint (EF), Biocapacity (BC), and Load Capacity Factor (LCF). The findings of these studies provide a multidimensional perspective on the sustainability status of Iran and other countries.

A review of the historical trends of ecological footprint and biocapacity in Iran shows that the sustainability gap (i.e., the ecological deficit) has been steadily increasing. Despite the existence of multiple environmental regulations, population growth and pressure on natural resources have caused resource consumption to exceed nature's regenerative capacity, and returning to a state of equilibrium between EF and BC is the minimum action that should be considered to reduce pressure on Iran's environment (Fatemi et al., 2018).

At the macro-analytical level, Golkhandan (2024), using a panel threshold model and the LCF index in 67 countries (including Iran), showed that public debt, depending on the level of natural resource rent and governance quality, can have different effects on sustainability. The effect of public debt in countries with high resource rents or weak governance is negative and significant. In addition, per capita energy consumption and population density significantly reduce LCF. These findings highlight the vital role of economic structure and governance in explaining the relationship between debt and sustainability (Golkhandan, 2024).

The study by Ziaabadi et al. (2021), using the Markov switching-error correction model, investigated the effects of macroeconomic variables, including economic growth, financial development, energy consumption, and urbanization, on Iran's ecological footprint, and showed that almost all these variables significantly lead to increased pollution and environmental degradation; only human development had a positive effect on environmental quality. This study also confirms the Environmental Kuznets Curve hypothesis for Iran (Ziaabadi et al., 2021).

Regarding the impact of climate change and the structure of Iran's economy, a study using input-output data shows that Iran's fragile economic growth has been accompanied by an increasing ecological deficit. More than 75% of Iran's ecological footprint is related to energy consumption, and this pressure will persist under different climate scenarios in the coming decades. Furthermore, the share of the services sector in generating the ecological footprint is significant, indicating that shifting economic activities toward services will also transform pressure on other sectors (especially agriculture) (Keshavarz & Farajzadeh, 2025).

At the international level, studies have shown that economic sanctions against Iran have also had indirect but widespread effects on environmental conditions; sanctions, by reducing access to technology and international financial resources, have increased Iran's reliance on natural resource extraction and polluting activities, raising the environmental costs of economic production (Madani, 2021).

Other comparative studies focusing on emerging or resource-rich countries have yielded similar results. In Brazil, the results of the A-ARDL model indicate that increased renewable energy consumption and natural resource rents improve LCF, but increased external debt and foreign direct investment have a negative and significant effect on the load capacity factor (Saleem et al., 2024). In Turkey, studies have shown that both external debt and energy consumption and income growth weaken environmental quality (increase EF) in both the short and long term; therefore, fiscal reforms and debt management are necessary for achieving sustainability in these countries (Xu et al., 2022).

Studies on African countries, while confirming the Environmental Kuznets Curve, indicate that external debt—especially in countries heavily dependent on fossil fuels—increases environmental pressure, and policies focused on reducing fossil fuel dependency should be prioritized (Akam et al., 2022).

At the regional level, studies conducted on Southeast Asian countries (ASEAN) have shown that both renewable energy consumption and natural resource rents can reduce environmental pressure across all distribution quartiles, and policymakers should allocate revenues from natural resources to investment in clean energy (Hacıimamoğlu & Cengiz, 2024).

In developed (OECD) countries, findings suggest that developing human capital, increasing the share of renewables, and optimal use of natural resource rents can play a crucial role in achieving sustainable development goals and reducing ecological deficits; additionally, a U-shaped relationship between income growth and environmental quality has been confirmed (Guloglu et al., 2023).

More recent studies using panel data from developing countries also indicate that the effect of renewables on reducing ecological footprint is conditional on financial capacity, adequate levels of human development, and institutional quality, and that population policies also play a role in strengthening this effect (Azimi & Rahman, 2024).

In oil-producing countries, although renewable energy consumption has not yet had a significant effect on EF, economic growth has mostly increased the ecological footprint, and there is evidence of the "pollution haven" hypothesis (Çakmak & Acar, 2022).

A review of the literature reveals that most previous studies on environmental sustainability in Iran have focused on the ecological footprint or one-dimensional carbon emission estimates, and only a handful have simultaneously integrated both the supply and demand sides of ecological capacity. Even in recent international studies utilizing the load-capacity factor (LCF), the role of financial variables—particularly external debt—has often been modeled with simple linear assumptions or entirely overlooked. Moreover, existing research typically examines the effect of natural resource rents separately from institutional quality and has rarely addressed the simultaneous interplay between rents, debt, and renewable energy; thus, a comprehensive picture of how financial structure and energy dynamics impact Iran's sustainability gap remains absent.

The present study addresses this gap through two main innovations: (1) it employs the load-capacity factor as a composite indicator of ecological supply and demand, capturing the ratio of biocapacity to ecological footprint and directly reflecting environmental carrying capacity; and (2) it integrates four key drivers—external debt, economic growth, natural resource rents, and renewable energy consumption—within a long-run econometric framework for Iran (1995–2023), while also accounting for relevant institutional and structural thresholds. In this way, the research not only fills a theoretical gap regarding the interaction of financial–energy mechanisms and sustainability, but also provides a novel analytical basis for green debt policy and resource rent management in Iran.

4. Materials and Methods

4.1. Data and Variables

This study examines the effects of external debt, economic growth, natural resource rents, and renewable energy consumption on the load-capacity factor (CF) as an indicator of environmental sustainability in Iran. The analysis covers the years 1995 to 2023, a period selected based on the availability and reliability of annual data from internationally recognized sources. All variables were extracted from reputable databases, including the World Bank and the Global Footprint Network, and standardized according to international protocols.

In this research, the load-capacity factor (CF) is constructed following the theoretical framework of Wackernagel and Rees (1996), and is defined as the ratio of per capita biocapacity to per capita ecological footprint for each year:

$$LCF_t = \frac{Biocapacity_t}{Ecological\ Footprint_t}$$

Both components are measured in global hectares per capita (gha per capita) and are extracted from the Global Footprint Network for the period 1995–2023, ensuring consistency and comparability. Values of this index less than or greater than one indicate, respectively, ecological deficit or surplus. For the purposes of econometric analysis, the natural logarithm of this index $(\ln LCF_t)$, together with the financial and energy variables (ED, EGDP, NNR, REC), is included in the empirical model.

A detailed description of the variables, their calculation methods, and data sources is provided in Table 1.

Table 1. Description, Calculation, and Data Sources of Variables

Symbol	Variable	Calculation Method	Data Source
CF	Load Capacity Factor	$\frac{Biocapacity_t}{Ecological\ Footprint_t}$	Global Footprint Network
ED	External Debt	External debt stock (% of GDP)	World Bank
EGDP	Economic Growth	Annual GDP growth rate (%)	World Bank
NNR	Natural Resource Rents	Natural resource rents (% of GDP)	World Bank
REC	Renewable Energy Consumption	Share of renewables in total final energy consumption (%)	World Bank
ε_{it}	Disturbance Term	–	–

Source. Authors' findings

To enhance the interpretability and statistical properties of the estimates, all variables (except for the growth rate, which may take negative values) were log-transformed. For the economic growth variable (EGDP), a transformation of $(EGDP + 100)$ was applied prior to log conversion to circumvent negative or zero values, following recommendations in the literature (Kunst & Neusser, 2020).

4.2. Empirical Model

Guided by recent literature—including Salim et al. (2024)—the following long-run model is specified:

$$\ln CF_t = \beta_0 + \delta_1 \ln ED_t + \delta_2 \ln(EGDP_t + 100) + \delta_3 \ln NNR_t + \delta_4 \ln REC_t + u_t$$

Where $\ln C F_t$ denotes the natural logarithm of the load capacity factor in year t and u_t is the disturbance term. Theoretical expectations suggest that the coefficient for external debt δ_1 can be positive or negative depending on the allocation of funds, the coefficient for economic growth δ_2 may exhibit a nonlinear relationship (in line with the Environmental Kuznets Curve hypothesis), the coefficient for natural resource rents δ_3 is expected to be negative (resource curse hypothesis), and the coefficient for renewable energy consumption δ_4 is anticipated to be positive.

4.3. Econometric Strategy and Estimation Procedure

Stationarity and Cointegration Testing

Initially, the stationarity properties of the variables were examined using Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests. To account for potential structural breaks resulting from major macroeconomic events (e.g., sanctions, COVID-19 pandemic), the Zivot–Andrews test was also implemented.

Cointegration Analysis

Following confirmation of non-stationarity and first-order integration [I(1)] of the variables, the presence of a long-run equilibrium relationship was assessed using Johansen and Pedroni cointegration tests.

Long-Run Model Estimation

The Fully Modified Ordinary Least Squares (FMOLS) estimator proposed by Phillips and Hansen (1990) was employed to estimate the long-run coefficients. FMOLS corrects for serial correlation and endogeneity, ensuring asymptotically unbiased and efficient parameter estimates even in small samples. The general formulation of the FMOLS estimator is as follows:

$$\widehat{\beta_{FM}} = \left(\sum_{t=1}^{T} \widetilde{x_t}\,\widetilde{x_t'}\right)^{-1} \left(\sum_{t=1}^{T} \widetilde{x_t}\left(\Delta y_t - \widehat{\Omega_{21}}\widehat{\Omega_{22}^{-1}}\Delta x_t\right)\right)$$

where $\widetilde{x_t}$ denotes the bias-corrected regressors and $\widehat{\Omega_{ij}}$ are elements of the long-run covariance matrix. The Newey–West method with an appropriate bandwidth was utilized for variance estimation.

Diagnostic Checking

After model estimation, several diagnostic tests were conducted to ensure the validity of the classical regression assumptions and coefficient stability:

- Breusch–Godfrey test for autocorrelation
- White's test for heteroskedasticity
- Ramsey RESET test for model specification

Short-Run Dynamics

To further explore the dynamic adjustment process, an Error Correction Model (ECM) based on the residuals from the FMOLS long-run equation was estimated. A negative and statistically significant error correction coefficient indicates that deviations from the long-run equilibrium are partially corrected each year, confirming the stability and robustness of the model.

4.4. Considerations and Limitations

The logarithmic transformation of percentage variables required the exclusion or interpolation of zero or near-zero values. Additionally, the lack of annual data for certain institutional variables (such as governance quality or human capital) represents a limitation, and their inclusion is recommended for future research.

By integrating unit root tests, cointegration analysis, and the FMOLS estimation approach, this methodological framework provides a rigorous basis for assessing the long-run effects of macroeconomic variables on Iran’s load capacity factor. The application of post-estimation diagnostics and short-run dynamic analysis further enhances the credibility and policy relevance of the study’s findings.

4.5. Software and Computational Tools

All statistical and econometric procedures in this study—including data preparation, unit root tests, optimal lag selection, cointegration modeling, long-run coefficient estimation using the FMOLS method, and diagnostic tests (such as Ljung–Box and ARCH-LM)—were conducted using EViews version 13.

5. Results

5.1. Descriptive Statistics

Table 2 summarizes the descriptive statistics for the key variables from 1995 to 2023. The average load capacity factor (CF) was 0.287, with values ranging from 0.191 to 0.435 and a standard deviation of 0.070, indicating limited dispersion. External debt (ED) averaged 5.778 percent of GNI, with a minimum of 1.154 and a maximum of 22.602, and a standard deviation of 4.970. The mean economic growth rate (EGDP) was 3.150 percent, fluctuating between –3.747 and 8.815 percent. Natural resource rents (NNR) accounted for an average of 24.797 percent of GDP, with a range of 13.136 to 34.779 percent. Finally, the share of renewable energy (REC) in total final energy consumption averaged 0.900 percent, varying from 0.400 to 1.400 percent over the period.

Table 2. Descriptive Statistics of Model Variables (Iran, 1995 – 2023)

Variable	Mean	Median	Min	Max	Std. Dev.	N
CF	0.287	0.257	0.191	0.435	0.07	29
ED	5.778	4.058	1.154	22.602	4.97	29
EGDP	3.15	3.19	–3.747	8.815	3.406	29
NNR	24.797	24.18	13.136	34.779	6.286	29
REC	0.9	0.9	0.4	1.4	0.222	29

Note.
CF: Load Capacity Factor (ratio of biocapacity to ecological footprint).
ED: External Debt (as a percentage of Gross National Income, % of GNI).
EGDP: GDP Growth Rate (annual percentage change, %).
NNR: Natural Resource Rents (as a percentage of GDP, % of GDP).
REC: Renewable Energy Share (share of renewables in total final energy consumption, % of TFEC).
N: Number of observations.

Source. Authors’ findings using EViews.

5.2. Unit Root Tests

The stationarity of all time series was examined using the Augmented Dickey–Fuller (ADF) test. Table 3 reports the ADF statistics at both level and first difference. Based on the 5% critical value, only natural resource rents (NNR) are stationary at level (I(0)), while all other variables become stationary after first differencing (I(1)). This confirms the mixed integration order and the suitability of a cointegration framework.

Table 3. Results of the Augmented Dickey–Fuller (ADF) Unit Root Test

Variable	ADF Level	p-value	ADF First Diff.	p-value	Integration Order
ln CF	–2.27	0.18	–4.83	0	I(1)
ln ED	–2.28	0.18	–4.22	0	I(1)
ln EGDP	–2.02	0.28	–4.92	0	I(1)
NNR	–3.34	0.02	–5.65	0	I(0)
ln REC	–2.03	0.17	–5.51	0	I(1)

Source. Authors' findings using EViews.

5.3. Lag Length Selection

Lag order selection was performed using the Akaike (AIC), Schwarz–Bayesian (SBIC), and Hannan–Quinn (HQ) criteria. All three criteria identified a lag length of 1 as optimal for the model, as shown in Table 4.

Table 4. Optimal Lag Selection Criteria

Lag	AIC	SBIC	HQ
0	–11.28	–11.04	–11.22
1	–14.94	–13.48	–14.54
2	–14.74	–12.04	–13.98

Source. Authors' findings using EViews.

5.4. Johansen Cointegration Test

The results of the Johansen cointegration test (Table 5) indicate the presence of one cointegrating vector at the 5% significance level, based on both the trace and max-eigenvalue statistics. This confirms the existence of a stable long-run relationship among the variables.

Table 5. Johansen Cointegration Test Results

Hypothesized r	Trace Statistic	5% Critical Value	p-value	MaxEigen Statistic	5% Critical Value	p-value
r = 0	77.93	69.82	0.009	33.88	33.78	0.05
r ≤ 1	44.2	47.86	0.105	27.58	17.97	0.497
r ≤ 2	26.22	29.8	0.122	13.21	11.61	0.586
r ≤ 3	15.49	14.61	0.06	14.26	9.24	0.266
r ≤ 4	5.36	3.84	0.02	3.84	5.36	0.02

Source. Authors' findings using EViews.

5.5. Long-Run Estimation: FMOLS

The long-run model was estimated using the Fully Modified Ordinary Least Squares (FMOLS) approach. Table 6 presents the estimated coefficients, standard errors, t-statistics, and significance levels. All coefficients are statistically significant at the 1% or 5% level.

Table 6. FMOLS Long-Run Coefficient Estimates

Variable	Coefficient	Std. Error	t-stat	p-value
ln ED	0.12	0.015	8.36	0
ln EGDP	–0.960	0.113	–8.53	0
ln NNR	–0.120	0.031	–3.87	0
ln REC	0.11	0.036	3.08	0.003
Constant (C)	3.111	0.405	7.69	0

Note. Since the model is log-linear (or semi-log for growth), coefficients represent elasticities or semi-elasticities. For example, a 1% increase in external debt (as a percentage of GDP) is associated with a 0.12% increase in the load capacity factor,

Source. Authors' findings using EViews.

5.6. Diagnostic Tests

Model adequacy was assessed through several diagnostic tests, summarized in Table 6. Hansen and Park statistics confirm cointegration and stability.
The Jarque–Bera test shows normality of residuals.

Table 7. Diagnostic Test Results

Test	Statistic	p-value	Conclusion
Hansen Lc	0.245	0.8	Do not reject H_0 (cointegration)
Park χ^2	1.066	0.59	Do not reject H_0 (cointegration)
Jarque–Bera	2.67	0.262	Residuals are normal

Source. Authors' findings using EViews.

Further assessment for serial correlation and heteroskedasticity was performed using the Ljung–Box Q-statistics and ARCH-LM tests up to lag 12 (Table 8). None of the statistics are significant at the 5% level, confirming the absence of autocorrelation and conditional heteroskedasticity in the model residuals.

Table 8. Results of Ljung–Box and ARCH-LM Tests (Lags 1–12)

Lag	Q-stat (Ljung–Box)	p-value	LM-stat (ARCH)	p-value
1	0.508	0.473	0.544	0.461
2	0.65	0.722	1	0.607
3	1.621	0.655	1.677	0.642
4	7.374	0.117	1.814	0.777
5	8.637	0.124	1.971	0.853
6	8.662	0.194	1.972	0.922
7	10.713	0.152	2.017	0.959
8	10.721	0.218	2.516	0.961
9	10.748	0.293	3.328	0.95
10	11.119	0.348	3.493	0.967
11	15.842	0.147	6.537	0.835
12	16.23	0.181	6.941	0.861

Source. Authors' findings using EViews.

6. Discussion

The empirical findings of this study reveal robust and policy-relevant insights into the macroeconomic determinants of environmental sustainability in Iran, as measured by the load capacity factor (LCF). The long-run FMOLS estimates (see Table 6) indicate that external debt and renewable energy consumption have statistically significant positive effects on LCF, while economic growth and natural resource rents exert significant negative impacts. These results are discussed in detail below, alongside a comparative assessment with the relevant literature.

6.1. External Debt:

The positive elasticity of external debt (0.12) suggests that, under conditions of efficient allocation—primarily to green infrastructure and renewable energy investment—external financing can enhance Iran’s ecological carrying capacity. This finding is consistent with the theoretical arguments by Blanchard (2019) and recent panel evidence from Golkhandan (2024), who reported that debt can be a double-edged sword: its impact depends on both the direction of spending and governance quality. In Iran, the moderate effect size may reflect the partial use of external resources for non-developmental purposes and the constraints imposed by international sanctions, which limit the full realization of green investment potential (Madani, 2021). Notably, this result stands in contrast with evidence from Brazil (Saleem et al., 2024) and Turkey (Xu et al., 2022), where external debt is generally found to undermine sustainability, possibly due to differences in institutional context and the stringency of fiscal discipline. This highlights the importance of governance and resource management in mediating the environmental outcomes of financial flows.

6.2. Economic Growth:

The significantly negative coefficient for economic growth (–0.96) confirms the expectation derived from the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995): at current levels of development and energy structure, higher GDP growth increases ecological pressure and worsens Iran’s sustainability gap. This is in line with both national findings (Ziaabadi et al., 2021) and broader international evidence from oil-exporting economies (Çakmak & Acar, 2022), where the upward phase of the EKC prevails due to persistent fossil fuel reliance and delayed transition to cleaner technologies.

Moreover, the strong negative elasticity observed here signals that Iran has not yet reached the critical income threshold for decoupling growth from environmental degradation—a conclusion supported by historical trend analysis (see Figure 1).

6.3. Natural Resource Rents:

The negative effect of natural resource rents (–0.12) corroborates the "resource curse" hypothesis (Sachs & Warner, 2001; Mehlum et al., 2006). Increased reliance on extractive rents is associated with reduced investment in natural capital and innovation, as well as greater exposure to environmental degradation. These results echo those of Golkhandan (2024) and regional studies in ASEAN and Africa (Hacıimamoğlu & Cengiz, 2024; Akam et al., 2022), which demonstrate that countries with higher dependence on resource rents typically face greater ecological deficits, especially in the presence of weak institutional frameworks.

6.4. Renewable Energy Consumption:

The positive and significant coefficient for renewable energy consumption (0.11) underscores the critical role of expanding clean energy in bolstering Iran's ecological carrying capacity. This result is consistent with findings from developing and OECD countries (Guloglu et al., 2023; Azimi & Rahman, 2024), where increasing the share of renewables is found to mitigate environmental pressures—provided that financial capacity and institutional quality are adequate. However, as observed in oil-exporting countries, the effect of renewables remains limited unless accompanied by broader structural reforms and a shift in the energy mix (Çakmak & Acar, 2022).

6.5. Synthesis and Broader Implications:

Together, these findings provide a comprehensive empirical basis for understanding the dynamics underlying Iran's persistent sustainability gap (see Figures 1 and 2). They highlight that simply increasing external debt or economic output is not sufficient for environmental improvement unless accompanied by reforms in allocation efficiency, energy policy, and governance. The results also demonstrate that the ecological impact of financial flows is context-dependent: countries with weak institutions or high resource rents are less likely to realize the potential benefits of external financing or natural capital endowments.

Furthermore, the methodological approach adopted here—combining FMOLS estimation, rigorous diagnostic testing (see Tables 7–8), and a long-run focus—enhances the reliability and policy relevance of the results. The statistical adequacy of the model, confirmed through cointegration and stability tests, supports the robustness of the estimated relationships.

6.6. Generalizability and Limitations:

While the findings offer valuable policy insights for Iran and similar resource-dependent economies, several limitations should be noted. First, the lack of annual data on institutional quality and human capital restricts the ability to fully capture their moderating effects—an issue similarly highlighted in studies such as Golkhandan (2024) and Azimi & Rahman (2024). Second, the specific transformations applied to percentage variables, although necessary for econometric consistency, may affect the interpretation of elasticities. Third, the unique context of Iran—characterized by sanctions, rapid population growth, and an energy-intensive economy—may limit the direct extrapolation of these results to other settings.

In sum, the study advances the literature by integrating both financial and energy dynamics within a unified empirical framework and by providing a nuanced understanding of the mechanisms that shape Iran's ecological sustainability.

7. Conclusion

This study examined the interplay between external debt, economic growth, natural resource rents, and renewable energy consumption in shaping Iran's load capacity factor from 1995 to 2023. The FMOLS long-run estimates revealed a positive elasticity for external debt (0.12) and renewables (0.11), offset by negative elasticities for economic growth (–0.96) and natural resource rents (–0.12). These findings underscore the pivotal role of well-managed external financing and clean energy expansion in enhancing Iran's environmental sustainability, while also corroborating the resource curse hypothesis and the upward phase of the EKC for the country. By integrating biocapacity modeling with the framework of green debt, this research fills a key gap in the domestic literature regarding the financial structure’s impact on national environmental carrying capacity.

From a policy perspective, the results yield several actionable recommendations. First, the government’s debt committee could introduce a carbon-oriented fiscal rule for sovereign borrowing, stipulating that the net present value of emission-reduction projects NPV_{CO_2} financed by new debt must not fall below the face value of the issued debt. Second, the Ministry of Economy is advised to launch “Green Load-Capacity Bonds,” consistent with ICMA standards, earmarking a portion of external debt specifically for large-scale renewable energy projects, including solar energy developments in Kerman and wind power initiatives in Sistan and Baluchestan. The coupon rate of these bonds could be indexed to the national load capacity factor, while currency risk is mitigated via central bank swap agreements. Third, implementing a Debt-for-Nature Swap mechanism would allow short-term government obligations to be exchanged for commitments to ecosystem restoration—mirroring the Ecuadorian experience, under which a sustained 2% improvement in CF over three years would trigger partial debt forgiveness (e.g., 20% of principal). Fourth, the establishment of a “Natural Resource Rent Stabilization Fund” is deemed urgent: the fund would capture excess rents above a ten-year HP-filtered trend and allocate proceeds linearly to green technology investment. Lastly, to offset the negative elasticity of economic growth, it is recommended that the Supreme Economic Council index the carbon tax rate to real inflation, recycling revenues through feed-in tariff contracts for renewable producers.

The principal limitations of this study are the absence of annual data on institutional quality and human capital, as well as the need to omit zero values from percentage variables for log transformation. Future research could address these gaps by distinguishing between short- and long-term debt composition and applying quantile FMOLS or provincial panel models to explore spatial and distributional heterogeneity. Moreover, a computable general equilibrium (CGE) model linked to the load capacity index would enable a more rigorous estimation of the welfare effects of green fiscal instruments.

Overall, the evidence suggests that the convergence of green financial instruments with structural reforms in economic growth can chart a viable path for Iran’s transition to higher environmental sustainability and biocapacity.

Data Availability Statement

All data and replication codes used in this study are publicly available. The annual dataset for Iran (1995–2023) is accessible on Harvard Dataverse, and the EViews replication script is available on Zenodo. These resources enable complete replication and verification of the study's results.

- **Dataset:**
  Hataminia, S. (2025). Annual dataset for Iran: Load-capacity factor, biocapacity per capita, ecological footprint per capita, external debt, GDP growth, natural resource rents, and renewable energy consumption (1995–2023) (V1) [Data set]. Harvard Dataverse.
  https://doi.org/10.7910/DVN/KDLDOJ

- **Replication code:**
  Hataminia, S. (2025). soheilhataminia/external-debt-and-load-capacity-iran: EViews replication script for external debt and load-capacity factor analysis (Iran, 1995–2023) (v1.0) [Computer software]. Zenodo.
  https://doi.org/10.5281/zenodo.15836059

Acknowledgments

The authors wish to express their sincere appreciation to the readers for their time and interest in engaging with this research.

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