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The nexus between CO_2 emissions from electricity generation, GDP and energy intensity using a complete maximum entropy approach: The case of Iran

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Abstract

This study examines the nexus between energy intensity (EI), gross domestic product (GDP) and carbon emissions from electricity generation (CEEG) in Iran, where energy intensity has been increasing during the last decades. Iran holds one of the world's largest fossil fuel reserves and its electricity sector is highly dependent on natural gas. In recent years, the empirical literature focuses on intensity and efficiency of energy due to global warming and climate change resulting from burning conventional fossil fuels. Therefore, finding the role and impact of energy intensity in an economy is assumed as a very important issue. The results of the current study show a positive impact of EI on CEEG, and no impact of EI on GDP. On the other hand, a nexus between CEEG and GDP is clearly identified in all the scenarios considered in the study. The generalized maximum entropy estimator is used to estimate all the parameters of the replicated models generated by the maximum entropy bootstrap for time series, which represents a novelty and an important improvement towards stability of the entire estimation procedure.

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Keywords: Economic growth; Environmental policies; Info-metrics; Time series

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1. Introduction

Energy intensity (EI) is an index that is measured as units of energy consumption measured in energy units per unit of gross domestic product (GDP), and it stands as a proxy for energy efficiency of the economy [1,2]. In the economies with high level of energy intensity, the cost of converting energy resources to GDP is high, that

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means increasing one percent in economic growth requires more than one percent increase in energy consumption. Therefore, along with improving economic growth, the intensive energy use leads to more environment pollutant and greenhouse gas emissions (GHG) in poor countries [3]. Accordingly, improving the energy intensity index means more savings in natural resources, higher energy security, lower production costs and more protection of the environment [2]. To achieve sustainable development, economic growth must be accompanied by socio-economic and environmental targets. For this end, the economies should set targets to reach higher economic growth along with lower energy consumption, energy intensity and environmental degradation. Higher economic growth requires either more inputs or increased productivity and efficiency of inputs. To aim sustainable development, the most important factor is increasing energy productivity by improving technology and better energy conservation that lead to the reduction of the Energy/GDP ratio that measures energy intensity [3].

The objective of this work is to examine the relationship between EI, GDP and CEEG, and the nexus between GDP and CEEG, in Iran as a developing country which has the world's fourth and second largest proven crude oil and natural gas reserves, respectively. According to the World Bank, 93.9% of electricity is generated from oil, natural gas and coal in 2015 (the latest available statistics), which shows the strong dependence of the power sector on fossil fuel resources. Since the energy is the main input for the economic growth, achieving higher economic growth requires increasing the quantity of inputs or productivity of them. As it is shown in Fig. 2. energy intensity has been increasing from 1995 to 2015 in Iran. It means that for economic development, the country has applied more energy input instead of higher productivity of energy resources. Currently, energy as well as the economic system of the country is mostly based upon fossil fuel resources [4]. Moreover, economic growth depends on electricity [5] and electricity generation is the major driver of carbon dioxide (CO_2) emissions [6].

Consequently, increasing the electricity generation in the country causes complex challenges, such as high emissions and depletion of fossil fuel resources. Due to inefficient energy sector, per capita CO_2 emissions in Iran is among the highest in the world and the energy intensity is 1.5 times higher than the global average. Continuing increasing energy intensity, Iran will loss the share in energy market and probably turn from energy exporting to energy importing country in the future [7]. Iran remains as an important case study to examine the effect of energy intensity on different sectors of economy specially energy-intensive sectors. As energy price is an information signal for making decisions about energy efficiency and conservation policies, some researchers study the role and impact of that on energy intensity. Energy carrier prices are set by the government, and due to the support of low-income groups, there is a large gap between the final price for customers and the actual prices [2]. This subsidized energy price causes loss of energy efficiency which is one of the important components of energy intensity. However, the reduction in subsidies that began in Iran in 2010 may not have a significant impact on energy consumption, so the increasing trend of energy intensity should be assessed beyond price and income factors [8]. Some scholars have examined effect of other factors by decomposing energy intensity in Iran over different time periods. They find that energy efficiency and structural changes are two main reason for increasing energy intensity in country [7,9,10]. So, technical and structural changes that influence the formation of increasing trend of energy intensity should be identified in future research.

The remaining of the paper is organized as follows. Section 2 presents data and methodology, and results and discussion are presented in Section 3. Conclusions are provided in Section 4.

2. Data and methods

The three variables in this paper are CO_2 emissions from electricity generation (CEEG) measured in million tons (Mt) per capita as a proxy for environmental degradation, gross domestic product (GDP) per capita measured in 2010 constant price US dollars as an indicator for economic growth, and energy intensity measured in megajoule (MJ) per unit of GDP in 2011 constant price US dollars that presents the ratio between total primary energy consumption and GDP. Annual time series of GDP, CEEG and EI were collected from International Energy Agency [11] and World Bank [12]. The data for GDP and CEEG is expressed in logarithms over the period 1995–2015, the latest available data. Fig. 1 presents the trend of GDP and CEEG, and Fig. 2 presents the trend of energy intensity in Iran during the time period under investigation (Source: IEA and World Bank).

As it is shown in the figures, all three variables have an increasing path along 21 years. Iran is a developing country, and its population has been growing rapidly over last decades, and the urban population is clearly larger than in rural areas [4]. The country benefits from large amounts of fossil fuel reserves, which makes the economy significantly dependent on these resources. As electricity generation is the main stimulus for economic growth and

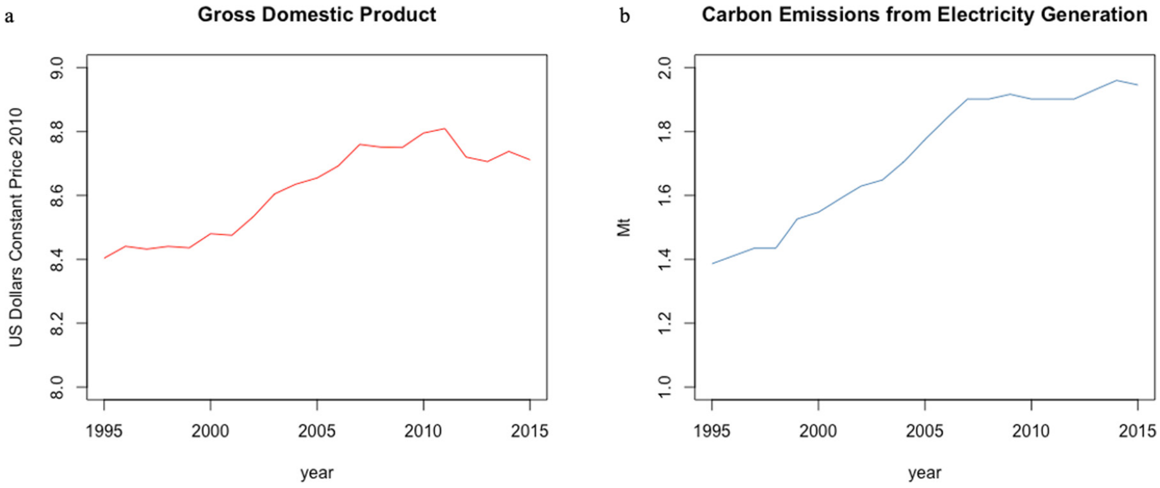

Fig. 1. (a) GDP per capita; (b) CEEG per capita, Iran, 1995–2015.

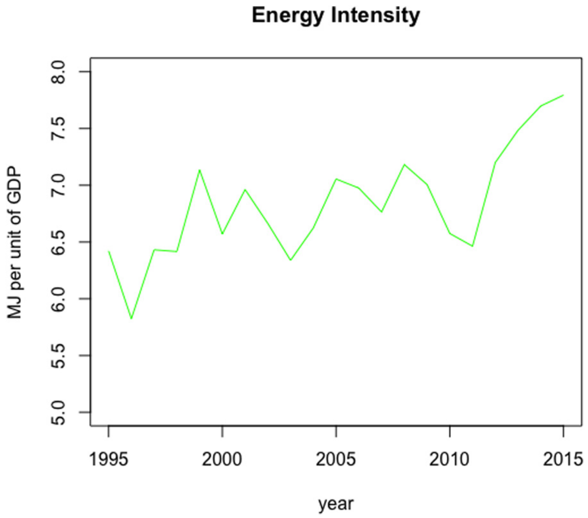

Fig. 2. EI of Iran, 1995–2015.

major driver of CO_2 emissions in the world [13], improving economic growth requires more electricity and causes environment damages. The studies show the lack of energy efficiency and insufficient technological improvement which can be the reason of increasing trend of CEEG and EI [7,9,10].

This research applies the maximum entropy bootstrap methodology to figure out possible nexus between CEEG, GDP and EI in Iran, from 1995 to 2015. Maximum entropy bootstrap for time series [14,15] is a powerful technique in time series analysis, which creates a large number of replicates, as elements of an ensemble, for inference purposes that satisfy the ergodic and the central limit theorems. Those generated elements of the ensemble retain the shape of the original time series, as well as the time dependence structure of the autocorrelation and the partial autocorrelation functions. The technique avoids all structural changes and unit root type testing, and all the usual shape-destroying transformations like detrending or differencing to achieve stationarity. See [14,15] for additional details and advantages of the algorithm, including the ones over the traditional bootstrap.

Golan et al. [16] introduced a reformulation of the classical linear regression model as $\boldsymbol{y} = \boldsymbol{X}\boldsymbol{Z}\boldsymbol{p} + \boldsymbol{V}\boldsymbol{w}$, where $\boldsymbol{\beta} = \boldsymbol{Z}\boldsymbol{p}$ and $\boldsymbol{e} = \boldsymbol{V}\boldsymbol{w}$. In this reformulation, $\boldsymbol{Z}$ is a $(K \times KM)$ matrix of support spaces for the parameters, $\boldsymbol{V}$ is a $(N \times NJ)$ matrix of support spaces for the errors, $\boldsymbol{p}$ and $\boldsymbol{w}$ are respectively a $(KM \times 1)$ and a $(NJ \times 1)$ vectors of probabilities to be estimated. Each β_k, $k = 1, 2, \ldots, K$, and each e_n, $n = 1, 2, \ldots, N$, are considered as expected values of discrete random variables z_k and v_n respectively, with $M \geq 2$ and $J \geq 2$ possible outcomes. The numerical optimization problem underlying the generalized maximum entropy (GME) estimator is established by $\text{argmax}_{\boldsymbol{p},\boldsymbol{w}} \left\{-\boldsymbol{p}' \ln \boldsymbol{p} - \boldsymbol{w}' \ln \boldsymbol{w}\right\}$, subject to the model constraints, $\boldsymbol{y} = \boldsymbol{X}\boldsymbol{Z}\boldsymbol{p} + \boldsymbol{V}\boldsymbol{w}$, the additivity constraints for $\boldsymbol{p}$, $\mathbf{1}_K = \left(\boldsymbol{I}_K \otimes \mathbf{1}'_M\right) \boldsymbol{p}$, and the additivity constraints for $\boldsymbol{w}$, $\mathbf{1}_N = \left(\boldsymbol{I}_N \otimes \mathbf{1}'_J\right) \boldsymbol{w}$, where $\otimes$ represents the Kronecker product. The GME estimator finds the optimal probability vectors from the previous optimization problem that are used to obtain point estimates of the unknown parameters and errors, by $\hat{\boldsymbol{\beta}} = \boldsymbol{Z}\hat{\boldsymbol{p}}$ and $\hat{\boldsymbol{e}} = \boldsymbol{V}\hat{\boldsymbol{w}}$, respectively. In this work, the GME estimator is computed with two different supports (centered on zero and with five equally spaced points each) for all the parameters: [−100, 100] and [−1000, 1000]. For each error support (centered on zero and with three points each) is used the three-sigma rule, considering the standard deviation of the noisy observations. Since the results remain stable regardless the support considered, only the results using [−100, 100] are reported in the next section. Additional details on maximum entropy and generalized maximum entropy estimation can be found in [16–18].

To test the existence and evaluate possible relations between CEEG, GDP and EI, different multivariate models were tested with different variables, but only the two most informative models are presented here. In the first model, described by (1), CEEG is the dependent variable and the impact of EI and GDP on CEEG is investigated. The second model, described by (2), tests the impact of EI and CEEG on GDP, the latter being now the dependent variable. The two models are presented as

$$CEEG_t = b_1 + b_2 GDP_{t-m} + b_3 EI_{t-m} + e_t, \tag{1}$$

and

$$GDP_t = b_1 + b_2 CEEG_{t-m} + b_3 EI_{t-m} + e_t, \tag{2}$$

for the lags $m = 0, 1, 2, 3$, where $CEEG$ represents carbon emissions from electricity generation, GDP represents gross domestic product, EI represents energy intensity, e represents the noise component, and t represents the time (year). The time period is from 1995 to 2015, for which there is information available on the three variables.

3. Results and discussion

The results provided by GME (instead the usual QR decomposition; a novelty introduced in this work) with maximum entropy bootstrap, considering 1000 replications of the original series, are presented in Tables 1 and 2. The percentile method is used here to compute confidence intervals (CI). The column Estimate represents the median of the estimates obtained from the 1000 models, and all the values inside both tables are rounded to four decimals.

An important result is that the null hypothesis $H_0 : b_2 = 0$ is rejected at a low significance level, regardless the model considered, which reveals the nexus between CEEG and GDP for Iran in the time period from 1995 to 2015. And since both limits of the corresponding confidence intervals are positive, this means that, on average, a unit increase in CEEG (GDP) implies an increase (its magnitude depends on the model considered) in GDP (CEEG), *ceteris paribus*. On the other hand, considering the model in (1), the null hypothesis $H_0 : b_3 = 0$ is also rejected at a low significance level, which shows that energy intensity has a positive impact on carbon emissions from electricity generation in Iran (both limits of the corresponding confidence intervals are positive). Since the main source of electricity generation is fossil fuels, any increase in energy intensity causes more CO_2 and environmental degradation.

Table 2 presents the results for the model in (2). The null hypothesis $H_0 : b_2 = 0$, as mentioned above, is rejected at the usual significance levels (1%, 5% and 10%), which reveals the impact of CEEG on GDP in Iran. However, the confidence intervals for coefficient b_3 lead to different conclusions. The null hypothesis $H_0 : b_3 = 0$ is not rejected in all the scenarios, except for lag zero and at the 10% significance level, since $CI_{90\%}(b_3) = (-0.1064, -0.0090)$. This decision of no rejection in almost the scenarios validates the assumption that there is no impact of EI over GDP in Iran along the period 1995–2015. To figure out the reason of this strange result, decomposing the energy intensity into its forcing factors, such as technology change, structural changes, energy efficiency and energy carrier prices was presented by some scholars (See [19,20]).

Although not reported here due to space limitations, models in (1) and in (2) were also tested without the variable energy intensity (bivariate models). The estimates for b_2 were different, as expected, but its sign remained positive, as well as both the limits of the corresponding CI.

Table 1. Results from model in (1) for different lags.

		Estimate	CI 90%	CI 95%	CI 99%
$m = 0$	b_1 ***	−8.6196	(−9.9026, −6.9361)	(−10.2681, −6.4630)	(−10.7798, −5.3526)
	b_2 ***	1.1046	(0.8857, 1.2730)	(0.8080, 1.3092)	(0.6880, 1.3701)
	b_3 ***	0.1189	(0.0742, 0.1809)	(0.0676, 0.1957)	(0.0518, 0.2356)
$m = 1$	b_1 ***	−8.0343	(−9.6625, −6.0078)	(−9,9571, −5.5327)	(−10.5110, −4.3143)
	b_2 ***	1.0397	(0.7959, 1.2367)	(0.7262, 1.2803)	(0.5719, 1.3351)
	b_3 ***	0.1172	(0.0708, 0.1800)	(0.0645, 0.2000)	(0.0437, 0.2305)
$m = 2$	b_1 ***	−7.5788	(−9.3134, −4.8873)	(−9.6194, −4.4084)	(−10.3017, −3.1016)
	b_2 ***	0.9979	(0.6744, 1.2040)	(0.6084, 1.2425)	(0.4588, 1.3479)
	b_3 ***	0.1082	(0.0598, 0.1696)	(0.0507, 0.1880)	(0.0338, 0.2206)
$m = 3$	b_1 ***	−6.8694	(−8.8315, −3.6348)	(−9.2147, −3.0339)	(−9.9658, −2.0753)
	b_2 ***	0.9349	(0.5447, 1.1630)	(0.4711, 1.2155)	(0.3455, 1.2949)
	b_3 ***	0.0881	(0.0355, 0.1557)	(0.0270, 0.1707)	(0.0144, 0.1883)

Note 1: Adjusted R^2 values lie, approximately, between 0.89 and 0.99 for these models.
Note 2: *, ** and *** means that the null hypothesis $H_0 : b_i = 0\,(i = 1, 2, 3)$ is rejected, respectively, at 10%, 5% and 1% significance level. This note is valid for Tables 1 and 2.

Table 2. Results from model in (2) for different lags.

		Estimate	CI 90%	CI 95%	CI 99%
$m = 0$	b_1 ***	7.7933	(7.5786, 8.0396)	(7.5414, 8.0929)	(7.4409, 8.2876)
	b_2 ***	0.7224	(0.5808, 0.8141)	(0.5504, 0.8366)	(0.4909, 0.8682)
	b_3 *	−0.0627	(−0.1064, −0.0090)	(−0.1195, 0.0031)	(−0.1439, 0.0237)
$m = 1$	b_1 ***	7.6639	(7.4479, 7.8678)	(7.4122, 7.9308)	(7.3230, 8.0628)
	b_2 ***	0.6168	(0.4508, 0.7267)	(0.3984, 0.7539)	(0.3269, 0.7888)
	b_3	−0.0132	(−0.0584, 0.0463)	(−0.0691, 0.0579)	(−0.0904, 0.0928)
$m = 2$	b_1 ***	7.5486	(7.2912, 7.7416)	(7.2252, 7.7980)	(7.0950, 7.8490)
	b_2 ***	0.5670	(0.4107, 0.6786)	(0.3776, 0.7052)	(0.3133, 0.7649)
	b_3	0.0197	(−0.0248, 0.0784)	(−0.0347, 0.0906)	(−0.0474, 0.1285)
$m = 3$	b_1 ***	7.5097	(7.2346, 7.7124)	(7.1792, 7.7522)	(6.9842, 7.8288)
	b_2 ***	0.4913	(0.3015, 0.6326)	(0.2617, 0.6586)	(0.1876, 0.7218)
	b_3	0.0484	(−0.0073, 0.1242)	(−0.0174, 0.1347)	(−0.0320, 0.1729)

Note: Adjusted R^2 values lie, approximately, between 0.84 and 0.99 for these models.

4. Conclusions

During the last decades, energy intensity has been increasing in Iran, accompanied by higher carbon emissions and economic growth. Burning fossil fuel resources and low energy efficiency cause critical environment damages. It is worth studying the effect of growing energy intensity on GDP and carbon emissions from electricity generation in this country. Based on the obtained results, energy intensity and GDP affect CEEG, in all the scenarios considered. As expected, increasing EI and GDP lead to higher CEEG, which may be due to the natural gas-base electricity generating system. The findings from the model expressed in (2) indicate that an increase in CEEG will raise GDP, but there is no evidence to confirm a nexus between EI and GDP. It means that an increase in EI does not affect GDP in Iran during 1995–2015. To justify this strange result, it may be useful to examine the effect of energy intensity components instead of aggregate EI in future studies.

In order to reduce energy intensity and environment damages, the government should apply new technologies to improve the energy efficiency of the electricity sector. In this regard, solar energy has a high potential in Iran comparing global status as the average daily solar radiation intensity is 19.23 MJ/m2 [4]. For that reason, it can be the most suitable renewable energy to replace fossil fuels, although due to huge fossil fuel resources, there is no significant strategy in renewable energy developments.

CRediT authorship contribution statement

Zeinab Zanjani: Investigation, Formal analysis, Validation, Writing – original draft, Data curation, Conceptualization. **Isabel Soares:** Investigation, Formal analysis, Writing – review & editing, Conceptualization, Supervision, Project administration, Funding acquisition. **Pedro Macedo:** Investigation, Formal analysis, Writing – review & editing, Conceptualization, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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