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Towards the vision of going green: The role of different energy research and development investments, urbanization and income in load capacity factor

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ABSTRACT

Environmental sustainability, one of the agendas of the 21st century, is an essential step in the transition to a low-carbon economy in developing countries. The motivation of this study is to investigate the impact of fossil energy research and development investments on environmental quality within the framework of the load capacity curve hypothesis, and urbanization is also added to the model to avoid omitted variable bias. To this end, the Augmented ARDL analysis examines the relationship between economic growth and ecological well-being in Turkiye from 1986 to 2022. The results from the empirical analysis support the accuracy of the load capacity curve hypothesis. Furthermore, it is observed that renewable energy research and development investments, which are the main component of the study, improve environmental quality.

On the other hand, it has been found that research and development investments in fossil fuels and urbanization reduce the load capacity factor. Based on the study's findings, the Turkish government should allocate more research and development budget to transition to a low-carbon economy. Considering Turkiye's intense fossil resource consumption, the government should plan research and development budget arrangements supported by law regarding energy efficiency.

Introduction

The attainment of environmental sustainability is one of the paramount objectives pursued by countries globally. However, the relentless pursuit of economic growth (EG) targets by governments and industrial activities is leading to environmental degradation (ED), thus posing significant challenges in achieving this goal. As countries become increasingly cognizant of the advantages of enhancing their educational and technological capacities alongside EG, there is a burgeoning emphasis on the imperative to execute the growth process in an environmentally sustainable manner. The Paris Agreement, the COP26 conference in Glasgow, and the Intergovernmental Panel on Climate Change (IPCC) collectively represent efforts to unravel the negative impacts of global warming on economic activity, human health, the environment, and various other facets [1]. The United Nations (UN) systematically addresses this issue within the framework of Sustainable Development Goals (SDGs).

Despite implementing various measures and pursuing planned targets, the enduring impact of economic activities on ED remains a persistent concern [2,3]. However, upon analyzing the research within the environmental literature, it becomes evident that the relationship between EG and the environment is contingent upon the stages of EG [4]. Initially, ED resulting from EG was assessed using indicators such as the accumulation of gases in the atmosphere and carbon emissions (CE). Subsequently, ED is determined using indicators such as greenhouse gases and ecological footprint (EF). While these indicators play a crucial role in assessing ED, they are deemed incomplete as they solely consider the issue from the perspective of environmental consumption. Ref. [5] investigated an indicator that incorporates supply and demand factors in the assessment of environmental quality (EQ), termed the load capacity factor (LCF). Following this, research on LCF extends the load capacity curve (LCC) hypothesis. The relationship between income and the LCF

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can be examined through the lens of the LCC. According to the hypothesis, a U-shaped relationship exists between income and LCF. In this respect, an initial rise in income is associated with a decrease in LCF; however, it leads to an increase in LCF once the income surpasses a certain threshold. Hence, the observed association is referred to as the LCC hypothesis.

Given the significance of achieving SDGs and sustaining EG for nations, it is imperative to transition energy resources, a key input in the growth processes, from fossil fuels to renewable sources. Hence, renewable energy (REN) plays a crucial role in shaping the LCF utilized to assess EQ [6,7]. An LCF ratio of biocapacity (BC) to EF below 1 signifies a rise in ED, whereas a ratio of 1 or higher signifies an increase in environmental sustainability. Hence, nations' heightened adoption of REN results in elevated LCF, contributing to enduring ecological sustainability. As RENs are acknowledged for their influential role in enhancing EQ, a pertinent question emerges concerning the impact of renewable energy research and development investments (RR&D) on achieving SDGs. While research in the literature often emphasizes the significance of infrastructure investment in REN, it is essential to recognize the importance of RR&D. In recent years, a limited number of studies have addressed the significance of RR&D in the environmental literature. Nevertheless, there remains room for further advancement in the literature. When these studies are examined, it is seen that the literature on this subject focuses only on a limited number of countries (G7, Japan, the USA and Germany) [8–10].

In the case of Turkiye, similar to other nations, achieving the SDGs and accomplishing sustainable environmental goals are crucial as part of these objectives. Fig. 1 shows Turkiye's SDG performance. It is seen in Fig. 1 that Turkiye needs various SDG policies. Simultaneously, the process of EG holds immense significance for Turkiye, as it represents a pivotal goal of transitioning from the category of developing nations to that of developed nations, which constitutes another of its paramount objectives. Hence, it is a subject of interest to what extent the linkage between the utilization of cheaper inputs, such as fossil fuel consumption for EG, aligns with the pursuit of environmental policies. As a result, an inquiry arises regarding the influence of Turkiye's RR&D and fossil energy research and development investments (FR&D) on achieving SDGs in this context. Within this framework, the path of RR&D and FR&D in Turkiye is illustrated in Fig. 2. In 1986, the allocation of

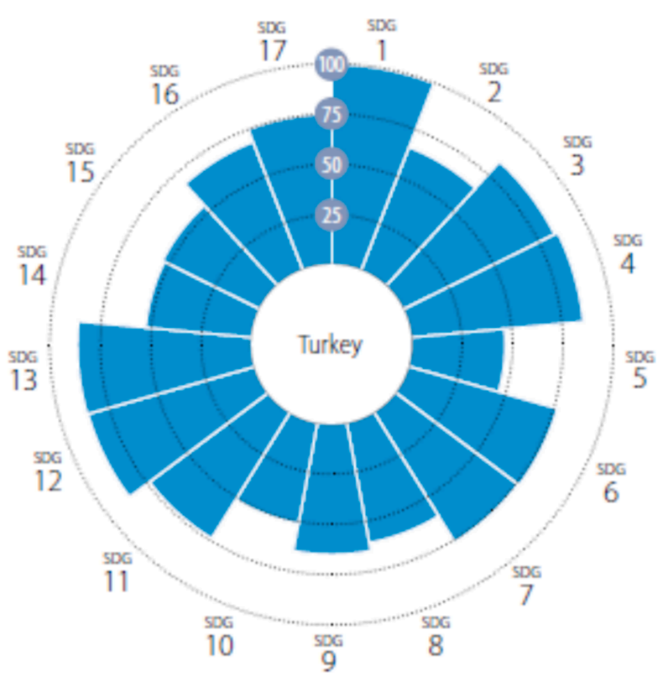

Fig. 1. SDGs performance of Turkiye.

resources for FR&D amounted to 9,298 million dollars, while that for RR&D was 3.04 million dollars. By 2022, the allocation of resources for FR&D had reached 10,723 million dollars, whereas the allocation for RR&D had increased to 37,550 million dollars [11]. Fig. 2 shows that until 2010, the allocations for FR&D and RR&D were nearly equal, with FR&D initially holding a slight advantage. After 2010, there was a substantial and widening gap between RR&D and FR&D, with RR&D gaining a significant advantage. This signifies Turkiye's commitment to the SDGs and its active initiatives to attain this objective.

For a more comprehensive examination of the research, development, and funding allocations for Turkiye, Table 1 has been generated. The table presents Turkiye's RR&D and FR&D values for each decade. Table 1 indicates that RR&D investments dramatically decreased to 0.50 million dollars in 1996, while FR&D investments did not experience a significant decline. An analysis of the 2006 values reveals that while RR&D had an investment of 4.27 million dollars, FR&D experienced a significant decrease, with an investment of only 1.58 million dollars. A review of the 2016 values reveals that the resources allocated for RR&D increased significantly this decade, reaching 83.17 million dollars [11]. During this period, the resources allocated for FR&D also increased, but less dramatically than those allocated for RR&D. Examining the resources allocated for RR&D and FR&D between 2006 and 2016 reveals that Turkiye shifted towards environmental sustainability policies, allocating resources accordingly. By 2022, it is observed that the resources allocated for RR&D decreased to 37.55 million dollars, representing a loss of 45.62 million dollars since 2016 [11]. However, there has been no significant change in the resources allocated for FR&D during this period. Given all these discussions, RR&D and FR&D cannot be neglected when examining Turkiye's sustainable policies. This study focuses directly on RR&D and FR&D and investigates their role in EQ.

Fig. 3 can serve as a means to gain insight into Turkiye's LCF values concerning sustainable thresholds. Accordingly, Turkiye has not attained the sustainable environmental standard from 1986 to 2022. Nevertheless, in 1986, the LCF value was the nearest to the sustainable threshold, but since then, despite fluctuations, there has been a declining trend. After 2010, it is noticeable that the LCF value follows a similar trajectory, with minor variations occurring intermittently. The ongoing trend implies that Turkiye's EQ has been progressively declining yearly, concurrent with its EG.

Furthermore, despite the observed increase in RR&D depicted in Fig. 3, the decrease in the LCF value in Turkiye gives rise to a dilemma. This study endeavours to address this dilemma. One of the additional objectives of this study is to ascertain the root causes behind the diminishing EQ performance, notwithstanding the escalation in RR&D efforts. The aim is to identify strategic measures that can be implemented to avert this decline. Hence, it is evident that Turkiye requires policies and measures to alter this trajectory.

This study seeks to make several contributions to the existing literature. The initial investigation to explore the connection between FR&D and RR&D variables and LCF in Turkiye enhances the expansion of literature in this domain. To our knowledge, no study has examined this relationship in Turkiye. Therefore, another anticipated contribution of this study is to increase awareness among policymakers in Turkiye regarding the impact of RR&D and FR&D investments on achieving future objectives. Secondly, it adds to the examination of the validity of the LCC hypothesis. In this context, testing the hypothesis using various indicators for Turkiye is essential to its validation. Upon reviewing the existing literature, it becomes evident that this is the inaugural study to assess the issue from this particular perspective for Turkiye. Thirdly, it aspires to contribute to attaining Turkiye's SDGs in the future by offering policy recommendations within the framework of SDG 7 (Affordable and clean energy) and 13 (Climate action). Lastly, it utilizes the Augmented ARDL (AARDL) model, and this approach allows for obtaining robust results, even when the sample size is limited and in the presence of issues such as endogeneity, autocorrelation, or mixed integration within the model. AARDL model employs three distinct tests to

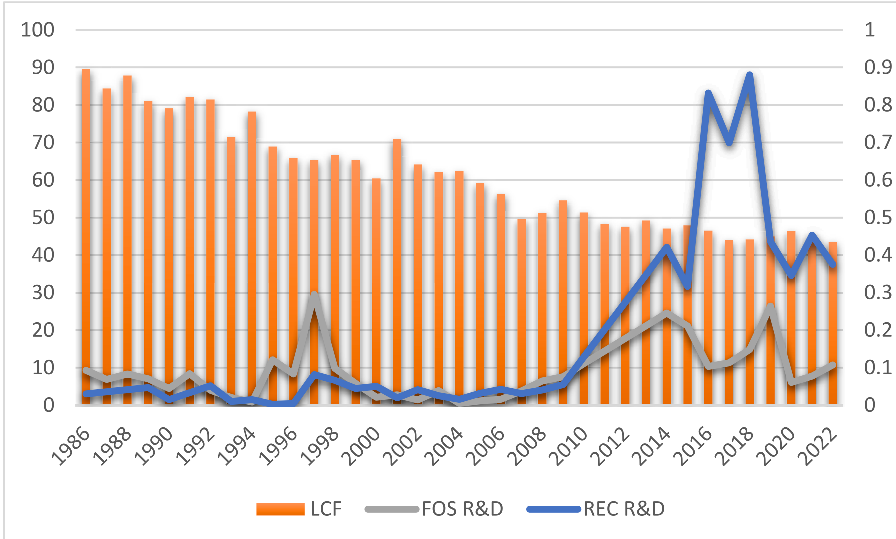

Fig. 2. The time path of LCF, FOS- and REN R&D budgets.

Table 1
RR&D and FR&D values in Turkiye.

Years	RR&D	FR&D
1986	3.04	9.30
1996	0.50	8.36
2006	4.27	1.58
2016	83.17	10.34
2022	37.55	10.72

identify cointegration within the model. Moreover, one of the primary advantages of the AARDL model is its ability to reveal the most reliable cointegration relationship by accounting for all possible degenerate situations compared to other alternative methods. As a result, this will enhance the significance of the policy recommendations that will be formulated based on the findings derived from the model.

The second section of the study provides an overview of the pertinent literature review. The third section outlines the data, model, and methodology. The fourth section presents the empirical findings and discussions. Finally, the last section provides the conclusions, policy implications, limitations, and future directions.

Literature review

The relationship between economic activities and the environment is a relatively recent development. The systematic examination of the connection between EG and the environment can be traced back to the seminal paper by Ref. [4]. They indicated that the relationship between EG and the environment pursues an inverted U-shaped curve, depending on income stages. Subsequently, literature examining the nexus between income and the environment has grown significantly. Studies have delved into the association between income and the LCF, one of the most comprehensive environmental indicators introduced by Ref. [5]. As the literature on the LCF has recently diversified, there is still ample room for further enhancement. Examining studies on the association between LCF and income uncovers disparate findings across various research endeavours. Refs. [12,13,15] collectively asserted that an increase in income leads to a reduction in LCF. On the other hand, Refs. [16–18] identified a U-shaped link between EG and LCF.

One of the essential prerequisites for a country's sustainability is its

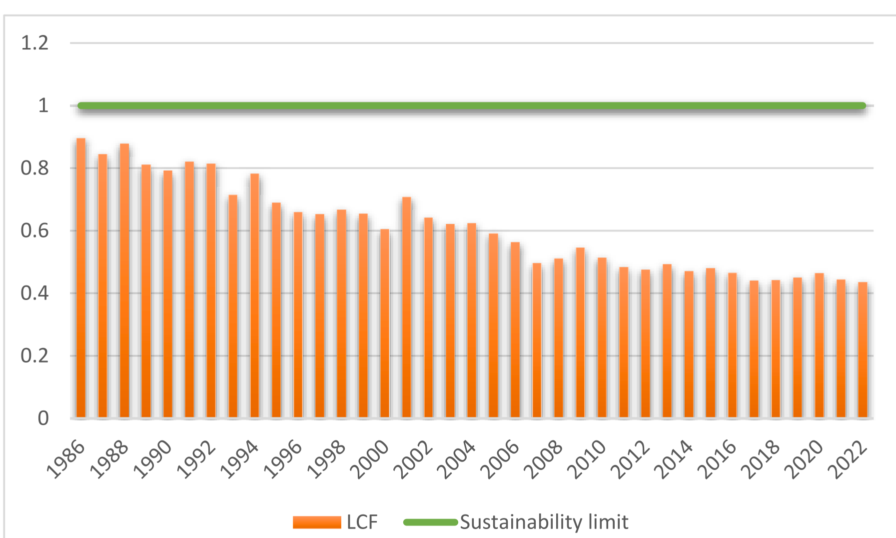

Fig. 3. Environmental sustainability of Turkiye.

capacity to maintain the production process. Undoubtedly, there is a requirement for energy to uphold the production process. Conversely, implementing an environmentally friendly production process constitutes another crucial aspect. Hence, the nature of energy sources utilized in production, whether from fossil fuels or renewable sources, is also a significant topic, and numerous studies are on this subject. Nevertheless, the allocation of resources for the development of these energy sources and the consumption of these resources is deemed to exert a non-negligible influence on achieving SDGs. Consequently, the literature examining the relationship between R&D expenditures and/or innovation and ED has recently expanded. Ref. [19,20] contended that R&D expenditures reduce CE.

In contrast, Refs. [21,22] demonstrated that energy R&D expenditures increase CE. Moreover, Ref. [23] indicated that R&D investments reduce CE and produce spillover effects. Ref. [24] stated that increased R&D investments boost renewable energy. Consequently, a consensus on the issue still needs to be discovered. When reviewing the studies focusing on the issue concerning fossil energy, Ref. [25] discovered that R&D in fossil energy resources is more effective in achieving EG than the consumption of fossil energy resources and, consequently, more effective in causing ED. Ref. [26] examined Chinese cities and contended that reductions in energy prices stemming from innovations in fossil energy technology fall significantly short of the desired level, highlighting the imperative to shift the focus toward innovations in REN-based technologies when we delve into recent research that has focused more specifically on the current issue, the papers of Refs. [8,10,22,27] deserve notable attention. Ref. [8] perused the impact of green energy R&D investments on CE, presenting findings that green energy R&D investments reduce CE in G7 economies. Ref. [22] concluded that public investments in developing clean energy technology reduce CE in Pakistan. In their research on Germany, Ref. [10] were pioneers in exploring the issue of LCF, concluding that RR&D contributes to its increase.

When considering the relationship between UR and the environment, it becomes apparent that there is a lack of consensus in the literature. How UR occurs plays a crucial role in determining its environmental impact. If a UR structure is composed of individuals with high levels of education, productivity, and environmental awareness, then it is anticipated that UR's contribution to the environment will be positive. However, in the context of a UR structure characterized by relatively lower levels of development, growth-oriented priorities, a lack of a qualified workforce, and individuals with limited environmental awareness, UR is likely to hurt the environment. In this regard, when reviewing studies investigating the relationship between UR and the environment, Ref. [28] demonstrated that UR has a mitigating effect on CE. On the contrary, Ref. [29] and Ref. [30] expounded in their studies that UR intensifies CE. Concerning EF, Ref. [31] illustrated that UR leads to an increase in EF, whereas Refs. [32,33] demonstrated that it decreases. Ref. [34] revealed that UR has a mixed effect on EP, while Ref. [35] asserted that no discernible relationship exists between UR and EP. Concerning LCF, Ref. [14] proclaimed no significant connection exists between UR and LCF, whereas Ref. [36] discovered that UR leads to a reduction in LCF.

The inclusion of the LCF curve in the literature is very recent. Naturally, the literature on the subject is very open to improvement. Ref. [37] found that the LCC is invalid in their study of the world's top tourism economies. On the other hand, Ref. [38] for fast-growing economies, Ref. [39] for the Russian Federation, Ref. [40] for India and Ref. [41] for BRICS economies found that LCC is valid.

Upon reviewing the existing literature, it becomes evident that the research body on this subject is not sufficiently comprehensive and still displays deficiencies warranting further development. This issue is primarily addressed concerning determinants that quantify ED, and our objective is to investigate the influence of RR&D and FR&D on LCF in Turkiye. This study aims to broaden the existing literature in this realm and address the gap in research, as there is currently no study that comprehensively examines both ED and EQ in the context of Turkiye. It is widely recognized that renewable energy is a crucial factor in improving EQ. However, it should not be overlooked that R&D investments in this field are essential for the infrastructure transformation to facilitate the widespread use of renewable energy.

Nevertheless, the literature review shows that, although many studies have emphasized the impact of renewable energy on EQ, the role of RR&D investments in this field has been neglected. In the case of Turkiye, as a developing country with the 2050 zero-emission target on its agenda, it needs to maintain its production process and ascend to the league of developed countries while achieving the zero-emission sustainable environment target. In this context, the main focus of the study is to reveal the role of policies implemented to achieve Turkiye's current targets by centring on RR&D investments. Besides elucidating the connection between the present study and the LCF, we also assess the validity of the LCC. To the best of our knowledge, no paper in the literature examines the LCC and assesses its validity for Turkiye regarding the determinants (RR&D and FR&D) of the load capacity factor. Therefore, this study aims to address this gap in the literature.

Methodology

Data and variable description

This study analyzes the relationship between RR&D, FR&D, and LCF for Turkiye. Therefore, the paper peruses the impact of EG, EG^2, FR&D, RR&D, and UR on LCF to achieve this objective. In addition to examining this relationship, the current paper also tests the validity of the LCC. Enhancing EQ and SDGs achievements is one of the goals that Turkiye, like many other countries worldwide, aspires to achieve. Regarding the independent variables employed in the model, EG is identified as one of the most significant determinants of the LCF. Ref. [4] elucidated the role of EG in gauging EQ and expounded on why it stands out as one of the most crucial variables. The authors define an inverted U-shaped link between EG and EP, contingent upon variations in income levels.

On the other hand, Ref. [7] advocated that there is a U-shaped link between EQ and EG based on this mechanism. They argue that improvement in income initially leads to a diminishing LCF. However, after a certain level of EG is reached, a further increase in income results in an increase in the LCF. They refer to this process as the LCC. The inclusion of EG^2 in the model is also motivated by the aim of testing the validity of this mechanism.

Converting resources into REN to transition to a low-carbon economy is important to achieving EQ. However, it is also true that this transformation process is highly costly. For this reason, there is no consensus in the literature regarding the effect of REN on the LCF. Since one of the primary reasons for the lack of consensus is the costs associated with REN transformation, the significance of RR&D, which constitutes the primary motivation of this study, becomes apparent at this juncture. In addition, Turkiye has set 2053 net zero emission targets, objectives aligned with the Paris Agreement, and goals about formulating sectoral roadmaps as part of the Green Deal Action Plan [42]. The significance of RR&D in achieving these objectives is another rationale for including this variable in the model. Therefore, RR&D, which constitutes the primary motivation of the study, serves as another independent variable in the model. The aim here is to ascertain the impact of RR&D on the achievement of EQ, particularly in Turkiye.

Another dependent variable utilized in the study is FR&D. Countries pay attention to their EG to stay caught up in the race for development. One of the most crucial input elements in this pursuit is the energy employed in production, typically sourced from fossil resources, notwithstanding countries' aspirations to achieve SDG-7 and countries also allocate resources for FR&D. For Turkiye, which aspires to join developed economies in this pursuit, the significance of fossil resources in the production process must be considered. However, the aim is to demonstrate to what extent the resources allocated for FR&D influence this goal for Turkiye, striving to achieve SDGs. In the current study, this variable is incorporated into the model to assess the impact of the resources allocated for FR&D on the LCF. Finally, another independent variable included in the model is UR. The inclusion of this variable in the model serves both to mitigate omitted variable bias and to prevent modelling errors. In light of these relationships, Table A1 (See Appendix A) presents the variables utilized in the study and the sources from which these variables were obtained.

Model formulation and analysis

The following equation, based on the previously mentioned relationships, is utilized to proceed with the analysis in this study:

$$LCF_t = \alpha_0 + \vartheta_1 EG_t + \vartheta_2 EG_t^2 + \vartheta_3 RR\&D_t + \vartheta_4 FR\&D_t + \vartheta_5 UR_t + \varepsilon_t \quad (1)$$

Table A1 defines the variables LCF, EG, RR&D, FR&D, and UR in the equation. In addition, α, ε, and t represent the fixed and error terms and the period, respectively. When commencing econometric analysis, most methods initially test for the presence of a unit root. Different techniques are applied depending on whether the variables are stationary or not. For instance, as proposed by Ref. [43,44], conventional cointegration processes are applied to non-stationary series, whereas such tests are unsuitable for stationary series. At this juncture, Ref. [45] introduced a method that can be applied irrespective of whether the independent variables are stationary. In this method, ARDL, the variables should not be I(2). Therefore, verifying whether there is an I(2) unit root is essential when employing this method.

For this reason, ADF [46] and ZA [47] unit root tests are employed to examine the presence of unit roots. The ADF test is commonly used in the literature to assess the presence of a unit root. However, the ADF test exhibits weaknesses in its power and size to rectify distortions in the presence of structural breaks in the series. Consequently, to address this issue, we also employ the ZA unit root test, which produces effective results in the presence of a structural break. Thus, with this test, the date of the structural break is also incorporated into the model. The following model is formulated to unveil the cointegration relationship using the ARDL approach in the subsequent step.

$$\begin{aligned}\Delta LCF_t = {} & \vartheta_0 + \vartheta_1 DU_t + \omega_1 \sum_{i=1}^{b} \Delta LCF_{t-i} + \omega_2 \sum_{i=0}^{j} \Delta EG_{t-i} + \omega_3 \sum_{i=0}^{k} \Delta EG2_{t-i} \\ & + \omega_4 \sum_{i=0}^{h} \Delta RR\&D_{t-i} + \omega_5 \sum_{i=0}^{t} \Delta FR\&D_{t-i} + \omega_6 \sum_{i=0}^{c} \Delta UR_{t-i} \\ & + \delta_1 LCF_{t-1} + \delta_2 EG_{t-1} + \delta_3 EG2_{t-1} + \delta_4 RR\&D_{t-1} \\ & + \delta_5 FR\&D_{t-1} + \delta_6 UR_{t-1} + \nu_t \end{aligned} \quad (2)$$

In Eq. (2), ν and t are the model's error term and time dimension. The coefficients preceding the summations denote the short-run coefficients, whereas $\delta_1, \cdots, \delta_6$ represent the long-run coefficients. Lastly, ϑ_1 denotes the coefficient of the dummy variable. A dummy variable introduces a particular break date into the model. When utilizing the AARDL method, it is crucial to integrate 2001, which marked a significant crisis period for Turkiye, into the model.

There are several factors to consider when applying the classical ARDL process. It is asserted that the cointegrated relationship is deemed valid in the model if the F-statistic value surpasses the upper critical value. On the other hand, the issue of endogeneity should be considered. It accounts for the absence of any link between the independent variables and the residuals. Within the context of the ARDL model, the endogeneity of a single independent variable is acknowledged [48]. Another crucial consideration is the requirement that the dependent variable is the unit root process. However, the dependent variable may exhibit I(0) in certain instances. Finally, degenerative conditions must also be taken into account. Ref. [45] employed F-tests and t-tests to test for cointegration, and two degenerate states occur in light of the results obtained from these tests. State_I occurs if the lagged level of the dependent variable is insignificant in Eq. (2), and State_II occurs if the lagged level of the independent variable is insignificant in Eq. (2). Refs. [48,49] explained that neglecting degenerate cases may result in erroneous interpretations of the results obtained from the F-test and *t*-test. Therefore, Ref. [48] developed a new test based on lagged explanatory variables to address this issue. The overall F-test can be significant, considering both lagged dependent and independent variables. However, to clarify this situation unequivocally, Ref. [48] assessed the significance of the lagged independent variables using the F-test for independent variables (F_{IDV}) test. This new test also relaxes the assumptions of the traditional ARDL test. Thus, the endogeneity of the variables and the necessity for the dependent variable to be I(1) are eliminated. The most significant advantage of the AARDL model over other models is its ability to perform robustness checks internally, thereby eliminating degenerate cases. Therefore, when considering the ARDL and NARDL approaches, it can be stated that AARDL is the approach that provides the most robust cointegration relationship. It also allows policy recommendations to be made easily based on the results.

Ref. [49] argued that to discuss the cointegration relationship between the relevant variables, the variables should pass the F_{IDV}-test developed by Ref. [49] in addition to the $F_{overall}$ and t-tests proposed by Ref. [45]. An exact cointegration relationship exists if all three hypotheses from the available tests are rejected. The first test examines the overall F-test for all lagged values (H_0: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$). Secondly, a *t*-test that exclusively considers the lagged dependent variable should be employed (H_0: $\delta_1 = 0$). Finally, an F-independent (F_{IDV}) test that exclusively considers lagged independent variables should be conducted (H_0: $\delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$). They also redefine the degenerate case_1 and case_2. The degenerate case_1 pertains to the scenario in which the lagged dependent variable (H_0: $\delta_1 = 0$) is significant, while the lagged independent variables (H_0: $\delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$) are deemed insignificant. Degenerate case_2 arises when the lagged independent variables (H_0: $\delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$) are deemed significant, while the lagged dependent variable (H_0: $\delta_1 = 0$) is considered insignificant. In both cases, there is no evidence of a long-run relationship. As there is a need to determine critical values for the F_{IDV} test, Ref. [48] employed the bootstrap resampling method to ascertain the applicable critical values. Fig. A1 displays all methodological steps in this paper.

Empirical findings

Preliminary analysis

In the preliminary phase of the analysis, the study examines the descriptive statistics of the variables. As depicted in Table A2, the mean value of LCF is observed to be 0.612 Gha. Hence, it is evident that the present value is below 1, indicating a high level of EP. When analyzed in terms of minimum and maximum LCF values, it is observed that they are 0.435 and 0.895 Gha, respectively. Therefore, based on this value, it can be inferred that Turkiye is inclined to enhance its EQ. Regarding EG statistics, Turkiye's average per capita income is 7,964.857 dollars. This indicates that Turkiye still has a substantial path to traverse in its growth process. Concerning FR&D and RR&D, the average values amount to 29,562 and 88,039 million dollars. This implies that Turkiye allocates a more significant amount of resources to RR&D. When examining the minimum and maximum values of RR&D, the increase from 0.266 to 88,039 million dollars suggests that Turkiye prioritizes the enhancement of EQ while also indicating the necessity for substantial investments.

In the context of the AARDL method, while the stationarity of variables at the level or first difference is not paramount, conducting unit root tests to ensure they do not exhibit I(2) characteristics remains

Table 2
Unit Root Test results.

Panel (a) ZA results

	Level		First difference	
Variables	Test statistics	Break date	Test statistics	Break date
LCF	−4.862***	2006	–	–
EG	−3.415	1999	−5.211**	2004
EG2	−3.216	1999	−5.141**	2004
FR&D	−3.851	2010	−5.129**	2006
RR&D	−4.058	2010	−5.199**	1997
UR	−4.850***	2017	–	–

Panel (b) ADF results

	Level	First difference
Variables	Test statistics	Test statistics
LCF	−1.219	−8.892
EG	0.534	−6.357
EG2	0.704	−6.210
FR&D	−2.706***	–
RR&D	−1.466	−4.573
UR	−5.681*	–

Notes: *, ** and *** indicate 1%, 5% and 10% significance levels, respectively. Constant model critical values for ZA unit root test at 1%, 5%, and 10% are −5.34—4.93 and −4.58, respectively.

crucial. The analysis utilizes the classical ADF and ZA unit root tests. The findings of the analysis are displayed in Table 2. The ZA unit root test shows that LCF and UR are stationary at the level, whereas EG, EG^2, FR&D, and RR&D variables exhibit stationarity at the first difference. Furthermore, upon analysis using the ADF test, it is ascertained that FR&D and UR variables exhibit stationarity at the level. Both test results indicate that none of the variables exhibit stationarity at I(2). Consequently, it is noted that the first condition for the AARDL is satisfied.

Cointegration findings and diagnostic check

According to Table 3, the ARDL (1,0,0,0,0,0) model, which is the most suitable model for estimation given the current state of the parameters, is initially established. Subsequently, a bounds test must be employed to utilize the model. At this point, the assumption that the lags of the dependent and independent variables are not equal to zero is examined. Hence, the overall F-test (Foverall) test statistics, which assesses the model as a whole, the *t*-test, which evaluates the dependent variable, and the F-test for independent variables (F_{IDV}) should surpass the upper bound value at all levels of significance. Upon examining the cointegration results presented in Table 3, it is evident that all $F_{overall}$, t, and F_{IDV} tests meet the condition and demonstrate a cointegrated relationship. Hence, it can be deduced that the model is adequate and is expected to produce robust results. To ensure the reliability of the results, the model must undergo specific diagnostic tests, including assessments for heteroskedasticity, autocorrelation, model specification, and adherence to a normal distribution. Looking again at the results in Table 5, the constructed model meets all the necessary prerequisites.

Table 3
Augmented ARDL cointegration findings.

DV|IV	Dummy	Lag length	Test stat.	Result
LCF|EG,EG2, FR&D,RR&D, UR	2001	(1,0,0,0,0,0)	F_{PSS} : 9.224* T_{DV} : −6.715* T_{IV} : 10.116*	Cointegration
Diagnostic Check				
White	LM	JB	Ramsey	Cusum and Cusumq
0.715 [0.659]	1.689 [0.204]	0.844 [0.655]	0.061 [0.915]	Stable

Short and long-run estimation

After confirming that the model complies with all the criteria, we estimate the model from which the ultimate results are derived. Both short- and long-term outcomes are derived from the model. According to the results presented in Table 5, when focusing on the short-term outcomes initially, it becomes evident that all parameters, except the dummy variable, RR&D and UR, exhibit statistical significance. When the variables are examined in the context of the long run (Table 4), it is discovered that all parameters are statistically significant. When interpreting the long-run coefficients, it becomes evident that increases in EG are associated with a rise in environmental pollution. A one-unit increase in FR&D leads to a decrease of 0.015 units in LCF, while a one-unit increase in RR&D results in an increase of 0.012 units in LCF. Concerning the UR, a one-unit increase in the current variable results in a decrease of 0.580 units in LCF. Furthermore, the error correction coefficient (ECT) is statistically significant and negative. Based on the ECT, it is inferred that 99.9 % of a deviation in the model will be rectified within one year.

Discussion

When analyzing the relationship between income and LCF, it is observed that both the EG and EG^2 variables are statistically significant in both the short and long term. An increase in EG leads to a decrease in LCF, while an increase in EG^2 results in an increase in LCF. Hence, the signs of the coefficients imply the validity of the LCC hypothesis for Turkiye. The findings align with those of Refs. [38–40]. Hence, sustained EG in Turkiye will further improve EQ. From the perspective of Turkiye, which aspires to be among the leading economies in the future, the findings obtained may have favourable consequences for the country. This is due to the available parameters confirming that Turkiye experiences an increase in its LCF after reaching a certain growth threshold. Turkiye has established several economic growth and development targets to achieve these objectives with environmental sensitivity [42]. When analyzing the current situation in Turkiye, it becomes evident that, despite embarking on a renewable energy transformation and implementing policies to increase investments in renewable energy resources in recent years, Turkiye still has a long way to go. However, it is also true that Turkiye possesses significant potential in renewable energy resources. Therefore, Turkiye needs a significant transformation process to make the most efficient use of this opportunity. This suggests that Turkiye should judiciously allocate and utilize its resources. If Turkiye allocates its resources to appropriate infrastructure investments aligned with sustainable environment goals, it can substantially reduce production costs. Despite the apparent advantages of production with fossil resources in the current situation, once the transition to REN is realized, it will become feasible to produce at lower costs. This will further expedite Turkiye's growth process and enhance its level of welfare, thereby allowing ascending to the ranks of advanced economies. The findings also indicate that Turkiye is poised to make significant contributions to advancing climate action, particularly in achieving SDG 13. This contribution will be realized through the transition of

Table 4
Long run estimation.

Dependent variable = LCF			
Variables	Coeff.	Std. Error	Prob
EG	−8.953	1.208	0.000
EG2	0.468	0.062	0.000
FR&D	−0.015	0.006	0.025
RR&D	0.012	0.006	0.045
UR	−0.580	0.275	0.044

Table 5
Short run estimation.

Dependent variable = LCF			
Variables	Coeff.	Std. Error	Prob
Δ EG	−8.943	2.176	0.000
Δ EG2	0.468	0.116	0.000
Δ FR&D	−0.015	0.008	0.060
Δ RR&D	0.012	0.008	0.158
Δ UR	−0.579	0.443	0.201
C	44.450	9.437	0.000
Δ DU01	0.048	0.042	0.262
ECT	−0.999	0.124	0.000

production processes towards environmentally friendly resources.

As a result of the study conducted to investigate the significance of RR&D for achieving SDG 7 determined that RR&D leads to a long-term increase in LCF, although it does not exert a significant short-term impact. The findings align with Ref. [19], and they employed the AMG and CCEMG methodologies. Although the estimators used yield robust results in their respective fields, it can be stated that the most substantial results are obtained with AARDL when compared to other methods. The AARDL method resolves both the unit root issue and the cointegration relationship unequivocally established through the F-test applied to the independent variables. Therefore, while the findings of the current study support previous research, it can also be stated that this study provides the most reliable results in terms of its findings. Observing a positive long-term impact on LCF implies the significance of current investments in Turkiye towards achieving SDG 7. In 2022, Turkiye's allocation for RR&D was 37.55 million dollars [11]. Considering the renewable energy infrastructure in Turkiye, the resources allocated for RR&D are insufficient to unlock its true potential. Given Turkiye's structural problems, including the recent issue of high inflation, it is imperative that the country utilizes its income in the most efficient way possible and invests in these areas. For Turkiye, which aims to achieve stable economic growth and development, it is crucial to use its income to ensure the sustainability of its current growth. Although the transition to renewable energy is burdensome, it offers a significant advantage in the long run that can reduce Turkiye's high dependence on foreign energy and help address its current account deficit problem. However, the coefficient obtained also suggests that these investments may not be sufficient. Consequently, Turkiye must allocate additional resources to RR&D to attain the SDG targets. Although the initial investment in preparing infrastructure for REN may be costly, the subsequent transformation allows Turkiye to enhance its EQ and foster sustainable growth through clean resources. In this manner, Turkiye will have the opportunity to attain its present targets and bequeath a sustainable environment for future generations. In particular, this will constitute a crucial stride towards achieving SDG 7, focusing on affordable and clean energy. Upon examining the findings concerning FR&D, it becomes evident that it leads to a reduction in LCF in both the short and long term. Refs. [25,26] similarly asserted in their studies that investments in fossil resources contribute to environmental damage, yielding findings that align with the results of the present study. The findings indicate that expenditures on FR&D have a detrimental impact on the enhancement of EQ in Turkiye. Turkiye's current infrastructure and production facilities are inherently inclined towards using fossil fuels, and the transition to REN is both time-consuming and cost-intensive.

For this reason, a significant portion of the production still relies on fossil resources. Nevertheless, as the analysis indicates, this approach has detrimental consequences for pursuing a sustainable environment. For Turkiye, it is easier to use fossil resources more intensively because they are both more accessible due to existing infrastructure and provide an effortless input for rapid growth. However, in the long run, when a profit and loss comparison is conducted, there is no doubt that the utilization of REN will propel Turkiye towards an advanced stage in both sustainable growth and environmental sustainability goals. For this reason, Turkiye should expeditiously discontinue production processes reliant on fossil resources and expedite the transformation by prioritizing investments in REN. This would also represent a significant stride towards achieving SDG 7.

Ultimately, when examining the relationship between UR and LCF, it is noted that while UR does not exhibit a significant impact on LCF in the short term, it results in a decrease in LCF in the long term. The findings do not align with Ref. [28] but are consistent with Refs. [29,30,50]. Based on the findings derived from the analysis, it is evident that the UR structure in Turkiye hurts EQ. At this juncture, the government's policies and implementation assume significance, as adopting policies and practices that promote a favourable UR structure could potentially mitigate this disadvantage. Should the current UR structure persist in its current trajectory, Turkiye may find itself compelled to relinquish its aspirations of attaining the SDGs. To circumvent this situation, a plan should be devised to attract qualified and skilled individuals to cities where sectors compatible with their skills are situated. Conversely, there should be encouragement for less skilled individuals to remain in settlements such as cities or villages, where the agricultural sector or sectors requiring lower skill qualifications are prevalent. Ref. [50] demonstrated that urbanization diminishes EQ in the short and long term for Turkiye. Therefore, this finding confirms the destructive impact of Turkiye's urbanization on EQ. The increase in urbanization also leads to a rise in public transportation services and the number of individual vehicles.

For this reason, the increase in urbanization further deteriorates EQ. However, to prevent this degradation or at least mitigate the extent of environmental damage, it is important to integrate environmentally friendly vehicles into everyday life and encourage individuals to use these vehicles sustainably. On the other hand, it would also be beneficial to implement policies aimed at preventing urbanization. Furthermore, it is believed that the planned implementation of migration mobility within the country will be advantageous in mitigating the distorting effect on this parameter. Fig. A2 shows the signs of the determinants of EQ.

Conclusion and policy inferences

Conclusion

This study investigates the effects of EG, UR, FR&D and RR&D on the load capacity factor for 1986–2022. This paper considers the LCC hypothesis and uses the AARDL approach for empirical application. Econometric analysis results confirm a long-run relationship between LCF and explanatory variables. The signs of EG and its square are negative and positive, respectively. Based on the findings, the LCC hypothesis is valid in Turkiye, and environmental quality is expected to increase after a certain period. Therefore, it is concluded that the increase in income in Turkiye is a significant factor in the rise of EQ. In addition, the finding that the square of EG is positive implies that Turkiye's production structure and social transformation will evolve into an environmentally sensitive phase due to its gradual improvement. As a result, the increase in income in Turkiye not only supports its aspiration to join the ranks of developed economies in the future but also plays a crucial role in achieving its sustainable environment goals by enhancing its EQ. Another finding is that the increase in UR decreases EQ in Turkiye. Drawing from this result, the UR process in Turkiye involves less skilled individuals, predominantly employed in sectors not demanding advanced skills, rather than highly qualified personnel. From this perspective, Turkiye needs to alter the current trend and adopt policies to retain skilled labor in urban areas while keeping less skilled labor in rural areas. Otherwise, it is unlikely that Turkiye will achieve a sustainable environment in line with its 2050 targets. Findings from the analysis reveal the role of RR&D, the primary factor in the study, in determining EQ. On the flip side, based on the analysis conducted, it is concluded that the increase in RR&D enhances EQ, thereby supporting the validity of the claim made in the study regarding Turkiye. Therefore, regarding SDG targets, especially SDG-7, Turkiye needs to increase the resources allocated for RR&D and encourage practices contributing to this process. Finally, the last finding of the analysis reveals the relationship between FR&D and LCF. As expected, the study confirms that EQ deteriorates as FR&D investments increase. It is known that investments in FR&D are inevitable due to both the availability of cheaper inputs in conventional processes and the incomplete orientation of infrastructure transformation towards renewable resources. Nonetheless, Turkiye still needs to progressively reduce the resources allocated to this area and shift focus towards increasing investments in research, development, and deployment to attain its future targets by 2050.

Policy inferences

The first finding of our study is that the LCC hypothesis is valid in Turkiye. Therefore, EQ in Turkiye will eventually increase after a certain income level. In Turkiye, a developing country, environmental sustainability should be targeted along with economic growth. These two elements (income and environment) should be considered together. Sustainable growth can only be possible with SDG targets. Therefore, the Turkish government should develop green growth models based on the SDGs. In this way, growth will occur, and EQ will not be compromised. Increasing income in developing countries depends on the industrial sector, and these countries are generally dependent on fossil fuels. Turkiye is a country that consumes heavy fossil resources and meets most of its energy needs through imports. This situation may disrupt Turkiye's energy security.

Moreover, sustainable growth can only be achieved if dependence on fossil fuels is reduced. The Turkish government can guarantee the SDGs through legislation and guide the industrial sector towards a green transformation. The private sector can then implement sustainable policies that start first in the public sector. However, profound privileges must be granted to the private sector for green transformation to occur. For example, tax reductions, subsidies, and incentives can be introduced to industrial sectors that develop workflow schemes according to SDG policies and realize this as output. Thus, the aim is for income to reach a certain level and EQ to increase. The Turkish government could enhance EQ by imposing additional environmental taxes on companies with fossil resource-intensive production to support the country's green transformation process further. The revenue generated from these taxes could then be allocated to funding green transformation initiatives. The government could also implement protectionist measures to support companies involved in the green transformation until these industries are robust enough to be self-sustaining. At the end of this process, the country has the opportunity to achieve its sustainable environmental goals in alignment with the SDG targets.

In our study, while RR&D investments increase EQ, FR&D investments cause EP. We note that the coefficient of fossil fuels is greater than that of renewables. This result is inevitable for Turkiye, which has intense fossil resource consumption. While Turkiye has taken essential steps within the scope of SDGs in recent years, it has also implemented policies that accelerate green transformation. Although the use of fossil fuels in Turkiye decreases yearly, approximately 80 % of its energy needs are still met by fossil fuels [51]. This situation is also reflected in energy R&D investments. RR&D investments have reached three times that of fossil fuels in recent years. This policy should continue for many years. In other words, Turkiye, on the path to green transformation, should reduce fossil fuel use and increase RR&D investments. However, reducing fossil fuel use should not affect EG. Because Turkiye, which is a developing country, also needs income growth. In this case, the energy needs of the industrial sector should be met with energy efficiency policies, and new energy sources should be discovered. Budgets should be allocated for these energy resources, especially in Turkiye, where weather conditions are suitable for wind and solar power plants. Electricity consumption from solar energy should be provided from the public sector to individual homes. Turkiye, which receives significant sunlight for most of the year, has yet to activate this potential. Individuals can meet their energy needs with the electricity produced at home and sell excess energy production to the state. Therefore, Turkiye has significant potential in terms of renewable energy resources, and to transform the infrastructure to utilize these resources actively in the production process, RR&D investments should be used effectively. Some cities in Turkiye are well-suited for wind energy, while others are more favourable for solar energy. In this context, it is possible to achieve sustainable energy use by establishing facilities that provide each city with the renewable energy source to which it is best suited. Ultimately, obtaining energy from each city with maximum efficiency reduces foreign dependence on energy use and supports the sustainability of this process by allocating the resources generated to RR&D.

Finally, UR puts pressure on EQ and in Turkiye, where urban migration is high, policies should be developed for individuals settling in cities. First, environmental awareness training can be given to city dwellers. Secondly, financial support can be provided to encourage settlement in rural areas. Particularly in Turkiye, where agricultural production conditions are favourable, financial support such as subsidies and tax reductions can be provided to increase agricultural activities in rural areas. In fact, although Turkiye has extremely fertile agricultural lands, it has lost its agricultural superiority in recent years due to rural–urban migration and has become dependent on foreign countries. However, with government support, establishing co-operatives in rural areas that are advantageous for agriculture and animal husbandry would provide employment, improve the quality of life for the rural population, and prevent the accumulation of unskilled labour in cities. Thus, EP caused by UR can be reduced.

Limitations and future directions

Naturally, this study has some limitations and suggestions for future studies. This study focuses on fossil and renewable energy investments. If the data set is long enough, nuclear energy and energy efficiency investments can also be included in the long-term model. The structural changes were assumed to be sharp because the data set was not long enough. Future studies could model EQ using Fourier functions. This study considers the quadratic function when investigating the LCC hypothesis. Future studies can make comparisons using quadratic and cubic functions together. Finally, using panel data analysis methods, the impact of fossil and renewable energy R&D investments on EQ can be investigated in countries such as G-7, BRICS, and EU.

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CRediT authorship contribution statement

Abdullah Emre Caglar: Project administration, Software, Writing - Review & Editing, Writing Original Draft. **Nazlı Gökçe:** Writing Original Draft, Writing - Review & Editing, Visualization. **Daniel Balsalobre-Lorente:** Writing Original Draft, Writing - Review & Editing.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.seta.2024.103888.

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