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RESEARCH ARTICLE

New environmental performance index for measuring sector-wise environmental performance: a case study of major economic sectors in Pakistan

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Abstract

The study develops slack-based environmental performance index (SBEPI) to conduct the environmental performance of Pakistan's major sectors of the economy, which include agriculture, manufacturing, transport, power, construction, and mining and quarrying (M&Q) sectors. The index computes environmental efficiency scores based on three critical indicators, total primary energy consumption (input indicator), gross domestic product (desirable output), and CO_2 emission (undesirable output). The study undertakes analysis for a period of 10 years from 2008 to 2017. SBEPI score of 1 is set to indicate efficient performance, while score of 0 translates inefficient performance. The results of the studied period reveal that all the sectors underperform for considered indicators. For instance, the top-performing agriculture sector could only achieve an SBEPI score of 0.00008275. The analysis also does not reflect any signs of performance improvement for the studied sectors. To validate the results of this study and highlight the advantages of SBEPI, the study compared SBEPI results with conventional environmental index (EI). The comparison results reveal that SEBPI results are more realistic and the index holds higher discriminatory power than conventional EI. Based on this study's results, some policy recommendations for the government and other sectoral leaders to improve sectoral environmental performance are provided.

Keywords Environmental performance · Energy efficiency · Environmental efficiency · DEA · Pakistan

Introduction

The 2018 Yale's environmental performance index ranked Pakistan on 169 among 180 countries (Yale University 2018). The index conducts environmental analysis based on 24 indicators, covering broader aspects of the environment, energy, and ecosystem vitality. The low ranking signifies poor environmental performance and alerts the country to take adequate measures to mitigate environmental deterioration. The index is renowned as it releases environmental scorecards every year, which helps countries to identify their standing. Although this index is useful, however, it only provides performance comparison at the national level and does not investigate the environmental performance of various sectors of the economy of a country. As such, more comprehensive analyses are required to identify performance gaps and understand the determinants of environmental progress that could provide useful insights for effective and deliverable environmental policymaking. This study, therefore, attempts and undertakes an inclusive environmental performance assessment for Pakistan's various economic sectors to present a more precise analysis.

Pakistan is a developing country located in the South Asian region. The country is strategically located; therefore, its economic stability is vital for the overall stability of the region. In contrast, nearly 40% of the total population of the country lives below the poverty line (Shah et al. 2019a). The country is under a great deal of pressure to increase economic development for improving the living standards of its population. However, the pursuit of economic growth also brings adverse impacts to the environment (Ali et al. 2019), (Shah 2019). For instance, the amount of CO_2 emission associated with economic activities increased from 85.68 metric tons in 1997 to 183.45 metric tons

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in 2017, which is an increase more than 100% in a couple of decades (IEA 2017). This increase is alarming as the country is already facing severe climatic events such as increased temperatures, erratic rains, flooding, and droughts. Also, the recent smog engulfing Lahore—the capital of Pakistan's most populated province is a significant repercussion of mounting air pollution. The country has also been listed among top ten climate vulnerable countries consecutively since 2016 (Shah and Solangi 2019). In such a scenario, decoupling CO_2 emission from economic activities seeks highest ever attention for both the mitigation and adaption measures at different levels.

As a first step to decouple the emissions from economic growth, it is sensible to identify environmental inefficiencies of various sectors of economy whose performance shapes the overall environmental performance of a country. This should follow the formulation of targeted policies to improve the identified inefficiencies (Ang et al. 2010). A sound justification for doing so lies in the fact that environmental performance of any economy depends on efficient utilization of energy sources by various sectors to maximize the production of desirable outputs such as goods and services while minimizing the production of undesirable outputs such as greenhouse gas (GHGs) emissions. Various studies have somewhat undertaken similar analysis with varying limitations. For instance, Pérez et al. (2017) disintegrated the energy efficiency and GHG emissions assessment of Chilean manufacturing into regions and sectors. This disintegration allowed authors to identify areas, where the manufacturing industry underperformed, and sectors, which operated inefficiently. Wang et al. (2017) also modeled China's energy efficiency and productivity analysis by disintegrating economy-wide sectors. This analysis facilitated the flexible modeling of various sectors' production processes, which also helped to assess sectors' influence on aggregated performance. Therefore, this kind of analysis can be more helpful for governments and policymakers to specifically focus on the inefficient sectors and their impact on the overall performance of an economy.

The first and foremost step involved in the environmental performance assessment is to develop an index that could adequately serve the purpose of the study. Since the production process of economic goods and services also produces byproducts—referred hereafter as undesirable outputs—most of the studies often used the production technology to model the environmental index (Wang et al. 2018). The use of production technology in environmental assessment commenced from Färe et al. (1989), who proposed a weak disposability of the production technology. This was aided by the subsequent researchers who, after specifying weak disposability, employed directional distance function to measure the environmental performance. Researches have used both parametric and nonparametric distance functions. However, most of the studies favored the nonparametric method, such as data envelopment analysis (DEA). The DEA models used in environmental assessments consider production technology as a piecewise linear combination of inputs, desirable outputs, and undesirable outputs and, therefore, consider desirable and undesirable outputs distinctly. Färe and Grosskopf (2004) have named such DEA models as environmental DEA models.

A sample of studies which have used environmental DEA methods to model environmental performance are as follows: Zhou et al. (2017) used a nonparametric frontier approach to develop a composite environmental index measuring environmental efficiency of manufacturing sectors in Los Angeles. The index efficiently addressed data irregularity and mixed measurability issues. Baležentis et al. (2016) integrated environmental DEA with the spirits of Hicks-Moorsteen to develop environmental index evaluating sustainable development and climate change goals of Lithuanian economic sectors. The study used labor, capital, and energy as inputs, value-added as desirable outputs, and nitrous oxide emissions as undesirable outputs. In another study, Jin et al. (2014) developed a stochastic environmental DEA model which evaluated environmental performance under random conditions. This model was employed for the environmental assessment of APEC countries. Meng et al. (2013) used non-radial DEA to develop an environmental index that could be used as both for static and dynamic measurements. The index enabled authors to model the environmental performance of various industrial sectors located in different Chinese provinces. A plethora of such studies is available in Sueyoshi et al. (2017) and Sueyoshi and Goto (2018), where authors have listed more than 700 articles, which employed environmental DEA.

It is pertinent to mention that most of the environmental DEA models assume that any increase or decrease in desirable and undesirable outputs is proportional which suggest that such models did not account for input and output slacks when evaluating environmental performance. Though these models have many promising theoretical characteristics, however, one key weakness is that many decision-making units (DMU) can achieve a score of 1 using these models, as such, causing it difficult to present a meaningful comparison. This provides uncertainty and doubt that even DMUs that obtained efficiency scores of 1 might not be operating at a fully adequate level. Thus, it becomes meaningful to add input and output slacks to get more realistic efficiency measures. As such, this study follows the slack-based DEA model proposed by (Zhou et al. 2006) towards modeling the environmental performance of Pakistan's economic sectors. The model quantifies slacks and has higher discriminating power, thus giving more accurate efficiency scores.

The rest of the paper proceeds as follows: "Methodology" presents methodology for modeling sectoral environmental performance assessment. "Area of study" introduces area of study. "Results" contains results of the analysis while "Discussion" discusses the overall study. The final section concludes the study and proposes some policy implications.

Methodology

In this study, the sectoral environmental performance modeling has been undertaken using the research framework shown in Fig. 1. In the first instant, three key indicators for the analysis, namely total primary energy consumption (input indicator), GDP (desirable output), and CO_2 emission (undesirable output), were selected based on comprehensive literature review provided in the precedent sections of the paper. This followed development of the SBEPI and employed same to compute environmental efficiency scores of the studied sectors of Pakistan's economy. Finally, SBEPI results were compared with the conventional environmental index (EI) for identical indicators and for same sectors of the economy to establish the effectiveness the SBEPI. Following the sub-section further discusses each of the indicators and SBEPI development and evaluation of the environmental performance using the same for various sectors of Pakistan's economy.

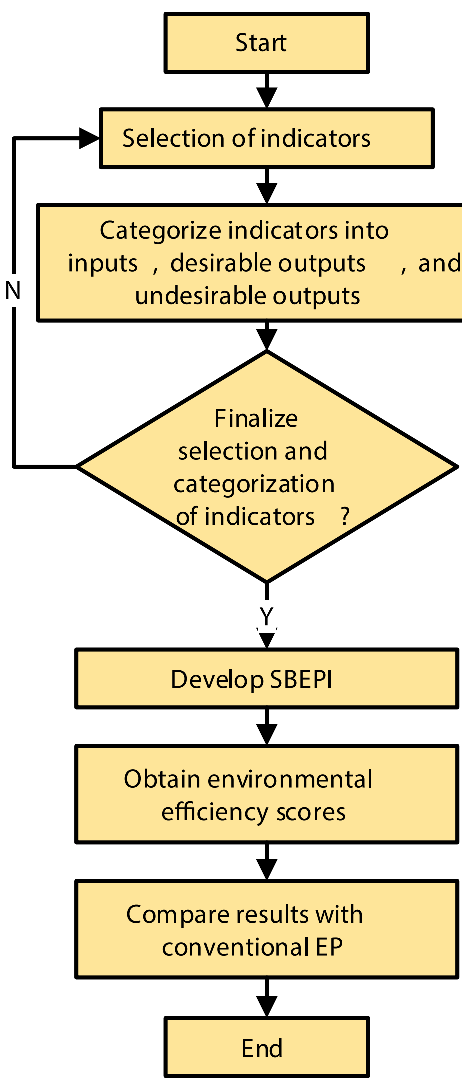


Fig 1 Schematic design of research

Selection of indicators

Taking into account the relevance to the scope of the study and based on the comprehensive literature review, three key indicators were selected, which were then categorized into input, desirable output, and undesirable output. Total primary energy consumption (TPES) was categorized as "input," gross domestic product (GDP) as "desirable output," and CO_2 emission as "undesirable output." Other rationale for the consideration of these indicators is for their higher significance in the sectoral environmental performance. Further indicators, such as NOx and other could have been included in this study analysis. However, due to the unavailability of reliable data, all and sundry indicators were not considered. It is also a pertinent fact that a small number of indicators are more favorable for the study and analysis as it allows better discrimination in the results.

Developing slack-based environmental performance index

Data envelopment analysis

DEA is a nonparametric mathematical technique, and therefore, it neither requires various assumptions arising from the use of statistical methods for estimating function or measuring efficiency, nor is it bounded by any functional form (Suganthi 2018). As such, DEA is a useful tool to measure DMU performance. Due to the established effectiveness of DEA, a variety of fields have extensively used such analysis, for instance, benchmarking of hospitals (Prior 2006; Du et al. 2014), supply chains of enterprises (Mahdiloo et al. 2012; Chen et al. 2006), energy and environmental performance (Zhu et al. 2019; Shah et al. 2019b), efficiency analysis of energy sources (Xu et al. 2019a), energy security evaluation (Mohsin et al. 2018), and many other fields. Similarly, DEA serves useful applications for measuring environmental efficiency. Therefore, this study introduces a DEA-like model as the primary approach to evaluate the sectoral environmental performance in Pakistan. Before introducing the model, it is a prerequisite to understanding environmental DEA technology as discussed in the subsequent sub-section.

Environmental DEA technology

Consider a production procedure that simultaneously produces desirable and undesirable outputs. Assume that inputs, desirable outputs, and undesirable outputs respectively are $x \in R^N$, $x \in R^M$, $x \in R^J$, then the production technology function can be written as follows:

$$P = (x, y, u) \text{and } x \text{ inputs produce } (y, u) \tag{1}$$

The production theory assumes P as a bounded and closed set that guarantees the closeness of outputs and entails that the finite inputs can produce finite outputs. Moreover, in production technology P, inputs and desirable outputs are freely and strongly disposable. For instance, $(x, y, u) \in P$ while $(x^{'} \geq x)$ or $(y^{'} \leq y)$, then $(x, y^{'}, u) \in P$ or $(x^{'}, y, u) \in P$. Details of production theory can be found in (Färe and Primont 2012).

In order to develop a production technology function which produces desirable and undesirable outputs, below given assumptions, proposed by (Färe et al. 1989), have been imposed on P:

- Weakly disposable outputs, for instance, if $(x, y, u) \in P$ while $1 \geq \theta \geq 0$, then $(x, y\theta, u\theta) \in P$.
- Null jointness of desirable and undesirable outputs, for instance, if $(x, y, u) \in P$, while u is zero, then y is also equal to zero.

The desirable and undesirable outputs are weakly disposable in the first assumption. This suggests that without reducing desirable outputs, it is not possible to decrease undesirable outputs. The second assumption states that only stopping the production process can eliminate undesirable outputs.

So far, weakly disposability of P, also referred to as polluting technology in (Färe et al. 2005), has been theoretically well modeled for producing desirable and undesirable outputs simultaneously. Following output set describes it as follows:

$$Q(x) = \{(y, u) : \text{where } ((x, y, u) \in P)\} \quad (2)$$

where $Q(x)$ denotes technologically feasible points at given inputs. It is evident that $(x, y, u) \in P$, whereas $(y, u) \in Q(x)$. Also, $Q(x)$ is considered as an environmental output set, because, strong disposability of undesirable outputs is prohibited in P (Färe and Grosskopf 2004).

Even though the production technology P has been thoroughly described, however, it is not directly useable in empirical applications. This requires that a balanced relationship between P and Shephard distance function be developed, which is considered to be the simplification of the additional single output production function. The distance function is calculated based on parametric and nonparametric conditions. More details can be found in (Lee et al. 2002) and (Färe et al. 2005) (Färe et al. 2006).

For nonparametric specification, empirical studies widely develop and use piecewise linear production technology. Färe and Grosskopf (2004) termed this production technology as environmental DEA because it is constructed in the DEA's structure. Suppose DMUs are $d = 1, 2, 3, \ldots, D$, and for DMU_d, data of inputs, desirable outputs, and undesirable outputs on the vectors are $x_d = (x_{1d}, x_{2d}, \ldots, x_{nd})$, $y_d = (y_{1d}, y_{2d}, \ldots, y_{md})$, $u_d = (u_{1d}, u_{2d}, \ldots, u_{jd})$, respectively. Furthermore, suppose that $\sum_{j=1}^{j} u_{jd} > 0, (d = 1, 2, \ldots, D)$ and $\sum_{d=1}^{D} u_{jd} > 0, (j = 1, 2, \ldots, J)$. Environmental DEA technology displaying constant return to scale (CRS) can be shown as follows:

$$P = \Big\{ (x, y, u) : \sum_{d=1}^{D} z_d x_{nd} \leq x_n, \Big(n = 1, 2, \cdots, N\Big) \\ \sum_{d=1}^{D} z_d y_{md} \geq y_m, (m = 1, 2, \cdots, M) \\ \sum_{d=1}^{D} z_d u_{jd} = u_j, (j = 1, 2, \cdots, J) \\ z_d \geq 0, (d = 1, 2, \cdots, D) \Big\} \quad (3)$$

It is evident that model (3) verifies all the properties mentioned above, for instance, weakly disposability and null jointness of desirable and undesirable outputs. Figure 2 depicts the output set of environmental DEA technology, in which three DMUs produce one desirable output (y) and one undesirable output (u) from the same amounts of inputs (x). The three output sets are written as A, B, and C, respectively. Environmental DEA technology is denoted by output set $Q^w(x)$ and confined by OABCD. If a strong disposability of undesirable outputs is allowed, then the $Q^s(x)$ shall become the OEBCD region.

Non-radial slack-based environmental DEA

Traditional DEA techniques, such as the CCR-DEA model, consider the maximization of all the outputs for a given input (Vyas and Jha 2017). However, the actual production process also yields undesirable outputs, such as several pollutants, as byproducts of desirable outputs (Rao et al. 2012), whereas the essence of environmental efficiency is focused at producing more desirable outputs and less undesirable outputs while using the minimum number of inputs (i.e., natural resources). In such scenarios, traditional DEA models do not fit for measuring environmental efficiency because undesirable outputs require exclusive handling to attain a more accurate efficiency measure. There are numerous DEA models used to evaluate the environmental efficiency by integrating undesirable

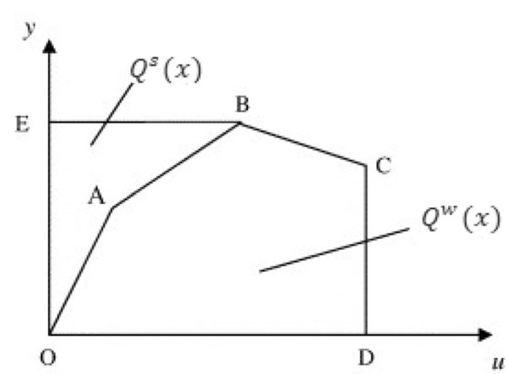


Fig. 2 Representation of the output set of environmental DEA (Zhou et al. 2006)

outputs in the traditional DEA framework. Among other models, DEA-based undesirable output-oriented model (4) presented by Tyteca (1996) and Tyteca (1997) is extensively used. In this model, subscript "0" symbolizes the DMU under evaluation. This model provides a standardized and aggregated efficiency measure (that is greater than 0 and less than 1) to assess the environmental performance. Moreover, the environmental index in this model is reciprocal of Shephard distance function applied in Färe et al. (2004) and Zaim (2004) as depicted below:

$$
\begin{aligned}
& EI = \lambda^* = \min\lambda \\
& \text{s.t.} \sum_{d=1}^{D} z_d x_{\text{nd}} \le x_{n0}, (n = 1, 2, \cdots, N) \\
& \sum_{d=1}^{D} z_d y_{\text{md}} \ge y_{m0}, (m = 1, 2, \cdots, M) \\
& \sum_{d=1}^{D} z_d u_{\text{jd}} = \lambda u_{j0}, (j = 1, 2, \cdots, J) \\
& z_d \ge 0, (d = 1, 2, \cdots, D)
\end{aligned}
\tag{4}
$$

Although model 4 is useful, however, it does not use slacks in inputs and provide desirable outputs. In simple words, even if any DMU performs slightly better than another, they might still get the same environmental efficiency score of 1. Whereas, according to the viewpoint of DEA methodology, at least one of these two DMUs operates below full efficiency level. Therefore, it is reasonable to measure these inefficiencies and reflect them into the environmental index. Zhou et al. (Zhou et al. 2006) followed the concept of slack-based efficiency measure in conventional DEA framework (Cooper 2007) (Tone 2001) and presented:

$$
\begin{aligned}
& \rho^* = \min \frac{1 - \frac{1}{N} \sum_{n=1}^{N} \frac{s_n^-}{x_{n0}}}{1 + \frac{1}{M} \sum_{m=1}^{M} \frac{s_m^+}{x_{m0}}} \\
& \text{s.t.} \sum_{d=1}^{D} z_d x_{\text{nd}} + s_n^- = x_{n0}, (n = 1, 2, \cdots, N) \\
& \sum_{d=1}^{D} z_d y_{\text{md}} - s_m^+ = y_{m0}, (m = 1, 2, \cdots, M) \\
& \sum_{d=1}^{D} z_d u_{\text{jd}} = \lambda^* u_{j0}, (j = 1, 2, \cdots, J) \\
& z_d \ge 0, (d = 1, 2, \cdots, D) \\
& s_m^+, s_n^- \ge 0
\end{aligned}
\tag{5}
$$

Model 5 imposes a set of constraints on undesirable outputs. These constraints ensure efficient practicing of DMU_0 in pure environmental performance. Also, it employs ρ^* (a slacks-based measure of efficiency), after the pollutants of DMU_0 have been set to minimum levels. Thus, it is indicative that this model is particularly suitable to evaluate the inefficiency of DMU_0. In order to identify the reasons for economic inefficiency, slack variables $s_n^-, s_m^+ \{(n = 1, 2, \ldots, N)$, $(m = 1, 2, \ldots, M)\}$ could be employed. The slacks-based efficiency measure (ρ^*) verifies $1 \ge \rho^* > 0$ and fulfills the properties of monotone and unit invariance. A larger value of ρ^* indicates better performance of DMU_0 in pure economic performance. On the other hand, if slacks in inputs are removed and outputs $s_n^- = s_m^+ = 0$, we get $\rho^* = 1$, which implies that the economic inefficiencies of two DMUs are zero. Thus, if we incorporate economic inefficiency and pure environmental inefficiency, then we obtain the below given slack-based environmental performance index (SBEPI):

$$
\text{SBEPI} = \lambda^* \times \rho^* \tag{6}
$$

SBEPI combines economic and environmental inefficiencies; therefore, it is considered as a composite index for measuring the economic and environmental performance. Also, SBEPI is a standardized index since it provides value between (0, 1) intervals, and fulfills property "the larger, the better." Additionally, in comparing environmental performance, the discriminating power of SBEPI is usually more significant than that of model 5. SBEPI, to a great extent, can reflect the standpoints of producers and regulators. Producers with lower economic inefficiencies prefer SBEPI because it imposes a punishing factor ρ^* on producers having higher economic inefficiencies. Also, this index encourages inefficient producers to improve their economic performance that is preferred by social managers and regulators.

It should be noted that model 5 involves complex calculations involving fractional programming problem. Therefore, the model is transformed into a linear programming problem using Charnes–Cooper transformation theory explained in (Tone 2001). If it is considered that let $z_d' = gz_d, s_n^- = gs_n^-, s_m^+ = gs_m^+$, then we have as follows:

$$
\begin{aligned}
& \rho^* = \min\left\{g - \frac{1}{N} \sum_{n=1}^{N} \frac{s_n^-}{xn_0}\right\} \\
& \text{s.t.} \sum_{d=1}^{D} z_d' x_{\text{nd}} + S_n^- = g x_{n0}, (n = 1, 2, \cdots, N) \\
& \sum_{d=1}^{D} z_d' y_{\text{md}} - S_m^+ = g y_{m0}, (m = 1, 2, \cdots, M) \\
& \sum_{d=1}^{D} z_d' u_{jd} = g\lambda^* u_{j0}, (j = 1, 2, \cdots, J) \\
& g + \frac{1}{M} \sum_{m=1}^{M} \frac{S_m^+}{ym_0} = 1 z_d' \ge 0, (k = 1, 2, \cdots, K) \\
& s_m^+, s_n^- \ge 0
\end{aligned}
\tag{7}
$$

As such, SBEPI of DMU_0 can be obtained by solving 4, 6, and 7 models in turn.

Data description and sources

The data for TPES is taken as input in tons of oil equivalent; data for GDP in a million PKR, and data for CO_2 taken in the unit of kilograms. TPES data was obtained from Pakistan's

Oil and Gas Regulatory Authority; CO_2 data was taken from the Climate Analysis Indicators Tool (CAIT) World's Resource Institute, and the Hydrocarbon Development Institute of Pakistan, while GDP data was taken from the Ministry of Finance and the State Bank of Pakistan. The abovementioned data have been considered for the period from 2008 to 2017.

Area of study

The SBEPI developed in this study has been used to measure the environmental performance of Pakistan's six key energy-consuming sectors which include agriculture sector, manufacturing sector, power sector, transportation sector, mining and quarrying sector, and construction sector. Pakistan is an essential player in the Southwest Asian region. It borders China to the northwest, India to the east, Iran to the southwest, and Afghanistan to the north and west. The country has the world's sixth largest population, which according to the recent census of 2017 is approximately 207 million. The economy of Pakistan, in terms of power purchasing parity, is the 23rd largest economy in the world while, in terms of nominal GDP, it comes on 38th in the world (Pakistan Bureau of Statistics 2017). Subsequent sub-sections provide a detailed overview of sectors selected under this study.

Agriculture sector

The agriculture sector remains the backbone of Pakistan's economy. The sector plays three leading roles in the economy; first, it delivers food to the population and supplies critical ingredients to industries; second, it earns a large share of foreign exchange; and third, it provides a market for industrial goods and machinery. In 2018, the sector contributed 23% to Pakistan's GDP, employed 42% of the labor force, provided livelihoods to 62% of the total population, and generated 65% of the country's export earnings. However, the share of agriculture in Pakistan's GDP has substantially dropped from 53% in 1949–1950 to 23% in 2018. Figure 3 depicts the trend of agriculture's share in the total GDP from 1960 to 2018. Numerous factors contributed to this shrinkage, including industrialization, urbanization, and lack of supporting policies. Nonetheless, the quarter of the total land in Pakistan is arable, and the country has eighth-largest farm output in the world. Figure 4 shows land use for significant crop production across the country. The major crops of the country include wheat, rice, cotton, sugarcane, vegetables, and fruits. According to the Food and Agriculture Organization, Pakistan is among the world's top ten producers of cotton, wheat, sugarcane, dates, mango, oranges, and is the 13th largest rice producer (UNFAO 2018).

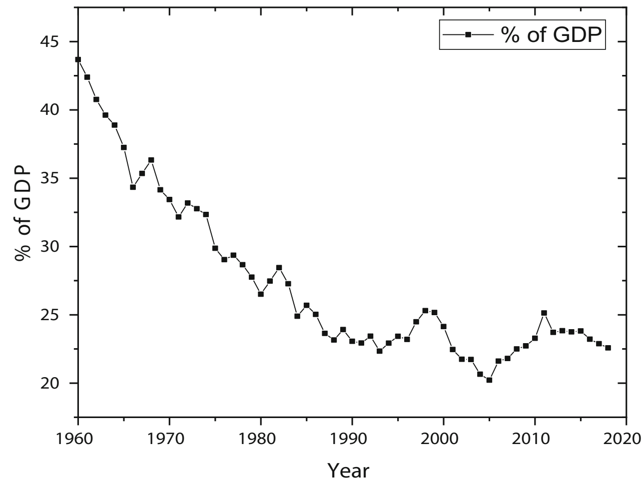


Fig. 3 The percentage share of agriculture sector in total GDP (MoF 2018)

Manufacturing sector

At the time of Pakistan's independence in 1947, the country had almost no base for large-scale manufacturing, which gradually increased through the decades. In 2018, the sector contributed 12.13% to the GDP and employed 55.88 million. However, the percentage change in the share of the manufacturing sector in the GDP only increased by 6% from 1960 to 2018. The trend of the manufacturing share in the GDP is provided in Fig. 5. It can be seen that the percentage was 11.43% in 1960, which increased to 12.13% in 2018. The highest contribution of the sector was in 2005 when it contributed 17.45% to the GDP. However, the share declined afterward, mainly because of the energy crisis, which led to industrial shutdown. Nonetheless, the sector holds significance in the overall economic growth of the country. The textile and apparel manufacturing industry is the primary industry in the manufacturing sector. In 2018, this industry generated 66% of the total manufacturing exports and employed 40% of the labor force in the sector (Wadho et al. 2019). The competitiveness of this industry is due to the easy access to cheap raw materials like skilled labor, and support from other sectors, including dying and chemical. Some other critical manufacturing industries include cement, fertilizer, steel, tobacco, machinery, leather goods, sports good, chemicals, and food processing.

Power sector

Electricity is vital for economic development. Almost all the sectors of the economy rely on electricity to perform their activities. Pakistan's power sector is under enormous pressure to meet the country's increasing demand for electricity (Xu et al. 2019b). Over the last few years, the power

Fig. 4 Crop production in Pakistan

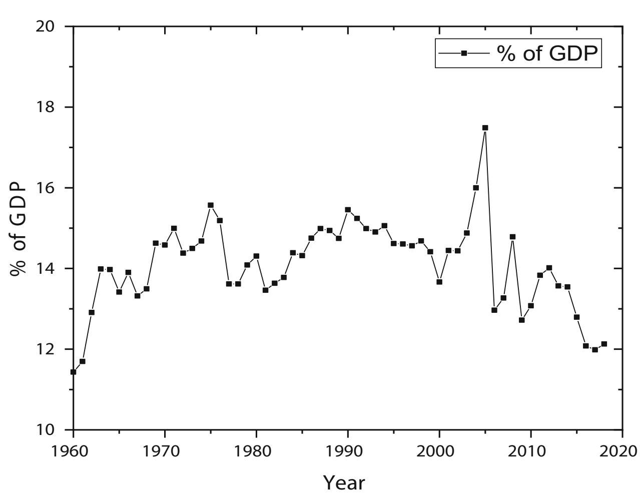


Fig. 5 The percentage share of the manufacturing sector in total GDP (MoF 2018)

sector has added a new generation to counter load-shedding, which prevails 10–12 h in urban areas and up to 20 h in rural areas (Solangi et al. 2019). The power generation capacity was increased from 23,000 MW in 2014 to 33,744 MW in 2018. However, scant attention has been given to updating infrastructure and improving energy efficiency; more than 50 million population is still not connected to the grid electricity. In 2015–2016, inefficiencies in the power sector cost $18 billion to the economy, which was 6.5% of the then GDP (Xu et al. 2019b). Almost a fifth of the total power produced is lost through inefficient infrastructure. Due to these losses, the share of electricity generation and distribution in the overall GDP has remained low, as shown in Fig. 6. In 2018, the share of electricity generation and distribution to the GDP was only 2%, which had declined from 3.18% in 1999. Overcoming inefficiencies in the sector can boost economic development and job creation (Shah et al. 2018).

Mining and quarrying sector

M&Q includes extraction of naturally occurring minerals such as solids, liquids, and gases. Pakistan has immense deposits of such minerals as gold, chromite, zinc, copper, rock salt, iron ore, graphite, marble, sulfur, fireclay, and silica; natural gas, coal, and crude oil; and precious stones including ruby, emerald, and topaz. Also, the country is among the top 11 cement producers in the world, and one of the leading producers of iron oxide pigments and barite (Ober 2017). In 2006, vast reserves of gold and copper were discovered in the Reko Dig area of Balochistan province. The M&Q sector grew by 3.04% from 2017 to 2018 when GDP from this sector increased from 339,747 PKR million in 2017 to 344,832 PKR million in 2018 (SBP 2018). Figure 7 presents the GDP contributions from 1999 to 2018. The average GDP contribution during this period remained 3.23%, reaching an all-time high of 4.29% in 2003 and a record low of 2.83% in 2016. However, the sector contributed 2.89%, which is a 14% decrease compared to 3.36% GDP contribution in 1999. Nonetheless, the sector is expected to grow after the introduction of the 18th Amendment in the Constitution of Pakistan, which provides autonomy to provinces to discover and use mineral deposits and natural resources available within their provincial boundaries. Figure 8 provides the mapping of vital oil, gas, and coal mining fieds across the country.

Transportation sector

The transport sector is one of the significant elements of Pakstan's economy. The sector comprises multiple segments, including roads, railways, air, and water. Altogether, the transport sector is estimated to have contributed 12.9% to the country's GDP in 2018. Of this, nearly 62% was added by road segment. Figure 9 provides the sector's contribution to the national GDP from 1999 to 2018. It can be seen that the sector's contribution had decreased from 13.66% in 1999 to 12.89% in 2018. Nonetheless, the average contribution is 13.2%, which is still quite significant (SBP 2018).

The transportation sector is also one of the primary energy-consuming sectors in Pakistan. It consumed nearly 12% of the country's total energy (48 Mtoe) and 38% of the petroleum products (19 Mtoe) in 2017. The demand for road transport has increased manifold over the last two decades. The number of registered road vehicles in Pakistan has increased from 11.77 million in 2012 to 12.13 million in 2018. Presently, the overall transport sector holds great importance, mainly due to the implementation of the China Pakistan Economic Corridor (CPEC) projects. These projects develop an efficient transport network that connects Pakistan to its neighboring countries, including China. Figure 10 presents a map of the current transportation network in Pakistan. Building up of transport network shall positively influence extensions of the market, mobility of factors of production, stimulate trade, and increase employment (Uddin Ahmed et al. 2019).

Construction sector

The construction sector plays a vital role in the economic development of the country. Recently, this industry has rapidly expanded, employing more than 3 million workers. During the fiscal year 2018, the sector contributed 2.5% of the national GDP declining from 2.8% in 2017. Figure 11 depicts the share of the construction sector in the national GDP from 1999 to 2018. The average contribution during these years is computed to be 2.5%. The year 2007 reported an all-time high contribution of 2.84% while the year 2003 recorded an all-time low contribution of 2.01%. Major sectors associated with the construction industry include energy, housing, communication, industrial, public health engineering, water resource development, and dam building. Almost

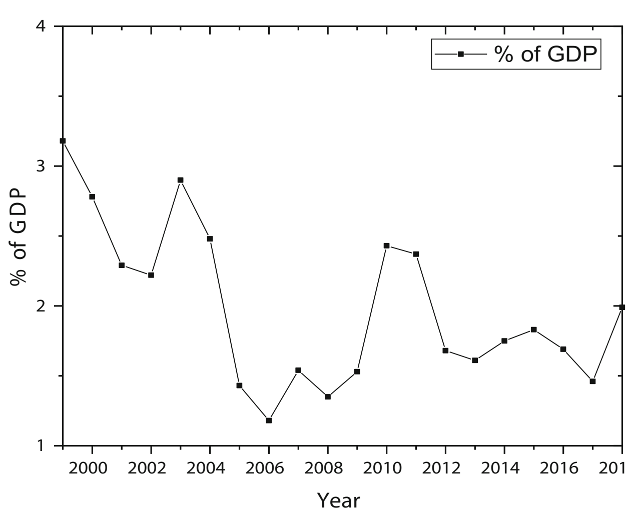


Fig. 6 The percentage share of electricity generation and distribution in total GDP (MoF 2018)

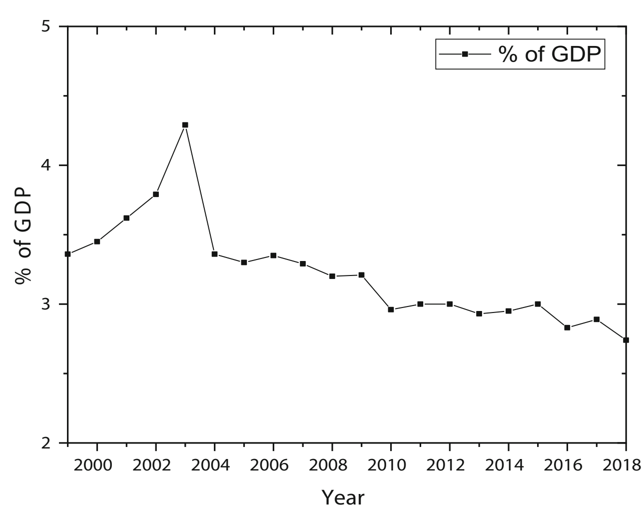


Fig. 7 The percentage share of M&Q in total GDP (MoF 2018)

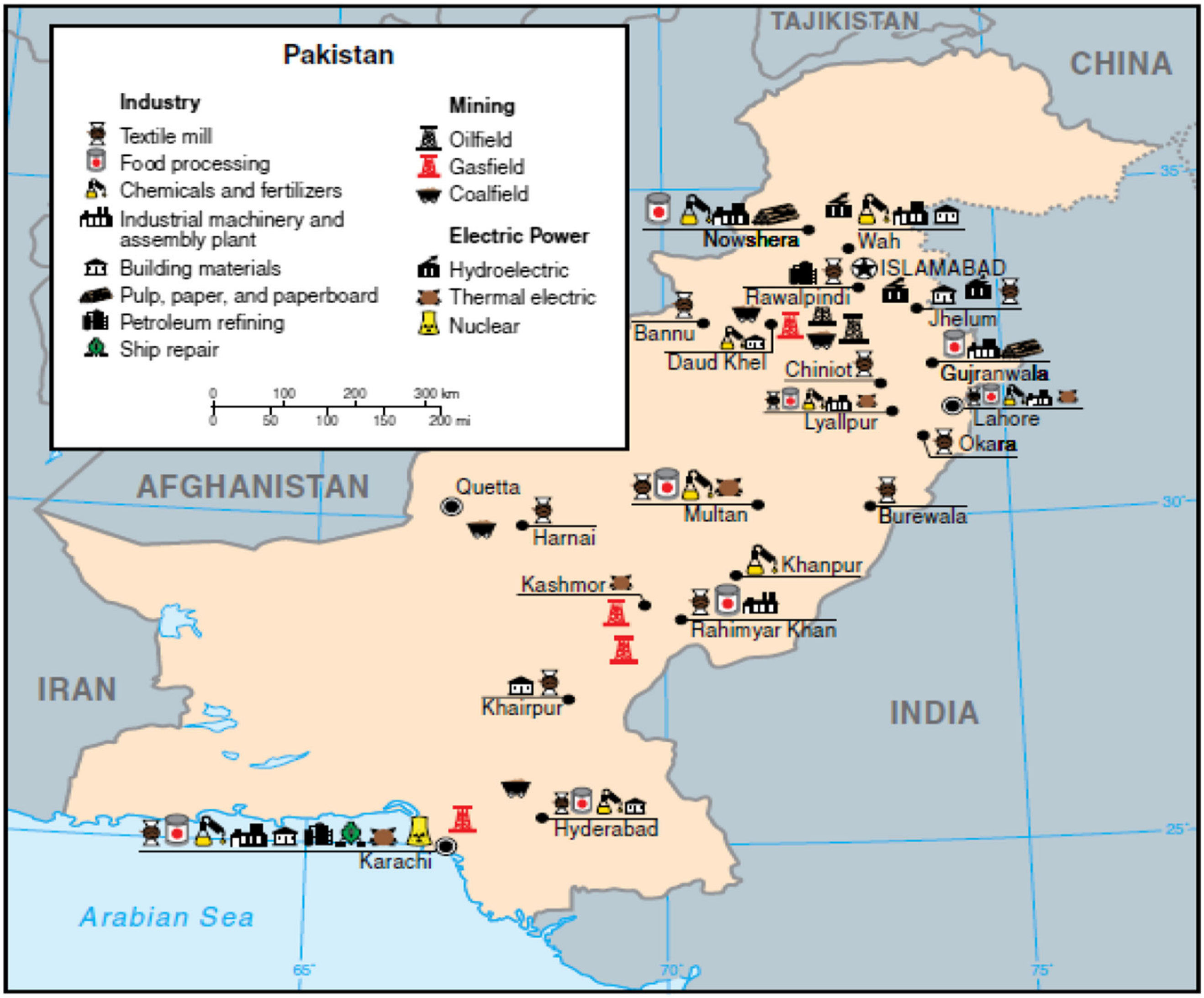


Fig. 8 Mining of oil, gas, and coal fields in Pakistan

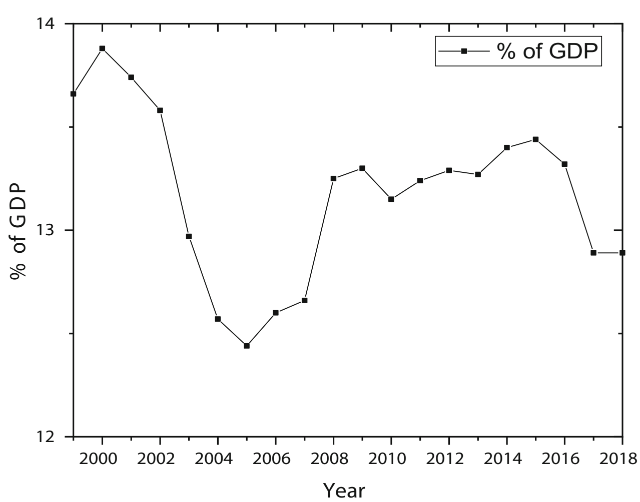


Fig. 9 The percentage share of the transport sector in total GDP (MoF 2018)

60 more sectors are linked directly or indirectly to the construction industry. The sector is also a significant recipient of foreign direct investment. The latest figures provided by the State Bank of Pakistan shows that the net inflow of construction sector in August 2017 was $35.7 million (SBP 2018). Furthermore, the government estimates that the construction industry shall gain further momentum due to increased spending on public sector development couples with the energy sector and infrastructure development under the CPEC.

Results

The results of the study are arranged as follows: firstly, descriptive statistical analysis of indicators is presented which discusses the trend of individual indicators. Later, SBEPI scores of studied sectors are computed and discussed. Finally, a comparison between SBEPI scores and EI scores

Fig. 10 The transportation network in Pakistan

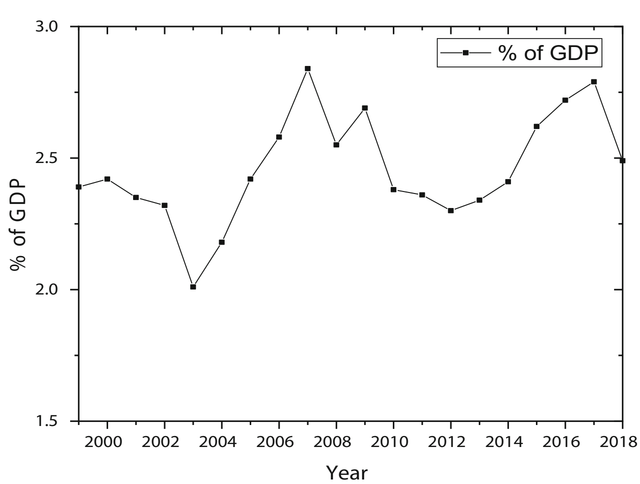


Fig. 11 The percentage share of the construction sector in total GDP (MoF 2018)

is drawn to obtain more understanding of sectors' environmental performance.

Input and output indicators

The descriptive statistics of individual indicators' growth rate for various sectors of economy from 2008 to 2017 are shown in Table 1. It is evident that mean energy consumption has decreased for all the sectors except the power sector. The agriculture sector reported the highest decrease of 15% energy consumption. The power sector, however, increased 3% mean energy consumption for the same period. The mean GDP had shown an increase for all the sectors. The highest GDP growth was reported in the power sector (20%), while the mining and quarrying sector had the lowest mean GDP growth rate. CO_2 emission shows a substantial mean decrease, such as 15% in the agriculture sector. Another sector reporting reduction in CO_2 emission is the mining and quarrying sector, with a 2%

Table 1 Descriptive statistics of indicators

		Agriculture	M&Q	Manufacturing	Transport	Construction	Power
Energy consumption	Mean	− 0.15	− 0.11	− 0.10	− 0.05	− 0.10	0.03
	Median	− 0.20	− 0.09	− 0.01	0.02	− 0.02	0.03
	SD	0.35	0.26	0.27	0.20	0.22	0.04
	Range	1.08	0.86	0.88	0.65	0.70	0.13
	Min	− 0.61	− 0.70	− 0.82	− 0.55	− 0.64	− 0.01
	Max	0.47	0.16	0.05	0.10	0.06	0.12
GDP	Mean	0.14	0.09	0.11	0.20	0.11	0.16
	Median	0.12	0.06	0.09	0.10	0.12	0.08
	SD	0.10	0.13	0.09	0.32	0.05	0.18
	Range	0.29	0.38	0.30	1.10	0.16	0.60
	Min	0.03	− 0.08	0.00	− 0.16	0.03	− 0.01
	Max	0.33	0.30	0.30	0.93	0.19	0.59
CO_2	Mean	-0.15	− 0.02	0.02	0.01	0.01	0.05
	Median	− 0.20	− 0.01	0.00	0.02	0.02	0.03
	SD	0.35	0.13	0.07	0.06	0.14	0.05
	Range	1.08	0.39	0.23	0.18	0.53	0.17
	Min	− 0.61	− 0.23	− 0.06	− 0.08	− 0.22	− 0.02
	Max	0.47	0.16	0.17	0.10	0.31	0.14

decrease. The rest of the sectors, such as construction and transportation sectors, individually contributed an increase in CO_2 level by 1%, the manufacturing sector recoded an increase by 2% while the power sector increased CO_2 level by 5%.

Based on the data whose descriptive analysis was provided in Table 1, SBEPI scores were computed which are presented in the succeeding sub-section.

SBEPI results

The SBEPI results of this study were computed for each sector using MATLAB. Table 2 presents the environmental efficiency scores obtained by each sector during the study period 2008–2017. The overall results reveal that all the sectors are performing inefficiently as no sector achieved an SBEPI score of 1, which translates fully adequate level.

Figure 12 illustrate SBEPI scores achieved by various sectors of the economy for the year 2017. Among other sectors, the agriculture sector ranked top performer in the year 2017 followed by M&Q, construction, manufacturing, transport, and power sector respectively.

In order to highlight the trend of environmental performance, Fig. 13 plots SBEPI scores of each sector for the period from 2008 to 2017. The trend illustrate no improvements in performance during the study period. The sectoral performance, as such, can be seen declining for this period. For instance, the agriculture sector's SBEPI score of 0.00019347 in 2008 fell to a new decreased level 0.00008275 in 2017. M&Q and construction sectors followed a similar trend that shows a decrease from 2010 to 2015 except during 2012 when both sectors achieved one of their highest scores. As per study analysis, the manufacturing sector has also recorded a consistent and substantial decline in SEBPI scores from 2008 to 2017. The transport sector received second-lowest scores throughout the study period. The sector's performance trend, similar to the pattern of the manufacturing sector, reveal a persistent decline while attaining lowest score in 2017. The power sector received the lowest environmental performance scores. The sector's performance decreased significantly from 2008 to 2009 and continued to portray poor performance, which reached the lowest in 2016, and further remaining same in 2017.

Comparison of SBEPI results with a conventional EI

To highlight the usefulness of SBEPI, the SBEPI results were compared with conventional EI assesment. The results obtained using EI approach are presented in Table 3. It can be seen from the EI results that the agriculture sector received an efficiency score of 1, which is a fully efficient level. Also, the construction and the M&Q sectors received exact efficiency scores for all the years, which seems a bit unrealistic. In contrast, SBEP revealed that the performance of the agriculture sector is way below the efficient level. Also, SBEPI computes different efficiency scores for construction and M&Q sectors.The SBEPI efficiency scores have also been found as much lower, which confirms that the index holds higher discriminating power than a conventional index since the former

Table 2 Environmental efficiency scores obtained using SBEPI

Sectors	SBEPI									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Agriculture	0.00019347	0.00016720	0.00008327	0.00006931	0.00006183	0.00007216	0.00008129	0.00009043	0.00008120	0.00008275
Construction	0.00016381	0.00005710	0.00003627	0.00001792	0.00000621	0.00001301	0.00003271	0.00001954	0.00000718	0.00000591
Power	0.00000017	0.00000004	0.00000004	0.00000005	0.00000002	0.00000002	0.00000004	0.00000003	0.00000001	0.00000001
Manufacturing	0.00005279	0.00001678	0.00001054	0.00000503	0.00000206	0.00000408	0.00000838	0.00000473	0.00000327	0.00000243
M&Q	0.00017816	0.00005808	0.00003725	0.00001926	0.00000737	0.00001326	0.00003351	0.00002072	0.00000777	0.00000607
Transport	0.00001985	0.00001351	0.00000786	0.00000226	0.00000063	0.00000133	0.00000252	0.00000191	0.00000030	0.00000017

incorporates both economic and environmental inefficiencies. Nonetheless, despite differences in the scores, both methods provided consistent rankings as shown in Fig. 14, except the construction sector, which was ranked third by SBEPI and second by the conventional EI.

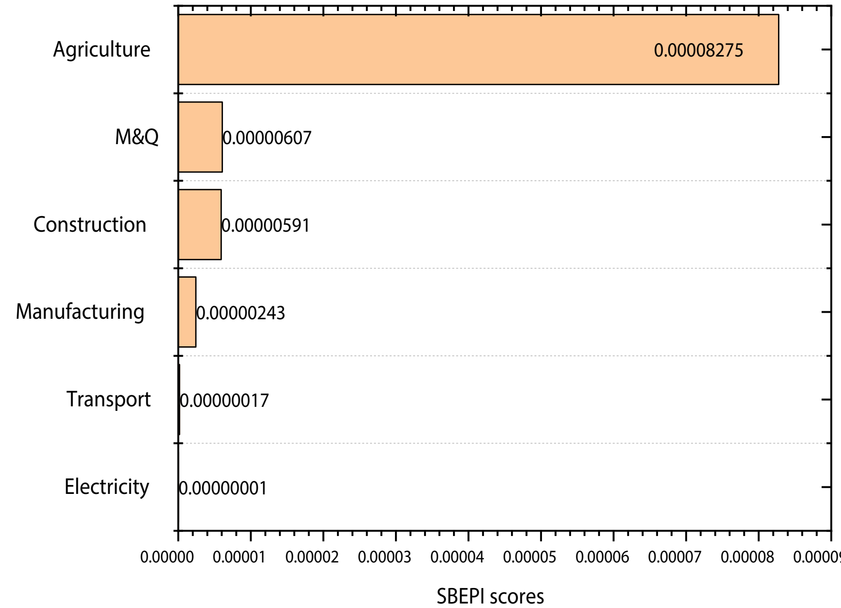
Discussion

The SBEPI is developed which is a more proficient measure of environmental performance and has higher applicability in evaluating segment-wise environmental performance of an economy. The index is developed based on the DEA which is a nonparametric mathematical modeling technique and has been widely applied in studies related to environmental performance modeling. The index developed in this study is first of its kind, designed specifically for segmented analysis, and has greater discriminatory power compared to previous indices, which also face limitations when the analysis is trickled down to the sector or segment level. Thus, the index is an addition to the literature and can be replicated for similar kind of studies undertaken for other economies or nations.

In this study, the developed SBEPI is employed to measure sectoral environmental performance of six primary energy-consuming sectors in Pakistan which include agriculture, construction, power, manufacturing, M&Q, and transportation. The index computes environmental performance based on three indicators which are TPES, GDP, and CO_2 emission. TPES is taken as input, GDP as desirable output, and CO_2 emission as undesirable output. Initially, indicators such as SO_2 and NOx were also considered as undesirable outputs; however, due to the lack of data availability for most of the sectors, these indicators were dropped from the analysis. Nonetheless, the small number of indicators—which is three in this study—is suitable for discriminatory analysis.

The study presents an inclusive environmental performance analysis which covers almost all the major economic sectors. Such study, in the context of Pakistan, was never been conducted before. Perhaps, therefore not much has been done to improve the environmental performance which, as revealed by this study, has been terrible. The results of this study are quite startling as not a single sector in the whole economy performs satisfactorily. Even the top-ranked sector (agriculture sector) could achieve 0.00008275 SBEPI score which is immensely below the fully efficient level that is indicated by a SBEPI score of 1. Such results are a clear indication that the environmental laws are not being implemented and go no further than a statute book. Also, the very recent act on the environmental protection was passed in 1997 and since then has not been revived with new policies such as carbon taxing. Nonetheless, the stringent and impartial accountability is more important to punish entities responsible for environmental violation.

Fig. 12 SBEPI scores 2017



The other major point reflected by the results is that the concepts of energy efficiency and energy conservation are not in practice. This is quite alarming since most of the energy in Pakistan comes from fossil fuels and if the concepts of energy efficiency and energy conservation are not applied then more energy shall be used to produce same amount of output with increased levels of emissions. Also, the amount of renewable energy in energy mix of Pakistan is negligible. According to (Shah et al. 2019a), Pakistan produced only 1% of energy from renewable energy sources in 2019. Lack of renewable energy usage can also be the prime factor behind the country's poor environmental performance because renewable energy technologies are clean and produce insignificant emissions while being used and therefore contribute substantially in the reduction of emissions.

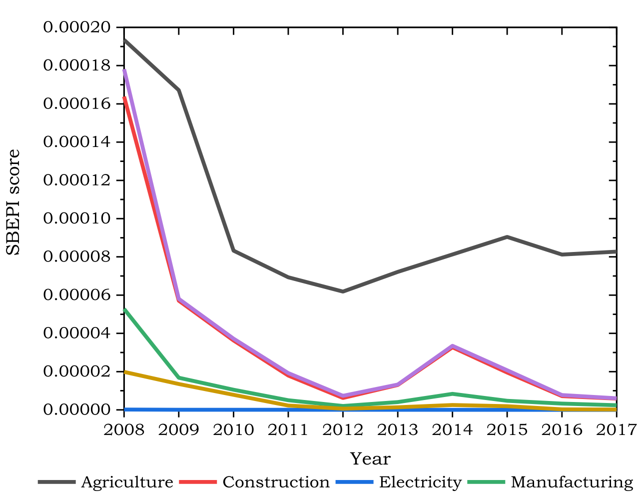


Fig. 13 The trend of SBEPI scores

Conclusion and policy implications

Decoupling greenhouse gas emissions from economic activities poses an immense challenge for governments, policymakers, and academic researchers. This challenge is even more significant in developing countries with a lack of regulations and assessment system to monitor and control emission levels. The situation holds for Pakistan, which is a developing country with no effective environmental monitoring system in place. A robust environmental assessment framework may enable Pakistan and other developing countries to identify environmentally inefficient sectors of the economy and then take appropriate measures to improve identified inefficiencies. An effort has been made in this study in which a slack-based environmental performance index was developed. The proposed index was employed to measure the environmental performance of Pakistan's six major sectors of the economy, which include agriculture, manufacturing, mining and quarrying, construction, power, and transportation. The SBEPI is found to be more proficient than a conventional EI since the latter can give an efficiency score of "1" to many comparable DMUs leading to a vague comparison among DMUs. This study also compared SBEPI results with EI and found that the former holds higher discriminating power and provides a more comprehensive measure.

The environmental assessment revealed poor performance of studied sectors. Furthermore, the trend shows no signs of improvement in the future. Therefore, Pakistan needs to initiate policy measures that can assist in improving sectoral environmental performance. Some of the significant policy implications are recommended as follows:

Table 3 Environmental efficiency scores obtained through conventional EI

Sectors	EI									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Agriculture	1	1	1	1	1	1	1	1	1	1
Construction	0.0154	0.0088	0.0071	0.0050	0.0031	0.0042	0.0066	0.0052	0.0017	0.0015
Power	0.0005	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001
Manufacturing	0.0085	0.0048	0.0038	0.0026	0.0017	0.0023	0.0034	0.0025	0.0008	0.0007
M&Q	0.0154	0.0088	0.0071	0.0050	0.0031	0.0042	0.0066	0.0052	0.0017	0.0015
Transport	0.0046	0.0038	0.0029	0.0016	0.0008	0.0012	0.0016	0.0014	0.0005	0.0004

I. Energy efficiency and increasing energy conservation can contribute to environmental protection because improved energy efficiency reduces energy consumption and energy-related GHG emissions.

II. Increased use of renewable energy can substantially reduce greenhouse gas emissions associated with economic activities. The government should increase the share of renewable energy in the national energy mix and promote renewable energy development across the country by introducing attractive incentives and subsidies.

III. A rating system should be introduced by the government to put a check on environmental performance. The government should also initiate stringent punishment for poorly performing entities.

IV. The adoption of eco-innovation in production technologies can help sectors reduce growth-driven environmental degradation by simultaneously obtaining higher eco-efficiency and productivity. Local research institutions, universities, and corporations should be engaged and encouraged to conduct research related to the advancement of eco-efficient technologies.

V. Policymakers should consider policy actions for active international engagement, which can aid in improving environmental performance by facilitating technology transfer and policy diffusion.

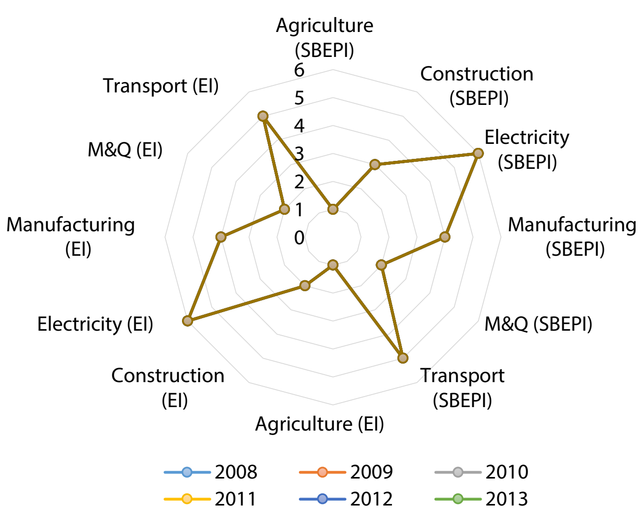


Fig. 14 Comparison of SBEPI and EI rankings

VI. Firms should regularly monitor, measure, and evaluate their environmental performance. Critical characteristics of activities and operations that can cause significant environmental impacts should also be controlled and recorded so that appropriate measures can be taken accordingly.

VII. Environmental improvement demands a firm commitment from top management. Without senior management's determination to control ecological degradation, it is almost impossible to reassure employees to take appropriate measures for environmental improvements.

VIII. Lack of training and encouragement to employees to do the right thing can devastate an industry's efforts to become environmentally responsible. Besides environmental training programs, other kinds of practices, such as team building, interactive skills, brainstorming, benchmarking, and consensus-building, shall promote a culture where employees can freely engage in the initiatives of environmental improvement.

IX. Ensuring better access to information and training, specifically at the micro-level, can enhance environmental management at small and medium scale industries.

X. Finally, effective implementation and compliance of internationally recognized environmental management systems can enhance environmental performance. ISO 14001 is the best international standard for an environmental management system that can help to control environmental degradation.

It must be noted that the process of improving environmental performance is a time taking process and does not occur abruptly. Therefore, success needs a dedicated and persistent commitment to implement the steps required to improve environmental performance. In this regard, an approach to measure environmental performance can play a pivotal role in assessing if an entity is on the right track to achieve the target or otherwise.

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