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Optimization of Multidimensional Energy Security: An Index Based Assessment

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Abstract: This study introduces Pakistan's multidimensional energy security index (PMESI) and indices across dimensions from 1991 to 2020 through indicator optimization. Based on criteria, expert participation, and reliability testing, 27 indicators were identified and weighted based on dimension reduction utilizing the Varimax Rotation technique. As a result of robust evaluation framework, there has been a considerable change in Pakistan's energy security when compared to other studies such as the energy security indicator of Pakistan (ESIP) and the energy security index of Pakistan (ESIOP). According to the findings, energy security decreased by 25% between 1991 and 2012, followed by a modest increase through 2020. During the study period, the "Affordability" dimension improved; however, the other four dimensions, namely "Availability," "Technology," "Governance," and "Environment," regressed. Few goals under the petroleum policy (1991), petroleum policy (2012), and power policy (2013) were partially met, while conservation programs, such as the renewable policy (2006) and national climate change policy (2012), fell short. Indicators such as price, reserves, governance, corruption, and consumption contributed to PMESI across five dimensions. Thus, PMESI and indices guiding policymakers to focus on improving governance and exploiting local energy resources in order to provide affordable and sufficient energy in the long run.

Keywords: energy security; Cronbach's alpha; principal component; varimax

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1. Introduction

Energy security is one of those concepts that is particularly prevalent because it does not have a definite meaning [1]. Various studies have proposed ways of interpreting energy security, such as the one by Cherp and Jewel (2014), which it is rooted in political, natural science, economic, and machine analysis [2]. Sovacool and Brown (2010) argued that the notion of energy security was either too narrow to consider energy issues or so broad that it lacked clarity and coherence [3]. Vivoda (2010) also stressed that a thorough concept of energy security is necessary, along with a workable mechanism for its analysis [4]. In addition, L. Chester (2010) claimed that, owing to multiplicity, energy security ensures that there can be "no-one-size-fits-all" [5]. Thus, Sovacool (2013) conceptualized energy security and then associated it with five dimensions, namely "Availability", "Affordability", "Technology", "Environmental Sustainability", and "Governance" [6]. The goal was to address how energy security problems are better quantified, calculated and strategized [7]. In this context, an ample number of studies have estimated the energy security performance via developing the indices to highlight the priority issues. For example, Narula (2014) used four aspects of SES to illustrate SES: availability, acceptability, affordability, and efficiency, as well as their accompanying indicators [8]. The study's weaknesses included the absence of ESIDs and the lack of an aggregated index, instead opting for an ad hoc trend analysis that was not statistically robust. In another study, K. Narula et al., 2016, reported across sectoral dimensions, as well as the aggregated SES index, based on weights obtained from an interview and the respondents' perceptions [9]. However, the index's absolute values fell short of the ideal index value of 1.0, indicating that there is still space for interpretation. Likewise, J. Martchamadol and S. Kumar (2014) used the EISD for Thailand to create the aggregated index [10]. The issue was that they only produced aggregated indices for the country and provinces, rather than indices across three dimensions of sustainability. In addition, several other research studies have been reviewed in light of the regional context. Shadman et al., 2021, for example, codified indicators using a mapping process to quantify Malaysia's energy security [11]. Their mapping took into account the 4A dimensions in order to assist policymakers and energy analysts with energy outlooks in designing data-driven energy security policies. Erahman et al. (2016) used outlier detection to estimate individual indices across five dimensions [12]. Only GDP and intensity data were utilized to depict Indonesia's social and economic difficulties. Notably, only six years of data were studied, resulting in a failure of Principal Component Analysis (PCA) in three dimensions. Tongsopit et al., 2016, used individual indices across four dimensions as well [13]. However, they concentrated on import indicators and assigned equal weight to indicators for the Association of Southeast Asian Nations (ASEAN). To that point, the literature suggests that using equal weight is ineffective since various economies have distinct goals for improving energy security in their respective states [14]. Other studies, on the other hand, have focused on hybrid renewable systems to increase performance based on consumption and supply linked with the environment domain. C. Ammari et al., 2021, focused on major categories of hybrid renewable energy system sizing, optimization, control, and energy management [15]. The advantages and disadvantages of each strategy were investigated in order to provide a comparison of several methods for ensuring the hybrid renewable energy system's best performance. S. Guo et al. (2018), on the other hand, conducted a thorough investigation of hybrid renewable energy (HRE) applications in terms of space heating, cooling, hot water usage, power generation, hydrogen production, drying, and multi-generation [16]. Furthermore, the challenges and outlook for HRE utilization were presented, including the proper use of local sources in light of renewable energy's dispersed and regional distribution to minimize costs in order to promote application and the clear identification of the supporting local renewable energy policies.

In the case of Pakistan, the energy security was presented a multidimensional phenomenon [17], as 85% energy consumed is imported in Pakistan at a cost of almost USD 14.7 billion per year [7]. As a result of the import bill, practically all foreign reserves were depleted in 2019–2020 [18]. On the other hand, Pakistan's natural gas reserves are nearing exhaustion, despite the fact that the country produces approximately four billion cubic feet of natural gas every day [19]. Mirjat et al. (2017) determined that, at this rate, gas reserves will last only 12 years [20]. Oil and gas shortages, significant transmission and distribution failures, low production output, and burdensome payment problems have all occurred in the power sector over the last two decades [21]. As early as 2021, an expected 21,000 MW of electricity demand during a heat wave resulted in 6500 MW of forced load shedding [22]. It was also alleged that load shedding and blackouts were endured for up to 20 h in certain rural areas, while similar incidents lasted up to 14 h in some cities [23]. In summary, Pakistan's energy insecurity has been exacerbated by susceptibility to energy imports, subsidies, energy intensity, the unpredictability of energy expenditures, supply and demand mismanagement, decrepit infrastructure, and corruption.

As a result of Pakistan's energy insecurity, indices have been developed using indicators [24–27]. For example, F.B. Abdullah et al., 2021, offered an aggregated index with multiple predictions for Pakistan's future energy security performance [25]. The indices across dimensions were ignored, and no expert-based indicator selection was used. Instead, the variance-based elimination of the indicators was used in the study. As a result, indicators based on intensity were omitted. In another study, F.B. Abdullah et al., 2020, used a framework to strategize the five dimensions of Pakistan's energy security. However, as stated in [13], indices across dimensions were not assessed to guide policy responses. Other flaws in the study were the selection of indicators and criteria used. For example, in Pakistan, the governance of the energy sector has been a source of contention for decades [17,28]. Pakistan's "Governance Effectiveness Index (GEI)" rankings have declined dramatically over the last two decades [29]. The indicator "Governance effective index (GEI)" was, however, ignored. Moreover, Pakistan's energy sector is plagued by corruption and inefficiency [21]. Its corruption rating is high and has recently deteriorated [29]. The indicator of corruption rating was not included in their study. Pakistan already has the world's lowest forest cover due to the arid and semi-arid climate in numerous parts of the country [19]. However, the forest-to-land-area ratio was not included in their analysis. Malik et al., 2019, included the environmental element, although the authors concentrated on imports and financial difficulties in indicator selection [26]. The study's major flaw was that it did not offer a weighting criterion or a data range from which to construct the indicators. Additionally, the governance dimension was not taken into account, and the study did not specify whether the change in performance was material or significant. Other studies, such as S.A.A. Shah et al., 2019, employed "Multiple-criteria decision analysis (MCDA)" and assigned the indicators a weight of 20% [30], while Anwar, 2016, investigated energy security by examining the effects of energy imports on emissions, and indicators were chosen at the author's discretion [31].

In summary, assessments of Pakistan's energy security have been offered in the form of an index based on several sets of indicators. Indeed, these studies have contributed in their own manner to policy decisions; however, they also have shortcomings. One clear shortcoming is that indices across dimensions were not given in the way that [6,13] emphasizes in order to provide targeted policy guidelines and priority areas. Likewise, the research has underlined that an energy index or indicator may provide minimal information if the indicators are chosen hastily [30]. Alternatively, an index is only legitimate if it includes a diverse and adequate set of indicators [32]. Furthermore, researchers acknowledged that no set of energy indicators could be final or decisive [14]. Nonetheless, there is agreement that indicators must be dynamic and change to suit country-specific challenges, capacities, and objectives [13,33]. As a result, in order to fill the void, this study will propose a framework for optimizing the indicators, followed by the development of a composite index. "Pakistan Multidimensional Energy Security Index (PMESI)" is the term referring to this index. Since energy security is a synergistic and complex ecosystem made up of individual species and their interactions, the framework will also include cross-dimensional indices to examine policy actions holistically, identify tradeoffs within the various dimensions, and highlight areas in need of improvement.

The uniqueness of this study is that it compares different indices and maps them against the goals and objectives of Pakistan's energy policies. This enables for the accounting of weaknesses while balancing energy security, economic competitiveness, and environmental sustainability. Other researchers will be interested in the framework and criteria employed to address the fundamentals of energy security assessment, such as indicator selection, weight estimations, and aggregation technique. The indicators used are robust because they are based on an expert's opinion as well as statistical methodologies. This is consistent with the fact that there is no standard set of indicators and no standard method of estimating indicator weights. The aggregation procedure is described in detail so that other researchers from around the globe can use it with ease.

2. Materials and Methods

The selection of indicators can be rather arbitrary [34]. Subjectivity, on the other hand, can be minimized by including stakeholders through questionnaires, interviews, or workshops [14]. Furthermore, each of the indicators should be reviewed in accordance with the applicable criteria for selecting the indicators [35]. To arrive at the assessment, a framework is developed that is based on three criteria (Figure 1). The first criterion is for expert's involvement. The appointment of an expert was based on whether he/she was engaged in the energy sector and whether he/she was involved in the implementation of energy policy in Pakistan. In the second criterion, the overall score is given to each indicator depending on how many experts chose the indicator. For instance, if an indicator is chosen by an expert from a list such as the one complied in [36] (Table 1), it has scored 1, and so on. Notably, there are principles to accept or reject the indicators in this criterion such as: (a) to be chosen, the indicator must score 3 or more; (b) an indicator with a score of 2 or less will be neglected.

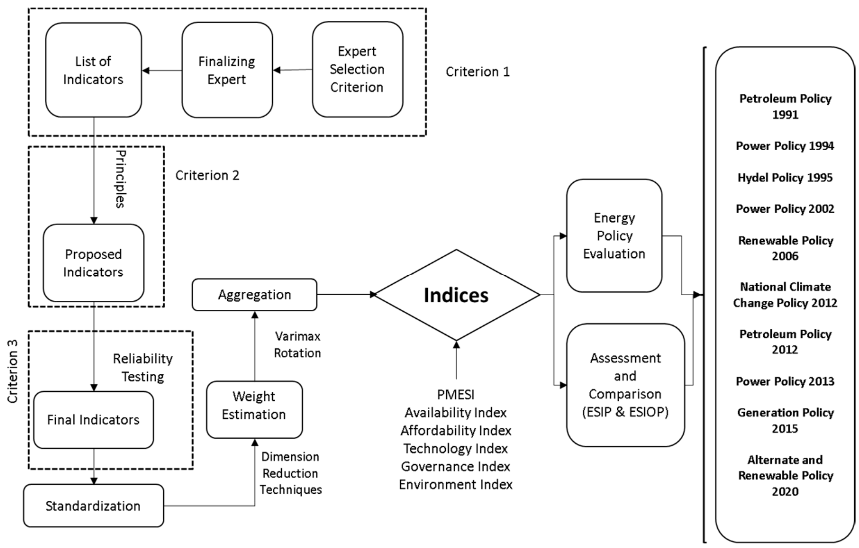

Figure 1. Framework for indicator and indices development.

Table 1. List of proposed indicators and expert selection. Source: [31].

Dimension	Indicator	Abbreviation	E1	E2	E3	E4	E5	Score	Decision
Availability	Electricity/Capita (KWh/Capita)	AV1	✓	✓	✓	✓	✓	5	Selected
	Transport consumption/FEC (%)	AV2		✓	✓			2	Rejected
	Access to Energy (%)	AV3	✓		✓	✓	✓	4	Rejected
	R/P Ratio (Years)	AV4	✓	✓	✓	✓	✓	5	Selected
	R/P Oil	AV5	✓			✓		2	Rejected
	R/P Gas	AV6	✓		✓			2	Rejected
	TPES/Capita (Kgoe/Capita)	AV7	✓	✓	✓	✓		4	Selected
	FEC/Capita (Kgoe/Capita)	AV8		✓	✓	✓	✓	4	Selected
	Renewable Share/FEC (%)	AV9	✓	✓	✓	✓	✓	5	Selected
	SWI	AV10	✓			✓	✓	3	Selected
	Transport Consumption/Capita (Kgoe/Capita)	AV11		✓				1	Rejected
	Electricity Consumed/FEC (%)	AV12	✓	✓				2	Rejected
	Household Energy/Capita (Kgoe/Capita)	AV13			✓	✓		2	Rejected
	Residential Energy/Household (Kgoe/Houses)	AV14		✓		✓		2	Rejected
	Electricity/Household (KWh/House)	AV15	✓				✓	2	Rejected
	Renewable Potential (KWh/Capita)	AV16	✓	✓				2	Rejected
	Indigenous/TPES (%)	AV17	✓	✓		✓	✓	4	Selected
	Oil Use In Transport% of Oil Consumption (%)	AV18	✓					1	Rejected
	Access *w/o* Electricity (%)	AV19	✓				✓	2	Rejected
	Share of Non- Carbon Carbon/TPES (%)	AV20	✓		✓			2	Rejected

Table 1. *Cont.*

Dimension	Indicator	Abbreviation	E1	E2	E3	E4	E5	Score	Decision
Affordability	Net Energy Import Dependency (NEID)	AF1	✓			✓		2	Rejected
	TPES/GDP (1000 Kgoe/USD)	AF2				✓	✓	2	Rejected
	Gasoline Price/Litre (2010 USD/L)	AF3	✓	✓	✓	✓	✓	5	Selected
	Diesel Price (2010 USD/L)	AF4	✓	✓	✓	✓		4	Selected
	Energy Imports/TPES (%)	AF5	✓	✓	✓	✓	✓	5	Selected
	Net Energy Import Ratio (NEIR) (%)	AF6	✓					1	Rejected
	Energy Imports/FEC (%)	AF7	✓				✓	2	Rejected
	Transport Intensity (1000 Kgoe/USD)	AF8		✓	✓	✓	✓	4	Selected
	Industrial Intensity (1000 Kgoe/USD)	AF9	✓	✓	✓	✓	✓	5	Selected
	Commercial Intensity (1000 Kgoe/USD)	AF10	✓	✓	✓	✓	✓	4	Selected
	Agricultural Intensity (1000 Kgoe/USD)	AF11				✓	✓	2	Rejected
	USDGDP/Capita (2010)	AF12	✓					1	Rejected
	% of Income towards energy	AF13	✓	✓				2	Rejected
	Imported Oil Consumption (%)	AF14	✓			✓		2	Rejected
	Imported Gas Consumption (%)	AF15	✓			✓		2	Rejected
Technology and Efficiency	T&D Losses (%)	TE1	✓	✓	✓	✓	✓	5	Selected
	TPES-FEC/FEC (%)	TE2		✓	✓			2	Rejected
	Electricity Utilization	TE3	✓		✓	✓	✓	4	Selected
	Demand Met Locally in Oil & Gas (%)	TE4				✓	✓	2	Rejected
	Oil & Well Exploration	TE5	✓		✓		✓	3	Selected
	Renewable Share/Electricity (%)-Non Hydro	TE6			✓		✓	2	Rejected
	Nuclear Share/Electricity (%)	TE7	✓	✓	✓	✓	✓	5	Selected
	Self Sufficiency FEC/TPES (%)	TE8	✓	✓				2	Rejected
	RE Share (Hydro)/Electricity (%)	TE9	✓		✓			2	Rejected
	Non-Carbon Fuel Portfolio (%)	TE10	✓					1	Rejected
	Access to Clean Fuels (%)	TE11	✓		✓	✓	✓	4	Selected
Governance and Regulation	Losses/TPES (%)	GR1			✓		✓	2	Rejected
	Corruption Ranking	GR2	✓	✓	✓	✓	✓	5	Selected
	Governance Effectiveness Index	GR3	✓	✓	✓	✓	✓	5	Selected
	Oil Rent (% of GDP)	GR4		✓	✓			2	Rejected
	Oil Stock/ Oil FEC (Days)	GR5	✓	✓	✓	✓	✓	5	Selected
	Oil Stock (% of Imports)	GR6			✓	✓		2	Rejected
	Resilience (Net Reserves/FEC) (%)	GR7	✓	✓		✓	✓	4	Selected
Environment and Sustainability	CO_2/TPES (Kg/Kgoe)	ES1	✓	✓	✓	✓	✓	5	Selected
	CO_2/Capita (Tons/Capita)	ES2	✓	✓	✓	✓	✓	5	Selected
	CO_2/Electricity (%)	ES3	✓		✓			2	Rejected
	CO_2/Household (tons/houses)	ES4		✓	✓			2	Rejected
	SO_2/Capita (Kg/Capita)	ES5	✓	✓	✓	✓		4	Selected
	Forest Area/Land Area (%)	ES6	✓		✓	✓	✓	4	Selected
	CO_2/GDP (Kg/USD)	ES7			✓		✓	2	Rejected

As a result, 27 indicators were chosen, as shown in Table 1. When it comes to strategic planning and making long-term decisions on dynamic phenomena, testing the methodology's reliability is critical [37]. The study of the reliability and acceptability of any technique is an incredibly significant step in the process of its adoption since it will assist in achieving the findings that will be used later in the process of developing the energy policy. Reliability is determined using Cronbach's alpha, which measures whether the same or similar data could be obtained in the case of multiple measurements of the same construct [38]. The confidence limit of Cronbach's alpha is $\geq$0.700. Here, the 27 indicators were tested based on the criterion referred to as the "Backward Elimination Method". This method is based on deleting one of the existing indicators to obtain the higher value of Cronbach's alpha. The process was to be continued until the acceptable range appears. Notably, the Cronbach's alpha for the chosen indicators came out in an acceptable range, as shown in Table 2, confirming that the indicators are correlated well together and are measuring the same concept. As in this case, backward elimination is not required.

Table 2. Reliability test results. Source: (Author's own).

Cronbach's Alpha: 0.712		**N of Items: 27**	
Sno	**Indicators**	**Corrected Item-Total Correlation**	**Cronbach's Alpha if Item Deleted**
1	Electricity/Capita	0.976	0.713
2	Access to Energy	0.790	0.711
3	R/P Ratio	−0.868	0.730
4	TPES/Capita	0.990	0.568
5	FEC/Capita	0.964	0.585
6	Renewable Share/FEC	−0.719	0.717
7	SWI	0.667	0.713
8	Indigenous/TPES	−0.359	0.718
9	Gasoline Price/Litre	0.883	0.712
10	Diesel Price	0.831	0.711
11	Energy Imports/TPES	−0.084	0.717
12	Transport Energy Intensity	−0.462	0.723
13	Industrial Energy Intensity	0.178	0.709
14	Commercial Energy Intensity	0.943	0.709
15	T&D Losses	−0.699	0.714
16	Electricity Utilization	0.071	0.713
17	Oil & Well Exploration	0.624	0.681
18	Nuclear Share/Electricity	0.812	0.691
19	Access to Clean Fuels	0.891	0.676
20	Corruption Ranking	0.868	0.606
21	Governance Effectiveness Index	0.293	0.704
22	Oil Stock/ Oil FEC	−0.660	0.726
23	Resilience (Net Reserves/FEC)	−0.702	0.726
24	CO_2/TPES	−0.709	0.714
25	CO_2/Capita	0.967	0.713
26	SO_2/Capita	0.836	0.701
27	Forest Area/Land Area Ratio	−0.949	0.716

Following the selection of indicators, data on time series from 1991 to 2020 were obtained from [31,39–42] (Supplementary File). The development of indexes was based on multiple steps. First step is to the transformation as indicators that have different units of measurements. In this context, literature indicates that indicators have been generalised in a variety of different forms, but none of them are prevalent [43,44]. As a result, the z-score approach was used, with the findings displayed in the Supplementary File. In the second stage, the dimensions reduction technique was utilized to estimate weight. There have been 13 dimensional techniques reported [45]. In contrast, Principal Component Analysis (PCA) outperformed all other dimensional reduction techniques. As a result, PCA was chosen as the research strategy. Table 3 shows how "Varimax Rotation" was used to complete the indicator grouping.

Table 3. Varimax-based extraction of components.

Rotated Component Matrix Availability Dimension		
	Component	
	1	**2**
AV7	0.904	
AV9	−0.899	
AV1	0.897	
AV8	0.863	
AV3	0.853	
AV4	−0.808	
AV17		−0.994
AV10		0.862
AF4	0.986	
AF3	0.984	
AF10	0.912	
AF5		0.868
AF9		−0.760
AF8		0.708
Rotated Component Matrix Technology and Efficiency Dimension		
	Component	
	1	**2**
TE11	0.962	
TE7	0.940	
TE5	0.824	
TE3		0.976
TE1		−0.679
Rotated Component Matrix Governance and Regulation Dimension		
	Component	
	1	**2**
GR7	0.907	
GR2	−0.735	
GR3		0.910
GR5		−0.669

Rotated Component Matrix SESi					
	Component				
	1	**2**	**3**	**4**	**5**
AV4	−0.928				
ES5	0.923				
TE11	0.897				
AF4	0.884				

Table 3. *Cont.*

Rotated Component Matrix SESi					
	Component				
	1	2	3	4	5
TE5	0.876				
GR7	−0.875				
AF3	0.865				
ES6	−0.862				
TE7	0.806				
ES1	−0.800				
AV3	0.786				
AV10	0.768				
AV8	0.752				
AV7	0.752				
AV1	0.724				
AF10	0.652				
AV17	−0.617				
AV9		−0.806			
GR5		−0.794			
ES2		0.714			
GR2		0.667			
TE3			0.925		
AF9			0.750		
TE1			−0.584		
AF5				0.897	
AF8				0.854	
GR3					0.909

The findings of "Rotation Sums of Squared Loadings" are required for weight estimates, as shown in Table 4. In the availability dimension, for example, the weight for group 1 indicators was determined to be W1 = 59.557/90.918 = 0.655 and W2 = 31.361/90.918 = 0.344. Except for the environment dimension, all other dimensions' weights were estimated in the same way. Therefore, the solution cannot be rotated for environment dimension, and only one component was extracted. In the third step, the performed aggregation was comprised of five stages. The first stage involves determining positive and negative indicators, followed by obtaining the inverse of just negative indicators (Equation (1)). The second stage involves scaling (Equation (2))), and the third stage requires estimating the group indices (Equation (3)). The final index (Equation (4)) [9,38] is calculated in the final stage. As a result, the composite index (PMESI) and five indices across dimensions, as indicated in Table 5, were created. The PMESI and the other five indices assign a score from "1 to 10" to Pakistan's energy security performance. The scores can be classified as "very-poor," "poor," "moderate," or "high" [10,46]. Other research scores, such as those from [24,25], are also included to assess the variations in composite scores (Table 5).

$$A_{ij} = \frac{1}{B_{ij}} \tag{1}$$

$$\beta_i = \left[10A_{ij}\right]/Max_{ij} \tag{2}$$

$$Gi_{kj} = \sqrt{\sum \frac{{\beta_{ij}}^2}{m}} \tag{3}$$

$$PMESI = \frac{\sum\{w_k \times gi_{kj}\}}{\sum w_k} \tag{4}$$

where β_i is relative indicator i of year j, X_{ij} and Y_{ij} is value of the positive indicator i of year j, Max_{ij} is maximum value of indicator i, and i is indicator i.

where GI_{kj} is group index 'k' of year j, β_i is the relative positive and negative indicator i of year j; also, m is the number of indicators in each group.
where $PMESI$ is the Aggregated Indicator of year j, GI_{kj} is group index 'k' of year j, and w_k is weighting factor of group index 'k'.

Table 4. Variance-based extraction by PCA. Source: (Author's own).

Dimension	Component	% of Variance	Cumulative %	Weight
AV	1	59.557	59.557	W1 = 59.557/90.918 = 0.655
	2	31.361	90.918	W2 = 31.361/90.918 = 0.344
AFF	1	51.171	51.171	W1 = 51.171/83.085 = 0.615
	2	31.915	83.085	W2 = 31.915/83.085 = 0.384
TE	1	57.940	57.940	W1 = 57.940/87.815 = 0.659
	2	29.876	87.815	W2 = 29.876/57.940 = 0.340
GR	1	41.589	41.589	W1 = 41.589/80.194 = 0.518
	2	38.606	80.194	W2 = 38.606/80.194 = 0.481
ES	1	82.851	82.851	No need for weight as one group was extracted

Table 5. Final scores of indices. Source: (Author's own).

Year	AV Ind	AF Ind	TE Ind	GR Ind	ES Ind	PMESI	ESIP	ESIOP
1991	6.42	2.84	7.11	0.22	4.14	4.98	8.36	7.94
1992	6.81	1.20	7.59	0.28	3.90	4.47	8.38	7.04
1993	3.98	0.86	2.66	0.24	3.68	2.96	8.16	6.69
1994	5.35	2.03	2.57	0.42	3.40	3.91	8.32	6.44
1995	3.20	0.76	2.44	0.13	3.62	2.53	8.04	6.12
1996	2.50	0.84	2.15	0.16	2.86	2.41	7.89	5.89
1997	2.61	0.82	4.15	0.18	2.58	2.73	7.79	5.79
1998	2.62	0.81	4.84	0.17	2.00	3.00	7.74	5.75
1999	3.96	0.83	4.46	0.39	2.23	3.49	7.59	5.50
2000	5.21	1.37	5.58	0.43	1.89	3.73	7.68	5.78
2001	3.99	1.09	4.50	0.28	1.69	3.00	7.70	5.66
2002	3.00	1.40	2.90	0.32	4.31	3.69	7.85	5.67
2003	2.98	1.24	1.18	0.44	1.06	2.87	7.95	6.06
2004	4.68	1.21	2.06	0.21	1.93	2.00	7.74	5.82
2005	1.62	1.79	1.90	0.41	1.67	1.98	7.95	5.85
2006	1.47	3.19	3.20	0.29	3.93	2.89	8.04	5.54
2007	2.79	4.71	2.08	0.41	0.88	2.91	7.80	5.43
2008	3.60	3.67	1.27	0.30	2.45	2.80	7.91	5.33
2009	3.15	2.10	1.72	0.25	3.31	2.45	7.89	5.32
2010	1.64	2.84	2.01	0.20	4.49	3.75	8.01	5.21

Table 5. *Cont.*

Year	AV Ind	AF Ind	TE Ind	GR Ind	ES Ind	PMESI	ESIP	ESIOP
2011	4.72	3.01	3.79	0.25	2.44	3.66	7.87	5.24
2012	4.40	0.64	3.47	0.22	4.96	3.69	7.92	5.31
2013	3.06	0.55	2.80	0.30	6.62	4.22	8.09	5.37
2014	3.35	0.64	2.69	0.39	2.76	4.94	8.11	5.26
2015	6.20	1.33	2.52	0.45	3.10	4.40	8.22	5.43
2016	8.35	0.93	4.81	0.53	3.08	5.41	8.29	5.59
2017	9.47	0.83	5.29	0.44	3.40	5.56	8.24	5.70
2018	4.67	1.88	2.50	0.19	3.66	3.40	8.29	5.14
2019	5.08	3.19	2.82	0.21	3.92	3.87	-	5.14
2020	5.47	5.89	3.43	0.44	4.23	5.11	-	5.14

3. Results

3.1. Pakistan's Multidimensional Energy Security Index (PMESI)

Any score between 2.6 and 5 is considered "poor" [46]. According to PMESI, Pakistan's energy security remained "poor" during the study period (Figure 2). Notably, the other two indices, ESIP and ESIOP, remained in the moderate-to-good range. The peak PMES score was 5.41 in 2016, and the ESIP peaked at 8.36 in 1992 and the ESIOP peaked at 7.94 in 1991. In 1991, the performance gap between PMES and ESIP and ESIOP was 40% and 37%, respectively. During the 2001–2010 period, the disparity grew to 64% and 49% on average in ESIP and ESIOP, respectively. Interestingly, the difference between these indices narrowed to 37% with ESIP and 17% with ESIOP between 2011 and 2020. The PMESI's poor performance was caused by all dimensions, with different indicators playing distinct roles, as discussed below:

1. During the study period, two indicators in the availability dimension, "FEC/Capita" and "R/P Ratio," influenced the PMESI. For example, consumption increased by 11% between 1991 and 2000, followed by a 20% increase between 2001 and 2010, and a further 13% increase between 2011 and 2020. Its impact on PMESI could be seen between 1991 and 2015, when PMESI declined by 12%;
2. PMESI demonstrates that "power-policy (1994)", "power-policy (2002)", "power-policy (2004)", and "power-policy (2013)" all failed in terms of execution. These techniques sought to reduce energy consumption by increasing conservation and efficiency. Despite the fact that almost every power strategy stressed development plans, the country faced a 5000 MW energy shortfall [47]. A measure termed "Electricity/Capita (KWh)" increased by 36% over the study period, which could support the argument;
3. Pakistan's governments have been restructuring the energy industry and focusing on keeping energy prices as low as achievable. However, the World Bank believes that reforms must have gone beyond simply liberalizing energy pricing in order to address numerous aspects of energy sector distortions, such as prioritizing fuel allocation for efficient energy generation and implementing tariff mechanisms that incentivize performance [48]. As previously identified, system inefficiencies result in an unreasonably high cost during the research period. In the affordability aspects, the indicators observed were "Gasoline Price/Litre" and "Diesel Price/Litre." Both gasoline and diesel grew by 60% between 1991 and 2000, increased by 65% between 2001 and 2010, and increased by another 28% between 2011 and 2020. It had a significant influence on PMESI between 1991 and 2010, when it fell by 24%;
4. During the study period, two of the indicators played a significant role in the technological dimensions. Both "T&D losses" and "Utilization" fluctuated significantly

throughout. "T&D Losses", for example, increased by 22% between 1991 and 2002, then by 31% between 2003 and 2010. In 2011, an increase of 11% was observed, followed by a gradual reduction of 15% between 2012 and 2020. Similarly, "Utilization" fell by 28% between 1999 and 2000; however, it improved by 16% in 2006. From 2007 to 2020, variations occurred, with a minor improvement of 2% recorded. Its impact could be seen between 2003 and 2012, when the PMESI experienced significant fluctuations (Figure 3);

5. The energy sector is governed by a number of institutions. The Ministry of Water and Power, for example, has 19 sub-agencies, and the Planning Commission and the Ministry of Petroleum and Natural Resources each have 16 [49,50]. According to the research, Pakistan's energy sector has been plagued by corruption and vested interests [28,49]. As previously stated, the rating grew substantially between 2003 and 2020. During that time, the ranking dropped by about 45%. Not only did corruption have an impact on the PMESI, but other variables also played a role in the poor performance of the governance index. For example, the "Governance effectiveness index" fell by 28% between 2006 and 2020, whereas the indicator "Stock" fell by 55% between 1992 and 2020 (Supplementary File). As a result, the PMESI remained low throughout the study period;
6. The "industrial" and "commercial intensities" increased by 2% and 33%, respectively (Supplemental File), implying that the energy production and conservation targets stressed in "petroleum-policy (1991)", "electricity-policy (2010)", and "power-policy (2013)" had no effect. As a result, the affordability index remained between 1 and 3 during the study period, pushing the PMESI below 5;
7. The international wind and solar sector is still to grow and become more inexpensive [50]. However, the use of renewable energy sources other than hydro, such as wind and solar, did not become widespread until 2013, at which point another 1500 MW of wind, solar, and bagasse facilities had been completed, with plans to extend this to 3500 MW by 2025. As a result, from 1991 to 2020, the "Renewable share/FEC" averaged 6.9%, leading the PMESI to fall below average;
8. The international wind and solar market has yet to be expanded and made affordable [50]. However, the usage of renewable energy sources other than hydro, such as wind and solar, did not become prevalent until 2013, and, by that time, another 1500 MW of wind, solar, and bagasse (a biowaste) facilities had been completed, with plans to increase this to 3500 MW by 2025. As a result, the "Renewable share/FEC" averaged 6.9% from 1991 to 2020, causing the PMESI to fall below average;
9. PMESI was influenced by all four indicators in the environment domain. Notably, all reduced during the course of the study. While "CO_2/TPES" reduced by 12%, "CO_2/Capita" increased by 26% during the study period. Likewise, "SO_2/Capita" grew by 78% while "Forest Area" declined by 50% (Supplementary File). As a result, these two indicators influenced PMESI more than the other two, particularly between 2003 and 2020.

In summary, analysis suggests that PMESI remained poor as compared to ESIP and ESIOP, as different indicators were involved with different weight values assigned during the study period. Consequently, examination across dimensions seems necessary, as emphasized in [13], to evaluate the policies governing the energy sector. As in 1991–2005, PMESI declined and adopted a trend similar to the affordability-index as shown in Figure 3. A peak occurred in 1994 as a result of the governance-index, followed by a sharp fall in 1999 as a result of the affordability-index. Additionally, an increase in PMESI was detected between 2000 and 2003 as a result of the availability and affordability-index. Moreover, between 2006 and 2013, the technology-index and the affordability-index were balancing each other. Thus, PMESI followed a similar pattern as the environment-index and the affordability-index over this time period. Furthermore, between 2014 and 2020, the technology-index and the affordability-index were balancing each other, resulting in the other three indices contributing to the PMESI (Figure 3). Notably, all sub-indices have caused changes in the PMESI during the time period under consideration; hence, a detailed examination of each is provided below, along with the dimensions and indicators involved.

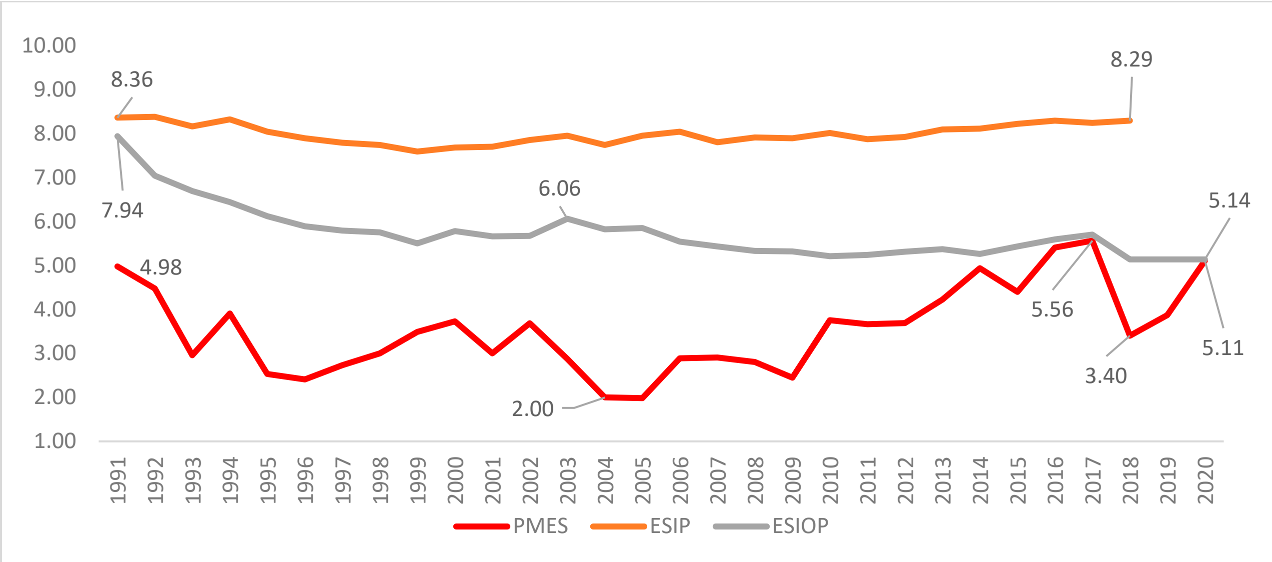

Figure 2. Energy security performance of Pakistan.

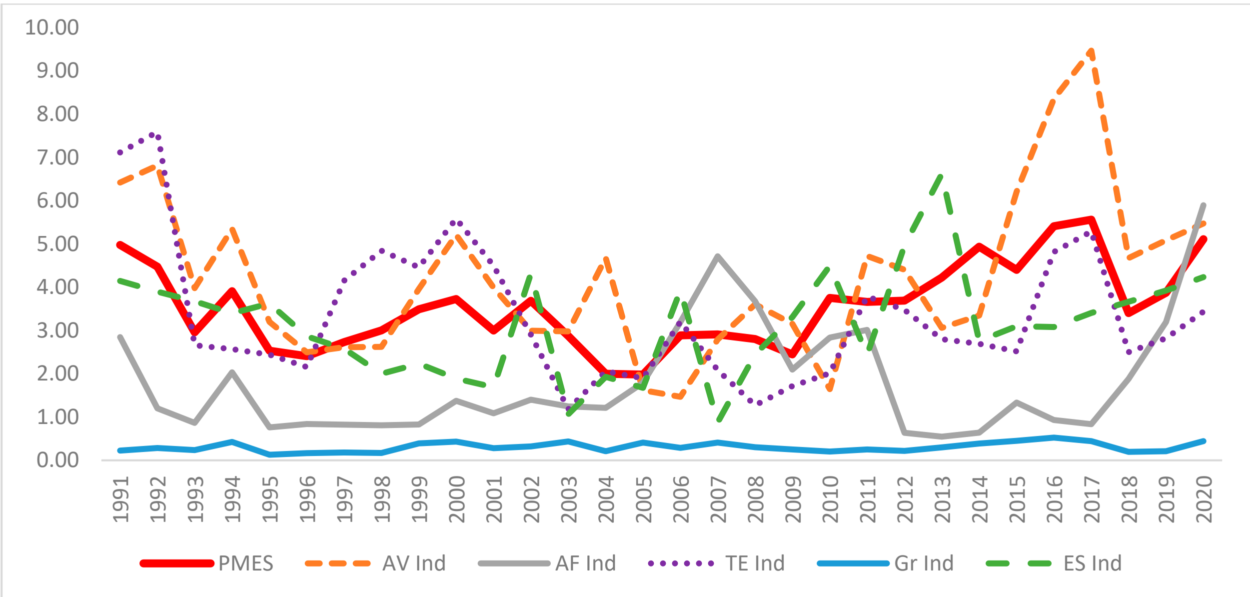

Figure 3. Indices across dimensions and PMESI.

3.2. Availability Dimension

The availability index indicates moderate performance between 2015 and 2020 (Figure 4). Overall, 15% of the index fell between the study period, with the lowest score emerging in 1996. Notably, performance fluctuated throughout the study period. There are two sub-indices of the availability index, as seen in Figure 4. The decline in the availability index between 1991 and 2010 was due to the G1-index, while the G2-index remained reasonably stable throughout the study period. In Pakistan, the supply of energy increased by almost 35%, which was met by imports. However, "Indigenous/TPES" rose from 84% to 90% between 1991 and 2000 (Supplementary File). In addition, the power policy (1995) and renewable policy (2006) were focused to rely on hydel energy to support renewables in the power sector [51]. Notably, "Renewable Share/FEC" suggests a 9% shift between

2006 and 2020, indicating that the policy targets have not been reached. Moreover, in 2005, the government of Pakistan decided to expand access to electricity; as a result, the "Access to Energy" indicator indicates a small improvement from 69% in 1991 to 71% in 2020.

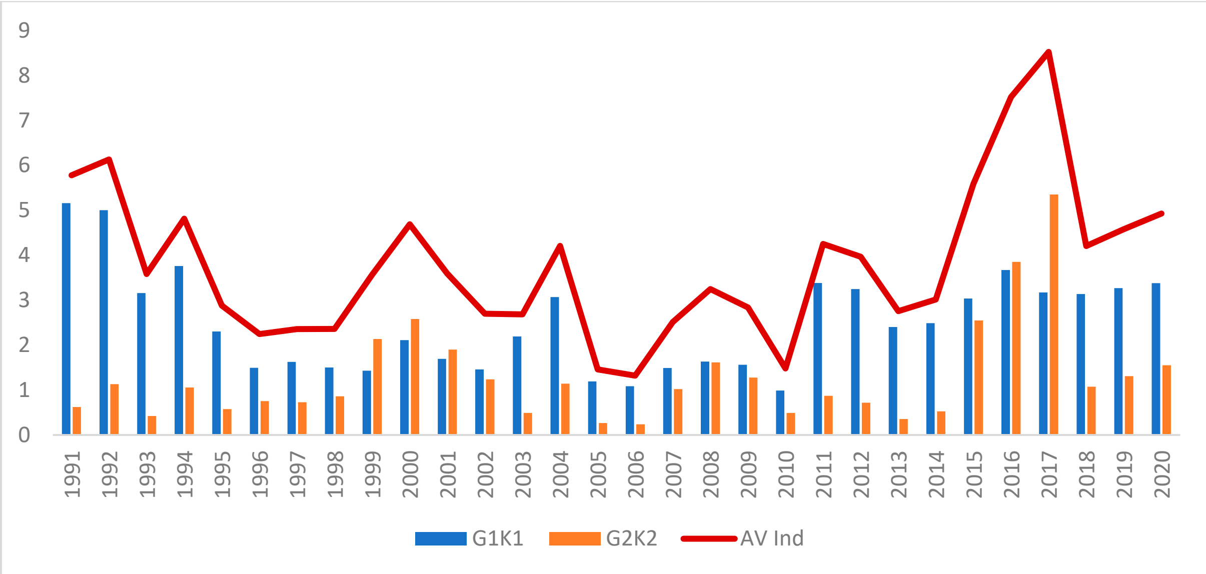

Figure 4. Availability index and sub-indices.

In Pakistan, all the power policies such as "power-policy (1991)", "power policy (2002)", "petroleum-policy (2012)", and "power-policy (2015)" were centered on the indigenous development [52,53]. However, the "R/P levels" of oil and gas have been diminishing until 2020. The oil and gas reserves declined sharply by almost 51% each between 1991 and 2020 (Supplementary File). At this pace, the reserves will be depleted within 10 years. The key contributing factors was that the government introduced the use of gas (in the form of CNG) in the transport sector in 1997 and, as a result, 2.5 million cars were upgraded to use CNG by the year 2010 [39]. Consequently, the government restricted the use of CNG in cars in 2010 to boost "R/P ratios" [54]. Moreover, oil and gas reserves decreased further by 23% between 2011 and 2020 (Supplementary File). The reserves and production are linked with the indicator "Oil & Well Exploration" [55]. Between 1991 and 2000, the activities remained constant; however, slight improvement was observed between 2001 and 2010. In last decade, the imports of oil grew by 5% and gas by 35% [22], indicating that past governments failed to enforce objectives set out in policies such as the "petroleum-policy (1991)", "power policy (2002)", and "petroleum-policy (2012)".

The conservation initiatives have been stressed by governments in "petroleum policy (1991)" and "power policy (2010)" [56]. However, "FEC/Capita" increased by 11% between 1991 and 2000, which was doubled (20%) by 2010 and also increased by 14% between 201 and 2020. Moreover, "Electricity/Capita" increased by 36% between 1991 and 2020 (Supplementary File). To this end, the intensity indicators also contribute to the gauging of developmental and sustainability goals. For sustainable growth, intensities need to be curbed, especially in commercial and industrial sectors, as they both contribute more than 50% of the final consumption in Pakistan [57]. As observed, the industrial intensity rose by 17% during 1991–2006 (Supplementary File). However, slight improvement was observed and reached a level of 83,000 kgoe/USD in 2020, which was the same as in 1991. On the other hand, commercial intensity increased by 33% during the study period. This suggests that the petroleum policy (1991) failed to deliver its conservation goal. In contrast, the energy policy (2010) achieved this target partially, as industrial intensity was observed to be curbed in last decade as compared to the period 1991–2010.

The indicator "Indigenous/TPES" reflects the self-sufficiency at the supply side [55]. Notably, indigenous supplies rose by 5% between 1991 and 2005 followed by 3% decline in a period between 2001 and 2010. In addition, indigenous supplies further decreased by 3% in last decade and reached a level of 83% in energy mix. Besides, self-sufficiency to enhance was focused in four different polices in the past (however, this trend reflects that "petroleum-policy (1991)" delivered it partially while "petroleum-policy (2012)" and "generation-policy (2015)" could not achieve this target. In summary, these indicators indicate that there has been loopholes in Pakistan's conservation efforts and supply targets and that, in return, more work is needed to strengthen the policy actions. Holistically, the availability index and sub-indices suggest that the policies and measures taken by the Government of Pakistan during the period 1991–2020 were met partially to increase the availability index and overall PMESI between 2011 and 2018.

3.3. *Affordability Dimension*

The affordability index has two sub-indexes, G1-index and G2-index, as seen in Figure 5. The affordability index improved due to the G1-index in 2001–2011, followed by the G2-index in 2017–2020. In the G1-index, large variations occurred in the "Gasoline Price/Litre" and "Diesel Price/Litre" and carried 20.6% weight each in the index, while the "Commercial Energy Intensity" rose at a steady pace during 1991–2007 (Supplementary File). Similarly, the G2-index has significant variations in "Oil Imports/TPES", whereas the "Transport Energy Intensity" was increased gradually until 2004, followed by an upward and downward trend until 2020. Both these indicators carried 12.6% weight in the G2-index.

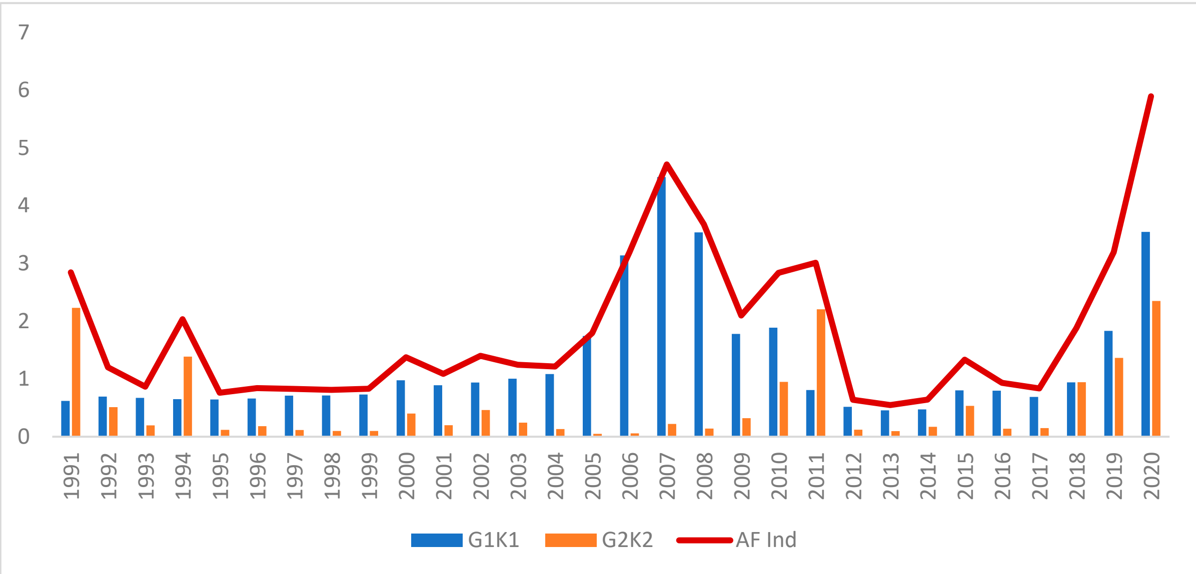

Figure 5. Affordability index and sub-indices.

In 1991–2000, a 56% increase in gasoline prices was announced, followed by a further rise of 62% in 2010. On the other hand, diesel prices rose by 64% between 1991 and 2000, followed by a further increase of 73% between 2001 and 2010. The effect of price hikes can be seen by "Oil Imports/TPES". Imports rose by 17% between 1991 and 2000, followed by 8% in 2010. In addition, imports rose by 37% in 2016 compared to 22% in 2011. This reflects that the indigenous production was insufficient. As a result, the affordability index deteriorated by 37% during 1991–2020.

The affordability and least cost were highlighted in the hydel policy (1995), power policy (2002), and generation policy (2015) [58]. Between 1996 and 2002, gasoline price rose by 51% and diesel by 63% and this trend continued between 2003 and 2015. The gasoline price rose by 52% and 72% more (Supplementary File). This suggests that these policies failed to keep the affordability goal between 1995 and 2015.

As observed, the G2-index remained low as compared to the G1-index between 1993 and 2009 (Figure 5). Between 1991 and 2007, the "Industrial Energy Intensity" contributed while, in a later period (2008–2020), "Transport Energy Intensity" contributed. Notably, the transport sector contributed 34% to the final energy consumption (FEC) [40]. However, the transport intensity decreased to 75 kgoe/USD in 1998 to 69 kgoe/USD in 2008. This improvement was brought on by an initiative to introduce the CNG in the sector. In contrast, the tradeoff was not anticipated, and reserves of gas declined significantly. Consequently, a launch of the CNG load management commenced in 2007.

Past governments have focused to improve the electricity prices via the enhancement of the renewable share in the mix. The share of hydro in the mix was the cheapest option [59]. Notably, hydro share could be optimized, as it declined by 34% between 1991 and 2001 and remained there until 2020. At this end, other renewable options were not optimized either until 2013. This suggests that goals set out in the "hydel-policy (1995)" and "power-policy (2002)" were not met. In brief, the affordability index declined between 1991 and 2009 (Figure 5). This reflects the fact that the objectives of the petroleum policy (1994) and exploration policy (2012) have not been achieved and that prices have risen due to a dependence on imports. Overall PMESI improved by 52% due to a decline in the affordability index, especially between 2012 and 2017.

3.4. Technology and Efficiency Dimension

In terms of the technology and efficiency dimension, a downward trend is observed instead of upward fluctuations in the period 1993–2020, as shown in Figure 6. Between 1991 and 1996, the G1-index exceeded the G2-index, followed by a continuous decline until 2020. A major improvement in the technology index occurred between 1995–2000 and 2010–2018 due to the G1-index throughout the study period, whereas the G2-index remained poor by improvement from 2002 onwards. The indicators "Nuclear share/Electricity", "Access to clean Fuels", and "T&D Losses" influenced the overall technology index and PMESI. The "Nuclear Share/Electricity" indicator was only 3% in the power mix in 1991. However, its share increased significantly up to 17%, as Pakistan built two additional nuclear power plants while renovating the first ever nuclear power plant between the study periods [60]. In nuclear domain, Pakistan has shown results in the technology side as well as developed the human resources. As per the energy security plan (2005), the country aimed to extend its nuclear share by up to 8000 MW by 2030 [50]. Currently, the country has five nuclear plants producing 1430 MW of power, and two plants are under construction of 2200 MW to be added by 2022. The Pakistan Atomic Energy Commission (PAEC) is a regulatory body which is responsible for nuclear safety and radiation protection. This analysis suggests that PAEC has delivered its targets in the last two decades and may be able to extend the nuclear power subject to geopolitics in the region.

The transmission losses were high, and the performance of the power plants was low, which led to a decrease in the G2-index between 1991 and 2003 (Supplementary File). Between 1991 and 2012, all polices and declared programs did not concentrate on "T&D Losses" and, as a result, losses were registered on average at 30% during this time. Consequently, power policy (2013) has been announced, and major steps have been taken to mitigate losses [39]. As a result, T&D losses decreased to 23% in 2020 compared to 35% in 2003. Furthermore, "Electricity Utilization" dramatically dropped from 62% in 1991 to 45% in 2000. However, since power policy (2013), improvement was observed and reached a level of 54%. This demonstrates that power-policy (2013) was successful in improving efficiencies via curbing losses at generating facilities along with distribution networks since inception.

"Access to clean fuel" increased at constant rate and reached a level of 36% in 2010 as compared to 22% between 1991 and 2000. The overall 38% improvement in this indicator was observed. Whereas, during 2011–2020, the improvement was 19% further, and increased to the level of 46% in 2020 (Supplementary File). The purpose of this indicator is to present the availability and affordability of energy services to the lower income population to guide the policymakers to look into human development and sustainable economics. This analysis indicates that the major progress was made between the period 1991 and 2010;

however, in last decade, its pace was slow under renewable policy (2006). In summary, the overall technology and efficiency index decreased by 52% during the period under study. This reflects the fact that the objectives of the "renewable energy-policy (2006)" to improve access to clean energy have been partially achieved. Similarly, "power-policy (2013)" since inception has led to some improvements in Pakistan's energy security. The technology and efficiency index therefore helped to maintain the overall PMESI score above 3.5 between 2010 and 2020 (Figure 2).

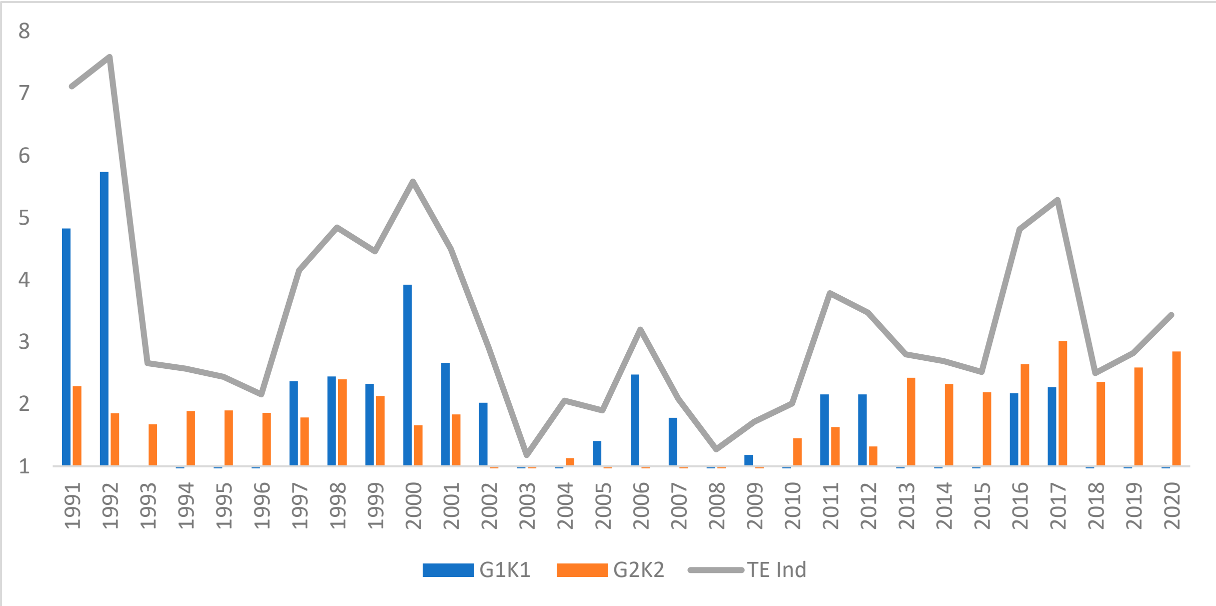

Figure 6. Technology and efficiency index and sub-indices.

3.5. *Governance and Regulation Dimension*

The governance and regulation index remained low and poor during 1991–2020, and was mainly contributed to by both of sub-indexes, as shown in Figure 7. Each sub index has two indicators and has same weighting factor within sub-indexes. The G1-index consist of "Corruption Ranking" and "Resilience" while G2-index has Governance Effective Index" and "Stock" indicators (Supplementary File). During 1991–2013, the governance index had the same trend as the G1-index, followed by the G2-index up to 2020 (Figure 7). As a result, both "Corruption Ranking" and "Resilience" have a significant role to play in this dimension as well as in PMESI. Notably, the "Corruption Ranking" is negative, while the "Resilience" has a positive relationship to the index. The "Corruption Ranking" increased, while the "Resilience" decreased, causing the index to be in poor region during 1991–2020. In Pakistan, corruption in the energy sector is present at all levels of institutions regulating the energy sector [61]. As a result, the "Corruption Ranking" rose by 61% in 1991–2001, followed by a further 44% rise in 2001–2010. However, in the 2011–2020 period, the growth in ranking fell to 19%. Its impact on the index was observed in the period 2007–2017. In addition, the resilience of the energy sector has been poor over the study period. It fell from 19% in 1991 to 16% in 2010 and decreased to 10% in 2020. The explanation for this is that resilience is specifically related to reserves which have declined by 50% (Supplementary File). Similarly, the "Oil-Stock" level was kept low, especially between 2006 and 2012, when it hit the lowest level of 9 days in 2007 (Supplementary File). The improvement was noted from 2013 onwards; however, it had not yet met a stock level of 26 days in 1994. The low stocks suggest that the government had failed to incorporate the measure of the length of time regarding stock to last in the energy policies. Here, analysis identifying that the policies could not anticipate and minimize the risks of supply disruptions. Notably, the G2-index remained lower than the G1-index from 2007 to 2020 (Figure 7).

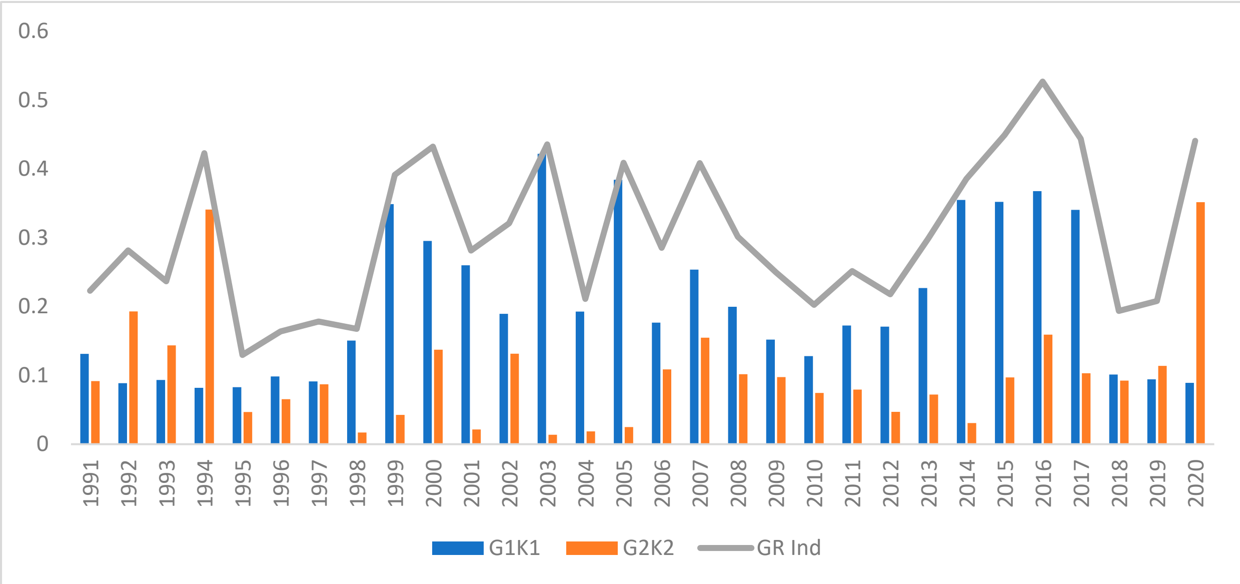

Figure 7. Governance and regulation index and sub-indices.

In brief, energy policies and governance have been identified as fragmented, as they have been dealt by Pakistan's Ministry of Finance, the Planning Commission, provincial governments, and state energy organizations. Moreover, significant decisions on energy policies and investment were normally reviewed and approved by the Economic Coordinating Committee [61,62]. While Pakistan has made strides in improving its institutions in the energy and power sectors [63], this review indicates that more remains to be done to strengthen its governance and transparency.

3.6. Environment and Sustainability Dimension

There is only one sub-index in the Environment and Sustainability Dimension that is composed of four indicators (Supplementary File). In 1991–2020, major variations occurred in "SO_2/Capita" and "Forest/Land Ratio", as shown in Figure 8. The "SO_2/Capita" indicator rose by 71% while the "Forest/Land Ratio" decreased by 49% during 1991–2020. On the other hand, "CO_2/TPES" decreased by 12% and "CO_2/Capita" increased by 26% during the study period. Overall, this index fell by 78% between 1991 and 2007. Form 2008 until 2013, the index improved and peaked driven by "CO_2/TPES" followed by gradual drop until the end of 2020.

In last decade, the national climate change policy (2012) was announced and the "Ministry of Climate Change" was formed by the Government of Pakistan in 2017 [64]. The goal was to respond and mitigate climate change and to reduce pollution from deforestation and land degradation. However, the "Forest/Land Ratio" decreased by 10% from 2013–2017, reflecting the lack of enforcement of the program. Moreover, the emissions of SO_2 in Pakistan have been caused by the transport sector, as they mostly use petroleum products [47,64]. SO_2 emissions increased as the number of vehicles increased from 2.7 million in 1990 to 5.5 million in 2005 and increased to 9.8 million by 2010 [65]. The number of vehicles increased further by 130% in 2013, making the transport sector the largest contributor in Pakistan. The Ministry of Power and Petroleum worked to this end and encouraged oil marketing companies (OMCs) to upgrade the quality of fuels. As a result, OMCs upgraded the quality and managed to raise a blend from EURO II to EURO V to reduce the pollution [22].

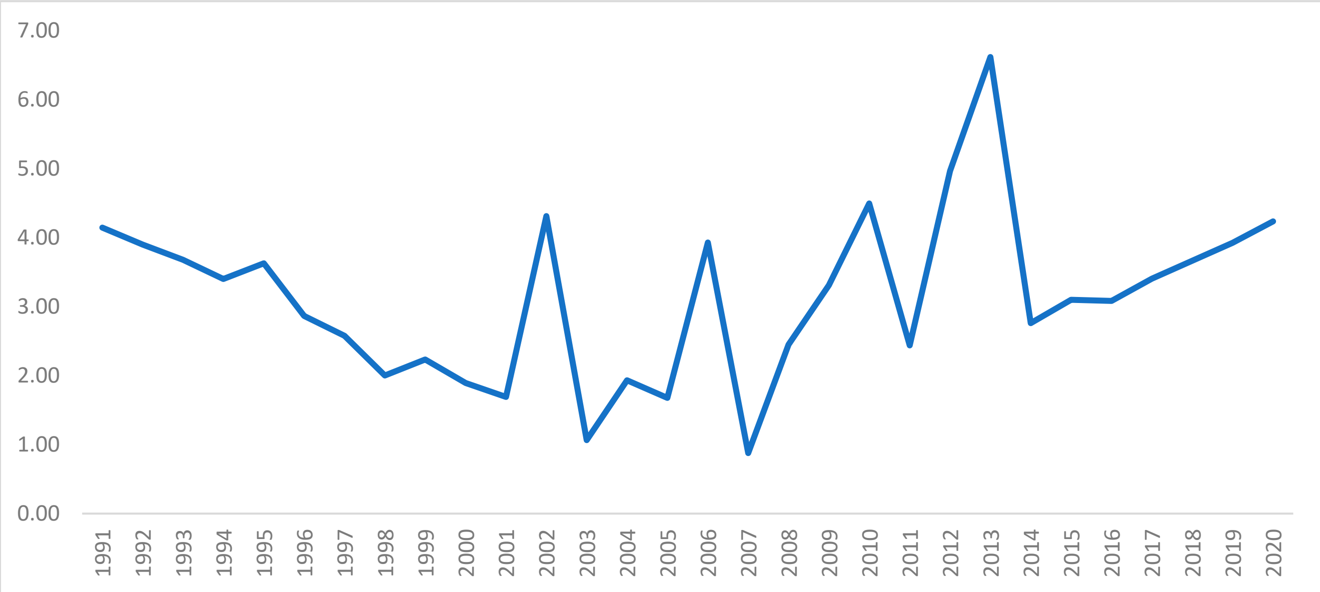

Figure 8. Environment and sustainability index and sub-indices.

The CO_2 emissions remained at 2.1 tons per year on average between 1991 and 2020, and an almost 3% change was observed between 2015 and 2020. The decrease in "CO_2/TPES" is due to the use of more gas than oil in the energy mix. Gas contributed 40% while oil contributed 34% during 2015–2020 [22]. On the other hand, "CO_2/Capita" increased by 13% between 1991 and 1999, followed by a decrease of 4% between 2000 and 2003 (Supplementary File). Notably, a significant increase (10%) was reported, as it increased from 0.67 tons/capita in 2003 to 0.74 tons/capita in 2004. This pattern continued and reached a level of 0.83 tons/capita in 2020, with an increase of almost 11% reported in the 2005–2020 period (Supplementary File). Further, coal consumption was 5.8% in 2001, which continued to rise to a level of 12% in 2020 [66]. In addition, the annual growth rate of coal imports increased from −15.92 ACGR in 2013 to 60.42 ACGR in 2014, followed by the same pattern, and reached 94.90 ACGR in 2018 [40]. This significant growth was caused by coal plants, as four coal plants had been added since 2016. As a result, its effects were observed in the emissions of the "CO_2/Capita" indicator. In summary, the analysis shows that the objectives of "climate change-policy (2012)" and "generation-policy (2015)" to protect the environment were not met. Similarly, the objective of "power-policy (2013)" to meet energy needs in a sustainable manner was also compromised. The Environmental and Sustainability Index, therefore, had been unable to maintain the overall PMESI scores between 2004 and 2020 (Figure 2).

4. Discussion

Various indicators have been identified across dimensions. For example, in policy formulations, "R/P ratio", "TPES/Capita", and "FEC/Capita" may be given priority. The oil and gas reserves decreased by about 50%, as the "TPES/Capita" increased by about 53% and the "FEC/Capita" increased by about 61%. This reflects the fact that demand is growing more than supply because Pakistan has not been able to use indigenous resources properly. As a result, there is no exemption from the mining of coal and hydro resources in Pakistan. Moreover, the country still needs to wait a few more years for wind and solar energy, since the foreign market is not yet open and within an affordable range [67]. Here, the government should prioritize transitioning to hydro and nuclear energy in order to ensure stable production and lower prices in the near future. Furthermore, priority should be given to nuclear power generation in the energy mix, as Pakistan has a wide pool of scientific personnel in this field and has a highly secured program [28]. In addition, the exploration policy (2012) applies to the low-priced oil system and does not cover high prices [68]. The indicator "oil and well exploration" illustrates the fact that the operations in this area have remained at a slower pace in the last decade or so (Supplementary File). Therefore, high-priced activities are to be offered up to USD 50 to 60 as an option to encourage foreign firms to participate in exploration activities [67]. Moreover, the consultancy firm should be hired to offer recommendations in this respect.

The prices of oil and gas had been substantially fluctuated and, in fact, the prices of gas will be almost those of oil in the future [41]. So far, the government has had no control over prices, especially in the case of oil, as prices have been allocated by foreign markets [54]. In comparison, taxes in "Gasoline" and "Diesel" values were up to 25–40% in Pakistan [69]. This benchmark was adopted from the US, which allocated price tax of 10–25%. However, there was an unwanted disagreement over the price of oil in Pakistan [70]. Currently, rates are reasonable, sustainable, and lower than in the region and lower than in Europe in comparison [28]. Therefore, a delicate balance point should be established, corresponding to the welfare of the population and the economic and budgetary importance of taxes. On the other hand, it is observed that Pakistan's electricity sector had been heavily dependent on gas, and its output had been seriously hampered by a decline in the production of gas caused by a misallocation of natural gas during the study period [71]. To this end, sustainable energy options such as "tight-gas", to satisfy demand, should be discussed. Notably, about 24 trillion cubic feet of tight-gas is available in Pakistan [66]. Although this alternative requires new technology and has a stabilization time of 15 years, special benefits and policy provision may draw investment in the future. In addition, average wellhead prices can be gradually increased near to foreign markets to encourage exploration investment. For this, two track rates can be adopted: one for the public sector and current productions, and the other for new productions and multinational companies [17].

The hydropower is closely related to the country's economic growth and could have a dominant role in Pakistan's future energy scenario [72]. Along with the large-scale hydropower generation plants, the small-to-medium-sized ones are also essential to contribute to the national mix of electricity supply [73]. Fortunately, this can be implemented at a faster rate, as literature suggests that almost 90% of Pakistan's hydro-electric power plants have a payback time of 2.5–4 years [49,74]. Conservation programs that have been outlined in the form of "petroleum-policy (1991)" and "power-policy (2013)" require more concrete initiatives, such as the creation and execution of vocational programs on a daily basis, to increase recognition among the public. This will minimize energy demand in the longer term [75]. The starting point will be to shift the current patterns in energy consumption that are incredibly inefficient [54]. Approximately 10% of energy consumption can be minimized with limited effort [61]. At this end, for the industrial sector, the idle operating time of manufacturing lines and equipment can be decreased by integrating motion sensors in industrial applications.

The "Governance Index" and the "Corruption Index" rose during the time analyzed [29]. In the short term, however, in order to strengthen governance, the government must urgently correct the framework of the sector by reorganizing it and building the capacity of organizations operating within the sector. These changes should start from the top, i.e., the "Ministry of Water and Power" and the "Ministry of Petroleum and Natural Resources" should be combined into one and designated as the "Ministry of Energy" [28]. This will ensure that the development of the sector is integrated, organized, and that there is a greater opportunity for executing the plans and policies. Furthermore, there are significant structural deficiencies in the energy divisions and a lack of requisite expertise and technical competence [68]. Authorities such as OGRA and NEPRA should organize their operations and prepare their employees, as the energy sector is comparatively more technological than the other sectors. The recruiting of workers should be merit-based and not politically motivated, as has been observed [50]. This would increase the potential of these organizations and can help to boost the "Governance Effectiveness Index" [76].

On the other hand, the emergence of circular debt has been a barrier between power-generating firms and oil supply companies [67]. In order to resolve the problem of circular debt, the reform of the collection system could be discussed for streamlining payments to energy production firms. For this, the government can allocate financial resources for the rehabilitation of power plants instead of paying a large sum against circular debt almost every quarter [77]. In this way, the funds may become available to power generation companies who might boost their efficiency or improve the "Electricity Utilization" indicator. In order to minimize corruption and improve accountability, the policy choices must be used to automate gasoline allocations, shipments, and payments [75]. Furthermore, in order to exercise zero tolerance for corruption, work contracts should be provided on the basis of expertise, market-based wages, and job development assurance [78].

"T&D loses" present a very serious risk to Pakistan's energy security [21]. T&D losses in Pakistan are about 20% higher than those in the Organization for Economic Co-operation and Development (OECD) countries [77]. These have been caused by poorly managed and obsolete transmission and grid systems, improper metering and billing, and the theft of electricity [74]. A two-pronged approach to policy response may be required to resolve this issue [61]. First, an annual energy inspection of the power plants should be carried out to track their thermal efficiency. This would promote proper efficiency-oriented rehabilitation and modernization between power generation and distribution companies [76]. Second, stricter regulation has to be extended to thefts and leaks. For this reason, the enforcement of the government writ is important to ensure a clear mandate on the part of the department concerned. To this end, illegal connections can be simplified by supplying customers with legitimate connections free of charge [71].

The "Nuclear share" of the energy mix in Pakistan has been moderate (Supplementary File). Pakistan has set a target of 8000 MW of capacity for development by 2030 [42]. Although Pakistan is not party to the "Nuclear Non-Proliferation Treaty", it has its capacity under item-specific "IAEA Safeguards" [60]. At this end, Pakistan needs to engage geopolitical strategies to obtain exemption from "Nuclear Supplier Group" trade sanctions to enhance its capacity [50].

The technology is the only dimension that has seen improvement (Figure 5). However, one of the weakest areas of the sector is the lack of a strong technical basis [79]. Concepts such as creativity, precision manufacturing, quality control, and standardization are unheard of [68]. Further local industry does not have any experience in energy technology. It does not know how to generate the main components of the energy grid, such as engines, generators, and control gadgets [20]. In order to improve supply and decrease costs, the government should promote the local production of energy and power devices, including drilling rigs, turbines, boilers, and generators. It is observed that improved performance can be obtained by concentrating on technical advancement and improving the productivity of power plants. In addition, lessons can be learned from India, as it recognized the value of technological advancement in relation to green energy in particular a few decades ago [9]. As a result, India has been a big exporter of clean energies such as wind turbines and solar photovoltaics. Moreover, to further enhance the usage of power plants, the "Availability Based Tariff" could be adopted to compensate for higher energy utilization [28]. This will motivate competitiveness, productivity, and success, and may result in lower prices [50]. Moreover, the government can also concentrate on traditional coal technology, coal gasification, cement briquette, and brink kilns, as they have the ability to make a substantial contribution to the energy mix [80].

Pakistan contributes only 0.8% of global emissions [22]. However, the environmental and sustainability dimension has cost Pakistan approximately USD 9.6 billion since 2010 [81]. Regrettably, so far it is observed that little has been undertaken before 2017 to protect the atmosphere and combat climate change [61]. The discharge of harmful industrial pollution into air and water has not been monitored [28]. The "CO_2/Capita" and "SO_2/Capita" emissions have been compounded by the poor condition of cars and engines combined with largely used, low-standard lubricants and fuels [50]. In addition, the use of fossil fuels has also played a catalytic role in exacerbating the environmental problem [65]. With more than 73% of fossil-based electricity generation, CO_2 emissions tend to increase in the future [31]. Moreover, deforestation (forest/land ratio) is another big problem, as Pakistan ranked 177th in the forest cover ranking [78]. Forest policy formulation has a long history in Pakistan, with the declaration of the first "Pakistan Forest-Policy" in 1955, followed by the Forest Policy of 1962, 1975, 1980, 1988, 1991, 2001, 2010, and 2015 [82]. However, these policies have been inefficient, as defined by indicators such as "CO_2/Capita", "SO_2/Capita", and "Forest/Land ratio". In order to strengthen these indicators, a concerted national effort is needed to ensure protection for the environment [65]. In addition, the environmental agencies and authorities can be revamped, and forestry conservation programs may also be initiated [83]. These programs include, first, the abolition of influential forestry and deforestation cartels and, second, lessons to be learned from the effective forest conservation programs being implemented in various countries [50].

In the environment and sustainability domain, the behavior of the population is also required to be altered through education and awareness. Here, the emphasis must also be improvised on the transport sector and urban areas of Pakistan. For example, eliminating the surplus of old cars and promoting the construction of energy-efficient commercial and residential buildings and further emphasizing lifestyle changes such as switching off additional electrical equipment, using energy-efficient lights, and walking a short distance instead of driving [81]. Lastly, the carbon tax policies may also be implemented in the future, particularly for the manufacturing sector, to minimize CO_2 emissions.

5. Conclusions

The study provided a comprehensive, index-based assessment of energy security. A comparison of PMESI, ESIP, and ESIOP was shown to explain the optimization of indicator selection. As a result, the expert opinion was intended to improve the development of the indicators, and a considerable change in Pakistan's energy security was noted. All through the study period, Pakistan's energy security remained poor. The top performance of PMESI was recorded in 2017 with a score of 5.94, and the lowest performance was identified in 2009 with a score of 2.45. The availability, technology, governance, and environment dimensions decreased with considerable changes over the study period. The availability decreased by 15%, technology decreased by 51%, governance decreased by 50%, and the environment decreased by 3%. Notably, affordability improved significantly; however, environmental dimensions improved marginally. During the study period, affordability increased by 52%. They all, however, remained in the poor region. To that purpose, quantitative indices such as the PMESI can be said to be capable enough to guide policymakers and the general public to assess a country's development in the energy sector. Although it is well known that constructing such a comprehensive index is challenging, the methodology used here addresses the drawbacks of previous studies in many ways. One of the drawbacks of the 2016 study by Erahman et al. was that the authors did not strategize the governance and technology dimensions and instead analyzed data from the previous six years. As a result, similar weights were used because the PCA failed in three dimensions [12]. Tongsopit et al., 2016, used the mean of normalization and scaling to calculate indices [13]. As a result, authors were forced to assign equal weights to indicators, which did not appear to be acceptable for some members of the Association of Southeast Asian Nations "ASEAN," as emphasized in [84]. The indices were also developed by other studies, such as Sharifuddin, 2014 [85]. However, the author overcame data restrictions by employing "proxy indicators". There were only three years of data used, and the indices were based only on the weighted averages of indicators. Nonetheless, the approach and methodology employed in this study integrated a review of the literature on indicators with expert guidance and statistical methods to track Pakistan's energy security. Notably, since the weight estimation and aggregation procedures were extensively discussed, the approach utilized in this work is robust. Therefore, other analysts and officials around the world may readily replicate it for any country.

Aside from the benefits of this study, several of its drawbacks are also addressed in order to guide future research. First, "New Criterion" may be required to complete a set of indicators because there is no uniform list of indicators in the literature. Furthermore, as stated in [86,87], there is no technique available to classify a broad variety of indicators. As a result, multiple parties, such as research specialists and international consultants, can be involved in overcoming challenges to indicator implementation and development. Second, various dimensions such as "Geopolitical," "Military," "Social Development," "Vulnerability," and "Sovereignty" are mentioned in the literature [2,88]. Future studies may include these dimensions, or they may be employed as a dimensional component instead of dimensions to improve energy security performance. Third, while PCA is sensitive to fluctuations and the presence of outliers, alternative weighting approaches should be examined [45]. "Data Enveloping," "Benefit of Doubt," "Unobserved Components Model," Budget Allocation Process," "Analytic Hierarchy Process," and "Conjoint Analysis" are some examples [89]. Fourth, utilizing the proposed indicators, more forecasts should be prepared using possible future routes for the growth of energy systems [90]. Lastly, the technique and indicators presented are insufficient for "regional cooperation." The indicators employed in this analysis may not be suitable for comparison nations. The reasoning is that different indicators may reflect different factors in different countries. As a result, it is critical to investigate the development of a single index in the region in the future.

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Abbreviations

FEC	Final Energy Consumption
TPES	Total Primary Energy Supply
Kgoe	Kilogram of Oil Equivalent
NEID	Net Energy Import Dependency
KWh	Kilo Watt Hour
Kg	Kilogram

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