

Regional Renewable Energy Resource Potential in Pakistan

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(Received December 29, 2019; Revised April 17, 2020; Accepted February 12, 2020)

Online First Publication

DOI: 10.33317/ssurj.153

Abstract— Pakistan is currently recovering from a severe, decade-long power crisis which affected the country's economy and disrupted its' development. On the other hand, the environmental concerns faced by the South-East Asian region combined with the sustainable development goals to be implemented by Pakistan under the Paris Agreement puts further emphasis on renewable energy deployment. This research investigates the solar, wind and hydro resource potential for power production in different regions of the country. A total of 15 data sources have been reviewed and meta-analytic review techniques is used for analysis. It is found that 13 sources out of 15 (86.67%) have reinforced availability of wind, 12 (80%) have indicated the availability of solar potential and 11 (73.33%) have supported hydro resource potential. With the help of the Spearman correlation test, it is found that wind potential is correlated to RE potential in Sindh and has a correlation coefficient of 0.643 with a significance value of 0.010. In KPK province, the availability of wind and hydro resources are found to be statistically significant. The correlation coefficient for wind potential in KPK is 0.511 with a significance value of 0.052 and the correlation coefficient for hydro potential in KPK is 0.788 having a significance value of 0.001. Unfortunately, statistical significance between any of the investigated RE sources and RE potential in Punjab and Balochistan could not be found. It is recommended that policymakers should design policies and strategies to maximize country's RE harnessing power and researchers should work towards finding more evidence to support RE deployment in an informed manner.

Index Terms— Renewable Energy, Resource Potential, Regional Deployment, Sustainable Development

I. INTRODUCTION

Pakistan, the second-largest economy in South-East Asia, is currently in a recovery phase from the decade long energy crisis with continuous development in the energy sector. According to the latest reports, the country has seen a huge increase in installed capacity from 22,800 MW in June 2013 to over 34,200 MW by June 2019 [1]. The country has been tipped as one of the resource-rich countries in terms of hydro, solar and wind energy and it has been stated in published research work that various areas of Pakistan has the capability of producing ample electricity using renewable sources only [2]. The Alternate Energy Development Board (AEDB) of Pakistan has been focusing on renewable resources in recent years which complements ongoing global energy production trends. The AEDB has worked tirelessly to initiate a process of green and sustainable electricity production and this is based

on the utilization of hydro, solar and wind energy resources in the country [3].

It can be said that sustainable power production has taken its baby steps in Pakistan and if the projected output using renewable energy projects is achieved then Pakistan can achieve the set target of 5% renewable energy share by the Planning Commission of Pakistan in its Vision 2030 document [4]. Figure 1 provides a review of the situation of solar and wind energy share in 2013 and in 2019 with respect to the Vision 2030 plan. When analyzing the current energy project deployment in Pakistan, one common theme emerges which is the high concentration of power projects based on conventional energy sources. Pakistan is one of the signee nations of the Sustainable Development Goals of the United Nations and the current scenario sets the country on the wrong path for sustainable energy production. However, if the available opportunities are availed to its full potential then the power profile of the country can be changed [5], [6]. However, much uncertainty regarding the future prospects of the utilization of the astounding renewable resource potential of the country remains [7], [8]. This has been based on the notion that how a country largely based on conventional energy production and a policy structure that has historically supported conventional energy projects will shift towards renewables.

Similar questions have been raised in other developing countries due to economic and policy issues when considering renewable energy deployment. Resource assessment and potential identification is the first step to provide an answer to this question. Once specific resource potential has been identified, only then appropriate policies and informed decisions can be made. Such informed decisions and evidence-based policies will improve financial support as well as investor interest in these resources. This research is focused on the assessment of resource potential of hydro, wind and solar energy in each province so that a comprehensive yet regionally specific resource evaluation can be conducted. Such an assessment will support prospective policy matters, legal and political management and administration, economic and social support, along with available technological muscle to utilize the identified resource potential for each region.

After the introduction section, research methodology is described in section 2, the results and statistical analysis is presented in section 3, the discussion is presented in section 4, and the last section offers a thought-provoking conclusion grounded on the evidence collected in this investigation.

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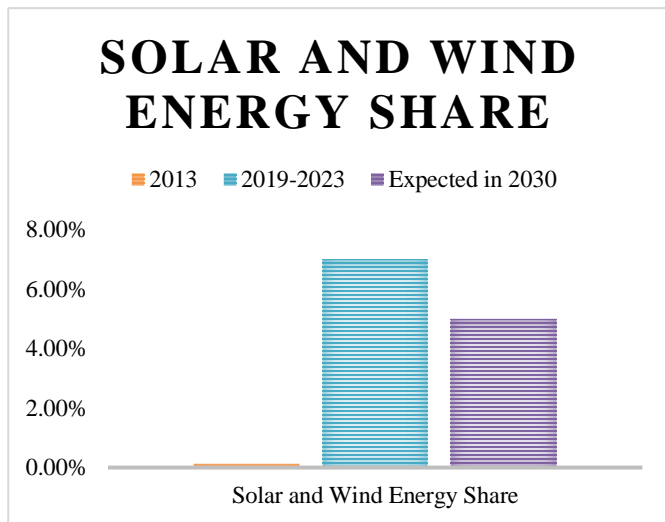


Fig. 1: Expected Solar and Wind Energy Share as per Vision 2030

II. RESEARCH METHODOLOGY

The methodology selected for this research is meta-analytic review. A meta-analytic review is based on secondary data collected from reviewed research articles and then the data is statistically evaluated. This provides both qualitative and quantitative evidence to support the research findings. In recent years, a number of research publications have used meta-analytic review methodologies to investigate renewable energy and power production related research topics. The effect of energy security and power management on economic aspects [9], the influence of economic development on energy requirements and demand [10], and the reliability related concerns associated with renewable energy projects [11] have all been researched in recent years using meta-analytic review techniques. For this research, a total of 15 research articles have been selected as data sources. Only those articles have been selected which have been published since 2015 and directly address the study topic. Spearman correlation has been used for statistical analysis using SPSS.

III. RESULT AND ANALYSIS

Here, the results of the 15 reviewed data sources are presented along with the statistical evaluation of the collected data. In Table 1, the summary of the selected data sources has been presented which provides an overview of the important points suggested by the authors.

In Table 2, the key renewable energy resource highlighted by the individual data sources have been offered along with the provinces discussed in that article so that a clear understanding of the found evidence can be established. On the basis of the data collected from the reviewed data sources, a statistical analysis is conducted to identify specific resource potential for each province.

Table I: Review Summary of Data Sources Related to Renewable Energy Potential in Pakistan

S. No	Source Details	Article Summary
1	Rauf, Wang, Yuan, & Tan, 2015 [12]	Pakistan has ample hydro, solar, wind, biomass and geothermal energy potential.
2	Ghafoor, ur Rehman, Munir, Ahmad, & Iqbal, 2016 [13]	Solar, wind, hydro, biodiesel, biogas and waste-to-energy potential of Pakistan is clearly evident.
3	Kamran, 2018 [14]	Micro hydro, solar, wind and biogas projects have been deployed in recent years.
4	Sadiqa, Gulagi, & Breyer, 2018 [15]	Pakistan can achieve a 100% RE grid by focusing on solar energy potential in southern regions.
5	Baloch, Kaloi & Memon, 2016 [16]	Renewables especially wind energy potential in Pakistan must be utilized to ensure safe future.
6	Ahmed, Mahmood, Hasan, Sidhu, & Butt, 2016 [17]	China, Pakistan and India have immense RE potential to base their energy future on it.
7	Raheem et al., 2016 [18]	Pakistan must use its RE potential to combat the on-going energy crisis.
8	Shoaib, Siddiqui, Amir, & Rehman, 2017 [19]	Wind energy potential in various regions can be utilized to create a sustainable power grid.
9	Stöckler, Schillings, & Kraas, 2016 [20]	Resource assessment reveals wide-ranged solar energy availability in Pakistan.
10	Tahir & Asim, 2018 [21]	Solar energy must be considered a viable option to handle the on-going energy crisis.
11	Malik & Maqbool, 2017 [22]	Energy security can be enhanced by a power grid based on conventional and renewable energy.
12	Valasai et al., 2017 [23]	Pakistan has a variety of sustainable electricity options to overcome its power crisis.
13	Hassan, Afridi, & Khan, 2017 [24]	Pakistan has immense renewable energy potential but faces various deployment challenges.
14	Kaloi, Wang, Baloch, & Tahir, 2017 [25]	Since the 1980s, Pakistan's southern region is tipped for wind energy deployment.
15	Solangi et al., 2019 [26]	Pakistan has vast RE potential including solar, wind, hydro, geothermal and biomass.

Table II: Identified Aspects during the Review Process of Data Sources related to Renewable Energy Potential

S. No	Source Details	Solar	Wind	Hydro	Sindh	Punjab	Baloch-istan	KPK
1	Rauf et al., 2015 [12]	✓	✓	✓	✓	✓	✓	✓
2	Ghafoor et al., 2016 [13]	✓	✓	✓	✓		✓	✓
3	Kamran, 2018 [14]	✓	✓	✓	✓	✓	✓	✓
4	Sadiqa et al., 2018 [15]	✓			✓		✓	
5	Baloch et al., 2016 [16]		✓		✓		✓	✓
6	Ahmed et al., 2016 [17]	✓	✓	✓	✓	✓	✓	✓
7	Raheem et al., 2016 [18]	✓	✓	✓	✓	✓	✓	✓
8	Shoaib et al., 2017 [19]		✓		✓	✓	✓	✓
9	Stöckler et al., 2016 [20]	✓	✓	✓	✓	✓	✓	
10	Tahir & Asim, 2018 [21]	✓			✓	✓	✓	

11	Malik & Maqbool, 2017 [22]	✓	✓	✓	✓	✓	✓	✓
12	Valasai et al., 2017 [23]	✓	✓	✓	✓	✓	✓	✓
13	Hassan et al., 2017 [24]	✓	✓	✓	✓	✓	✓	✓
14	Kaloi et al., 2017 [25]		✓	✓	✓		✓	
15	Solangi et al., 2019 [26]	✓	✓	✓	✓	✓	✓	✓

A. Sindh

When considering the renewable energy potential discussed in the data sources in regards to Sindh province, wind resource potential is found to be most correlated with Sindh RE potential. The result of the Spearman correlation test is provided below in Table 3.

Table III: Spearman Correlation Results for RE Potential in Sindh

		Correlations				
			Sindh RE Potential	Solar Potential	Wind Potential	Hydro Potential
Spearman's rho	Sindh RE potential	Correlation Coefficient	1.000	.054	.643**	.130
		Sig. (2-tailed)	.	.847	.010	.645
		N	15	15	15	15
	Solar Potential	Correlation Coefficient	.054	1.000	-.198	.385
		Sig. (2-tailed)	.847	.	.479	.156
		N	15	15	15	15
	Wind Potential	Correlation Coefficient	.643**	-.198	1.000	.474
		Sig. (2-tailed)	.010	.479	.	.074
		N	15	15	15	15
	Hydro Potential	Correlation Coefficient	.130	.385	.474	1.000
		Sig. (2-tailed)	.645	.156	.074	.
		N	15	15	15	15

** . Correlation is significant at the 0.01 level (2-tailed).

B. Punjab

In case of Punjab, no significant correlations could be found. The outcome of the Spearman correlation test are presented below in Table 4.

Table IV: Spearman Correlation Test Result for Renewable Energy Potential in Punjab

		Correlations				
			Punjab RE Potential	Solar Potential	Wind Potential	Hydro Potential
Spearman's rho	Punjab RE potential	Correlation Coefficient	1.000	.127	-.177	.338
		Sig. (2-tailed)	.	.653	.529	.218
		N	15	15	15	15
	Solar Potential	Correlation Coefficient	.127	1.000	-.198	.385
		Sig. (2-tailed)	.653	.	.479	.156
		N	15	15	15	15
	Wind Potential	Correlation Coefficient	-.177	-.198	1.000	.474
		Sig. (2-tailed)	.529	.479	.	.074

		N	15	15	15	15
Hydro Potential	Correlation Coefficient		.338	.385	.474	1.000
	Sig. (2-tailed)		.218	.156	.074	.
	N		15	15	15	15

C. Balochistan

In case of Balochistan, ample evidence supporting solar energy potential in Balochistan has been found. However, statistical significance could not be achieved. This will be discussed further in the next section of this research paper. The results of the Spearman correlation test are presented below in Table 5.

Table V: Spearman Correlation Test Results of Renewable Energy Potential of Balochistan

		Correlations				
			Balochistan RE Potential	Solar Potential	Wind Potential	Hydro Potential
Spearman's rho	Balochistan RE potential	Correlation Coefficient	1.000	.208	-.223	-.342
		Sig. (2-tailed)	.	.458	.424	.212
		N	15	15	15	15
	Solar Potential	Correlation Coefficient	.208	1.000	-.198	.385
		Sig. (2-tailed)	.458	.	.479	.156
		N	15	15	15	15
	Wind Potential	Correlation Coefficient	-.223	-.198	1.000	.474
		Sig. (2-tailed)	.424	.479	.	.074
		N	15	15	15	15
	Hydro Potential	Correlation Coefficient	-.342	.385	.474	1.000
		Sig. (2-tailed)	.212	.156	.074	.
		N	15	15	15	15

D. Khyber Pakhtunkhwa

In Khyber Pakhtunkhwa province, significant correlation has been found between wind and hydro potential with RE potential has been found. The results of the Spearman correlation test are presented below in Table 6.

Table VI: Spearman Correlation Test Results of Renewable Energy Potential in KPK

		Correlations				
			KPK RE Potential	Solar Potential	Wind Potential	Hydro Potential
Spearman's rho	KPK RE potential	Correlation Coefficient	1.000	.112	.511	.788*
		Sig. (2-tailed)	.	.692	.052	.000
		N	15	15	15	15
	Solar Potential	Correlation Coefficient	.112	1.000	-.198	.385
		Sig. (2-tailed)	.692	.	.479	.156
		N	15	15	15	15
	Wind Potential	Correlation Coefficient	.511	-.198	1.000	.474
		Sig. (2-tailed)	.052	.479	.	.074
		N	15	15	15	15

Hydro Potential	Correlation Coefficient	.788**	.385	.474	1.000
	Sig. (2-tailed)	.000	.156	.074	.
	N	15	15	15	15
**. Correlation is significant at the 0.01 level (2-tailed)					

IV. DISCUSSION

On the basis of the research findings presented in the above section, here an informed discussion is presented.

A. Focus on Solar and Wind Resource

The abundance of the renewable energy potential of Pakistan has been reported by many scholars that have been reviewed in this research. In this research, three main resources have been investigated in terms of their potential which are hydro, solar and wind resources. Interestingly, a high number of researchers have reported solar and wind resource potential when compared to hydro resource potential for power production. Out of the studied 15 sources, 13 (86.67%) have shed light on the importance of the availability of the wind resource in various parts of the country. Also, 12 out of 15 sources (80%) have indicated the availability of solar potential in different regions. Both these resources have a high availability indication than hydro resource availability which is suggested by 73.33%. Figure 2 presents a pictorial demonstration based on the research findings.

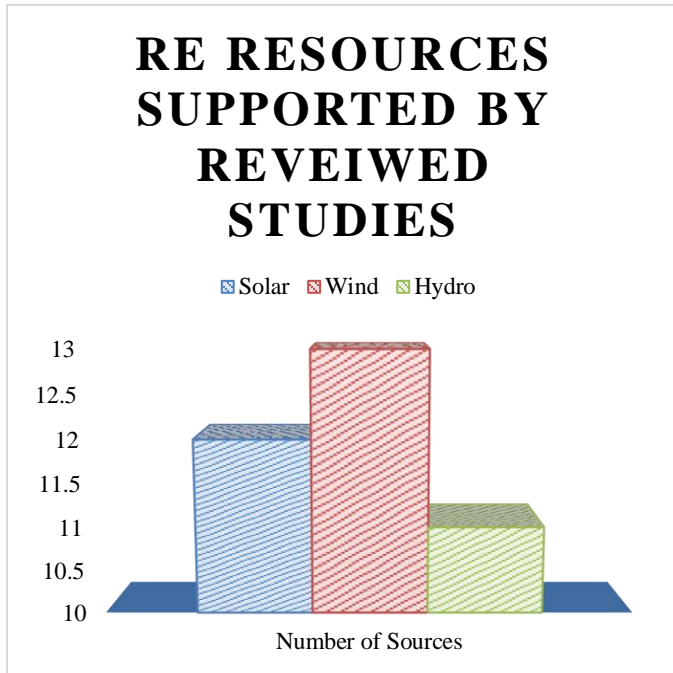


Fig. 2: RE Resources Supported by Reviewed Studies

This can be grounded on the fact that hydro potential is already being exploited by the government authorities. Also, the government is working on a number of hydropower projects namely the Diamer-Bhasha Dam of 4500 megawatts and the Mohmand Dam of 800 megawatts power capacity. On the other hand, there are also small and large scale hydropower projects which are already operational. On the contrary, when considering the solar and wind power projects, it can be suggested that none to very few major power projects have

been deployed until now. The Quaid-e-Azam Solar Power Park in Southern Punjab and the wind projects in the Jhimpir corridor in the Southern Sindh region are some of the prominent projects. However, most of these operational projects are less than 100 megawatts which represents a very small proportion of the potential of these regions in regards to these renewable resources [27], [28]. Based on this consideration, it can be understood that why the researchers have focused more on solar and wind energy resources over hydro resource.

B. Wind Resource in Sindh

When considering the findings presented in this research in regards to the Sindh province, it can be suggested with evidence that strong statistical support has been found for wind resource deployment. With the help of the Spearman correlation test, it is found that wind potential is correlated to RE potential in Sindh and has a correlation coefficient of 0.643 with a significance value of 0.010. This is a vital finding as it has been well-documented by the reviewed resources. Here, the statistical evidence further supports the qualitative support available in this research. This is now beyond all doubt that the provincial government must provide all possible support to wind energy projects in Southern areas like Jhimpir and Thatta. Also, the local investors can be targeted in this regards as energy projects will not only solve the power shortage issues but will also provide economic progress and job opportunities to the locals. Also, these projects supported by appropriate policies and research evidence like this can result in informed and sustainable development in the region. Knowledge-based and evidence-based policy formulation is an important factor for growth and sustainable development [29]. This is not only important for the power sector as well as in Pakistan's policy structure in general.

C. Wind and Hydro Potential in KPK

In KPK province, the availability of wind and hydro resources are found to be statistically significant. The correlation coefficient for wind potential in KPK is 0.511 with a significance value of 0.052. This highlights a confidence level of over 90%. In addition to this, the correlation coefficient for hydro potential in KPK is 0.788 having a significance value of less than 0.001 which refers to confidence level of at least 99%. This provides strong support for regional renewable energy potential and its implementation in KPK. The deployment of hydropower projects in the province has been on the rise during the last few years. However, small off-grid hydro projects are vital for rural electrification in KPK. In combination with small hydro projects, wind projects must also be used to maximize the RE potential of the region.

Based on the evidence found in this research, it can be stated that KPK is the resource-rich region of the country when it comes to renewable energy resources. Exploiting these resources for rural electrification and for power production in general can improve the economic situation of the region considerably. This is strong research evidence that has linked rural electrification with economic development, entrepreneurship and social community development [30]. Therefore, the provincial government and the federal authorities must look into this RE potential with great

seriousness and should formulate policies that can translate this potential into sustainable development and regional growth.

D. RE potential in Punjab and Balochistan

Unfortunately, in this research, statistical significance between any of the investigated RE sources and RE potential in Punjab and Balochistan could not be found. However, it can be stated that there is some serious solar potential in both these provinces. This has been stated based on the notion that all the reviewed data sources that have discussed Balochistan province in this research has highlighted solar potential. Yet, statistical significance could not be proven. For Punjab province, the solar potential in the Southern region [31] and the wind potential in the Northern region is supported by researchers [32], [33]. But, the data sources reviewed in this research could not provide clear evidence of these RE sources. Although, research is being conducted related to various aspects of solar energy resources [34] as well as other RE sources. However, further research is needed to understand the available potential and deployment effect on local social, economic and environmental aspects. Hence, it is high time that further research is conducted for the investigation and deployment of these sources. The provincial governments must work in conjunction with federal agencies like the AEDB and NEPRA to formulate policies and strategies to enhance investor interest and financial security of RE projects in the region. In fact, regional security, financial stability and policy support are found to be some of the key factors for the successful implementation of energy projects in Pakistan [9], [35].

Here, one important aspect that must be highlighted that could be one of the reasons of lack of statistical significance in regards to RE potential in Punjab is that almost all the articles reviewed here have shed light on at least one of the resources but the supported is scattered among the three resources discussed in this paper. In addition to this, the availability of bagasse potential in Punjab further complicates RE potential related discussion in the reviewed articles. This is based on the findings of this research as only 73% of research articles discussed hydro potential which is one of the most utilized RE source in the country and is one of the main sources of energy in Punjab. This is possibly due to the current exploitation of hydro sources and the lack of deployment of solar and wind projects that researchers preferred to discuss solar and wind potential more than hydro potential. Hence, a larger research body with high number of articles will need to be reviewed to ensure that enough support for each resource separately can be found. Only then statistical significance can be achieved for Punjab province. Nonetheless, RE potential in Punjab cannot be doubted and a review of a higher number of research sources will surely establish it.

Similarly, in case of Balochistan, researchers have presented support to solar and wind potential however, the small sample size and scattered support led to a statistically insignificant outcome. It is only a matter of time that the RE potential of Balochistan is realized as more and more research is being conducted on the solar potential of the province and the wind potential in Southern Balochistan region. A combined assessment focusing on wind potential in Southern Balochistan

and Southern Sindh is also recommended to the researchers as it found during this review that these regions tend to have high level of wind potential. A larger sample size and a resource focused investigation can surely present strong evidence of RE potential in Balochistan.

V. CONCLUSION

Pakistan has gone through a severe power crisis during the last decade and is now in a recovery phase. The power crisis not only affected the energy sector but had far-reaching consequences on the economy of the country. This combined with the environmental issues the South-East Asian region faces at the moment and the impending future makes it extremely vital to move towards RE sources for power production. This research has provided substantive proof in regards to the RE resource potential in the different regions of the country. It is clear that there is sufficient hydro, solar and wind potential in the country to meet the Vision 2030 targets. However, the policymakers must work towards maximizing the harnessing power of the energy sector by formulating appropriate policies to support RE deployment. This is only possible when government agencies recognize the potential and then work towards designing a comprehensive framework involving federal and provincial stakeholders.

This research has presented clear proof with statistical evidence to support wind power project deployment in Sindh and wind and hydropower project deployment in KPK. In addition to this, ample research support has been found in favor of solar and wind potential in the country. Moreover, RE potential could not be proven statistically in case of Punjab and Balochistan. However, this points towards further research to establish the potential of solar, wind and hydro resources in these regions. Also, it calls for more scrutiny to understand why researchers have refrained from pointing out the vast solar potential of Balochistan and Southern Punjab regions. Nonetheless, this research points out an important area for investigation to support sustainable development and growth of the power sector in the light of the Paris Agreement and the environmental issues the country faces.

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