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Distributed Solar Energy Generation in Pakistan: Potential, Barriers and Policy Recommendations

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Abstract

Pakistan's energy generation mix remains heavily reliant on imported fossil fuels, contributing to current account deficit and fiscal pressures, high circular debt in the energy sector, and inflationary pressures for the population. Pakistan is endowed with tremendous solar energy potential that can be proactively capitalised to reduce reliance on foreign energy supply to meet domestic energy needs. Distributed solar energy generation is a promising means of exploiting this tremendous potential. However, its growth pace in Pakistan, notwithstanding the increase over recent years, is still considered unsatisfactory compared to the country's solar power generation potential. Given this, the present research sought to identify the strengths, weaknesses, opportunities, and threats for the adoption and diffusion of distributed solar energy generation in Pakistan. The viability of developing a thriving distributed solar energy generation market will be contingent on addressing the weaknesses while proactively seizing opportunities and mitigating threats.

Keywords: Solar Power, Distributed Energy Generation, Renewables, Net metering.

Introduction

The world is currently undergoing a process of energy transition that rests on a shift away from fossil fuels as the major energy source towards renewable sources of power. This transition is the product of a global push to reduce the impact of energy production and consumption on the environment. Distributed Solar Energy Generation (DSEG), sometimes referred to as on-site solar energy generation, distributed solar or decentralised generation, now plays a vital role in this transition towards a clean energy future, and according to the International Energy Agency (IEA), it can potentially become the principal contributor to the global transition to renewable energy.[1]

Distributed solar involves production of solar electricity closer to the point of use, such as on individual buildings, at industrial sites, or within communities.[2] On-grid and off-grid systems are the two major categories of DSE systems. Whereas an off-grid system functions independently of the power grid, an on-grid system is connected to the utility grid. The market size of DSEG was valued at USD 130.31 billion in 2022.[3] It is estimated to rise at a Compound Annual Growth Rate (CAGR) of 6.96%, reaching USD 195.12 billion by 2029, driven by factors such as declining costs of solar photovoltaic (PV) panels or escalating global temperatures,

1 Redex, "The Growth of Distributed Solar Power," Accessed 26 April, 2024, https://redex.eco/the-growth-of-distributed-solar-power/.

2 L. Mehigan, J. P. Deane, BP. Ó Gallachóir, and V. Bertsch, "A Review of the Role of Distributed Generation (DG) in Future Electricity Systems," *Energy* 163 (2018): 822-836, https://doi.org/10.1016/j.energy.2018.08.022.

3 GII Global Information, "Distributed Solar Power Generation Market – Global Size, Share, Trend Analysis, Opportunity, and Forecast Report – 2019-2029, Segmented by Solar Module; By Type; By End Use; By Region," December 26, 2023, https://www.giiresearch.com/report/blw1401181-distributed-solar-power-generation-market-global.html.

stimulating a greater push to reduce global carbon dioxide (CO_2) emissions.[4]

Developing countries, in general, have the highest solar potential,[5] and decentralised generation is an effective way for these nations to exploit their rich solar resources. Pakistan, a developing country in South Asia, has considerable potential for solar power generation, and it can fulfil its present electricity demand 'if just 0.071% of its area is exploited for solar energy generation.'[6] Moreover, 1,015 potential (large size and high density) mini-grid sites with an average PV capacity of 158 *kilowatt peak* (kWp) can cover the energy needs of Pakistan's 1.8 million rural population.[7]

DSEG has been increasing in popularity within the country, particularly within the residential sector.[8] The use of solar PV in the agricultural sector has also amplified. Residential, industrial, agricultural, and commercial sectors are the major consumers of

4 GII Global Information, "Distributed Solar Power Generation Market."

5 Nick Ferris, "How Countries with Potential can Reap Big Benefits from the Solar Boom," *Energy Monitor*, November 5, 2021, https://www.energymonitor.ai/renewables/the-world-is-primed-for-a-solar-boom-will-countries-with-the-most-potential-reap-the-benefits/.

6 The World Bank, "Expanding Renewable Energy in Pakistan's Electricity Mix," November 10, 2020, https://www.worldbank.org/en/news/feature/2020/11/09/a-renewable-energy-future-for-pakistans-power-system.

7 The World Bank, Pakistan Least-Cost Electrification Study, report (Washington, D.C: The World Bank, 2024), https://documents1.worldbank.org/curated/en/099071824081524723/pdf/.

8 Naila Saleh and Sara, "Distributed Generation Landscape in Pakistan: An Overview," (paper, Institute of Policy Studies, 2020), https://www.ips.org.pk/wp-content/uploads/2020/08/DISTRIBUTED-GENERATION-LANDSCAPE-IN-PAKISTAN-final.pdf.

electricity, and the transition to solar PV in these sectors has important implications for Pakistan's energy landscape.

Specifically, with the introduction of the National Electric Power Regulatory Authority's (NEPRA) net metering regulations in 2015, deployment of distributed solar PV systems grew.[9] Net metering regulations allow consumers from all categories—including residential, agricultural, commercial, and industrial—with three-phase connections to be compensated at the off-peak retail tariff for contributing excess electricity to the grid after availing this facility.[10] The total number of net metering consumers increased from 108 in June 2017 to 157,844 by the end of June 2024, with 1,181 MW of total capacity added from net metering during FY 2023-24 compared to 583 MW during FY 2022-23.[11] The uptake of grid-independent solar installations, such as residential standalone systems, solar water pumps, and solar street lighting, has also increased. PV technologies have definite prospects for these off-grid applications. For instance, street lighting and irrigation account for over 350 megawatts (MW) and 1000 MW of electricity consumption, respectively and can be easily shifted to solar power.[12]

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9 Naila Saleh and Paul Upham, "Socio-technical Inertia: Understanding the Barriers to Distributed Generation in Pakistan," *Economics of Energy and Environmental Policy* 11, no. 1 (2022): 79-100, https://doi.org/10.5547/2160-5890.11.1.NSAL.

10 Saleh and Upham, "Socio-technical Inertia."

11 National Electric Power Regulatory Authority, *State of Industry Report 2017*, report (Islamabad: National Electric Power Regulatory Authority, 2018), https://nepra.org.pk/publications/State%20of%20Industry%20Reports.php; –– *State of Industry Report 2024,* report (Islamabad: National Electric Power Regulatory Authority, 2025), https://nepra.org.pk/publications/State%20of%20Industry%20Reports.ph.

12 Private Power and Infrastructure Board, "Solar Energy Applications Viable in Pakistan," Accessed August 8, 2024,

However, the growth pace of distributed solar, notwithstanding the increase over recent years, is still considered unsatisfactory compared to the country's solar power generation potential.[13] This is reflected in the meagre contribution of solar energy to Pakistan's total energy mix. In the first half of fiscal year 2024 (FY24), Pakistan produced 0.6% of its electricity through solar, as against 14% by coal, 14.2% by Re-Gasified Liquefied Natural Gas (RLNG), and 11.3% by gas.[14]

Pakistan's energy sector depends heavily on imported petroleum group commodities,[15] accounting for around 30% of the country's import bill.[16] This is a major impediment to Pakistan's economic growth and development. Expanding solar energy generation, including DSEG is, therefore, imperative to reduce excessive dependence on imported commodities and diversify the country's energy mix. A thriving DSEG sector can play an instrumental role in achieving the Government of Pakistan's aim to increase the contribution of renewables in the country's energy mix. The Indicative Generation Capacity Expansion Plan (IGCEP) 2024-34

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https://ppib.gov.pk/wp-content/uploads/2023/07/SOLAR-ENERGY-APPLICATIONS-VIABLE-IN-PAKISTAN.pdf.

13 Saleh and Upham, "Socio-technical Inertia."

14 Arif Habib Limited, "Pakistan Power Sector: Actual Generation in 2QFY24 fell by 15.2% Compared to the Reference," January 18, 2024, https://arifhabibltd.com/api/research/open?path=178/65a8cd1a15fdcdc42f1634fa.pdf.

15 Lubna Riaz, "Navigating Pakistan's Power Sector Challenges: Tackling High Electricity Cost," (paper, Institute of Policy Studies, 2023), https://www.ips.org.pk/navigating-pakistans-power-sector-challenges-tackling-high-electricity-cost/.

16 State Bank of Pakistan, "Import Payments by Commodities and Groups," Accessed April 26, 2024, https://www.sbp.org.pk/ecodata/Import_Payments_by_Commodities_and_Groups.pdf.

envisages an increase in the share of electricity generated by solar sources from 1% in 2024 to 7% by 2029 and 10% by 2034.[17]

In view of this, the study aimed to identify the potential and barriers to DSEG in Pakistan through a SWOT (Strengths (S), Weaknesses (W), Opportunities (O), and Threats (T)) analysis technique. More specifically, it identified the 'strengths' that provide Pakistan with an advantage in solar power generation and the 'opportunities' to promote uptake of distributed solar energy systems. In addition, it explored 'weaknesses' restricting greater adoption and diffusion of DSEG in Pakistan and the 'threats' that could hinder its prospects. Numerous studies have been undertaken on the potential and barriers to solar energy generation in Pakistan. However, given that solar PV is a fast-evolving domain characterised by rapidly emerging challenges and opportunities, the subject necessitates constant research and updates. Given this, the present study was undertaken to identify both the past and new developments.

The paper has been structured into five sections. Following the introduction, the next section presents an overview of the theoretical framework. Section three outlines the study's methodology, and section four presents the results. Section five presents a discussion of the findings. Section six concludes the study and offers recommendations.

Theoretical Framework: Diffusion of Innovation Theory

The present study applies the Diffusion of Innovation (DOI) theory to provide a roadmap for discussion. Everett Rogers, a sociologist

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17 National Transmission and Dispatch Company, *Indicative Generation Capacity Expansion Plan*, report (Islamabad: National Transmission and Dispatch Company, 2024), https://nepra.org.pk/Admission%20Notices/2024/05%20May/IGCEP%202024-34%20Report.pdf.

and a communication scholar, developed this theory in 1962.[18] The theory describes how innovation develops and spreads in a specific social system over time. Rogers outlined the innovation-decision process to explain how decision-making units reject or adopt innovations. He divided the process into five distinct steps or phases: knowledge, persuasion, decision, implementation, and confirmation. These five steps have been detailed in Table I. In the knowledge phase, the decision-making unit learns about the existence of innovation and seeks information about it, while the persuasion stage involves shaping one's attitude (positive or negative) towards the innovation after learning about it. In the decision phase, the decision-making unit chooses to accept or reject an innovation, followed by the implementation phase, which involves implementing the innovation. In the confirmation stage, the decision-making unit evaluates whether or not the innovation achieves the expected value.

[18] Fredrik Lind and Beatrice Åman, "Diffusion and Adoption of Renewable Energy Products for Enhanced Societal Wellbeing," (Bachelor Thesis., Karlstad University, Karlstad, 2022).

Table I: Five Phases of the Innovation-Decision Process

Phase	Description
Knowledge	The moment the individual becomes aware that the innovation exists and gains knowledge of how it works
Persuasion	When the individual forms a negative or positive attitude towards the innovation
Decision	The individual engages in activities that will lead to a decision whether to adopt the innovation or not
Implementation	The individual implements the innovation and continues learning about it
Confirmation	The individual evaluates during the use of the innovation whether it achieves the expected value or not. If the expected value is achieved, the individual continues to use the innovation, otherwise, may discard it.

Source: Lind and Åman, "Diffusion and Adoption of Renewable Energy Products."

Materials and Methods

The study employed the SWOT analysis technique, identifying the strengths (S), opportunities (O), weaknesses (W), and threats (T) for the adoption and diffusion of DSEG in Pakistan through a comprehensive review of the literature. Secondary data sources were utilised, including articles from reputable national and international journals, books, reports from NEPRA, National Transmission and Dispatch Company (NTDC), International Institute for Sustainable Development (IISD), the World Bank, and newspaper articles. Majority of the utilised sources were published between 2019 and 2024.

SWOT analysis is one of the most prevalent and results-oriented methods used for strategic planning.[19] It offers the advantage of analysing multiple domains quickly and seamlessly through multidimensional modelling.[20] This tool has been extensively applied, and in recent years, it has also been employed in studies related to energy, including wind and solar power generation,[21] evidencing its appropriateness for the present study.

Results and Findings of the SWOT Analysis

The following section details the findings of the SWOT analysis. It amalgamates all findings, including those relevant to residential, agricultural, and industrial sectors and those applicable to specific sectors.

Strengths

Strong solar irradiation: The amount of irradiance falling over a surface horizontal to the ground, i.e., the global horizontal irradiance (GHI), is an important determinant of the electricity generated by solar power systems. The GHI depends on factors such as geographic latitude, atmospheric transparency, sunshine time, altitude, or air quality. Pakistan's annual mean daily GHI is noticeably high compared to the global average—5.30 kilowatt

19 Marilyn M. Helms and Judy Nixon, "Exploring SWOT Analysis – Where Are We Now?" *Journal of Strategy and Management* 3, no. 3 (2010): 215-251, DOI 10.1108/17554251011064837.

20 Christine Namugenyi, Shastri L Nimmagadda and Torsten Reiners, "Design of a SWOT Analysis Model and its Evaluation in Diverse Digital Business Ecosystems Context," *Procedia Computer Science* 159 (2019): 1145-1154, 10.1016/j.procs.2019.09.283.

21 Hengtian Wang, Xiaolong Yang, Qihe Lou and Xinxin Xu, "Achieving a Sustainable Development Process by Deployment of Solar Power in ASEAN: A SWOT Analysis," *Processes* 9, (2021): 630, https://doi.org/10.3390/pr9040630.

hours per square metre (kWh/m2),[22] while in the southwestern parts of the country, irradiance levels go as high as 6.5 to 7 kWh/m2.[23] In comparison, the global mean yearly daily GHI is 3.61 kWh/m2.[24]

Enough sunshine hours: Pakistan is situated at a favourable location as far as the duration of sunlight availability is concerned. Solar panels, on average, require 1000 watts of sunlight per square metre (W/m2) daily in order to run optimally, for which roughly four to five hours of peak solar hours are sufficient.[25] According to most estimates, the average sunshine duration in the majority of Pakistan is between eight and ten hours per day,[26] while peak solar hours range from four to six hours a day.[27]

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22 Z. R. Tahir and Muhammad Asim, "Surface Measured Solar Radiation Data and Solar Energy Resource Assessment of Pakistan: A Review," *Renewable and Sustainable Energy Reviews* 81, (2018): 2839-2861, http://dx.doi.org/10.1016/j.rser.2017.06.090.

23 Haleema Qamar, Hafsa Qamar and Muhammad Umair Khan, "Solar Irradiance and On Grid Solar Power Systems with Net Metering in Pakistan," *Advances in Science, Technology and Engineering Systems* 1, no. 2 (2016): 1-5, https://www.astesj.com/publications/ASTESJ_010201.pdf.

24 Tahir and Asim, "Surface Measured Solar Radiation Data," 4.

25 JFK Electrical Solar and Air, "How Much Direct Sunlight Do Solar Panels Need," June 21, 2022, https://jfkelectrical.com.au/does-solar-panel-need-direct-sunlight/.

26 FengCheng Chien, Hafiz Waqas Kamran, Gadah Albashar and Wasim Iqbal, "Dynamic Planning, Conversion, and Management Strategy of Different Renewable Energy Sources: A Sustainable Solution for Severe Energy Crises in Emerging Economies," *International Journal of Hydrogen Energy* 46, (2021): 7745-7758, https://doi.org/10.1016/j.ijhydene.2020.12.004.

27 Ecospark Solar, "Peak Sun Hours in Pakistan (Islamabad, Punjab, KPK, Baluchistan, and Sindh," Accessed April 21, 2024, https://ecosparksolar.com/peak-sun-hours-in-pakistan/.

Fairly consistent availability of sunshine throughout the year: The reasonably consistent availability of sunshine throughout the year establishes solar as a reliable energy source in Pakistan. The seasonal variability in the sunshine hours is low, with annual mean daily sunlight period ranging from seven to eight hours during winter and nine to ten hours during summers across most of the country, except the Northern Areas.[28] Additionally, on average, most of the country receives more than 300 sunshine days a year.[29]

Weaknesses

High initial costs of solar energy systems, specifically for low and middle-income earners*:* The cost of hardware for solar energy systems, such as solar PV panels or solar batteries, has decreased over time.[30] While this has increased the affordability of solar energy use for a relatively larger segment of society, for many low and middle-income earners and households, the initial cost of a solar energy system continues to be high.

Concerns about the quality of solar system equipment in the market: The quality control and supervision of solar system equipment in Pakistan is not up to par, which lowers customers'

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28 Sara Batool Naqvi, "Solar Energy in South Punjab/Pakistan: Domestic Users' Perceptions," *American Scientific Research Journal for Engineering, Technology, and Sciences* 67, no. 1 (2020): 171-182, https://asrjetsjournal.org/index.php/American_Scientific_Journal/article/view/5889.

29 Z. R. Tahir and Muhammad Asim, "The Evaluation of Reanalysis and Analysis Products of Solar Radiation in Sindh Province, Pakistan," *Renewable Energy* 145, (2020): 347-362, https://doi.org/10.1016/j.renene.2019.04.107.

30 Mehreen Gul, Yash Kotak and Tariq Muneer, "Review on Recent Trend of Solar Photovoltaic Technology," *Energy Exploration and Exploitation* 34, no. 4 (2020): 486-526, DOI: 10.1177/0144598716650552.

trust in solar technology.[31] Poor quality solar system equipment, including solar PV panels, can pose many challenges, resulting in cost overruns or solar energy systems running down earlier than expected. For instance, microcracks due to the usage of low quality silicon cells in PV panels, among other factors, are a significant cause of solar panel malfunctions, or low quality plastics in solar panels can result in delamination, involving separation of the plastic backing of a solar panel from the glass.[32]

Inadequate dissemination of technical information: Insufficient knowledge about the long-term operation and maintenance of solar energy systems increases the actual or perceived complexity of solar energy use. Although campaigns to promote investment in solar energy usage are rising, there is still inadequate dissemination of practical information among consumers regarding the usage of a solar energy system, such as information about routine maintenance of the system, system performance monitoring, backup power options, or net metering system, among others, to alleviate the complexity of transitioning to solar energy use.[33]

Challenges of solar net metering uptake*:* Net metering is the billing mechanism that credits owners of solar energy systems for adding excess electricity to the grid and offers a strong incentive for uptake or expansion of solar energy usage. Pakistan has been among early

31 Muhammad Irfan, Zhen-Yu Zhao, Munir Ahmad and Marie Clarie Mukeshimana, "Solar Energy Development in Pakistan: Barriers and Policy Recommendations," *Sustainability* 11, no. 4 (2019): 1206, https://doi.org/10.3390/su11041206.

32 Durbek Fattakhov, "Problems Which You May Face Using Low-Quality PV Modules," *LinkedIn*, December 28, 2017, https://www.linkedin.com/pulse/problems-which-you-may-face-using-low-quality-pv-durbek-fattakhov/.

33 Irfan et al., "Solar Energy Development in Pakistan," 16.

movers in the net metering space.[34] However, multiple obstacles have continued to affect consumers' ease of net metering installation. Among them are the high upfront cost of net metering, inadequate tailored lending mechanisms to facilitate its uptake, cumbersome procedures for obtaining net metering licences, or non-cooperation of concerned authorities.[35] Additionally, the current net metering market is limited to three-phase users. It excludes single phase customers, while research has shown that 7.54 Terawatt hour (TWh) can be renewably added to the grid by just allowing 5% single phase net energy metering.[36]

Challenges in accessing finance for solar products: Solar financing is vital to encouraging greater uptake of solar energy systems by facilitating initial capital investment and increasing return on it. Solar financing facilities in Pakistan exist; however, certain factors impede the ease with which potential adopters of solar energy systems can access finance. The State Bank of Pakistan (SBP) introduced a 'concessionary financial scheme' requiring commercial banks to extend loans to applicants at easy terms and subsidised interest rates. However, according to a follow-up evaluation, not all commercial banks have embraced this scheme.[37]

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34 Hina Aslam, Ahad Nazir and Ubaid ur Rehman Zia, *Annual State of the Renewable Energy Report Pakistan 2021-2022*, report (Islamabad: Sustainable Development Policy Institute, 2022), https://sdpi.org/assets/lib/uploads/SDPI-RENEWABLE%20ENERGY%20REPORT-2022.pdf.

35 Aslam et al., *Annual State of the Renewable Energy Report*, 67; Naila Saleh and Paul Upham, "Sociotechnical Misalignments and Micro-Renewables Adoption: The Case of Distributed Solar PV in Pakistan," *Renewable and Sustainable Energy Transition* 4, (2023): 100071, https://doi.org/10.1016/j.rset.2023.100071.

36 Muhammad Usman Tahir, Kiran Siraj, Syed Faizan Ali Shah and Naveed Arshad, "Evaluation of Single-Phase Net-Metering to Meet Renewable Energy Targets: A Case Study from Pakistan," *Energy policy* 172, no. 7 (2023): 113311, DOI:10.1016/j.enpol.2022.113311.

37 Saleh and Upham, "Sociotechnical Misalignments," 6.

The strict eligibility criteria set by many banks to acquire finance under the scheme further limit potential adopters' accessibility to solar financing.[38] Additionally, interest rates have increased significantly since 2023,[39] which has posed challenges to acquire financing facilities from banking institutions.

Reliance on the single buyer electric power market model: The current structure of Pakistan's electricity market is based on the single buyer model, where the Central Power Purchasing Agency (CPPA-G) purchases electricity on behalf of distribution companies (DISCOs). In 2020, NEPRA approved a Competitive Trading Bilateral Contract Market (CTBCM) model, providing a roadmap for opening the wholesale electricity market in Pakistan. A CTBCM model allows bulk power consumers to purchase electricity from a competitive supplier or DISCOs.[40] Such an arrangement means better pricing for the solar adopters for the sale of excess electricity, thus making adoption of solar energy systems more economically attractive.However, although several announcements have been made since its approval, the materialisation of the CTBCM model appears unlikely in the near future.[41]

Opportunities

Declining solar PV panel costs: Solar PV panels constitute the largest portion of the solar energy system cost. Their prices have been steadily declining over an extended period. Domestically, in 2022, the Government of Pakistan (GoP) announced removal of the 17% General Sales Tax (GST) on imported solar panels, significantly

38 Saleh and Upham, "Sociotechnical Misalignments," 6.
39 Trading Economics, "Pakistan Interest Rate," Accessed August 3, 2024, https://tradingeconomics.com/pakistan/interest-rate.
40 National Electric Power Regulatory Authority, "Competitive Trading Bilateral Contracts Market," Accessed August 3, 2024, https://www.nepra.org.pk/ctbcm.php.
41 Afia Malik, "IPPs and Capacity Payments," *Dawn*, July 29, 2024, https://www.dawn.com/news/1848654.

alleviating price pressures and facilitating the adoption of solar PV systems.[42] Globally, technological advancements have increased the light-to-electricity conversion efficiency of solar panels, thus lowering their cost per watt.[43] Additionally, with the proportion of solar panel production in China having risen, the cost of producing solar panels has reduced due to lower production costs of firms from China compared to firms from other parts of the world. Moreover, manufacturing capacity of firms producing solar technology and equipment is growing worldwide while capital equipment prices have decreased.[44] As a result, global solar PV panel prices have been declining. The trend has picked up momentum, and in just 2023, the spot prices of solar PV modules decreased by almost 50% year-on-year (YoY).[45] In Pakistan, the price of solar panels also decreased from PKR 80 per watt in 2022 to PKR 37 per watt in 2024, representing more than 50% decrease.[46] This trajectory is likely to be maintained in the ensuing period. The global solar manufacturing capacity will remain at more than double annual installation in the upcoming years, which will continue to put downward pressure on global solar panel prices.[47]

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42 Imran Ayub, "PM Removes 17pc GST on Solar Panels," *Business Recorder*, May 21, 2022, https://www.dawn.com/news/1690683.

43 Unni Pillai, "Drivers of Cost Reduction in Solar Photovoltaics," *Energy Economics* 50, (2015): 286-293, http://dx.doi.org/10.1016/j.eneco.2015.05.015.

44 Pillai, "Drivers of Cost Reduction in Solar Photovoltaics," 288.

45 International Energy Agency, "Renewables 2023," Accessed April 22, 2024, https://www.iea.org/reports/renewables-2023/executive-summary.

46 "Solar Panel Prices Drop Further in Pakistan," *News International*, 11 May, 2024, https://www.thenews.com.pk/print/1187754-solar-panel-prices-drop-further-in-pakistan.

47 Alex Blackburne, "World Stuck in Major Solar Panel 'Supply Glut'; Module Prices Plummet: IEA," *S&P Global*, January 12, 2024, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/011224-world-stuck-in-major-solar-panel-supply-glut-module-prices-plummet-iea.

Improvements in efficiency of solar PV panels: The overall conversion efficiency of solar panels has been on the rise, resulting from improvements in solar cell technology and manufacturing processes. One notable advancement, for instance, has been development of passivation techniques to minimise energy losses at the solar cell's surface.[48] As a result of these advancements, the average panel conversion efficiency, over recent years, has risen to over 23% from 15%, increasing the power rating of a standard size panel from 250W to more than 440W.[49] A higher light-to-electricity conversion efficiency of solar panels increases the amount of electricity produced for a similar area,[50] thus shortening the solar payback period or the time the investment takes to break even its cost.

Advances in battery technologies for solar applications: Advancements in solar storage battery technologies are key to increasing solar energy systems' efficiency, scalability, and reliability. Innovations in manufacturing and battery chemistries have reduced the costs of lithium-ion batteries and improved their performance.[51] Sodium-based batteries are also emerging as a promising alternative to traditional lithium-ion batteries as they utilise a less expensive and more abundant resource for energy

48 M. M. Hasan, Shakhawat Hossain, M. Mofijur, Zobaidul Kabir, Irfan Anjum Badruddin et al., "Harnessing Solar Power: A Review of Photovoltaic Innovations, Solar Thermal Systems, and the Dawn of the Energy Storage Solutions," *Energies* 16, no. 8 (2023): 6456, https://doi.org/10.3390/en16186456.

49 Jason Svarc, "Most Efficient Solar Panels 2024," *Clean Energy Reviews*, February 23, 2024, https://www.cleanenergyreviews.info/blog/most-efficient-solar-panels.

50 Pillai, "Drivers of Cost Reduction in Solar Photovoltaics," 287.

51 "A Global Review of Battery Storage: The Fastest Growing Clean Energy Technology Today," *Energy Post*, May 27, 2024, https://energypost.eu/a-global-review-of-battery-storage-the-fastest-growing-clean-energy-technology-today/.

storage, i.e., sodium ions. Moreover, emerging storage technologies, such as flow batteries and hydrogen storage systems, show promising results in enabling large-scale and long-duration solar energy storage.[52] Flow batteries and hydrogen storage systems have longer lifetimes and can store relatively larger amounts of energy than lithium-ion batteries.[53]

Growing possibilities of solar technology utilisation: The evolution of solar technologies is not just improving efficiency of solar energy systems but also expanding the possibilities of solar technology utilisation, particularly at space-constrained sites. For instance, building-integrated photovoltaics (BIPV) is one major solar solution involving PV materials that replace conventional building materials, such as on rooftops, facades, or skylights.[54] Likewise, solar carports are another popular alternative involving ground-mounted solar panels that can be installed in vehicle parking lots, allowing for better land utilisation.[55] Similarly, in the agricultural sector, agrivoltaic systems have emerged as a promising solution. These include PV panels positioned at a height, allowing for regular farming practices to be carried out below. These growing

52 Hasan et al., "Harnessing Solar Power," 15-16.

53 Hasan et al., "Harnessing Solar Power."; Aditi Ambadkar, "What is a Flow Battery: A Comprehensive Guide to Understanding and Implementing Flow Batteries," *Wevolver*, June 23, 2023, https://www.wevolver.com/article/what-is-a-flow-battery-a-comprehensive-guide-to-understanding-and-implementing-flow-batteries.

54 Zuher R. Khalifa Abojela, Mohd Khairunaz Mat Desa and Ahmad H. Sabry, "Current Prospects of Building-Integrated Solar PV Systems and the Application of Bifacial PVS," *Frontiers in Energy Research* 11, (2023), DOI:10.3389/fenrg.2023.1164494.

55 Salman Habib, Muhammad Tamoor, Muhammad Ans Zaka and Youwei Jia, "Assessment and Optimisation of Carport Structures for Photovoltaic Systems: A Path to Sustainable Energy Development," *Energy Conversion and Management* 195, (2023): 117617, https://doi.org/10.1016/j.enconman.2023.117617.

possibilities of solar technology utilisation can enhance the prospects of solar PV uptake.

Reducing subsidies on commercial fuel: The GoP has been phasing out subsidies for commercial fuel in recent years to address the country's mounting fiscal pressure.[56] This inevitably increases the monetary incentive for solar PV adoption, as any decision to consider between renewables and conventional energy sources is influenced by the cost of the latter. Research has repeatedly shown that commercial fuel subsidies slow down uptake of renewable energy by improving the relative cost of traditional energy sources.[57]

Solar support schemes: The federal and provincial governments have announced solar support schemes, specifically for farmers and financially constrained households. Notable among them is the 'CM Punjab Solar Panel' scheme under the *'Roshan Gharana'* programme announced in April 2024, which aimed to provide 50,000 solar panels to users of up to 100 units of power per month.[58] Similarly, the federal and Balochistan governments signed an agreement worth PKR 55 billion in July 2024 to solarise

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56 Rubina Ilyas, Khadim Hussain, Mehreen Zaid Ullah and Jianhong Xue, "Distributional Impact of Phasing Out Residential Electricity Subsidies on Household Welfare," *Energy Policy* 163, (2022): 112825, https://doi.org/10.1016/j.enpol.2022.112825.

57 Richard Bridle and Lucky Kitson, *The Impact of Fossil Fuel Subsidies on Renewable Electricity Generation*, report (Geneva: International Institute for Sustainable Development, 2014), https://www.iisd.org/system/files/publications/impact-fossil-fuel-subsidies-renewable-electricity-generation.pdf.

58 Directorate General Public Relations, "CM Punjab Solar Panel Scheme: A Step Towards Sustainable Energy," June 13, 2024, https://dgpr.punjab.gov.pk/index.php/node/33574.

agricultural tube-wells.[59] Similar schemes have also either been announced or are in the implementation stage.

Prioritisation of sustainability in the global markets: A significant transformation is forthcoming in global trade as countries consider trade instruments to apply a carbon price on imported goods. In this regard, the European Union (EU) has led the way by introducing the first Carbon Border Adjustment Mechanism (CBAM). CBAM is set to be fully integrated with the EU's Emissions Trading System (ETS) by 2026, placing an import tariff on carbon-intensive products from non-EU countries.[60] This implies that exporters from non-EU countries may face increased costs if they do not enhance their carbon efficiency, which will inevitably reduce their competitiveness and profit margins.[61] The mechanism presents an opportunity for the growth of DSEG at the industrial level in non-EU countries, including Pakistan, by providing industries with an impetus to invest in sustainable and cleaner production practices.

Growing stakeholder pressure for Environmental, Social, and Governance (ESG) reporting*:* Stakeholder pressure on companies to report on Environmental, Social, and Governance (ESG) practices has been growing worldwide, including Pakistan.[62] Commitment to sustainable practices is vital for companies to ensure investor confidence, maintain a strong reputation, and build a positive brand

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59 Zulqernain Tahir, "Accord Signed to 'Solarise' Tube Wells in Balochistan," *Dawn*, July 9, 2024, https://www.dawn.com/news/1844774.

60 Rahat Sabyrbekov and Indra Overland, "Small and Large Friends of the EU's Carbon Border Adjustment Mechanism: Which non-EU Countries are Likely to Support It," *Energy Strategy Reviews* 51, (2024): 101303, https://doi.org/10.1016/j.esr.2024.101303.

61 Sabyrbekov and Overland, "Small and Large Friends of the EU's Carbon Border Adjustment Mechanism."

62 Pakistan Stock Exchange Limited, "Environmental Social Governance," Accessed July 31, 2024, https://www.psx.com.pk/psx/environmental-social-governance.

image. This provides a strong imperative for industries to transition to renewable energy as part of their Corporate Social Responsibility (CSR) strategies.

Pakistan's approval for Renewable Energy Certificate (REC) issuance: The Renewable Energy Certificate (REC) is among the major policy instruments that countries have widely adopted to provide market demand for renewable electricity and accelerate the uptake of renewables.[63] In 2022, Pakistan and eight other markets received approval for International-REC (I-REC) issuance.[64] A REC is a 'tradable, non-tangible energy commodity representing proof that 1 MW-hour (MWh) of electricity was generated from renewable sources.'[65] It can be sold through bilateral trades or exchanges and can be a source of additional revenue generation.

Threats

Unstable/uncertain government policies: Previous research has suggested that countries that have experienced rapid growth in solar PV have maintained relatively stable policies.[66] Although Pakistan has implemented incentive policies to promote solar PV uptake, such as removal of GST on imported solar equipment,[67] it needs a better track record of policy consistency and certainty. As a case in point, in 2022, the GoP announced removing 17% GST on imported solar panels, contributing to a reduction in the prices of

63 Qingyuan Zhu, Xifan Chen, Malin Song, Xingchen Li and Zhiyang Shen, "Impact of Renewable Electricity Standard and Renewable Energy Certificates on Renewable Energy Investments And Carbon Emissions," *Journal of Environmental Management* 306, (2022): 114495, https://doi.org/10.1016/j.jenvman.2022.114495.

64 Lotus Shaheen, "Seven I-REC Trends to Watch Out for in 2023," *First Climate*, March 30, 2023, https://www.firstclimate.com/post/7-i-rec-trends-to-watch-out-for-in-2023?lang=en.

65 Zhu et al., "Impact of Renewable Electricity Standard."

66 Wang et al., "Achieving a Sustainable Development Process," 13.

67 Ayub, "PM Removes 17pc GST on Solar Panels."

solar panels. However, days later, the SBP imposed de facto restrictions on the import of solar panels. The restrictions were later removed but, for a time, contributed to shortage and an increase in the prices of solar panels.[68]

Another example relates to the buyback rates for net metered electricity. At the time of writing, net metering users received PKR 21 per unit for the surplus solar electricity fed back into the grid.[69] However, multiple times the government considered slashing solar net metering buyback rates,[70] bringing uncertainty for solar participants. Moreover, at the time of the writing, speculations also existed regarding the government's consideration to potentially transition from net metering to a 'gross metering' system, under which solar energy generated by the end-users will be fed directly into the national grid, and the end-users will then draw electricity solely from the grid.[71]

Currency depreciation: Currency depreciation causes fluctuations in the price of solar equipment, thus posing challenges for advancing solar energy use in Pakistan. The country continues to depend heavily on imported solar equipment and technology to meet domestic demand,[72] particularly from China, due to limited

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68 Mujtaba Raza, "Blunders vis-a-vis Solar Energy," *Dawn*, November 21, 2022, https://www.dawn.com/news/1722214/blunders-vis-a-vis-solar-energy.

69 "Govt Considers Cutting Buyback Rates from Rs 21 to Rs 11/unit for Net-Metering," *Profit*, April 25, 2024, https://profit.pakistantoday.com.pk/2024/04/25/govt-considers-cutting-buyback-rates-from-rs-21-to-rs-11-unit-for-net-metering/.

70 Mushtaq Ghumman, "Net Metering Power: Govt Mulling Bringing Buyback Rates Down to Rs 11/Unit From Rs 21," *Business Recorder*, April 25, 2024, https://www.brecorder.com/news/40300217.

71 "Govt to Shift from Net to Gross Metering for Solar Panels Amid IMF Talks," *Profit*, Accessed August 3, 2024, https://profit.pakistantoday.com.pk/2024/05/19/govt-to-shift-from-net-to-gross-metering-for-solar-panels-amid-imf-talks/.

72 Irfan et al., "Solar Energy Development in Pakistan," 13.

internal supply, although domestic production of these technologies and equipment has been gradually rising.[73] Any notable depreciation of the Pakistani Rupee can affect the progress of solar PV uptake by increasing the cost of imported solar technologies/equipment and reducing the return on solar PV uptake.

Pakistan's growing smog problem: Since the past few years, major Pakistani cities, particularly Lahore and its surroundings, have been experiencing recurring episodes of smog due to industrialisation and traffic pollution, causing smog to be labelled as the country's 'fifth season.'[74] Its intensity is expected to worsen if adequate measures are not implemented. Smog reduces the intensity of sunlight reaching solar panels, impacting the performance of solar energy systems. Research indicates that electricity output loss can reach up to 70% during heavy smog, while light smog can cause losses ranging from 20% to 30%.[75]

Independent Power Producers (IPPs) and capacity payments conundrum: Numerous reports suggest that there remains a persistent uncertainty among policymakers in Pakistan about whether to promote or discourage solarisation.[76] At the root of the uncertainty lies the concern that rapid solarisation is reducing demand for traditional grid-based power, which is increasing the

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73 Syed Akhtar Ali, "Solar PV Indigenisation: Strategy and Scope," *Business Recorder*, August 10, 2022, https://www.brecorder.com/news/40257195.

74 Farah Naz and Abedullah, "Smog: The Fifth Season in Pakistan," *Policy and Research* 3, no.2 (2022), https://pide.org.pk/research/smog-the-fifth-season-in-pakistan/.

75 Wenjun Chen, Mengshi Yang, Sunfang Zhang, Phillip Andrews-Speed and William Li, "What Accounts for China-US Difference in Solar PV Electricity Output? An LMDI Analysis," *Journal of Cleaner Production* 231, (2019): 161-170, https://doi.org/10.1016/j.jclepro.2019.05.207.

76 Shahbaz Rana, "For Fourth time: Govt Stalls Solar Panel Policy," *Express Tribune*, June 23, 2024.

government's burden of idle capacity payments to private Independent Power Producers (IPPs) and the cost of electricity for the consumers. [77] For context, the state's contractual obligations with the IPPs require it to pay them for the entire installed capacity throughout the year, regardless of utilisation.[78] In FY 2025, the per-unit capacity payments have increased to PKR 17.31 per kWh from PKR 16.22 per kWh in FY24.[79] Unless a sustainable solution is implemented, the challenge of burgeoning capacity payments will continue to hinder implementation of stronger incentive policies for solar uptake and cloud the future of solarisation in Pakistan.

Discussion

Recent research has revealed a rise in overall awareness about the benefits of renewables.[80] Of the many means, 'word-of-mouth' has strongly influenced knowledge dissemination about solar PV. Likewise, there is a growing awareness of solar PV energy generation in the agricultural and industrial sectors. However, while awareness about solar PV is becoming more widespread, solar energy generation, including on-site solar generation by end-consumers, remains well below potential and desired levels.

Roger's innovation-decision process suggests that persuasion and decision-making phases that follow the knowledge phase and precede the implementation phase involve meticulous assessment of the relative advantages of adopting a technology by the decision-making unit. During these phases, the decision-making units also

77 "Govt to Shift from Net to Gross Metering for Solar Panels."

78 Fahd Ali and Fatima Beg, "The History of Private Power in Pakistan," (paper, Sustainable Development Policy Institute, Islamabad, 2007), https://sdpi.org/sdpiweb/publications/files/A106-A.pdf.

79 Malik, "IPPs and Capacity Payments.".

80 Abdullah, Deyi Zhou, Tariq Shah, Khalil Jebran, Sajjad Ali et al., "Acceptance and Willingness to Pay for Solar Home System: Survey Evidence from Northern Area of Pakistan," *Energy Reports* 3, (2017): 54-60, http://dx.doi.org/10.1016/j.egyr.2017.03.002.

seek out information very actively. The same applies to the confirmation phase, where technology adopters assess the decision to continue or expand the use of that technology based on whether or not it achieves the expected value. [81] Roger posited that incentives, specifically financial incentives, are key to increasing the relative advantage of a technology and serve as a cue to action. This is also corroborated by studies showing an association between the termination of incentives and a reduction in the adoption of an innovation and vice versa.[82]

The present SWOT analysis findings have highlighted strengths and opportunities to encourage positive attitudes towards adopting distributed solar energy systems. The federal and provincial governments have also introduced a few solar support schemes to boost the renewable energy sector. However, the slower-than-expected growth of solar energy generation[83] suggests that significant challenges and weaknesses must be addressed. Government incentive policies will need to be more robust to encourage greater adoption of distributed solar energy systems. For instance, at the time of this writing, the government was buying a unit of electricity from roof-top solar producers at PKR 22.9 compared to PKR 38.59 from the solar IPPs, and speculations still exist regarding possible reduction of the PKR 22.9 buyback rate.[84]

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81 Lind and Åman, "Diffusion and Adoption of Renewable Energy Products."

82 Genevieve Simpson and Julian Clifton, "Testing Diffusion of Innovations Theory with Data: Financial Incentives, Early Adopters, and Distributed Solar Energy in Australia," *Energy Research and Social Science* 29, (2017): 12-22, http://dx.doi.org/10.1016/j.erss.2017.04.005.

83 Saleh and Upham, "Socio-technical Inertia."; Arif Habib Limited, "Pakistan Power Sector."

84 Bilal Hussain, "Net-metering: Turning Up the Heat on Pakistani People instead of IPPs," *Business Recorder*, May 23, 2024, https://www.brecorder.com/news/40304924.

Major incentive schemes other than net metering are non-existent.[85]

Conclusion and Recommendations

Pakistan possesses substantial solar energy resources, capable of meeting its high energy demand and reducing reliance on fossil fuels, which have dominated the country's energy market for decades. Distributed solar energy generation offers a promising pathway to harness this immense potential. However, the study highlights that developing a robust distributed solar energy market faces several barriers and threats that must be addressed.

Globally, advancements in solar technology and growing manufacturing capacity of firms have been playing a crucial role in increasing the efficiency of solar PV panels and decreasing their costs. Pakistan must seize this opportunity by passing on such benefits to consumers, particularly by reducing the pressure of additional costs on imported hardware for solar PV systems. This can be achieved through strategies including but not limited to streamlining and improving customs procedures and clearances, diversifying the market for imports, addressing economic fundamentals to boost confidence in the PKR with the aim of preventing excessive currency depreciation. The end goal should be to further reduce the costs of solar equipment and technology in the domestic market to mitigate price pressures for the uptake of solar PV systems. In addition, concessionary solar financing ought to be made more accessible to individuals and entities looking to acquire PV systems. Simultaneously, efforts to indigenise quality solar equipment and technology, which are already underway, must be accelerated to reduce excessive

85 Hamza Naeem and Lubna Riaz, "Renewable Energy-Based Distributed Generation in Pakistan: Status, Importance, and Electrification Opportunities," *Policy-Perspectives* 19, no. 1 (2022): 65-84, https://doi.org/10.13169/polipers.19.1.ra3.

dependence on imported technologies as a medium to long-term goal.

It is paramount that domestic policies for the solar sector remain continuous and stable and only adjusted when necessary. Furthermore, investments to enhance grid stability and reliability must be implemented to not merely facilitate solar PV uptake but also disseminate the benefits of distributed solar energy generation to the broader populace by facilitating the export of excess power to the electricity grid. The process of net metering should be made seamless to ensure that a larger number of distributed solar PV systems can be connected to the grid. A debate is ongoing that expediting net metered connections will lead to an additional pricing burden on consumers who do not have net metered systems, as the requirement to pay a large number of solar adopters will reduce the government's revenue generation in the power sector and lead to electricity price hikes to cater to the burgeoning capacity payments burden. While such concerns are valid, the way forward should be to address the root cause of the capacity payments burden rather than slowing down the pace of solarisation. Addressing the capacity payments burden necessitates renegotiating power purchase agreements with the IPPs, conducting a forensic audit of the latter to verify their claims, and transitioning to a competitive electricity market based on market dynamics of supply and demand. Furthermore, export of excess electricity produced by distributed solar energy systems, along with large-scale government-funded solar projects, can also help alleviate, if not wholly address, the adverse impacts of reducing commercial subsidies on non-adopters of solar energy.

In addition, with the increase in overall awareness about the benefits of renewables and the social acceptability of solar energy use, the public must also be encouraged to towards solar PV uptake by transmitting information, including through 'word-of-mouth.' Government and solar industry professionals must also direct efforts towards disseminating technical information for solar

energy use among the population, such as information about routine maintenance, system performance monitoring, and backup power options.

As the global shift toward renewable energy accelerates, Pakistan faces a critical juncture. The country's ability to develop a thriving distributed solar energy market depends on effectively addressing existing weaknesses, such as policy gaps, financial constraints, and infrastructural challenges. Success will require capitalising its abundant solar resources and the growing demand for clean energy while proactively taking advantage of emerging opportunities, such as lowering international costs and technological advancements, to mitigate threats like market volatility and trust barriers. Falling behind in this transition risks exacerbating energy insecurity and economic vulnerabilities.

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