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SMALL HYDROPOWER TOOLKIT: CONSIDERATIONS FOR IMPROVING GLOBAL DEVELOPMENT AND AN ACCOMPANYING CASE STUDY FOR PAKISTAN

Gina S. Warren,[*] Thomas M. Mosier,[**] Kendra V. Sharp[***] &
David F. Hill[****]

ABSTRACT

Approximately 14% of the world's population—1.1 billion people—live without access to electricity, and countless more lack access to *reliable* electricity. This article looks at electrification opportunities via small hydropower strategically placed within rural communities. We approach the challenge through a unique blend of technical feasibility and policy/legal dimensions to create a "toolkit" that promotes small run-of-river hydropower development. Emerging economies can use this toolkit to ensure that the necessary conditions are in place to facilitate successful development. It includes at a minimum: (1) assessment of site-specific hydropower resource potential; (2) a stable and accessible governance structure; and (3) social acceptability of development and an involved local community. Pakistan is used as a case study, because Pakistan is actively seeking to increase its power generation capacity, is rich in hydropower resources, and is in the process of amending its regulatory scheme.

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I. INTRODUCTION

This Article presents an approach to planning and assessing small run-of-river hydropower development that incorporates both physical resource assessment, as well as policy and legal dimensions. Our approach is a "toolkit" that includes both freely available computer models[1] for assessing physical resource potential and an intellectual framework for considering the social and legal policy dimensions influencing the success of small hydropower development. The necessary conditions for small hydro development include, at a minimum, (1) assessment of site-specific physical resource potential within the region of interest; (2) a stable and accessible governance structure; and (3) social acceptability of development and an involved local community. Pakistan is used as a case study for demonstrating application of our Small Hydropower Toolkit because: (a) Pakistan is actively seeking to increase its power generation capacity, (b) is rich in hydropower resources but has limited ground-based data on river flows, (c) its small hydropower regulatory scheme is currently evolving, and (d) it has an opportunity to utilize subsidiarity measures to include local community participation.

We start with an overview of the social and economic benefits of electrification and the opportunities for use of small hydropower in rural electrification. This includes a brief overview of the global potential for small hydropower to meet the need for clean, reliable, and modern electricity. We then discuss our Small Hydropower Toolkit and apply it to Pakistan as a case study. We provide an overview of the Hydropower Potential Assessment Tool (HPAT),[2] which is a numeric model capable of assessing site-specific information to identify sites within regions that are well suited for small hydropower development; through our case study, we illustrate the significant small hydropower potential within the Upper Indus Basin in Pakistan. We identify the minimum social and legal framework needed to support small hydropower development, such as a stable yet flexible regulatory scheme that includes local governance, financial incentives, and community participation. Through our case study, we illustrate its opportunities in Pakistan. Finally, we conclude by offering suggestions for how emerging economies can improve opportunities for successful small hydropower development.

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[1] *See* Or. State Univ., Coll. of Eng'g, *Hydropower Assessment Data*, GLOBAL CLIMATE DATA, http://globalclimatedata.org/node/18 (last visited May 17, 2018) (follow hyperlink, input name and email address and tool will be sent to email address).

[2] *See* Thomas M. Mosier, Kendra V. Sharp & David F. Hill, *The Hydropower Potential Assessment Tool (HPAT): Evaluation of Run-of-River Resource Potential for Any Global Land Area and Application to Falls Creek, Oregon, USA*, 97 RENEWABLE ENERGY 492, 493 (2016).

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II. BACKGROUND

Approximately 14% of the world's population—1.1 billion people—live without access to electricity,[3] with countless more living without access to *reliable* electricity. It is no surprise that in emerging economies, the vast majority of people live without electricity access.[4] In September 2015, the United Nations adopted the Sustainable Development Goals ("SDGs") aimed in part at rectifying this inequity.[5] The SDGs are composed of 17 goals ranging from ending poverty, inequities, and injustices, to addressing climate change and protecting our natural resources by 2030.[6]

In practice, meeting most of the SDGs requires improving access to electricity, and goal seven (7) explicitly seeks to "[e]nsure access to affordable, reliable, sustainable and modern energy for all."[7] Providing electricity access to both urban and rural populations is a moral imperative. Access to affordable, reliable, and sustainable electricity provides a myriad of important social and economic benefits. Specific benefits include:

- decreased mortality rates and negative health impacts from indoor air pollution caused by using wood or other biofuels for cooking;[8]
- improved educational outcomes due to light to study by in the evening;[9]

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[3] INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK 2017 (2017).

[4] *See* INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK 2017 EXECUTIVE SUMMARY 6 (2017) (identifying India, Indonesia, and sub-Saharan Africa as areas with low access to electricity).

[5] *Sustainable Development Goals: 17 Goals to Transform Our World*, UNITED NATIONS, http://www.un.org/sustainabledevelopment/sustainable-development-goals/ (last visited May 10, 2018).

[6] *See id.*

[7] *Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all*, UNITED NATIONS, http://www.un.org/sustainabledevelopment/energy/ (last visited May 10, 2018).

[8] Gina S. Warren, *Small Hydropower, Big Potential: Considerations for Responsible Global Development*, 53 IDAHO L. REV. 149, 161 (2017).

[9] SHAHIDUR R. KHANDKER, DOUGLAS F. BARNES & HUSSAIN A. SAMAD, WORLD BANK, WELFARE IMPACTS OF RURAL ELECTRIFICATION: A CASE STUDY FROM BANGLADESH 22 (2009) [hereinafter KHANDKER ET AL., WELFARE IMPACTS OF RURAL ELECTRIFICATION]; SHAHIDUR R. KHANDKER, HUSSAIN A. SAMAD, RUBABA ALI & DOUGLAS F. BARNES, WORLD BANK, WHO BENEFITS MOST FROM RURAL ELECTRIFICATION? EVIDENCE IN INDIA 14 (2012) [hereinafter KHANDKER ET AL., WHO BENEFITS MOST FROM RURAL ELECTRICIFICATION?]; DEV. PROGRAMME & ENERGY SECTOR MGMT. ASSISTANCE PROGRAM, UNITED NATIONS, RURAL ELECTRIFICATION AND DEVELOPMENT IN THE PHILIPPINES: MEASURING THE SOCIAL AND ECONOMIC BENEFITS 43 (2002) [hereinafter UNDP & ESMAP]; Mathias Gustavsson, *Educational Benefits from Solar Technology—Access to Solar Electric Services and Changes*

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- reduced burdens on women and children from fetching fuelwood and water;[10]
- improved agricultural or enterprise productivity;[11] and
- in some areas, improved access to electronic forms of information that facilitate economic growth.[12]

Electrification has been shown to yield up to a 30% improvement in household income[13] by bringing short- and long-term jobs that increase gross domestic product.[14]

The largest contiguous populations without access to electricity are in portions of Sub-Saharan Africa and Southern Asia (**Figure 1**). This estimate was produced by comparison of stable "night light" data from space and population distribution data, and is in agreement with the International Energy Agency.[15] It is estimated that up to 85% of those still without access are rural populations.[16] Electrification efforts

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in Children's Study Routines, Experiences from Eastern Province Zambia, 35 ENERGY POL'Y 1292 (2007); Makoto Kanagawa & Toshihiko Nakata, *Assessment of Access to Electricity and the Socio-Economic Impacts in Rural Areas of Developing Countries*, 36 ENERGY POL'Y 2016 (2008).

[10] KHANDKER ET AL., WHO BENEFITS MOST FROM RURAL ELECTRIFICATION?, *supra* note 9, at 16; PAUL COOK, RURAL ELECTRIFICATION THROUGH DECENTRALISED OFF-GRID SYSTEMS IN DEVELOPING COUNTRIES 25 (S. Bhattacharyya ed., 2013).

[11] DOUGLAS F. BARNES, THE CHALLENGE OF RURAL ELECTRIFICATION: STRATEGIES FOR DEVELOPING COUNTRIES 7 (2007); COOK, *supra* note 10, at 26; ALEXANDRA NIEZ, INT'L ENERGY AGENCY, COMPARATIVE STUDY ON RURAL ELECTRIFICATION POLICIES IN EMERGING ECONOMIES 13 (Mar. 2010); Charles Kirubi, Arne Jacobson, Daniel M. Kammen & Andrew Mills, *Community-Based Electric Micro-Grids Can Contribute to Rural Development: Evidence from Kenya*, 37 WORLD DEV. 1208 (2009); Maximo Torero, *The Impact of Rural Electrification: Challenges and Ways Forward*, RESEARCHGATE 5 (Nov. 24, 2014), https://www.researchgate.net/publication/269096141_The_Impact_of_Rural_Electrification_Challenges_and_Ways_Forward.

[12] COOK, *supra* note 10, at 27; NIEZ, *supra* note 11; UNDP & ESMAP, *supra* note 9, at 52.

[13] KHANDKER ET AL., WELFARE IMPACTS OF RURAL ELECTRIFICATION, *supra* note 9, at 22–23.

[14] Warren, *supra* note 8, at 160.

[15] *See* INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK 2016 EXECUTIVE SUMMARY 2 (2016); *see also* Ctr. for Int'l Earth Sci. Info. Network, Int'l Food Policy Research Inst. & World Res. Inst., *Gridded Population of the World (GPW), Version 2.0*, COLUM. U. (June 19, 2001), http://www.ciesin.columbia.edu/metadata/sample_record_pprint.html#IDENTIFICATION (providing population distribution data). *See generally* Nat'l Oceanic Atmospheric Admin., *Nighttime Lights Annual Composites V4*, DATA.GOV, https://catalog.data.gov/dataset/nighttime-lights-annual-composites-v4 (last updated Nov. 10, 2015) (providing stable nightlight data).

[16] NIEZ, *supra* note 11, at 12; INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK 2009 (2009).

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since 2000 have largely served urban areas, widening the pre-existing energy poverty divide between urban and rural populations.[17] Furthermore, current electrical grid extension efforts are only targeting about 30% of rural areas that currently lack access.[18]

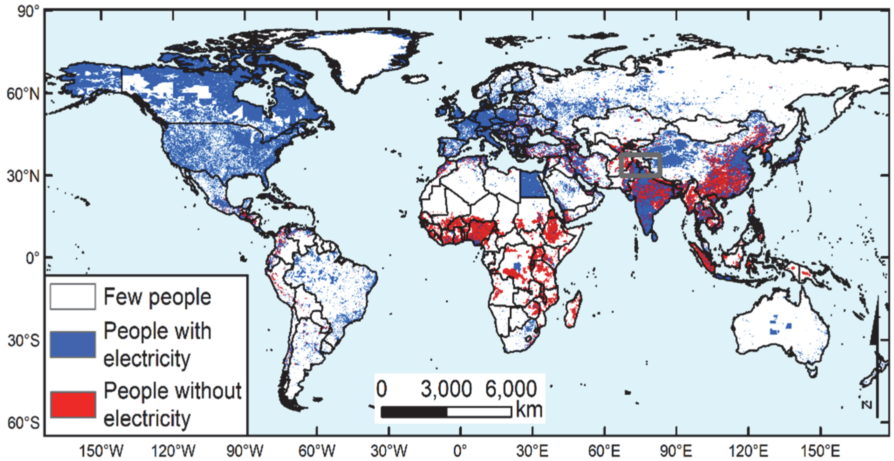

Figure 1: Distribution of people who do and do not have access to electricity. Dark gray rectangle encasing portion of Pakistan and India indicates the Upper Indus Basin (UIB) study region used in the present HPAT demonstration. The classification of few people (white) represents areas where there is no electricity access and 0–24 people per square kilometer. The classification of people without access to electricity (red) represents more populated areas where there is no electricity and 25+ people per square kilometer.

In Pakistan alone (used for the case study), over 140 million people have either no access to a power grid or access is limited to 12 hours of power a day. The overall electricity deficit in Pakistan is on the order of 3-6 GW[19] and at least 45% of the

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[17] *See* DIV. FOR SUSTAINABLE DEV. & DEP'T OF ECON. & SOC. AFFAIRS, UNITED NATIONS, A SURVEY OF INTERNATIONAL ACTIVITIES IN RURAL ENERGY ACCESS AND ELECTRIFICATION (2014).

[18] *See* INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK 2013 (2013).

[19] K. Harijan, Muhammad Aslam Uqaili & Mujeebuddin Memon, *Renewable Energy for Managing Energy Crisis in Pakistan*, *in* WIRELESS NETWORKS, INFORMATION PROCESSING AND SYSTEMS 449, 449 (D.M.A. Hussain et al. eds., 2008); M.J.S. Zuberi, S.Z. Hasany, M.A. Tariq & M. Fahrioglu, *Assessment of Biomass Energy Resources Potential in Pakistan for Power Generation*, RESEARCHGATE 1301 (May 2013), https://www.researchgate.net/profile/Jibran_Zuberi/publication/261348740_Assessment_of_

population is estimated to be without access to *reliable* electricity from either grid or non-grid sources.[20] Rural communities are disproportionally impacted.[21] Despite rich natural resources for hydropower, this energy deficit has led to a national energy crisis.

While there is no "one-size fits all" solution for providing universal access to electricity, the use of renewables in addressing energy needs is growing; renewables are responsible for nearly one-third of new access over the last five years.[22] Further, the use of decentralized sources is projected to be the most cost-effective approach for access by the majority of new rural users through 2030.[23] Though the composition of appropriate solutions is dependent on local contexts, untapped small hydropower potential exists worldwide, and could deliver upwards of 173 GW of new energy globally.[24] In Pakistan specifically, hydropower, in *all* its forms (*i.e.* small and large), has been estimated to have a total potential of over 40 GW, with up to 75% of this potential undeveloped.[25] Currently, Pakistan is estimated to have approximately 128 MW of operational small hydropower with another 877 MW of small hydropower currently being developed.[26]

Nearly 160 countries generate electricity from some form of hydropower, accounting for approximately 16% of the world's electricity generation;[27] however,

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biomass_energy_resources_potential_in_Pakistan_for_power_generation/links/585a35c408aeffd7c4fe2b98/Assessment-of-biomass-energy-resources-potential-in-Pakistan-for-power-generation.pdf.

[20] Nadia Ahmad, *"Turn on the Lights"—Sustainable Energy Investment and Regulatory Policy: Charting the Hydrokinetic Path for Pakistan*, 5 WASH. & LEE J. ENERGY, CLIMATE & ENV'T 165, 172 (2013); Harijan et al., *supra* note 19; Zuberi et al., *supra* note 19.

[21] Ahmad, *supra* note 20.

[22] INT'L ENERGY AGENCY, *supra* note 3.

[23] *Id.*

[24] Warren, *supra* note 8, at 152.

[25] Umar K. Mirza, Nasir Ahmad, Tariq Majeed & Khanji Harijan, *Hydropower Use in Pakistan: Past, Present and Future*, 12 RENEWABLE & SUSTAINABLE ENERGY REV. 1641, 1648 (2008); Afreen Siddiqi, James L. Wescoat, Salal Humair & Khurram Afridi, *An Empirical Analysis of the Hydropower Portfolio in Pakistan*, 50 ENERGY POL'Y 228, 228–29 (2012).

[26] *Potential and Progress in Small Hydropower*, ALTERNATIVE ENERGY DEV. BOARD, http://www.aedb.org/index.php/ae-technologies/small-hydro (last visited May 10, 2018).

[27] *Hydropower*, WORLD ENERGY COUNCIL, https://www.worldenergy.org/data/resources/resource/hydropower/ (last visited May 10, 2018).

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small hydropower only makes up a modest fraction of the current generation.[28] Utilizing small hydropower is particularly important for emerging economies such as Pakistan, where most modern, utility-scale, energy efficient technologies are too costly, and the highest areas of need are too remote to be serviced by the national electricity grid.[29] Many areas currently lacking access to electricity have natural hydropower resources that can be a component of an overall energy solution.[30] Reservoir, run-of-river, and hydro-kinetic hydropower systems are each important and have their own set of strengths. Small and micro-hydropower technologies are particularly useful for micro-grid or stand-alone off-grid applications because they can be less capital intensive and more stable than other renewable sources, such as wind and solar.[31] We therefore focus on small hydropower resources to find solutions for energy access in the rural and remote areas less likely to gain grid access in the coming years.

Several models for estimating small hydropower energy generation potential, development costs, and decision support for infrastructure development have been published recently.[32] Combining information of technical site-specific hydropower and climate data with legal and policy analysis, this article will offer a more holistic approach to developing a Small Hydropower Toolkit for nations looking to incentivize small-scale run-of-river hydropower projects. Pakistan provides a good case study due to its lack of energy supply and increased demand for reliable, cost-efficient electricity production.[33]

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[28] INTERNATIONAL ENERGY AGENCY, *Technology Roadmap: Hydropower* at 15, https://www.iea.org/publications/freepublications/publication/2012_Hydropower_Roadmap.pdf (last visited June 7, 2018).

[29] Abdul Waheed Bhutto, Aqeel Ahmed Bazmi & Gholamreza Zahedi, *Greener Energy: Issues and Challenges for Pakistan-hydel Power Prospective*, 16 RENEWABLE & SUSTAINABLE ENERGY REVIEWS 2732, 2743 (2012).

[30] *Id.*

[31] INT'L CTR. ON SMALL HYDRO POWER, INDUS. DEV. ORG., UNITED NATIONS, WORLD SMALL HYDROPOWER DEVELOPMENT REPORT 2013, at iv (2013).

[32] *See* G.A. Aggidis, E. Luchinskaya, R. Rothschild & D.C. Howard, *The Costs of Small-Scale Hydro Power Production: Impact on the Development of Existing Potential*, 35 RENEWABLE ENERGY 2632 (2010); *see* Claudio J.C. Blanco, Yves Secreten & Andre L. Amarante Mesquita, *Decision Support System for Micro-Hydro Power Plants in the Amazon Region Under a Sustainable Development Perspective*, 12 ENERGY FOR SUSTAINABLE DEV. 25 (2008).

[33] Bhutto et al., *supra* note 29, at 2732.

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III. ASSESSING HYDROPOWER RESOURCE POTENTIAL

A. Overview

As with any investment, stakeholders need confidence in the technical viability and risks associated with the project. In the case of hydropower, this includes understanding the current resource potential and any projected changes that may occur over the lifetime of the project. For hydropower, a significant source of future uncertainty regarding the physical resource potential is impacts from climate change. Since small run-of-river systems have a limited ability to impound water and regulate flows, optimal siting and engineering of these systems requires understanding the possible range of seasonal flow conditions over the design life of the potential investment. This section of this paper discusses the Hydropower Potential Assessment Tool (HPAT), which is a publicly available computer-based model that estimates run-of-river hydropower potential distributed across a region.[34] HPAT is written in Matlab, a numerical computing environment. Two analysis packages, namely: (i) a global climate data downscaling package needed to generate climate inputs for HPAT; and (ii) HPAT itself are freely distributed at www.GlobalClimateData.org. These analysis packages are described in Sections III.B.1 and III.B.2. We demonstrate the application of HPAT through our case study in Pakistan.

Previous studies estimate that there is more than 1 GW of undeveloped small-scale (micro and mini) hydropower in Pakistan, most of it in the mountainous Northern regions.[35] Despite the overall estimates, descriptions of methodologies are too brief to permit independent validation of the spatial distribution of the estimates or rigor of the underlying methodologies. HPAT fills this gap in understanding because it relies on open-source, scientifically rigorous methods and estimates the spatial and seasonal distribution of resource potential within a given region of interest.[36] In previous work, we have demonstrated the use of HPAT for assessing projected climate change impacts at Falls Creek, an existing hydropower facility in Oregon, USA.[37] In this present case study, we demonstrate HPAT by implementing it for the Upper Indus Basin (UIB), which is predominantly within Pakistan and India (**Figure 2**). We chose the UIB for the case study because the region contains a significant number of people who currently lack access to electricity (**Figure 2**), is

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[34] Mosier et al., *supra* note 2, at 493.

[35] Siddiqi et al., *supra* note 25, at 234–35; Munawar A. Sheikh, *Energy and Renewable Energy Scenario of Pakistan*, 14 RENEWABLE ENERGY & SUSTAINABLE ENERGY REV. 354, 359–60 (2010).

[36] *See* Mosier et al., *supra* note 2.

[37] *Id.* at 494.

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extremely mountainous (i.e. has the elevation gradients necessary for hydropower, (**Figure 3**), and possesses significant river flows. Portions of the UIB are also extremely rugged and it would be costly to connect many of the area's communities to the national transmission grid. Therefore, small-hydropower systems connected to micro-grids may serve as a cost-competitive strategy for supplying electricity to many of the remote villages within the region.

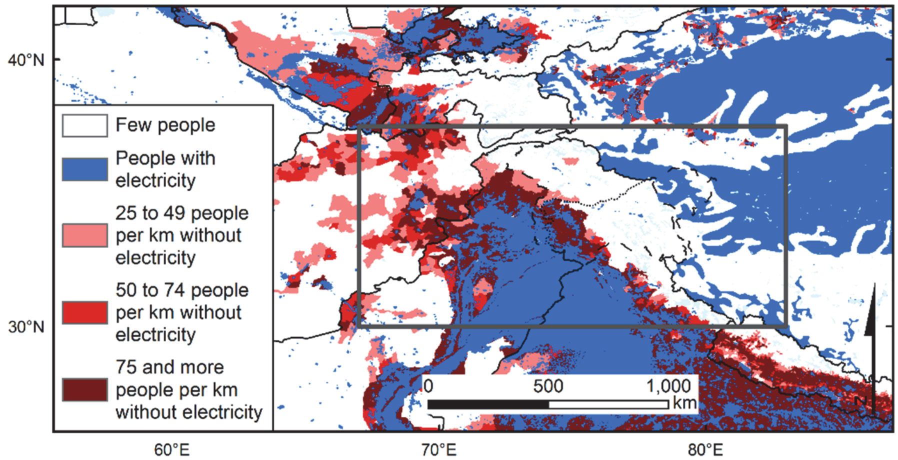

Figure 2: Population density in a portion of Central and South Asia without access to electricity. Dark gray rectangle encasing portion of Pakistan and India indicates the UIB study region used in present HPAT demonstration.

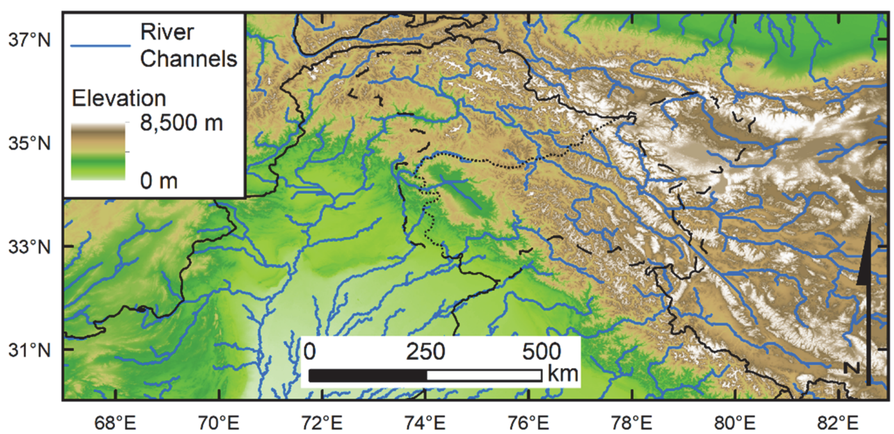

Figure 3: Elevation map of the UIB study region used for demonstrating HPAT (CGIAR, 2014). River channels are approximated based upon the elevation model. Extent of this figure corresponds to the gray box outline in Figure 2.

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B. *Methods*

1. Programmatic Flow of Model

HPAT integrates the sequential implementation of a collection of computer-based models to estimate current and projected future climate conditions (precipitation and temperature), model streamflow throughout the region, and assess the associated run-of-river hydropower potential.[38] As is further detailed in Sections III.B.2–III.B.4, HPAT automatically outputs several diagnostic statistics to assess the average resource potential and its seasonal stability; HPAT can also be programmed to estimate other quantities of interest, such as the portion of the year when river flows are above a given threshold.[39] As demonstrated in this case study, HPAT can also be implemented to assess long-term stability under projected climate change conditions.

The primary inputs to HPAT, as shown in **Figure 4**, are:

> (a) a digital elevation model ("DEM") representing the topography of the study region, effectively an elevation map;
> (b) streamgage data for calibration, typically streamflow measurements taken daily at one or more river or stream locations in the study region; and
> (c) daily or monthly precipitation and temperature estimates over the time period of interest and on a high-resolution spatial grid (usually the spatial grid is 30 arcseconds, which is approximately 1 km at the equator).[40]

Appropriate DEMs (input (a)) are publicly available for all land areas around the globe but must be pre-processed in geographic information system ("GIS") software so that they are suitable for use with the hydrologic model. Ideally, the streamflow observations (input (b)) should include daily measurements and be available for multiple consecutive years. In the demonstration of HPAT for the UIB, we use streamflow observations at four locations within the study domain. The monthly precipitation and temperature time-series data, otherwise referred to herein as high-resolution climate data (input (c)), can be synthesized by accessing publicly-available monthly climate data datasets and processing them using the Global

[38] Mosier et al., *supra* note 2, at 493.

[39] *Id.* at 496, 497, 500.

[40] *Id.* at 493, 494, 495.

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Climate Data ("GCD") package also developed by the authors and available for free online.[41]

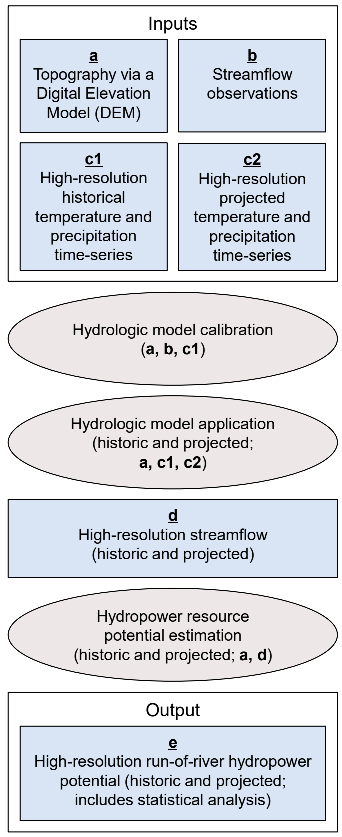

Figure 4: Programmatic flow of the Hydropower Potential Assessment Tool (HPAT). Input and output data are denoted with square boxes and modeling algorithms are denoted with ovals. Lowercase letters are used to identify inputs, and which algorithms utilize them.

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[41] Thomas M. Mosier, David F. Hill & Kendra V. Sharp, *30-Arcsecond Monthly Climate Surfaces with Global Land Coverage*, 34 INT'L J. CLIMATOLOGY 2175 (2014) [hereinafter Mosier et al., *30-Arcsecond*]; Thomas M. Mosier, David F. Hill & Kendra V. Sharp, *Update to the Global Climate Data Package: Analysis of Empirical Bias Correction Methods in the Context of Producing Very High Resolution Climate Projections*, 38 INT'L J. CLIMATOLOGY 825, 825–40 (2017) [hereinafter Mosier et al., *Update to the Global Climate Data Package*].

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Once the input data have been gathered and provided to HPAT (top row of **Figure 4**), HPAT uses a hydrologic model to simulate streamflow in the study region based on the inputs.[42] Note that the conversion of precipitation and temperature inputs (inputs (b1 and b2)) into either historic or projected future streamflow estimates through application of the hydrologic model *does* depend on physical parameters in the study area; input (c) of calibration data helps account for study area-specific physical characteristics. Once the streamflow estimates have been output from the hydrologic model for the region of interest, they can be combined with elevation and slope information from the DEM (input (a)) and HPAT can estimate the relationship between streamflow and run-of-river hydropower resource potential.[43] These steps can be carried out with equal ease for a single location (*e.g.*, modeling the watershed upstream of an existing penstock), or for a large region, such as the UIB region that we use in this demonstration case study.

A detailed description of HPAT methodology is provided in previous work.[44] In the present article, we provide only a brief overview. Section II.B.2 outlines the sources of input data that we utilize, Section II.B.3 summarizes the hydrologic model, and Section II.B.4 explains how hydropower potential is estimated based on information about topography and streamflow.

2. Case Study Input Data

HPAT can accept a variety of input data formats for each of the required input data types (a, b, or c). The examples provided here are not exhaustive but are representative of the recommended data characteristics and sources.

Topography (input a): We use a DEM generated from measurements taken during the Shuttle Radar Topography Mission (SRTM).[45] This DEM provides elevation data at a spatial resolution of 30 arcseconds, which corresponds to a spacing of approximately 1 km at the equator.[46] Thirty arcseconds is a commonly used spatial resolution for analyses of regional-scale water resources.

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[42] Mosier et al., *supra* note 2, at 495, 496.

[43] Mosier et al., *supra* note 2, at 496.

[44] *See id.* at 494–97.

[45] *See generally* A. Jarvis, H.I. Reuter, A. Nelson & E. Guevara, *SRTM 90m Digital Elevation Database v4.*, CIGAR-CSI (2007), http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1.

[46] GLOBAL CLIMATE DATA, *supra* note 1.

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Calibration Data (input b): Before applying HPAT to the entire UIB (the area shown in **Figure 3**) we calibrate and validate the hydrologic model contained within HPAT by applying it to four test sites—Donyian, Hunza, Karora, and Naltar—that are in the UIB (**Figure 5**). Daily streamgage observations for 2000–2015 at these four sites are used for calibration. The calibration procedure is built into HPAT and described in previous work.[47]

Historic Climate (input c1): We synthesize high-resolution monthly time-series of precipitation and temperature using the GCD modeling package, which requires selecting two types of input climate data sources. We cannot use these input climate data sources *directly* because one has a sufficient monthly time-resolution, but too low of a spatial resolution (~55 km), and the other has sufficient spatial resolution (~1 km) but too low of a time-resolution. Our GCD package effectively combines the two input types, producing a data series with sufficient monthly time-resolution and sufficient spatial resolution (~1 km) for any global land area.[48] The two historical climate data sources used here are time-series data from the Climate Research Unit ("CRU")[49] and climate averages from WorldClim[50] as described in detail in previous work.[51] We produce the historic baseline climate data for the years 1986 through 2015.

The specific climate variables that can be estimated with our GCD package are precipitation, mean temperature, minimum temperature, and maximum temperature. The strength of the GCD package is that it is easy to implement for any global land area. In certain circumstances, daily climate time-series would be preferred over GCD's monthly information.[52] For example, daily data can provide greater insight into the timing and magnitude of extreme events. However, one of the tradeoffs is that, in many regions where reliable on-the-ground observations and data are

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[47] *See* Thomas M. Mosier et al., *How Much Cryosphere Model Complexity Is Just Right? Exploration Using the Conceptual Cryosphere Hydrology Framework*, 10 CRYOSPHERE 2147, 2158 (2014); Mosier et al., *supra* note 2, at 494.

[48] Mosier et al., *30-Arcsecond*, *supra* note 41.

[49] *See* I. Harris, P.D. Jones, T.J. Osborn & D.H. Lister, *Updated High-Resolution Grids of Monthly Climatic Observation—the CRU TS3.10 Dataset*, 34 INT'L J. CLIMATOLOGY 623 (2014).

[50] *See* Robert J. Hijmans, Susan E. Cameron, Juan L. Parra, Peter G. Jones & Andy Jarvis, *Very High Resolution Interpolated Climate Surfaces for Global Land Areas*, 25 INT'L J. CLIMATOLOGY 1965 (2005).

[51] Mosier et al., *30-Arcsecond*, *supra* note 41, at 2176.

[52] Mosier et al., *30-Arcsecond*, *supra* note 41; Mosier et al., *Update to the Global Climate Data Package*, *supra* note 41.

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relatively sparse (*e.g.*, the UIB), daily weather values are often more uncertain than monthly weather values.

Projected (Future) Climate (input c2): Many regions where significant hydropower potential exists receive extensive snowfall, and some regions (including the UIB) additionally receive glacier melt. There is strong consensus between climate models that temperatures are increasing and will continue to increase over the lifetime of installed hydropower assets. These temperature increases will impact the seasonal storage of water as snow and the timing of streamflow. Therefore, in regions such as the UIB where snowfall impacts hydropower potential, it is valuable to assess how changes in snowpack and glacier melt will impact both yearly total hydropower potential and its seasonality. We incorporate an analysis of projected future impacts on hydropower through consideration of projected precipitation and temperature changes projected by climate models. We note that precipitation projections are much less certain than temperature projections. Thus, the primary result of climate change analysis for precipitation projections is to add uncertainty to projected hydropower potential.

Climate models are the primary tool used to project and understand long-term changes in the climate. They are typically run at very low spatial resolutions (approximately 100–300 km).[53] The GCD package is designed to bias correct and downscale these climate model simulations to the same 30-arcsecond resolution spatial grid as the historic climate data.[54] Climate models are run for multiple scenarios to estimate the climatic response to different anthropogenic greenhouse gas emissions trajectories. Each scenario in the Coupled Model Intercomparison Project Phase 5 is described by a Representative Concentration Pathway (RCP).[55] Two commonly used scenarios are RCPs 4.5 and 8.5, which correspond to approximately 2.0 and 2.5°C of global annual average warming by 2050 relative to pre-industrial levels.[56] RCP 4.5 describes a scenario in which some collective action is taken to limit emissions, while RCP 8.5 is more consistent with a "business as usual" scenario.

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[53] DATA DISTRIBUTION CENTRE, *Frequently Asked Questions, Intergovernmental Panel on Climate Change*, http://www.ipcc-data.org/ddc_faqs.html (last visited June 16, 2018).

[54] Mosier et al., *Update to the Global Climate Data Package*, *supra* note 41.

[55] Karl E. Taylor, Ronald J. Stouffer & Gerald A. Meehl, *An Overview of CMIP5 and the Experiment Design*, 93 BULL. AM. METEOROLOGICAL SOC'Y 485, 488 (2012).

[56] IPCC WORKING GROUP I, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (Thomas F. Stocker et al. eds., 2013).

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Typically, an ensemble of climate models run by different research groups is used to estimate the range of uncertainty in future conditions. For example, our previous work[57] uses models from six different research groups with contrasting representations of historic climate.[58] Here, for illustrative purposes we use simulation output for RCP 4.5 for the years 2036 through 2065 from a single climate model, CESM-CAM5.[59]

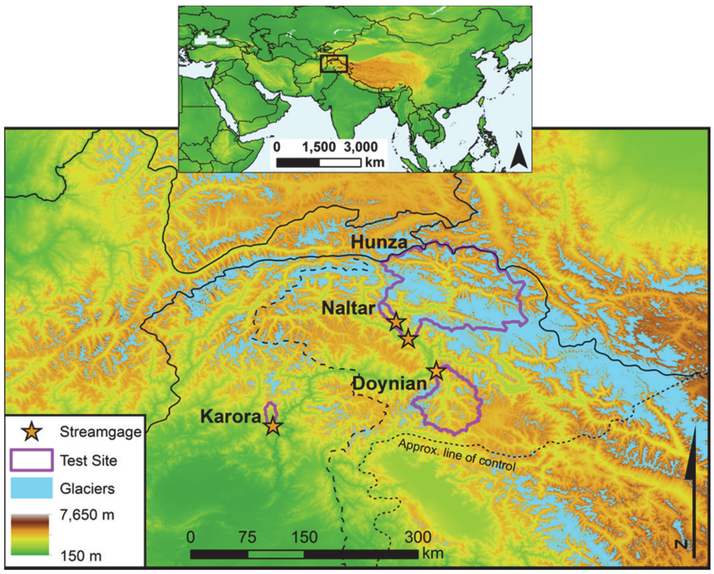

Figure 5: Hydrologic model calibration sites in the UIB.

3. Hydrologic Model

Hydrologic models are scientific models used to understand, evaluate, and predict water resources. In our case, the hydrologic model serves as the link between climate data (precipitation and temperature) and streamflow estimates. Our hydrologic model must be calibrated using on-the-ground streamflow data measured

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[57] Mosier et al., *supra* note 2, at 498.

[58] J. Adler, S. Hostetler & D. Williams, *An Interactive Web Application for Visualizing Climate Data*, 94 EOS, TRANSACTIONS, AM. GEOPHYSICAL UNION, May 28, 2013, at 197.

[59] *See generally* James W. Hurrell et al., *The Community Earth System Model: A Framework for Collaborative Research*, 94 BULL. AM. METEOROLOGICAL SOC'Y 1339 (2013).

in the region of interest; such a calibration is one way of accounting for the physical characteristics that influence the hydrologic cycle and water balance in the system.

The hydrologic model integrated with HPAT was developed specifically for use in data-sparse regions.[60] Other more sophisticated hydrologic models[61] are often used when the physical characteristics of a system are well-measured and well-defined; however, by design, ours can be used to link the climate data to streamflow estimates even when the availability of physical characterization of the environment is more sparse, as is common in lower-resource regions.

Our hydrologic model is based on the Conceptual Cryosphere Hydrology Framework (CCHF).[62] The default version of our hydrologic model implemented in HPAT models snow persistence and melt—important physical phenomena in our case study—by characterizing snowmelt as a function of temperature.[63] Our model also accounts for water contributions from glacier melt. We use a relatively standard "bucket model" formulation to represent the infiltration of water into the ground and subsequent release of water into the stream channel.[64]

The default hydrologic model formulation in HPAT contains seven parameters that are optimized during calibration using deterministic methods.[65] In this demonstration, we calibrate these parameters by simultaneously implementing the hydrologic model for four small, gaged water catchments within the UIB (**Figure**

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[60] Mosier et al., *supra* note 2, at 495.

[61] *See* N.S. Arnold, I.C. Willis, M.J. Sharp, K.S. Richards & W.J. Lawson, *A Distributed Surface Energy-Balance Model for Small Valley Glacier. I. Development and Testing for Haut Glacier d'Arolla, Valais, Switzerland*, 42 J. GLACIOLOGY 77 (1996); *see* Regine Hock & Björn Holmgren, *A Distributed Surface Energy-Balance Model for Complex Topography and its Application to Storglaciären, Sweden*, 51 J. GLACIOLOGY 25 (2005); *see* Andrew H. MacDougall & Gwenn E. Flowers, *Spatial and Temporal Transferability of a Distributed Energy-Balance Glacier Melt Model*, 24 J. CLIMATE 1480 (2010).

[62] *See generally* Thomas M. Mosier, David F. Hill & Kendra V. Sharp, *How Much Cryosphere Model Complexity is Just Right? Exploration Using the Conceptual Cryosphere Hydrology Framework*, 10 THE CRYOSPHERE 2147 (2016).

[63] Mosier et al., *supra* note 2, at 495.

[64] *See generally* R.D. Moore, J.W. Trubilowicz & J.M. Buttle, *Prediction of Streamflow Regime and Annual Runoff for Ungauged Basins Using a Distributed Monthly Water Balance Model*, 48 J. AM. WATER RESOURCES ASS'N 32 (2012).

[65] *See* SØREN ASMUSSEN & PETER W. GLYNN, STOCHASTIC SIMULATION: ALGORITHMS AND ANALYSIS (B. Rozovskii et al. eds., 2007); *see* Riccardo Poli, James Kennedy & Tim Blackwell, *Particle Swarm Optimization: An Overview*, 1 SWARM INTELLIGENCE 33 (2007).

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5).[66] The benefit of concurrent calibration for multiple sites is that it ensures that the model parameters are representative of average conditions across the domain.

4. Hydropower Estimation

The simulated streamflow produced by the calibrated hydrologic model is combined with elevation information to estimate run-of-river hydropower potential. Statistics of interest can be estimated for each spatial grid cell (approximately 1 km)

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[66] HPAT's performance relies on the underlying performance of the various integrated models, such as the accuracy of the climate data and hydrologic model. As discussed in Sections III.B.2 and III.B.3, the hydrologic model must be calibrated to capture location-specific physical characteristics that influence physical processes in the hydrologic cycle and water balance. The Kling Gupta Efficiency (KGE) was used to define the objective function for calibrating the hydrologic model and assessing model performance. *See* Hoshin V. Gupta, Harald Kling, Koray K. Yilmaz & Guillermo F. Martinez, *Decomposition of the Mean Squared Error and NSE Performance Criteria: Implications for Improving Hydrological Modelling*, 377 J. HYDROLOGY 80 (2009). Although there is no precise threshold for determining what constitutes "acceptable" hydrologic model performance, a well-performing model in mountain regions should typically have a KGE value of 0.2 or greater—depending on the property being assessed—with a value of one indicating no error. Therefore, the hydrologic model used for demonstration purposes only performs to a reasonable standard for the Karora and Naltar test sites. There are several straightforward changes to the model implementation that would likely improve model performance considerably across the group of test sites, including using alternative sources of climate data and different hydrologic model parameterizations. In particular, the climate data used here have a monthly time-step, which is done for computational efficiency; however, daily climate data would be better able to represent mountain weather conditions and hydrology.

Table: KGE values for HPAT calibration at the four UIB test sites (Figure 5).

Region	Donyian	Hunza	Karora	Naltar
KGE value	0.13	0.03	0.32	0.72

For this demonstration of HPAT, we used CRU time-series data and WorldClim high-resolution reference climatologies downscaled with the GCD package as our source of climate information inputs as described in Sec III.B.1 and III.B.2. It has been shown, though, that time-series climate data from CRU considerably underestimates the amount of precipitation in the Himalaya. *See* W.W. Immerzeel, N. Wanders, A.F. Lutz, J.M. Shea & M.F.P. Bierkens, *Reconciling High-Altitude Precipitation in the Upper Indus Basin with Glacier Mass Balances and Runoff*, 19 HYDROLOGY & EARTH SYS. SCI. 4673 (2015). Other climate models, such as ERA Interim, better reproduce the historic patterns of precipitation over the UIB. Therefore, a more accurate representation of climate would likely be possible with alternative climate data sources.

Further, the simple degree index model we used to relate snow storage and melt performs well when calibrated for single catchments, but does not perform well across multiple catchments. *See* Mosier et al., *supra* note 47. Instead, a more sophisticated representation of snow storage and melt within the hydrologic model would be more suitable for large study domains such as the UIB. *Id.* More sophisticated snow process parameterizations would represent melt as a function of not just temperature but also shortwave solar radiation, and they would use a more complex representation for snow internal energy.

in the implementation region for the period of interest.[67] Statistics for the historic period can be compared to those for climate change projection scenarios to estimate projected changes and associated uncertainties.

C. *Results and Discussion: Applying the Hydropower Assessment Tool (HPAT) in Pakistan*

The results presented here are designed to demonstrate the potential utility of HPAT in evaluating run-of-river hydropower potential over a very large region. The demonstration includes conceptually representative analyses of long-term historic and climate change conditions. The presented results are not intended for operational use, but to simply illustrate the analysis workflow. For illustrative purposes, we use one climate model to project future conditions; in operational analysis, it is necessary to use a large ensemble of climate models (typically between six and twelve) that represent the uncertainty range of possible future climate conditions. For example, our previous work includes a full climate change impact assessment study that utilizes six climate models for two climate scenarios.[68] Then, historic hydropower potential estimates for the region are presented in Section III.C.1. Finally, the illustrative climate change analysis is summarized in Section III.C.2.

1. Historic Hydropower Estimates

For the baseline simulation presented here, HPAT outputs estimates of monthly average streamflow at the model spatial resolution of approximately 1 km (exactly 30 arcseconds) for 1986–2015. Run-of-river hydropower potential is then estimated from these streamflow grids.[69] The two main outputs presented here are power stability and power quality.[70]

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[67] The basic run-of-river hydropower potential formulation is $P_{x,y} = \eta\, H_{x,y}\, \dot{V}_{x,y}\, \rho\, g$ (Eq. 1) where $P_{x,y}$ is the power potential at grid cell x,y (units of Watts), η is an efficiency parameter (unitless), $H_{x,y}$ is the change in elevation across the grid cell (units of meters), $\dot{V}_{x,y}$ is the volumetric flow rate within the grid cell (units of meters cubed per second), ρ is the density of water (units of kilograms per meters cubed), and g is gravitational acceleration (units of kilograms per meters squared).

Stability of the hydropower potential throughout the year is also an important determinant of the quality of a site for hydropower development. We estimate the hydropower stability using a metric that we refer to simply as the "stability metric" *SM*. Mosier et al., *supra* note 2, at 496. A perfect *SM* score is one, which only occurs if all months have equal power. The worst case is represented by an *SM* of zero, which occurs when all of the power is generated in a single month. We then define "power quality," *PQ*, in each grid cell as the product of the amount of power (Eq. 1) and the stability metric, thus $PQ_{x,y} = P_{x,y} * SM_{x,y}$ (Eq. 2) where $P_{x,y}$ refers to Eq. 1 and $SM_{x,y}$ is the stability metric as described in previous work. *Id.*

[68] Mosier et al., *supra* note 2.

[69] *See supra* note 67 for equations.

[70] *Id.*

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Power stability is close to zero for most of the high elevation portions of the UIB (meaning that all the power is delivered in a single month) and increases to approximately 0.9 (representing good stability throughout the year) in the flow channels at lower elevations (**Figure 6**). Low power stability at higher elevations is expected because the temperature at these locations is below freezing for the majority of the year and there is less liquid water for driving hydropower installations. At the lower elevations that lie within the flow channel, the portion of the flow derived from rainfall is higher relative to snowmelt. Additionally, the streamflow in the lower portions of the UIB integrates the runoff occurring throughout the region, which has the tendency to smooth the streamflow.

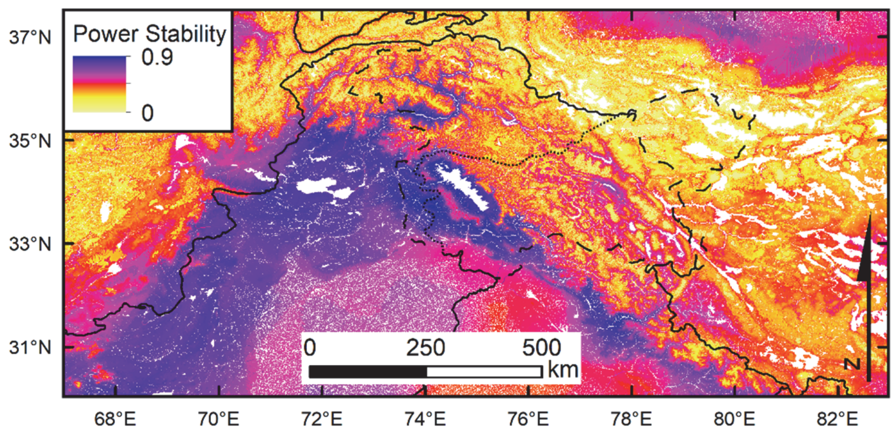

Figure 6: Power stability (Eq. 4) for the UIB from 1986–2015.

As formulated here, the power quality is calculated[71] through multiplying the power potential by the stability metric.[72] Thus, high power quality tends to indicate both high stability and high potential; however, it is possible for one of the two factors to dominate in the power quality calculation. For the UIB, we normalize the power quality values to a representative scale of 1–4, where a value of 4 indicates the best run-of-river hydropower potential quality **(Figure 7)**.

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[71] *See supra* note 67 for equations.

[72] Mosier et al., *supra* note 2, at 500.

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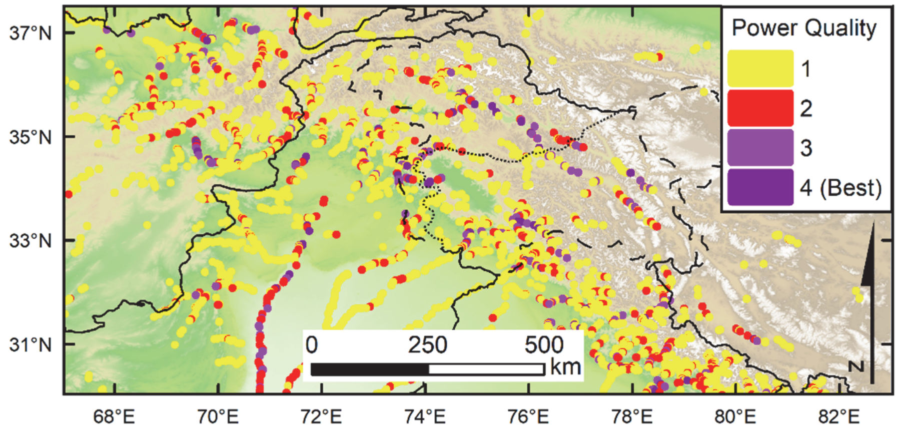

Figure 7: Normalized power quality (Eq. 2) for the UIB from 1986–2015.

One utility of the HPAT methodology is that it allows hydropower potential to be evaluated simultaneously over a large geographic area. An advantage of such a methodology is that it facilitates bundling of many small-scale hydropower projects, which then become easier for developers to package and pursue.

Historic hydropower potential alone may not be the only criteria by which a developer chooses to invest in hydropower. For example, given the long design life of hydropower systems, impacts of climate change may need to be considered. Additionally, depending on the type of project, local customers, transmission infrastructure, and legal issues will also be important. Based on the precise needs of a project, different types of analyses can be conducted using either the default or customized output from HPAT. For example, it may be useful to overlay the power quality estimates (**Figure 7**) with auxiliary information such as the density of people without access to electricity (**Figure 2**). A strength of HPAT is that because the code is open-source, it is relatively straightforward to design and implement specific analyses to meet the needs of a given project.

2. Assessing Potential Impacts of Climate Change

For the illustrative climate projection simulation, HPAT outputs estimates of monthly average streamflow at the model spatial resolution of approximately 1 km (exactly 30 arcseconds) for 2036–2065. The illustrative climate change simulation corresponds to a moderate climate warming scenario. The HPAT output is processed using the same statistics as in the historic baseline case (Section III.C.1) to allow a direct comparison. In this demonstration, climate change uncertainty is not considered; however, it is imperative that an operational study does assess the uncertainty in the HPAT projection results.

Climate change analysis can reveal how both the annual magnitude and stability of hydropower potential is likely to change. For example, if a large percentage of annual streamflow tends to occur during a short period due to rapid snowpack melt, increased temperatures can actually increase the seasonal stability.[73] This feature of increased seasonal stability under a warming climate is present in the UIB for the elevation band at the base of the mountainous areas (compare climate change simulation results in Figure 8 to elevation in **Figure 3**).

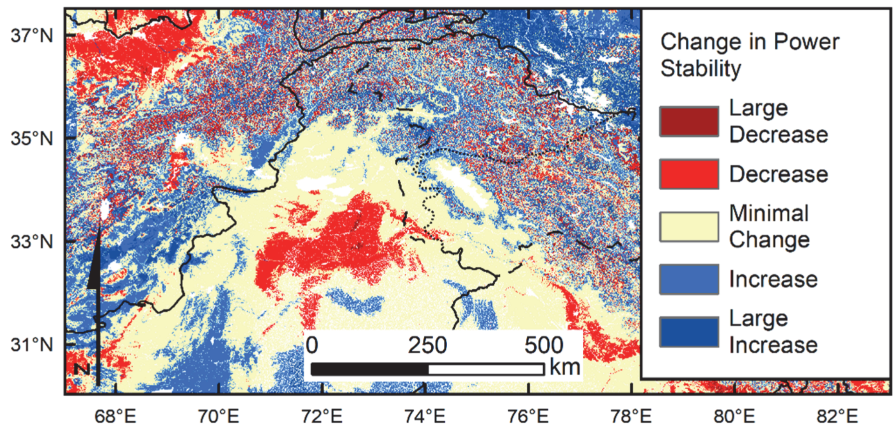

Figure 8: Projected change in power stability (Eq. 1).[74] Change is calculated relative to values for the historic period (Figure 6).

Changes in power quality vary from location to location in the UIB under the demonstration scenario (Figure 9), reflecting changes to either the total annual power potential, or the seasonal stability, or both. Increases in annual streamflow are expected under a near-term warming climate scenario (such as the one used) because the UIB receives a substantial portion of its melt from glaciers, and increased temperatures will enhance glacier melt.[75] The demonstration results are also illustrative, though, that these general trends in climate change impacts on hydropower quality do not apply to equally all locations within the UIB (**Figure 9**). This reinforces the potential investment and operational benefits of including climate change analysis into the siting of small hydropower generation assets.

[73] *Id.* at 496.

[74] *See supra* note 67 for equations.

[75] A.F. Lutz, W.W. Immerzeel, P.D.A. Kraaijenbrink, A.B. Shrestha & M.F.P. Bierkens, *Climate Change Impacts on the Upper Indus Hydrology: Sources, Shifts and Extremes*, PLOS ONE 2 (Nov. 9, 2016), https://doi.org/10.1371/journal.pone.0165630; A.F. Lutz W.W. Immerzeel, A.B. Shrestha & M.F.P. Bierkens, *Consistent Increase in High Asia's Runoff Due to Increasing Glacier Melt and Precipitation*, 4 NATURE CLIMATE CHANGE 2 (2014).

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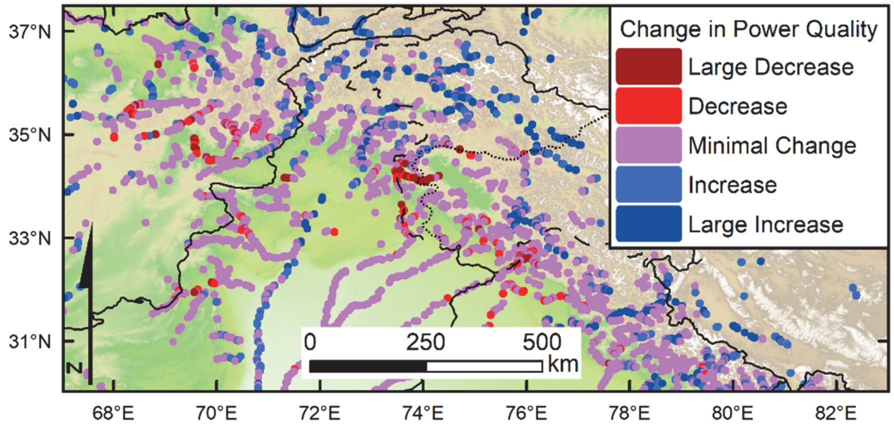

Figure 9: Projected change in power quality (Eq. 2).[76] Change is calculated relative to values for the historic period (Figure 7).

D. Conclusions: Assessing Hydropower Resource Potential

HPAT is designed to identify the distribution of run-of-river hydropower resource potential within a given region of investigation (*e.g.*, **Figure 6-Figure 7**) or at a specific site.[77] The tools allow many types of analyses to be conducted, including estimating monthly time-series of streamflow, average hydropower potential, seasonal and interannual variability, and impacts of climate change. The default HPAT settings are easy to implement for any global land area where streamflow observations are available for calibration. The specific model configuration and implementation can be tailored to individual projects, however, depending on the project needs, geography and hydrology of the region, and data availability.

The UIB is extremely large and remote, highlighting the global applicability of HPAT. Further, the UIB contains immense hydropower resource potential, and a large deficit in the current supply of electricity. As seen in **Figure 7**, HPAT makes it easy to simultaneously identify multiple potential run-of-river hydropower sites within a target area. This provides greater economies of scale for investments, potentially increasing the viability of small-scale infrastructure projects through bundling of multiple small generation asset investments. While hydropower alone cannot meet the growing demand for power globally, it can be a significant part of the solution. We believe HPAT and similar tools can be leveraged to help realize this international hydropower potential.

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[76] *See supra* note 67 for equations.

[77] Mosier et al., *supra* note 2.

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IV. SOCIAL AND LEGAL POLICY CONSIDERATIONS

After identifying the availability of small hydropower resources, the next step is to identify the social and legal policy considerations that will allow for development within hydropower rich areas. This section focuses on the social and legal policy considerations necessary for successful small hydropower development, which requires at a minimum: (1) stable, local, and flexible local licensing policies; (2) tariff designs that incentivize investment; and (3) an educated and knowledgeable local community. For each section (IV.A–IV.D), we begin with general legal and policy considerations, then illustrate analysis of these considerations through examination of the energy policies in our case study focus country, Pakistan. This is followed by a discussion of opportunities for improvements to Pakistan's existing legal structure and recommendations for increased local research and development, worker education, and public participation in the process.

A. Stable, Local, and Flexible Hydropower Licensing Scheme

Overly complex national (top-down) licensing schemes can inhibit small hydropower investment. If the costs of licensing outweigh the potential local benefits, investors will look to other projects that are less complex, costly, and time-consuming. One way to prevent the significant costs and time-delay of small hydropower licensing is to delegate the licensing and permitting processes to local government authorities. This is particularly important due to the distributed nature of small hydropower, where local communities receive the benefit and local communities have the greatest interest in developing small renewable resources within their borders.

In previous work, we have embraced subsidiarity and discussed the benefits of local governance and control of small hydropower facilities.[78] Subsidiarity is the theory that the most efficient regulatory body should be the least or lowest centralized authority capable of undertaking the licensing and regulatory process.[79] Localizing licensing responsibilities can be a beneficial means of ensuring that the project is developed expeditiously, and is economically and environmentally viable. This structure empowers local communities to harness sustainable electricity while

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[78] *See, e.g.*, Gina S. Warren, *Hydropower: It's a Small World After All*, 91 NEB. L. REV. 925, 969 (2013) [hereinafter Warren, *Hydropower: It's a Small World*]; Gina S. Warren, *Hydropower: Time For a Small Makeover*, 24 IND. INT'L & COMP. L. REV 249, 258 (2014); Warren, *supra* note 8, at 174.

[79] *See generally* Paolo G. Carozza, *Subsidiarity as a Structural Principle of International Human Rights Law* 97 AM. J. INT'L L. 38, 38–79 (2003) (discussing subsidiarity as an important factor of human rights law).

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protecting their natural and environmental resources. It also makes for a more streamlined "one-stop" process, which provides stability and reassures investors.[80] This form of subsidiarity, however, requires that local governments have competency in the tools and financial resources available for implementation. Local agencies must have the tools and financial resources to develop and implement licensing schemes that are simple, transparent, and encourage local public participation.

Pakistan is a country where small hydropower licensing is left mostly to provinces and local policymakers, while conventional hydropower licensing remains with the federal government.[81] When Pakistan became an independent country in 1947, it only had 60 MW of hydropower generation capacity, which was linked to a few small hydropower facilities.[82] In the last several decades, Pakistan has installed approximately 6,618 MW of hydropower—mostly in the northern part of the country—only 253 MW of that total have been small to micro plants.[83]

The Federal Ministry of Water and Power is Pakistan's executive agency head for all issues relating to power from generation to distribution.[84] It formulates policy incentives and establishes plans for the nation's power sector.[85] It is also the liaison to provincial governments.[86] Within the Ministry is the Alternative Energy Development Board (AEDB), which was established in May 2003 to facilitate the development of renewable energy by implementing policies and programs, encouraging indigenous technology manufacturing, and undertaking commercial scale projects.[87] The overarching goal is to achieve 5% renewable power generation

[80] INT'L CTR. ON SMALL HYDRO POWER, INDUS. DEV. ORG., UNITED NATIONS, WORLD SMALL HYDROPOWER DEVELOPMENT REPORT 2016 EXECUTIVE SUMMARY 36 (2016).

[81] Shah Jahan Mirza, *Overview of Pakistan Power Sector*, ISLAMIC MARKETS (Sept. 30, 2015), https://www.islamicbanker.com/publications/overview-of-pakistan-power-sector.

[82] Bhutto et al., *supra* note 29, at 2738.

[83] *Id.*

[84] GOV'T OF PAK., POLICY FOR DEVELOPMENT OF RENEWABLE ENERGY FOR POWER GENERATION: EMPLOYING SMALL HYDRO, WIND, AND SOLAR TECHNOLOGIES 1 (2006).

[85] *Id.*

[86] *Id.*

[87] *About AEDB*, ALTERNATIVE ENERGY DEV. BOARD, http://www.aedb.org/index.php/ae-technologies/biomass-waste-to-energy/53-about-aedbwww.aedb.org (last visited May 10, 2018). *See also Potential and Progress in Small Hydropower*, ALTERNATIVE ENERGY DEV. BOARD, http://www.aedb.org/index.php/ae-technologies/small-hydro (last visited May 25, 2018).

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by 2030.[88] The AEDB also has a rural electrification program with the goal of providing renewable electricity to nearly 8,000 remote villages in Sindh and Balochistan.[89]

The AEDB's website refers to two documents for small hydropower development:[90] the first is a model Implementation Agreement between Pakistan and the private investor;[91] the second is a model Energy Purchase Agreement between Pakistan's distribution companies and the private investor.[92] However, neither of these agreements appear to be specifically restricted to small hydropower. They appear instead to be general hydropower agreements for any size facility.

National Electric Power Regulatory Authority (NEPRA) was established by the 1997 Pakistan Regulation of Generation, Transmission and Distribution of Electric Power Act.[93] It issues licenses for, regulates, and determines rates for generation, transmission, and distribution of electric power.[94] As will be discussed *infra*, NEPRA has recently experimented with tariff design intended to promote nation-wide small hydropower development (as well as wind and solar development).[95]

Since 2002, provincial governments have been involved in implementing renewable energy projects—including small hydropower projects of less than 50 MW within their geographic boundaries.[96] Each province has an Irrigation and Power (I&P) Department that manages water resources for agriculture and small

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[88] *About AEDB*, *supra* note 87.

[89] *Id.*

[90] *EPA & IA Documents*, ALTERNATIVE ENERGY DEV. BOARD, http://www.aedb.org/index.php/component/judownload/28-epa-ia-documents (last visited May 10, 2018).

[91] ALT. ENERGY DEV. BD, MINISTRY OF ENERGY, IMPLEMENTATION AGREEMENT RELATING TO A MW (NET) HYDRO-ELECTRIC POWER GENERATION COMPLEX (2016), http://www.aedb.org/component/judownload/28-epa-ia-documents/78-implementation-agreement?Itemid=101.

[92] ALT. ENERGY DEV. BD, MINISTRY OF ENERGY, ENERGY PURCHASE AGREEMENT RELATING TO A MW (NET) HYDRO-ELECTRIC POWER GENERATION COMPLEX (2016), http://www.aedb.org/component/judownload/28-epa-ia-documents/77-energy-purchase-agreement-epa?Itemid=101.

[93] NAT'L ELEC. POWER REG. AUTH., NOTIFICATION 1 (2015), http://www.nepra.org.pk/Legislation/Regulations/NOTIFICATION%20SRO%20892%20-2015.PDF.

[94] *Id.*

[95] *See infra* text accompanying notes 124–33.

[96] PRIVATE POWER & INFRASTRUCTURE BD., MINISTRY OF ENERGY, POLICY FOR POWER GENERATION PROJECTS YEAR 2002, at 22 (2002).

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hydropower generating units.[97] The role of the province is to expedite and facilitate renewable energy development through permitting, educational promotion of renewable energy use, and allocation of land use rights.[98]

Local provinces also have a voice in larger projects through the Private Power Infrastructure Board (PPIB) of the Ministry of Water & Power, which is made up of representatives from the provinces and facilitates conventional private sector hydropower projects of more than 50 MW capacity.[99] PPIB has obtained around $9.4 billion in investment from international and local investors and lenders.[100] In August 2010, the PPIB issued a set of guidelines for private power investors.[101] These guidelines are intended to inform on all aspects of private power development including finance, insurance, installation, testing, owning, operating, and maintaining power generation facilities within Pakistan.[102] It sets forth some of the steps, though with little detail, in receiving approval for a proposed project. The typical timeline is 40 months from submission to receipt of final approval.[103] Thereafter, operations are required to commence within 24 and 33 months, depending on the circumstances.[104] The guidelines, while helpful for large projects, are not applicable for small projects less than 50 MW.

Pakistan's Water and Power Development Authority (WAPDA) was created in 1958.[105] It was one of two original vertically-integrated, government-owned utilities (WAPDA and KESC).[106] WAPDA plays the lead role in implementing Pakistan's

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[97] GOV'T OF PAK., POLICY FOR DEVELOPMENT OF RENEWABLE ENERGY FOR POWER GENERATION: EMPLOYING SMALL HYDRO, WIND, AND SOLAR TECHNOLOGIES 2 (2006).

[98] *Id.* at 2–3.

[99] *Private Power and Infrastructure Board*, GOV'T PAK, http://www.ppib.gov.pk/ (last visited May 25, 2018).

[100] *Id.*

[101] PRIVATE POWER & INFRASTRUCTURE BD., MINISTRY OF ENERGY, GUIDELINES FOR SETTING UP OF PRIVATE POWER PROJECTS (2010).

[102] *Id.* at 1.

[103] *Id.* at 3–4.

[104] *Id.* at 3.

[105] *Introduction to WAPDA*, PAK. WATER & POWER DEV. AUTHORITY, http://www.wapda.gov.pk/index.php/about-us/present-setup-2 (last visited May 10, 2018).

[106] *An Overview of Electricity Sector in Pakistan*, ISLAMABAD CHAMBER COM. & INDUS. 4, http://icci.com.pk/data/downloads/63/1293619048_1.pdf (last visited May 25, 2018).

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water and power policies because it owns and manages the majority of Pakistan's existing hydropower and it is still the country's largest electricity producer.[107] WAPDA is known for its 2001 Water Vision 2025 program with a goal of generating 16,000 MW of hydroelectricity by 2025, mostly by developing large conventional hydropower dams.[108]

In addition to the Water Vision 2025, Pakistan has announced several energy policies through the years including 1994, 1998 and 2002 power policies and the 1995 Hydel Power Policy, which have sought to increase demand for hydropower and to attract private foreign investors.[109] Most recently, the Ministry of Water and Power announced the 2013 National Power Policy.[110] The policy sets forth several goals, including "Ensur[ing] the generation of inexpensive and affordable electricity for domestic, commercial, and industrial use by using indigenous resources such as coal (Thar coal) and hydel."[111] Pakistan has one of the largest coal reserves in the world (about 175bn tons of coal reserves that were discovered in Thar, 400 km east of Karachi),[112] and Pakistan has been working with China to build large coal facilities.[113] This decision has been met with international and local concern, but as of the writing of this article, the two countries appear to be moving forward with the $50bn-plus China-Pakistan Economic Corridor plan.[114] On the other side of the coin

[107] *See Power Wing*, PAK. WATER & POWER DEV. AUTHORITY, http://www.wapda.gov.pk/index.php/about-us/wapda-as-an-organization/power-wing (last visited May 25, 2018).

[108] *See The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of Gaps and Recommendations for Action* 141 (last visited June 11, 2018), http://www.pk.undp.org/content/dam/pakistan/docs/Environment%20&%20Climate%20Change/Report.pdf ("WAPDA has been working on an ambitious plan called the National Water Resources and Hydropower Development Programme Vision 2025 with the goal to develop 16,000 MW of hydropower capacity.").

[109] Bhutto et al., *supra* note 29, at 2740.

[110] GOV'T OF PAK., NATIONAL POWER POLICY 2013 (2013).

[111] *Id.* at 4.

[112] *See, e.g.*, *Coal in Pakistan*, WORLD ENERGY COUNCIL, https://www.worldenergy.org/data/resources/country/pakistan/coal/ (last visited May 25, 2018).

[113] Saleem Shaikh & Sughra Tunio, *Pakistan Ramps Up Coal Power with Chinese-Backed Plants*, REUTERS (May 2, 2017), https://www.reuters.com/article/us-pakistan-energy-coal/pakistan-ramps-up-coal-power-with-chinese-backed-plants-idUSKBN17Z019.

[114] *See id.*

is the goal of increasing hydropower potential. Several projects have begun with a goal of adding 1,900 MW of medium-sized hydropower generation.[115]

One opportunity for Pakistan is for local provinces to work through the I&P Department to issue a set of guidelines for small hydropower development, similar to the PPIB-issued guidelines for large hydropower, to encourage small hydropower private power investment. As noted above, the I&P Department manages local water resources within the province and has a stated goal of facilitating renewable energy development, including small hydropower. This is also important because many canals currently used solely for water irrigation could be powered with little to no negative impacts on agriculture or the environment. Further, given that it already has an established structure, the I&P Department could issue guidelines for small hydropower development like those issued by the PPIB for large hydropower development. The PPIB has been successful in garnering significant international investment, and provinces should establish a local committee to follow its lead. These guidelines should inform all aspects of licensing and development, including the fees, process, consultation requirements, grid connection agreements, and a development timeline. Unlike large hydropower that can take up to 40 months for final approval,[116] small hydropower should have shortened timeframes akin to those of solar and wind projects that typically only take 18–24 months from submission to completion.[117]

B. *Rate Design to Incentivize Investment*

The capital cost of small hydropower projects depends on a lot of factors, including location, equipment imports, and administrative costs for licensing and permitting. However, it is estimated that small hydropower can generally cost between $1.0–1.4 million per MW, with payback occurring within 5–7 years.[118] Micro-hydro utilizing imported turbines of up to 50kW can cost between $500–1,000 per kW (*i.e.* $0.5–1.0 million per MW).[119] As will be discussed in greater detail

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[115] GOV'T OF PAK., *supra* note 110.

[116] PRIVATE POWER & INFRASTRUCTURE BD., MINISTRY OF ENERGY, GUIDELINES FOR SETTING UP OF PRIVATE POWER PROJECTS 4 (2010).

[117] Warren, *Hydropower: It's a Small World*, *supra* note 78, at 968.

[118] Bhutto et al., *supra* note 29, at 2742.

[119] *Id.* at 2743.

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below, facilities using locally manufactured turbines can be between $170–250 per kW.[120]

With capital costs in the millions, rate design is an important aspect of incentivizing small hydropower development. Stakeholders need some level of assurance that they will receive a return on their investment.[121] Otherwise, they will choose a different product in which to invest. For small hydropower, this generally means a government incentive (such as some form of tax break), but it could also mean the assurance that they will recover their costs through reasonable rates charged to the end consumer. While all business investment contains some level of risk, small hydropower should not be disadvantaged by a poor tariff design. Local governments can encourage reasonable returns on investments by adopting rate designs that are commensurate with the costs of the project, whether through private contracts or through regulated rates.

Consumer rates for electricity in Pakistan have historically been artificially low, with the government subsidizing utilities to help incentivize investment. These power generation subsidies are the fourth biggest federal governmental expense.[122] Due to the magnitude of the expense, the government has set the subsidies too low for many utilities to fully recover their investments.[123] As a result, utilities have not had the capital or incentives to continue upgrading and investing in new electricity generation assets.

In 2013, NEPRA sought to nationally even out some of these costs by raising tariffs rates for commercial and industrial customers by 44% and for residential customers by 32% (except for the poorest quintile).[124] The government had hoped that the increased tariffs would reduce the demand-supply gap through incentivizing private investment, providing capital for utilities to become more efficient, and

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[120] *Id.*

[121] INT'L CTR. ON SMALL HYDRO POWER, *supra* note 80.

[122] RASHIN AZIZ & MUNAWAR BASEER AHMAD, U.S. INST. OF PEACE, PAKISTAN'S POWER CRISIS THE WAY FORWARD 3 (2015).

[123] *Id.* at 1.

[124] *Id.* at 11–12.

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encouraging utilities to utilize a larger portion of their installed generation capacity.[125]

In April 2015, NEPRA gave small hydropower (with generation capacity of up to 25 MW) an additional incentive by issuing a new tariff determination.[126] Projects with installed capacity of less than 25 MW could opt in to this new tariff design, but they were required to do so by March 27, 2018.[127] The stated goal of the new tariff was: "[to] simplify[] the tariff process, provid[e] certainty to the potential investors, fast track[] the development of commercially attractive small hydropower sites, allow[] material risk coverage to the investor, that were already available to them under the cost plus tariff regime and incentiviz[e] early commissioning of hydropower projects."[128]

The new tariff design provides multiple incentives, including rates of return equal to or better than Thar coal, insurance, carbon credits, simplifying the tariff process, and loan incentives.[129] Pakistan's incentive rate allows for a 20% return on equity.[130] NEPRA also allows qualifying small hydropower facilities (with generation capacity of up to 50 MW) to sell electricity to either the central power agency or to a local distribution company so as to maximize renewable energy into the grid.[131]

It is too early to tell the extent to which NEPRA's 2015 tariff determination has helped incentivize investment by ensuring a reasonable rate of return and access to the grid through centralized or distributed energy companies. As of April 2017, only

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[125] *Id.* at 12–14; Kwon Gi Mun, Raza Rafique & Yao Zhao, Designing Hydro Supply Chains for Water, Food, Energy and Flood Nexus (Apr. 27, 2016) (unpublished manuscript) (https://ssrn.com/abstract=2771519).

[126] NAT'L ELEC. POWER REGULATORY AUTH., DETERMINATION OF NATIONAL ELECTRIC POWER REGULATORY AUTHORITY IN THE MATTER OF UPFRONT TARIFF FOR SMALL HYDRO POWER GENERATION PROJECTS UPTO 25 MW INSTALLED CAPACITY 1–2 (2015).

[127] The original deadline was March 27, 2017. NAT'L ELEC. POWER REGULATORY AUTH., DECISION OF THE AUTHORITY IN THE MATTER OF UPFRONT TARIFF FOR SMALL HYDRO POWER GENERATION PROJECTS UP TO 25 MW INSTALLED CAPACITY—EXTENSION OF DATE OF ACCEPTANCE OF UPFRONT TARIFF 1–2 (2017).

[128] NAT'L ELEC. POWER REGULATORY AUTH., *supra* note 126.

[129] *Id.* at 41–42.

[130] NAT'L ELEC. POWER REGULATORY AUTH., ANNUAL REPORT 2015–16, at 26 (2016).

[131] NAT'L ELEC. POWER REGULATORY AUTH., *supra* note 126, at 38.

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two public hydropower projects and one private project had been approved for the new tariff,[132] while several other projects were still in the application process.[133]

Recent economic research highlights the financial incentive challenges for small hydro in developing countries.[134] In Thailand, for example, researchers conclude that hydropower must have a rate of return of at least 12% over a 25-year period to incentivize investment.[135] Pakistan's 20% incentive tariff is far above that recommendation; however, to date, only a handful of small hydro investors have taken advantage of it. In contrast, incentive rates for wind and solar projects in Pakistan are at 17% and do appear to have spurred investment.[136] As of 2016, Pakistan added 50 MW of wind power and 300 MW of solar.[137] While it is beyond the scope of this article to draft a rate tariff that would sufficiently incentivize small hydropower, one thing is certain—rates need to be set at a level sufficient for

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[132] Tariff determinations were issued for Olympus Energy (Private) Limited (20 MW), Punjab Power Development Company Limited (PPDCL)—Deg-Outfall HPP (4.04 MW) and Alka Power Private Limited (1.8 MW). NAT'L ELEC. POWER REGULATORY AUTH., *supra* note 126. *See also* NAT'L ELEC. POWER REGULATORY AUTH., DECISION OF THE AUTHORITY IN THE MATTER OF UPFRONT TARIFF FOR SMALL HYDRO POWER GENERATION PROJECTS UP TO 25 MW INSTALLED CAPACITY—EXTENSION OF DATE OF ACCEPTANCE OF UPFRONT TARIFF (2017). One project is referred to in NEPRA's State of Industry Report 2016. NAT'L ELEC. POWER REGULATORY AUTH., STATE OF INDUSTRY REPORT 2016, at 78 (2017) [hereinafter STATE OF INDUSTRY REPORT 2016] ("Alka Power (Pvt.) Limited having installed capacity of 1.8 MW, applied for approval of upfront tariff for HPP. The Authority processed the application of Alka Power (Pvt.) Limited under the upfront tariff regime and granted an upfront tariff of US cents 10.9163/kWh.").

[133] NAT'L ELEC. POWER REGULATORY AUTH., *supra* note 127. Tariff petitions filed by Punjab Power Development Company Limited—Chianwali HPP (5.38 MW) and Kandiah Hydropower (Private) Limited (5.45 MW) are under process.

[134] *See* Helene Ahlborg & Martin Sjöstedt, *Small-Scale Hydropower in Africa: Socio-Technical Designs for Renewable Energy in Tanzanian Villages*, 5 ENERGY RES. & SOC. SCI. 20 (2015); Rakhshanda Khan, *Small Hydropower in India: Is it a Sustainable Business?*, 152 APPLIED ENERGY 207 (2015); Mukesh Kumar Mishra, Nilay Khare & Alka Bani Agrawal, *Small Hydro Power in India: Current Status and Future Perspectives*, 51 RENEWABLE & SUSTAINABLE ENERGY REV. 101 (2015); Ameesh Kumar Sharma & N.S. Thakur, *Assessing the Impact of Small Hydropower Projects in Jammu and Kashmir: A Study From North-Western Himalayan Region of India*, 80 RENEWABLE & SUSTAINABLE ENERGY REV. 679 (2017); Thanaporn Supriyaslip, Montchai Pinitjitsamut, Kobkiat Pongput, Apinya Wanaset, Suree Boonyanupong, Saksri Rakthai & Thana Boonyasirikul, *A Challenge of Incentive for Small Hydropower Commercial Investment in Thailand*, 111 RENEWABLE ENERGY 861 (2017); Nor F. Yah, Ahmed N. Oumer & Mat S. Idris, *Small-Scale Hydro-Power as a Source of Renewable Energy in Malaysia: A Review*, 72 RENEWABLE & SUSTAINABLE ENERGY REV. 228 (2017).

[135] Supriyaslip et al., *supra* note 134, at 868.

[136] NAT'L ELEC. POWER REGULATORY AUTH., *supra* note 126, at 27.

[137] STATE OF INDUSTRY REPORT 2016, *supra* note 132, at 25.

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investors to receive a return on investment that is equal to or greater than other forms of electricity generation, including wind and solar.[138]

NEPRA has also approved net metering for customers generating their own renewable energy, which means that customers will only get billed for their net electricity used at the end of the month.[139] The AEDB has held net metering workshops and issued roadmaps for investors; in January 2017, it issued net metering guidelines for connecting solar energy systems to the national grid.[140] The guidelines are intended for all sizes of solar energy systems (including commercial grade); however, they emphasize Pakistan's goal of promoting investment in small-scale, renewable, distributed generation.[141] While net metering is helpful for incorporating consumer generated solar and wind, access to consumer-generated hydropower can be more complicated and would be more likely to occur with community or cooperative ownership of small hydropower facilities.

C. Local Participation and Knowledgeable Workers

Successful local governance and regulation of small hydropower requires knowledgeable local workers as well as community participation and support.[142] Strong community participation and use of local knowledge will result in local social, economic, and environmental benefits. Public participation generally includes transparent sharing of information, the opportunity for public hearings or comments, and some level of consultation with impacted communities. Scholars from Thailand performed a study to determine whether local public participation in Thailand would provide benefits to small hydropower development.[143] They found in part that planners need a "working knowledge of how a community operates before being able to effectively plan development," and that projects will generally be more successful where the benefits and costs are transparently relayed early in the planning process,

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[138] *Id.*

[139] Khaleeq Kiani, *Nepra to Promote Power Generation by Consumers*, DAWN (Sept. 4, 2015), https://www.dawn.com/news/1204847.

[140] MASOUD WAHID, AEDB, NET-METERING REFERENCE GUIDE FOR ELECTRICITY CONSUMER: HOW TO GET YOUR SOLAR SYSTEM CONNECTED TO NATIONAL GRID IN PAKISTAN 1 (2017).

[141] *Id.*

[142] Nadia Ahmad & Mushtaq ur Rasool Bilal, *Monsoons, Hydropower, and Climate Justice in Pakistan's River Communities*, *in* CLIMATE JUST.: CASE STUDIES IN GLOBAL AND REGIONAL GOVERNANCE CHALLENGES 471 (Randall S. Abate ed., 2016).

[143] Pannathat Rojanamon, Taweep Chaisomphob & Thawilwadee Bureekul, *Public Participation in Development of Small Infrastructure Projects*, 20 SUSTAINABLE DEV. 320, 320 (2012).

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and community members have an opportunity to collaborate and comment.[144] They also found that local regulators should facilitate transparent exchanges of information early in the licensing process to encourage community involvement in small hydropower development.

In addition to the benefits of public participation, the use of local resources (materials, labor and knowledge) can significantly reduce project costs. Locally manufactured turbines, local engineers and advisors decrease the cost of development and provide services to ensure quality design, control, and management of the projects. The price differential can be significant. By some estimates, the use of local resources can decrease the cost for micro hydro projects (with a generation capacity of up to 50 kW) from $500–1,000 per kW to $170–250 per kW.[145] Further, our research shows that a lack of qualified, educated, and knowledgeable workers can be a hindrance for the installation and maintenance of hydropower projects.[146]

The province of Khyber Pakhtunkhwa, located in northwest Pakistan, provides a poignant example of the linkages between hydropower development and the need for a knowledgeable local labor force. In 2016, the province of Khyber Pakhtunkhwa completed 37 community-based micro hydro projects with a total capacity of 2MW.[147] It plans to further construct approximately 350 micro plants over the next several years to reach a total installed capacity of 35 MW.[148] It also plans to build nearly 600 distributed micro hydro projects (generation capacity of 50–150 kW) for remote areas located off the main electrical grid.[149] The province's reasoning for

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[144] *Id.* at 321, 332.

[145] Bhutto et al., *supra* note 29, at 2743.

[146] *See infra* notes 147–63; *see also* RUPERT MACLEAN, SHANTI JAGANNATHAN & BRAJESH PANTH, EDUCATION AND SKILLS FOR INCLUSIVE GROWTH, GREEN JOBS AND THE GREENING OF ECONOMIES IN ASIA 7 (2017) (discussing how "skills shortages for green jobs could thwart government efforts toward green growth and targeted environmental outcomes"); *see also* NORM BISHOP ET AL., NEW PATHWAYS FOR HYDROPOWER: GETTING HYDROPOWER BUILT—WHAT DOES IT TAKE? 28–30 (2015) (discussing general need for educated workforce for hydropower); *see also* HANS HARTUNG ET AL., ADVANCED SCOPING FOR TECHNICAL CAPACITY BUILDING ON SMALL HYDROPOWER IN EAST AFRICA 16–18 (discussing lack of educated workers in East Africa).

[147] Gregory B. Poindexter, *Pakistan Brings Micro-Hydroelectric Projects Online*, HYDROWORLD.COM (May 16, 2016), http://www.hydroworld.com/articles/2016/05/pakistan-brings-micro-hydroelectric-projects-online.html.

[148] *Id.*

[149] Michael Harris, *Interest High in Pakistani Technical School's New Small Hydropower Program*, HYDROWORLD.COM (Jan. 27, 2016), http://www.hydroworld.com/articles/2016/01/interest-high-in-pakistani-technical-school-s-new-small-hydropower-program.html. The total estimated cost of

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investing in small hydropower was to increase the stability of their power supply.[150] The province cited a lack of qualified workers as one impediment to the successful implementation of their small hydropower development plan.[151] The province therefore established a technical and vocational training program (The Technical Education and Vocational Training Authority) to provide training and jobs in the small hydropower sector.[152] This training program was financed with the assistance from the European Union, German government, and the Dutch and Norwegian embassies.[153]

Equally important is research and development for small hydropower technologies. The Pakistan Council of Renewable Energy Technologies (PCRET) coordinates research and development for renewable energy technologies.[154] It has been working on micro hydropower with a focus on promoting micro hydro plans in isolated rural areas.[155] PCRET recognizes that areas far from the national grid are especially susceptible to environmental degradation and so research and education has been dedicated to sustainable development.[156] Thus far, PCRET has facilitated the installation of 538 micro-hydro plants with a consolidated installed capacity of 8 MW.[157] Nearly half of the plants have been installed through public sector and community development, as well as various governmental and nongovernmental organizations. PCRET promotes significant community participation in all phases of the project planning, and once built, the plants are operated and maintained by the

construction for these projections is approximately $82.3 million, which is funded through Pakistan's Hydel Development Funds. Poindexter, *supra* note 147.

150 Poindexter, *supra* note 147.

151 Harris, *supra* note 149.

152 *Id.*

153 *Id.*

154 *Welcome to Pakistan Council of Renewable Energy Technologies (PCRET)*, PAK. COUNCIL OF RENEWABLE ENERGY TECH., http://www.pcret.gov.pk/index.html (last visited May 25, 2018).

155 Jawwad Rizvi, *Demystifying Pakistan's Energy Crisis*, MIT TECH. REV. PAK., http://www.technologyreview.pk/demystifying-pakistans-energy-crisis/ (last visited May 25, 2018).

156 *Welcome to Pakistan Council of Renewable Energy Technologies (PCRET)*, *supra* note 154.

157 Rizvi, *supra* note 155.

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communities.[158] The communities, through Local Management Committees, generate tariffs for the power use and collect customer payments.[159]

As noted above, lack of educated and knowledgeable employees and researchers is a hindrance to development. To facilitate the availability of knowledgeable local workers, provinces could consider establishing vocational and technical training for local community members interested in entering the energy workforce. By establishing a training program, like that in Khyber Pakhtunkhwa, provinces can promote a knowledgeable workforce to outside hydropower investors and provide short- and long-term jobs to the local community.

Another great example of this is the Barefoot College model established by Bunker Roy in India in 1972.[160] Barefoot College is an innovative educational movement where only the rural poor can enroll and learn how to become experts in water, electricity, housing, health, and education. Women—mostly grandmothers—from 83 countries in Asia, Africa, and Latin America have been trained to build, install, and maintain solar facilities.[161] They even take responsibility for collecting fees in their communities.[162] According to the college's website, the women are responsible for installing solar systems to power more than 18,000 households, and have avoided some 4,020 grams of harmful carbon emissions by displacing kerosene as a source of light, heat, and cooking.[163]

D. Conclusions: Social and Legal Policy Dimensions

As discussed above,[164] the minimum social and legal framework needed to support small hydropower development includes a stable, yet flexible, information driven regulatory framework that allows local communities to govern their own small-scale renewable energy to the extent possible.

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[158] *Id.*

[159] *Id.*

[160] *Built by the poor, for the poor*, BAREFOOT C., https://www.barefootcollege.org/about/ (last visited May 10, 2018).

[161] *A Story of Impact*, BAREFOOT C., https://www.barefootcollege.org/solution/solar/#stats (last visited May 10, 2018).

[162] *Id.*

[163] *Id.*

[164] *See supra* text accompanying notes 142–46.

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Pakistan is in the middle of an energy crisis. It does not have enough power to meet its current demand, let alone to electrify rural areas that have historically been too remote to be included in the national grid. Pakistan has identified hydropower as a viable energy source to fill the demand gap. It has significant small hydropower potential and has prioritized hydropower development with new policies aimed at increasing incentives and reducing risk of investment in conventional hydropower. Further, small hydropower has been mostly left to the provinces to develop. This local control can be beneficial in helping to expedite licensing decisions by providing early identification of local environmental or social concerns, encouraging local participation, and facilitating local employment. However, provinces cannot take advantage of these opportunities without adequate financial resources, which will most likely need to come from international investors.

We recommend the creation of a single local agency to oversee the entire licensing process for small hydropower. As discussed,[165] local control can be beneficial in helping to expedite licensing decisions, by providing early identification of local environmental or social concerns, by encouraging local participation, and by facilitating local employment. The licensing scheme should be transparent and stable, but flexible to the local needs. Toward that end, each province should create a set of clear guidelines to facilitate small hydropower development within its borders. This will allow a streamlined, one-stop process that will provide private investors with some assurances of a stable licensing structure so that the time commitment and costs of small hydropower licensing do not outweigh its benefits. Further, rates must be sufficient to recoup the capital costs of investment within a reasonable period. The risk of investment should be abated by reasonable rate design and financing and incentive structures. Provinces should develop well-defined opportunities to facilitate successful investment return.

Finally, small hydropower investors need community support and participation, as well as a knowledgeable workforce. This community involvement and use of local resources will help promote small hydropower development by decreasing social anxieties and environmental concerns, decreasing overall project costs, and increasing local job opportunities. Investors will seek to invest in local communities that show competence for constructing, maintaining, and operating small hydropower facilities.

V. OVERALL CONCLUSION

Over a billion people globally live without access to electricity, and countless more live without access to clean, reliable, and affordable electricity. While there is

[165] *See supra* text accompanying notes 142–46.

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no easy solution to this inequity, small hydropower development can be a viable option to increase electrification in many rural areas. Many hydropower generation assets provide a more stable source of electricity than other intermittent renewable energy resources. Hydropower can be clean, reliable, and cost-efficient. As set forth in this paper, certain conditions are important for successful development of small hydropower. Our Small Hydropower Toolkit is intended to aid in this regard by setting forth the minimum conditions for successful development: (1) technical, site-specific data; (2) a stable, yet flexible regulatory scheme with incentives for investment; and (3) an educated and involved community and workforce.

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