Collaborative Research for the Development of Localized Solar PV Output Forecasting Models for the Philippines Using Geospatial Data

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Abstract

This paper presents a collaborative effort to develop localized solar photovoltaic (PV) power output (PPV) forecasting models for the Philippines using geospatial data. It underlines the importance of solar energy in the country and discusses the opportunities and challenges associated with PPV forecasting. Project SINAG, a two-year research project, aimed to develop solar PV output forecasting models through a collaborative approach with academic institutions, solar energy industries, and government agencies. Actual PPV data from 43 solar PV installations were analyzed alongside meteorological data from the PAGASA weather bureau, ERA5, AHI-8, and FY-4A. These datasets were filtered based on a one-year period to ensure quality. The study employed SARIMAX, LSTM, and XGBoost models individually and in hybrid models to develop the forecasting models. Model performance was evaluated using root mean square error (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE). In a case study in Baguio City, the SARIMAX model exhibited strong seasonal dependence, providing more accurate forecasts in dry seasons than in wet seasons. Additionally, the forecasting accuracy of each model (SARIMAX, LSTM, and XGBoost) varied based on the month and location of the installation, emphasizing the need for local and season-based PPV forecasting models. Despite implementation challenges, such as collaboration arrangements, bureaucratic barriers, and budget constraints, the project produced thirteen research publications and provided data for three student theses. This paper also demonstrated diverse engagements and contributions that emphasize the significance of collaborative research in conducting nationwide-scale data-driven projects.

1. Introduction

1.1 Solar PV in the Philippines

The Philippines ranked fourth in the most attractive emerging markets for power sector investments and sixteenth in the global power ranking (Maria Eugênia Machado Mitri et al., 2023), with solar energy capacity additions exceeding 2030 targets (Department of Energy and National Renewable Energy Board, 2022). The Philippine Renewable Energy Resource Mapping from LiDAR Surveys (REMap), a Department of Science and Technology-funded project, identified that there is enough sunlight available in the country to make it a viable and useful power source (Ang et al., 2017). Based on the Competitive Renewable Energy Zone (CREZ) process, the Philippines has a potential solar photovoltaic (PV) generating capacity of 58,110 MW (Lee et al., 2020).

1.2 Solar PV Output Forecasting

While the Renewable Energy Act of 2008 encourages the use of renewable energy, such as solar, to promote economic growth and reduce carbon emissions (Congress of the Philippines, 2008), its variable and uncertain nature must be addressed first to integrate the technology into the power system successfully. Knowing how much solar PV output can be generated in a specific period makes it easier for power grid operators to balance energy supply and demand, keeping the overall costs of running the system low. A study on the impacts of solar PV generation variability and uncertainty in multiple timescales found that an improved day-ahead forecast reduces production cost while a five-minute forecast interval instead of an hourly interval allows better corrections when there are imbalances in the power system (Ela et al., 2013).

Solar PV output forecasting methods are well documented in the literature (Antonanzas et al., 2016; Inman et al., 2013; Sobri et al., 2018; Yang et al., 2018). Forecasts can be indirect and direct (Das et al., 2018). On one hand, the indirect method forecasts the amount of solar irradiance (sunlight) an area will receive and uses that to forecast solar PV output. On the other hand, the direct method uses historical solar PV output data. Both methods use various forecasting techniques such as statistics, machine learning, or their combination. Regardless of methodology type, it is implied that accurate and reliable forecasts depend on the input data quality, with high-quality input data leading to more accurate forecasts and poor input data quality resulting in unreliable and misleading forecasts. Since forecasting is as good as its input data, data availability becomes a constraint in producing accurate solar PV output forecasts.

Solar PV output forecasting utilizes several variables, including solar PV output, solar irradiance (Gupta and Singh, 2022; Harrou et al., 2020; Paulescu et al., 2013), cloud cover (Kim et al., 2021), temperature, humidity, and wind speed (Pawar et al., 2020). Data on such variables can be acquired *in situ* if recording instruments are available. However, access to these data is often not allowed for use by external research due to company-specific data privacy rules. In a solar PV output forecasting study in the Philippines using statistical techniques, results showed that using *in situ* solar irradiance data yielded better forecasting performance than using a remotely sensed data alternative (Ibañez et al., 2023).

1.3 Purpose of the Collaborative Research

Project SINAG, a two-year research project under the Joint Research Project between the Department of Science and Technology (DOST) of the Philippines and the Ministry of Science and Technology (MOST) of the People's Republic of China, aimed to accurately assess the potential output power that can be harnessed from solar PV installations in the Philippines using remotely sensed data and forecasting models. To develop localized solar PV output forecasting models in the Philippines, the project needed to acquire in-situ data to validate its models that used remotely sensed data. Localized here means the models should account for the location-specific weather parameters when creating the forecasting models. Because collaborative research helps researchers get what they need and achieve their goals better than working alone (Wray, 2002), Project SINAG saw the need for a collaborative research approach to realize its goals within two years. The collaborative research approach that Project SINAG undertook is defined as working with the academe (composed of state universities and colleges, SUCs, and higher education institutions, HEIs) across the country, various solar energy industries, and relevant government agencies to acquire the data needed to conduct its research. At the same time, Project SINAG provided them with processed data and training on its project methodologies as a form of capacity building.

Although the main purpose of the collaborative research was data acquisition, data availability remained a problem. Project SINAG also identified some challenges in implementing a collaborative research approach, such as (1) cooperation from the academe, solar energy industries, and the relevant government agencies, (2) bureaucracy, and (3) project budget constraints that limited its research team from meeting the project objectives.

2. Methodology

2.1 The Collaborative Research Framework

One of the main objectives of Project SINAG is to provide localized solar PV output forecasting models for the Philippines using solar PV output data from installations spread across the country. To expedite data collection, the project implemented a collaborative research approach, seeking help from the academe, solar energy industries, and relevant government agencies. Project SINAG developed a collaborative research framework, as shown in Figure 1, to streamline its research collaboration process throughout the duration of the project.

Project SINAG first identified research areas in the Philippines, ensuring that the institutions are spread across the country, from Luzon, Visayas, and Mindanao. Then, the project identified prospective collaborators within the selected research areas and sent them a Letter of Intent (LOI) via email expressing the intent of the collaboration, which is mainly to support its data and processing requirements. A positive response is defined as an expression of interest from the other party that is sent via email in response to the initial email. If the project receives a positive response, Project SINAG then sets a schedule for an online meeting to discuss the scope of collaboration and the possibility of a Memorandum of Understanding (MOU) agreement between parties. Before dropping the collaboration attempt, Project SINAG sent email follow-ups to give the prospective collaborators time to reconsider. If there has been no positive response after a series of follow-ups, only then will the project drop the attempt for collaboration. From the initial online meeting, once the other party (from the academe, solar energy industries, and relevant government agencies) expresses further interest in the collaboration through email exchanges, it will be regarded as a positive response, calling for the drafting of a Memorandum of Understanding (MOU). The MOU is not as formal as a contract but is a sign of commitment from both parties to fulfill the areas for collaboration they agreed to provide.

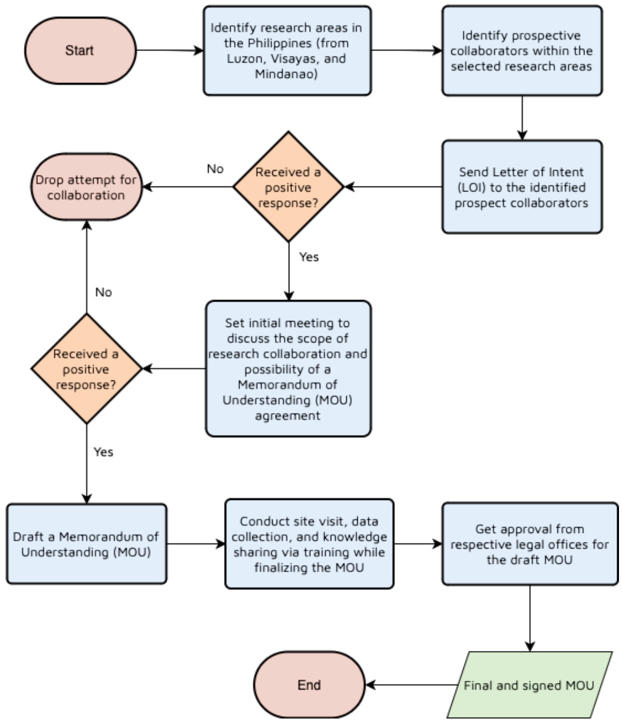

Figure 1. The Project SINAG collaborative research framework provides the steps it undertook to narrow the number of potential research collaborations and establish partnerships for ease of knowledge and data sharing.

Institution	Role
Academe	• Provide necessary manpower in the implementation of the research and development of collaboration areas • Conduct the experiments and data gathering based on the areas of collaboration • Provide the necessary data to develop the solar PV output forecasting models • Provide the venue for training as the need arises
Solar Energy Industry	• Provide the necessary data to develop the solar PV output forecasting models
Government Agencies.	• Provide the necessary data to develop the solar PV output forecasting models • Provide policy insights whenever applicable

Table 1. A detailed summary of the roles of the SUCs, solar energy industries, and relevant government agencies in the research collaboration for developing the localized solar PV output forecasting models in the Philippines.

Working through an MOU document entails a back-and-forth draft exchange between parties, which takes months depending on how fast each legal office can go through it until both parties agree to a final draft. Once both parties agree to a final draft of the MOU, they must sign the document with wet signatures, formalizing the partnership. A face-to-face MOU signing is encouraged but not required. Table 1 summarizes the roles of academe, solar energy industries, and relevant government agencies in the research collaboration.

2.2 Data Collection

Once the MOU draft is awaiting approval from the legal offices of each party, data sharing ensures that data analysis will be conducted within the project duration. There are two kinds of data that the project expects from its collaborators: (1) solar PV output for forecasting models and (2) dust collection for solar panel performance experiments. Figure 2 provides in detail the steps Project SINAG undertook to acquire the solar PV output data, while Figure 3 presents the steps for the dust collection.

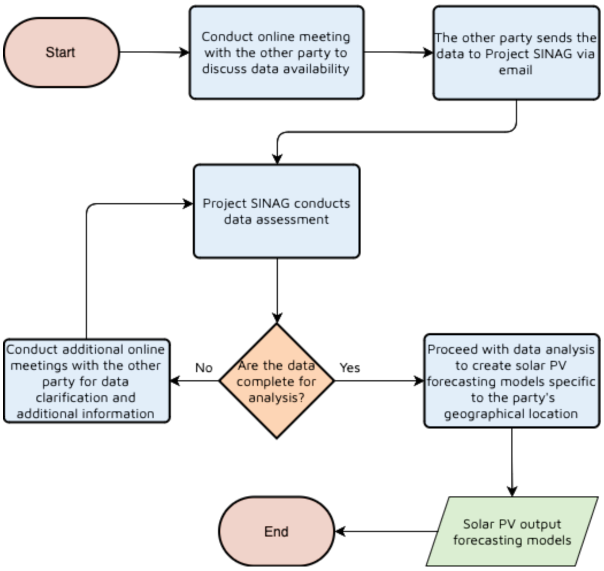

Figure 2. Steps undertaken to acquire solar PV output data during the research collaboration.

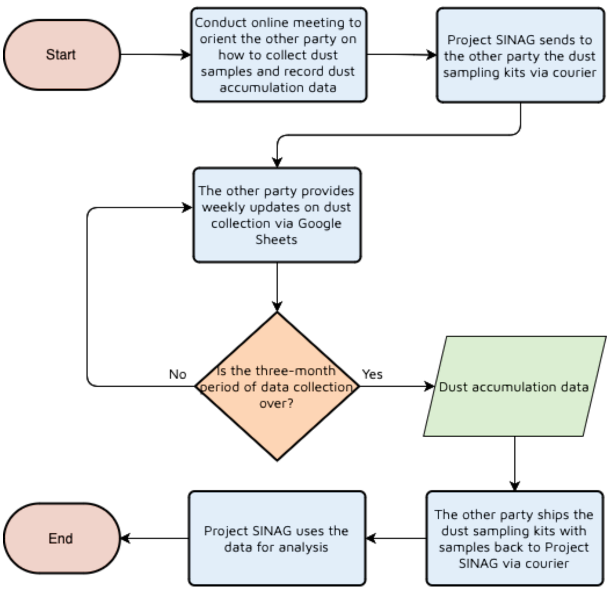

Figure 3. Steps undertaken to acquire dust accumulation data during the research collaboration.

Communication via email remained active throughout the duration of data collection. The online medium served as a quick highway to quickly address concerns and ensure the conduct of time-sensitive data collection, such as dust accumulation. The dust accumulation data were organized and shared using Google Sheets, a virtual spreadsheet that can be accessed and shared with parties in real-time. Meanwhile, solar PV output data were shared via email either in Microsoft Excel spreadsheets or a portable digital file (PDF) that requires conversion to an Excel file for easier data manipulation and analysis.

2.3 Developing the Solar PV Forecasting Models

The study initially assessed solar PV output data from 43 solar PV installations in the Philippines, as presented in Table 2, and filtered them based on their completeness for a one-year period to ensure data quality. Each dataset represents a location in the Philippines. Table 3 summarizes details on the parameters used in this study which were sourced from a weather-monitoring government agency (*PAGASA:* Philippine Atmospheric, Geophysical and Astronomical Services Administration) and three geospatial data sources namely, *ERA5* (fifth generation of the ECMWF's global climate and weather reanalysis), *AHI-8* (Advanced Himawari Imager 8), and *FY-4A* (FengYun-4A).

Institution	**Count of time-series datasets**
Academe	2
Solar Energy Industry	33
Government Agency (Department of Energy)	8

Table 2. Breakdown of the number of solar PV output time-series data sets acquired from various institutions.

Source	**Data**	**Resolution**		**Type**
		Spatial	Temporal	
PAGASA	Weather parameters and solar irradiance	Ground	Hourly	In-situ
ERA5	Weather parameters and solar irradiance	27 km	Hourly	Remotely sensed
AHI-8	Solar irradiance	4 km	10 minutes	Remotely sensed
FY-4A	Solar irradiance	4 km	Hourly	Remotely sensed

Table 3. Summary of weather parameters and solar irradiance data sources categorized by data resolution and type.

The data were subjected to several processing steps. This included an outlier detection and filling data gaps using a modified column mean imputation approach documented in (Benitez et al., 2023a), decomposition of time series data, feature selection using variance inflation factor to address multicollinearity and redundant variables, and unit root testing to address autocorrelated errors. The data were split into training and testing sets following a specified ratio for accurate model evaluation. For the forecasting techniques, the study employed SARIMAX (seasonal autoregressive integrated moving average with exogenous variables), LSTM (long short-term memory), and XGBoost (extreme gradient boosting), both individually and in hybrid models. To evaluate the forecasting performance of the models, the study utilized error metrics such as the root mean square error (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE).

3. Results and Discussion

3.1 Research Collaboration

The implementation of the project objectives was made possible through a collaborative research approach. By tapping various institutions across the country (from the academe, the private sector, and the government), Project SINAG was able to develop localized solar PV output forecasting models for the Philippines. However, the initial steps also brought about setbacks in establishing collaboration with target institutions. The project attempted to reach out to 17 academic institutions, sending them letters of intent via email. Even with continuous follow-ups, while some expressed interest, nine did not push through. Some just dropped in the middle of communications, while others simply did not respond. Hence, the project dropped further attempts to collaborate with them. Only eight academic institutions were formalized into partnerships through an MOU. Instead of allowing the months to go by doing nothing while waiting for the final MOU draft, Project SINAG actively engaged with them through site visits and knowledge sharing, aside from data collection. Project SINAG conducted knowledge sharing by providing these academic institutions with training on how to forecast solar PV output using historical solar PV output data and other weather parameters. The project also contacted two solar energy companies and three government agencies, all formalized into partnerships. The research areas considered in the study were finalized based on where each successful collaboration resides, as summarized in Table 4.

Institution Type	Attempt	Success
Academe	17	8
Solar Energy Industry	2	2
Government Agency	3	3

Table 4. A summary of the count of collaboration attempts and successes.

Although the collaboration with the two solar energy companies was successful, leading to non-disclosure agreements (NDA), only one disclosed solar PV output data that the project could use to develop localized solar PV output forecasting models. After the NDA, the other company stopped responding to email communications.

The academe was considered an essential part of the research collaboration because they often have diverse expertise, allowing for a multidisciplinary approach towards research projects. They also have specialized equipment and data that can be leveraged, as well as academic support through students, faculty, and researchers who can contribute new insights to the research. In the same way, working with the academe allowed capacity building to nurture and establish new research areas within the academic system. Meanwhile, private companies that are already working on solar PV projects also helped Project SINAG by offering data that would otherwise be challenging to access without their help. They also offered insights about forecasting challenges and ideas on how to refine the models and develop a user-friendly forecasting tool. Collaboration with relevant government agencies also provided easy data access, which is often challenging in conducting data-driven research projects. Through official partnerships, a more efficient research process was established, enabling easier data requests and project monitoring. Aside from helping Project SINAG have a wider reach in terms of contacting other companies from the solar energy industry, they also provided policy guidelines that equally benefited the project.

In conducting a data-driven project on a nationwide scale, one of the main challenges that researchers face is data availability, which a collaborative research approach lends a hand. However, there are still factors affecting how Project SINAG effectively implemented its collaborative research efforts, and the following sections elaborate on the three hurdles that influenced the pace of the project and its success.

First is the collaboration with target partners. Project SINAG experienced a varied range of responses while working with various institutions. Initially, after some parties expressed keen interest during the online meetings they agreed to, their commitment to continue with the collaboration waned over time. While certain collaborators proved easy to engage and work with, others seemed to stall, waiting for a more favorable collaboration arrangement to their benefit before making any progress. Most contacted collaborators from the academe required a Memorandum of Agreement (MOU) before continuing the research collaboration. Such a request led to the second hurdle, which was bureaucracy. Meanwhile, the collaboration between Project SINAG and two local government agencies was through project staff members who provided data, while the collaboration with another international government agency was only through a collaboration letter to formalize data sharing. Navigating the bureaucratic landscape, particularly the lengthy process of securing required approvals and obtaining official document signoffs and reviews, has delayed the overall progress of the collaboration. The third hurdle the project went through was budget constraints because some collaborators were reluctant to participate if they did not receive any honoraria actively. This reluctance has led to unsuccessful attempts to engage with some of the academic institutions contacted during the initial phases of the project. However, having a budget dedicated to research collaboration expedited certain aspects of the project, such as data collection, which improved efficiency. Moreover, providing the necessary materials, such as the toolkits for dust data collection, signaled that Project SINAG is intentional in having a successful collaboration, motivating the partners to participate actively.

To address the identified challenges, the project proposes the following long-term solutions and strategies to avoid similar pitfalls in future projects:

(1) Collaboration Arrangements
Ensure consistency in follow-up communications after receiving expressions of interest from prospective institutions. During the preliminary stages of forming the collaboration, it is crucial to ascertain or clarify the commitment of the other party by setting a deadline for confirmation. This confirmation should explicitly detail the contributions the institution commits to the partnership, rather than imposing tasks predetermined by the project team. Given the research-centric nature of the collaboration, the project must prioritize engaging institutions that are already acquainted

with or are leaning toward conducting research. This approach will enhance the likelihood of achieving successful and synergistic collaboration outcomes.

(2) Bureaucratic Barriers
Given the inherent time constraints associated with the MOU, collaboration can commence even prior to the finalization of the approved MOU. Another workaround is to use an official collaboration letter instead of a signed MOU, provided this is acceptable to the collaborating partner. Creation and finalization of a collaboration letter are faster than an approved MOU, which typically involves multiple iterative draft revisions and extensive legal arrangements.

(3) Budget Constraints
Given the constraints of limited funds, delegating venue costs can significantly ease the financial burden of the project. In the case of Project SINAG, collaborators were amenable to this arrangement, recognizing the mutual benefit: they incurred venue expenses in exchange for free training. This arrangement proved to be mutually beneficial for both parties.

It is evident that Project SINAG has benefited from the collaboration. At the same time, it also provided a valuable avenue, particularly to academic institutions, enabling them to conduct research using the data they acquired through the project. Figure 4 shows the geographical locations of the Project SINAG collaboration partners summarized in Table 5, which includes the collaboration areas the institutions shared and contributed to the project.

Figure 4. Project SINAG collaboration partners from various institutions across the Philippines.

3.2 Knowledge Transfer and Data Sharing

The research collaboration provided an avenue for ten training sessions, engaging a total of 233 participants nationwide. These training sessions were focused on providing technical knowledge for academic faculty, researchers, and students on how to forecast solar PV output using historical and geospatial data. The training was also used as an avenue for the project to beta test its forecasting software. Throughout the project duration, Project SINAG conducted two colloquiums attended by 182 participants, bringing together its partner institutions and users of data to foster an engaging and active research community focused on using geomatics for solar energy research and applications. It also hosted 11 student interns

Map Label	Name	Institution	Collaboration Area
1	Cavite State University	Academe	• Dust Data Collection • COMSOL Training • Solar PV Resource Assessment Training • Introduction to Solar PV Output Forecasting Training
2	China Meteorological Administration	Government Agency	• Satellite Solar Irradiance Data • Training on Data Extraction
3	Colegio De Muntinlupa	Academe	• Solar PV Output Data Collection at Different Tilt Angles • Undergraduat e Student Research: 1
4	Department of Energy	Government Agency	• Solar PV Output Data • Coordination with Solar PV Companies for Support
5	Ilo-ilo Science and Technology University	Academe	• Solar PV Resource Assessment Training • Introduction to Solar PV Output Forecasting Training

Table 5. List of the collaboration areas where the academe, solar energy industry, and government agencies shared and contributed to the project.

Map Label	Name	Institution	Collaboration Area
6	Mariano Marcos State University	Academe	● Dust Data Collection ● Solar PV Resource Assessment Training ● Introduction to Solar PV Output Forecasting Training
7	Mindanao State University GenSan	Academe	● Dust Data Collection ● Solar PV Resource Assessment Training ● Undergraduate Student Research: 2
8	Philippine Atmospheric, Geophysical and Astronomical Services Administration	Government Agency	● Weather Data
9	Saint Louis University	Academe	● Solar PV Output Data ● Solar PV Resource Assessment Training
10	Sasonbi Inc.	Solar Energy Industry	● Solar PV Output Data
11	University of Southeastern Philippines	Academe	● Dust Data Collection ● Solar PV Resource Assessment Training
12	University of the Philippines Los Baños	Academe	● Utilization of high-performance computing device

Table 5 (cont’d). List of the collaboration areas where the academe, solar energy industry, and government agencies shared and contributed to the project.

who actively participated in the research while learning the ins and outs of the project implementation. The project also handled 21 data requests from various academic institutions in the country, which helped researchers in the country access geospatial data for their research interests. With knowledge and data sharing, 13 Project SINAG publications stemmed from this collaborative research and are summarized in Table 6 in the Appendix section. There were also three unpublished student theses from its academic partners.

3.3 Solar PV Output Forecasting Models

The project evaluated the accuracy of various forecasting models for different seasons and geographic locations. In one case study that assessed the performance of SARIMAX models in forecasting solar PV output in Baguio City, Philippines, results showed that seasons affect forecasting accuracy and that the dry seasons yield more accurate forecasts than the wet seasons (Benitez, et al., 2022). Another study evaluated the forecasting accuracy of SARIMAX, LSTM, and XGBoost models using one-year data from three solar PV installations in the Philippines and concluded that the accuracy levels of each model depend on the month and the location of the solar PV installation (Benitez, et al., 2023b). These studies underscore the importance of developing solar PV output forecasting models that are based on local conditions and seasonal variations while identifying the variables contributing to accurate forecasts.

The practical application of the forecasting models includes enhanced predictive accuracy and improved decision-making in balancing energy supply and demand, thereby optimizing operational costs. These forecasting models facilitate informed planning and investment decisions, which helps in the integration of solar PV systems into the grid. Findings from these models enable businesses and distribution utilities to operate solar power plants more efficiently, trade energy, plan and develop projects, manage energy use, and maintain grid stability. The existing models are currently in the testing phase, utilizing actual plant data, and the project seeks entities that are willing to adopt them. Although the forecasting models produced by the project were plant-specific, the methodologies are adaptable and replicable for other solar PV power plants.

4. Conclusion

The collaborative research efforts focused on developing localized solar PV output forecasting models for the Philippines using geospatial data have seen both successes and challenges. Through the Project SINAG collaborative research framework, various institutions from the academe, the solar energy industry, and the government contributed to the project. Thirteen (13) publications and three student theses stemmed from this research collaboration. The project also facilitated knowledge and data sharing that benefited the project and enabled the partners from the academe to conduct their own research using the data from the project. While the collaboration showcased the potential of such efforts, it also brought to light hurdles that the project encountered, including varying levels of cooperation, bureaucratic barriers, and budget constraints. Despite these challenges, the collaboration areas that were highlighted in this paper demonstrated diverse engagements and contributions that emphasize the significance of collaborative research in conducting nationwide-scale data-driven projects.

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Appendix

Title	Type	Reference
Use of SARIMAX Model for Solar PV Power Output Forecasting in Baguio City, Philippines.	Conference Paper	(Benitez et al., 2022)
Preliminary Analysis on the Difference Between Solar PV Power Output Forecasts Derived from Remotely Sensed and In-Situ Solar Radiation Data	Conference Paper	(Benitez, I. et al., 2022)
A Novel Data Gaps Filling Method for Solar PV Output Forecasting	Journal Article	(Benitez et al., 2023a)
Outdoor Performance Analysis of Mono-Si and Poly-Si Solar PV Panels in the Philippines	Conference Paper	(Principe et al., 2023)
Accuracy Assessment of Satellite-Based and Reanalysis Solar Irradiance Data for Solar PV Output Forecasting Using SARIMAX	Journal Article	(Ibañez et al., 2023)
Day-Ahead Hourly Solar Photovoltaic Output Forecasting Using SARIMAX, Long Short-Term Memory, and Extreme Gradient Boosting: Case of the Philippines	Journal Article	(Benitez et al., 2023b)
Assessment of Potential Solar PV Output Derived from Remotely-Sensed Solar Irradiance Data and Different Tilt Angles	Conference Paper	(Sotto et al., 2023)
Comparison of CLOT-Adjusted AHI-8/9 and FY-4A Solar Irradiance Products for Solar PV Output Forecasting Using LSTM	Conference Paper	(Benitez et al., 2024a)
Assessment of Solar PV Output Performance With Varying Tilt Angles And Weather Data From ERA5: Case of Muntinlupa City, Philippines	Conference Paper	(Benitez et al., 2024b)
Assessment Of Reanalysis Data For Solar PV Output Forecasting in The Philippines: Case of Pangasinan, Negros Occidental, and Davao Del Norte	Conference Paper	(Gavina et al., 2024)
Development of a WebGIS For Solar PV Resource and Installation Assessment using Geospatial Technologies (SINAG)	Conference Paper	(Cañete et al., 2024)
Slope Analysis of CLOT-adjusted SSI FY4A Data for Solar PV Power Potential in the Philippines	Conference Paper	(Dizon et al., 2024)
Comparative Analysis of CLOT-Adjusted AHI-8/9 And FY-4A Solar Radiation Data For Solar PV Power Potential Assessment in the Philippines	Conference Paper	(Sotto et al., 2024)

Table 6. A summary of all the publications that stemmed from the research collaboration.