EXPLORING LAND COVER TRANSITION TO SOLAR FARMS AND ITS IMPACT ON NIGHTTIME LIGHTS USING RS AND GIS

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ABSTRACT: Global utilization of solar photovoltaic (PV) systems for electricity generation has been increasing for the past several decades mainly due to its scalability, being low carbon, maturing solar cell technology, and decreasing cost of initial investments. The Philippines has enormous potential when it comes to harvesting energy from solar due to its geographical location. However, due to limited available spaces, some of prime agricultural lands have been converted to solar farms which may pose concerns with regards to food security. Nonetheless, expansion of solar farms in the country contributes to ensuring energy security. This paper presents a time-series analysis of land cover (LC) change of areas converted to solar farms using remotely sensed (RS) satellite data and its impact on the total sum of lights (SOL) in two Philippine provinces where two of the largest solar PV farms in the country are located. The objective of this study is two-fold: first is to assess the effectiveness of MODIS Land Cover product (MCD12Q1) to track LC changes that would signal conversion to solar farms; and second is to quantify the effect of such LC conversion to the SOL. A zonal statistical analysis in ArcGIS Pro™ was performed to extract the majority of LC class for years 2001 to 2019 using the MCD12Q1 data on areas covered by two large solar power plants (SPP) in Tarlac City and Toledo City located in Tarlac and Cebu provinces, respectively. Lastly, annual global Visible and Infrared Imaging Suite (VIIRS) nighttime lights data were used to quantify the change in the SOL for the two provinces pre-, during and post- construction years of the said SPPs. Results show that there was an apparent uncertainty in the actual LC due to the relatively course spatial resolution of MCD12Q1 which generalizes possible mixture of classes within a 500-m pixel resolution. The said problem was noticeable in the Toledo City SPP which produced an erratic LC transition. However, in the case of Tarlac City SPP, a rather smooth LC transition was identified showing a change from cropland to grassland at a timescale of 16 years, which may signal a possible LC conversion to solar farm. Lastly, results show that there was an increase of about 42% and 69% in the SOL for the Toledo and Tarlac SPPs, respectively. This may indicate positive socioeconomic impact in the two provinces since higher SOL may be interpreted to higher electrification rates and increased economic activity. For future work, an LC map can be generated from a finer resolution satellite images and analysis on SOL change to socioeconomic variables can be done.

1. INTRODUCTION

It was reported that from 2000 to 2014, the annual energy production in Asia has increased by 5.5%, 6.7%, and 1.1 % for gas, coal, and oil, respectively, which was more than twice the global rate (AIIB, 2018). Such increase in energy production was necessary to support the also increasing energy demand for better life environment and development in technology and economy (Sampaio, P. and Gonzalez, M., 2017). However, the burning of fossil fuels emits CO_2 that contributes to climate change. It was estimated that the current estimated reserves and resources for fossil fuels contains enough carbon that can yield radiative forcing that can overshoot the required limit to global mean temperature change of less than 2°C (Buckner, T., et al 2014). The Philippines contributed 1.34 tons of CO_2 equivalent (tCO_2e) for the total Greenhouse Gas (GHG) emissions for every PhP 100,000 of economic output (measured in terms of real GDP) (Department of Energy, 2018). Aware of the negative impacts of the country's heavy reliance on fossil fuels, the Philippines Department of Energy (DOE) has included the intensification of renewable energy (RE) resource development as one of its targets in its strategic directions for energy self-sufficiency (Department of Energy, 2018). One such renewable source of energy is solar—a low carbon resource with both scalability and technological maturity to meet the fast-growing global demand for electricity (Chandler, D. L., 2018). The total installed capacity for solar is estimated at 285 MW by 2030 with a total of 320 Renewable Energy (RE) solar projects as of September 20, 2020 according to the national renewable energy program of the Philippines (DOE, 2011; DOE, 2020).

Large tract of land is required for solar farms especially for projects that target high installation capacities. The conversion of agricultural lands to solar farms may pose serious concerns in terms of food security. This led the Philippine Department of Agrarian Reform (DAR) to propose a two-year moratorium on land conversions (Gomez, E. J., 2019). Meanwhile, night-time lights from satellite data have been extensively used for different applications including but not limited to the estimation of economic activities, detection of lit and unlit areas, and extraction of electric power lines (Pérez-Sindín, X. S. et al. 2021; Min, B. et al. 2014; Principe, J. & Takeuchi, W. 2019). The impact of agricultural land conversion to solar farms on socioeconomic factors can therefore be quantified using night-time lights.

To date, there is no detailed study yet that dealt with a quantitative impact assessment of agricultural land conversion to solar farm by looking at the historical trend of land use/land cover conversion and nighttime lights. The objective of this study is two-fold. First is to assess the effectiveness of MODIS Land Cover (MCD12Q1) product to track changes on land cover (LC) from an initial LC type to its current state and signal a major change, such as conversion to solar farms. Second is to estimate the socioeconomic impact of such land cover conversion by using satellite-derived sum of lights (SOL) from nighttime lights. Results of this study may help in the assessment of the impacts of land conversions (specially, of agricultural areas) by determining their previous state prior to being converted to solar farms and its corresponding socioeconomic impact.

2. STUDY AREAS

For this study, two large solar farms that are currently in commercial operation were considered. The first solar farm is in Tarlac City, Province of Tarlac and is called the Tarlac Solar Power Project (Tarlac SPP). The construction of Tarlac SPP has started in October 2015 covering more than 189,000 solar PV modules with an installed capacity of 50 megawatts (MW) (DOE, 2020; Syntegra Solar, 2021). The second solar farm, First Toledo Solar Energy Corporation (Toledo SPP), is located in Toledo City, Province of Cebu. The 60-MW Toledo SPP was commissioned in January 2016 and is currently using more than 193,000 solar PV modules (DOE, 2020; Bunachita, 2018). True color composite images from Google Earth Pro of the two solar power stations are shown in Fig. 1.

(a) **(b)**

Figure 1. Solar farms in Tarlac City, Tarlac (a) and Toledo City, Cebu (b). Images © 2021 Maxar Technologies.

3. DATA AND METHODS

3.1 Data Description

Boundaries of the two solar farms were digitized in the Google Earth Pro using the latest satellite images that were either cloud-free or with less amount of cloud cover. Fig. 1 shows satellite images of the solar power plants in Tarlac and Toledo acquired on December 17, 2019 and August 16, 2020, respectively. Digitized boundaries were exported as KMZ files which were converted to SHP file format in ArcGIS Pro.

Table 1 summarizes the dataset used in this study. The global land cover dataset from Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Type Product MCD12Q1 was downloaded from the Land Processes Distributed Active Archive Center (LP DAAC) of NASA's Earth Observing System Data and Information System (EOSDIS) (L.P. DAAC, 2019). MCD12Q1 is available annually at 500-m spatial resolution from year 2001 and was generated by performing a supervised classification on MODIS reflectance data. For this study, Collection 6 of MCD12Q1 was downloaded and processed, and the IGBP was adopted for the land cover classification system (Belward, 1999) (Fig. 2). MCD12Q1 Collection 6 has undergone updates from its previous version including changes in the algorithm, pre-processing and classifying data, and input features used in image classification (Sulla-Menashe & Friedl, 2018).

Table 1. Satellite data products used in this study.

Data	Description	Temporal/ Spatial Resolution	Year	Source
MCD12Q1	Land cover types	Annual/500m	2001-2009; 2011-2019	https://appeears.earthdatacloud.nasa.gov
VNL (v2.1)	Nighttime lights	Annual/500m	2013, 2015-2017	https://eogdata.mines.edu/products/vnl

Figure 2. MCD12Q1 2019 land use/cover data for Tarlac SPP (a) and Toledo SPP (b) using IGBP classification system (middle).

The Version 2.1 of the annual global Visible and Infrared Imaging Suite (VIIRS) nighttime lights (VNL) were downloaded from the Earth Observation Group of Payne Institute for Public Policy (https://eogdata.mines.edu/products/vnl). The said VNL version is an upgrade of Version 2, corrected for a bug in calculating for the annual average radiance filtering technique (Elvidge et al, 2021). VNL v2.1 products for years 2013-2017 (except 2014 due to data inconsistency) were downloaded to cover the pre-, during and post- construction years of the two solar power plants considered in this study.

3.2 Methodology

The general methodology used in this study is shown in Fig. 3. The MCD12Q1 global land cover dataset was downloaded to cover the whole Philippines for years 2001 to 2019. However, data for 2010 was corrupted, so this year was not included in the analysis. For year 2010, it was assumed that the current LC was the same as in the previous year (2009). The raster dataset was then reprojected to WGS84 reference system from sinusoidal projection used by MODIS grid files (Sulla-Menashe & Friedl, 2018). The digitized boundaries in shapefile format were used as zones in performing zonal statistics via the spatial analyst tool in ArcGIS Pro. The tool summarizes raster values within the predefined zones and output a table containing the selected statistic type (ESRI, 2021). For this study, "majority" statistic was selected to determine the LC class that occurs most often at all grid cells within each zone. Output tables from the two zones (i.e., SPPs) were merged for further analysis. Lastly, VNL data were used to quantify the change in the night-time lights for the two provinces pre-, during and post- construction years of the said SPPs. A zonal statics analysis was also utilized for VNL data to get the sum of lights (SOL) using sum as the statistics to compute.

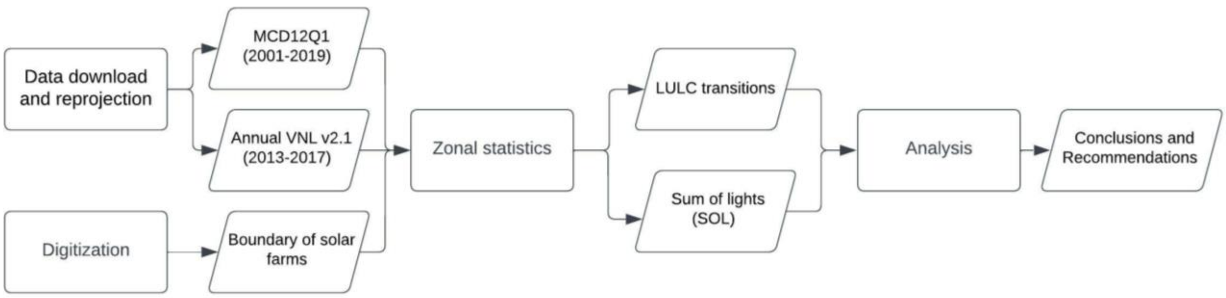


Figure 3. General methodology of the study.

Results from the two zonal statistics analyses were analyzed to assess the effectiveness of MCD12Q1 product to track changes on land cover from an initial LC type to its current state and signal a major change such as conversion to solar farms, and to quantify the change in the SOL (pre-, during and post- construction years) in the municipalities that are within the vicinity of the Tarlac and Toledo SPPs.

4. RESULTS AND DISCUSSIONS

4.1. Land Cover Change Transition to Solar Farm

LC changes can be seen in Figs. 4 to 5 which show the LC maps from 2001 to 2019 (excluding 2010). In the case of Tarlac SPP, the site was consistently a cropland area for fifteen years (2001-2016), but a patch of grassland has started to appear in 2017 until it dominated the area for the next two years (Fig. 5). However, in the case of Toledo SPP, a rather erratic trend of LC changes can be seen. From 2001 to 2005, majority of the site were "Savannas" until they were converted to "Grasslands" from 2006 to 2009 (2010), became "Woody savannas" in 2011 until 2015 and finally back to "Savannas" until 2019 (Fig. 5).

The timeline in Fig. 6 summarizes the LC transition for the two sites. As there are no savannas in the Philippines, the two classes—savannas and woody savannas—as defined in the IGBP system can be attributed to the percent of canopy/vegetation cover with the latter having higher percentage than the former (Table 2). As such, in dealing with these classes, their percentage of vegetation canopy cover was used to indicate possible conversion to solar farms, with the decrease in canopy cover suggesting a high possibility of conversion from vegetation to solar farm. Conversion to grassland areas from croplands can be easily attributed to the commissioning of Tarlac SPP which happened in January 2016. Although no clear trend for Toledo SPP, the LC change from higher (woody savannas) to lesser (savannas) canopy cover from 2015 to 2016 may also suggest conversion to solar farms with the start of its construction in October 2015. Due to the course resolution of the global land cover data, local variations in LC class distribution were not detected. Moreover, the spectral response of solar panels was not distinguished effectively from vegetation cover most probably due to over-generalization of spectral reflectance from an area which was predominantly covered with vegetation. It is therefore recommended to use a finer resolution LC data (e.g., Landsat) to solve this problem.

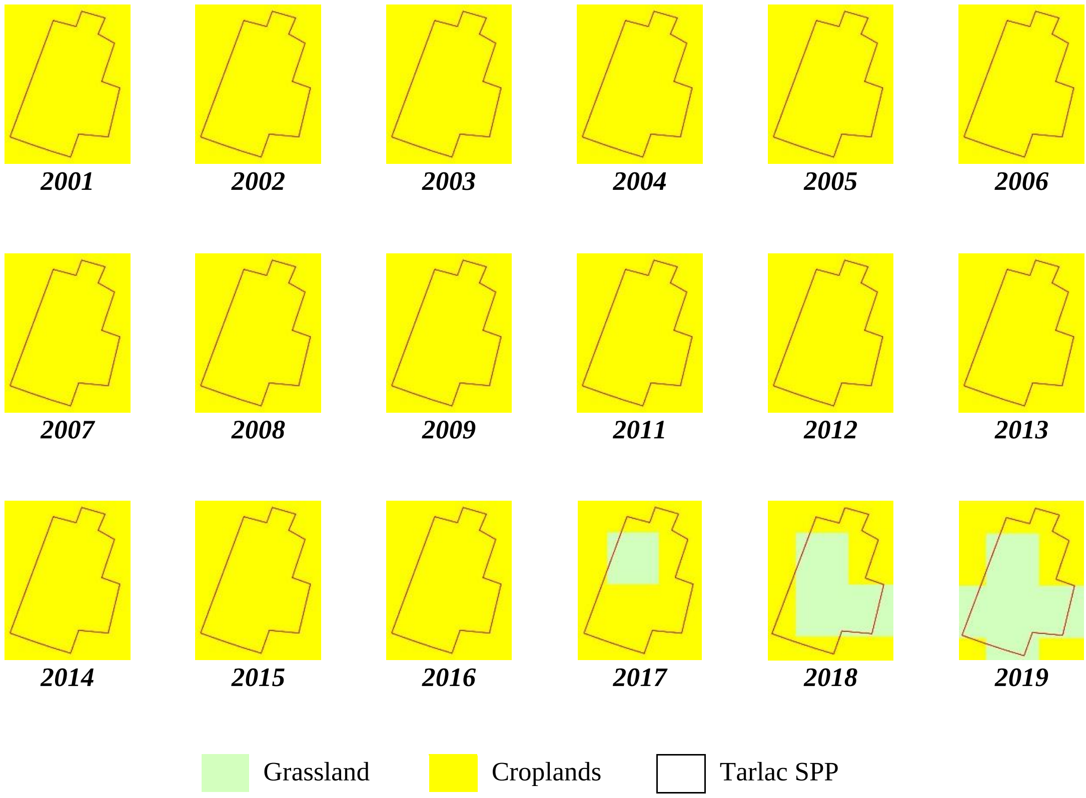


Figure 4. LC maps for Tarlac SPP (2001-2019). One pixel is approximately 500x500 m on the ground.

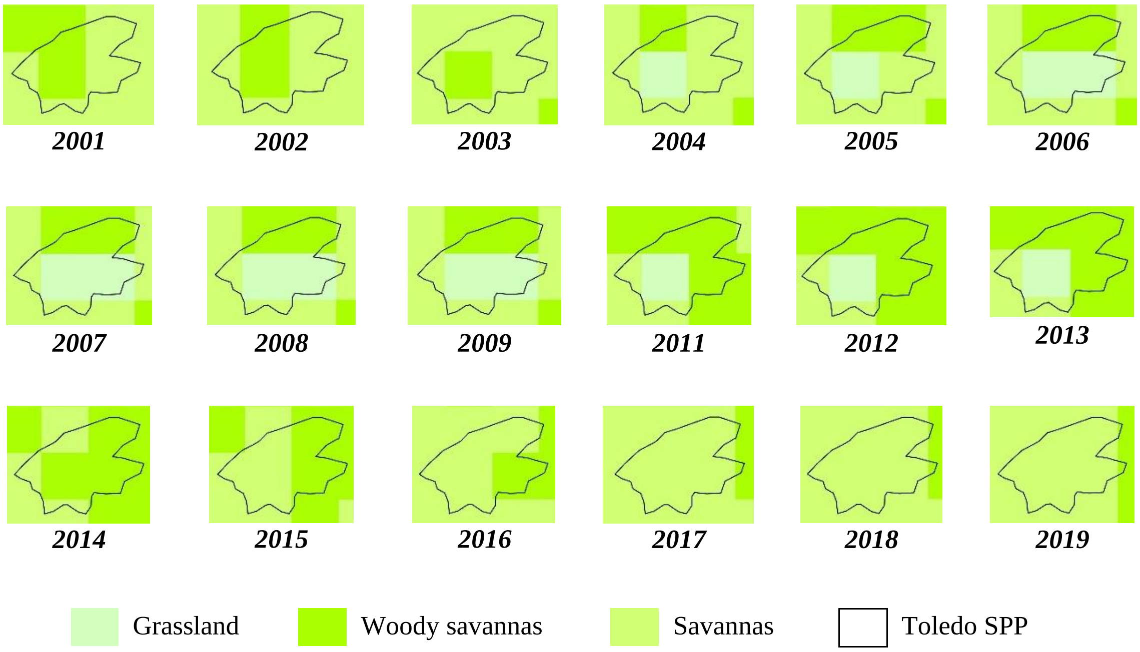


Figure 5. LC maps for Toledo SPP (2001-2019). One pixel is approximately 500x500 m on the ground.

Table 2. Canopy cover for woody savannas, savannas, and grasslands based on IGBP classification system.

IGBP Class	Canopy cover (forest/shrub) (%)
Woody savannas	30-60
Savannas	10-30
Grasslands	<10

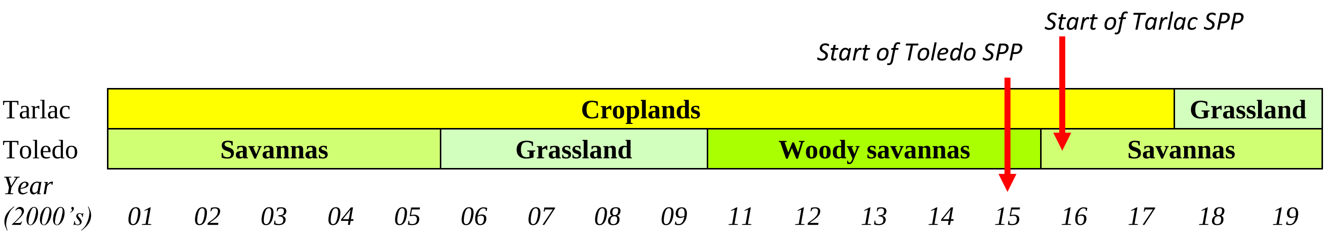
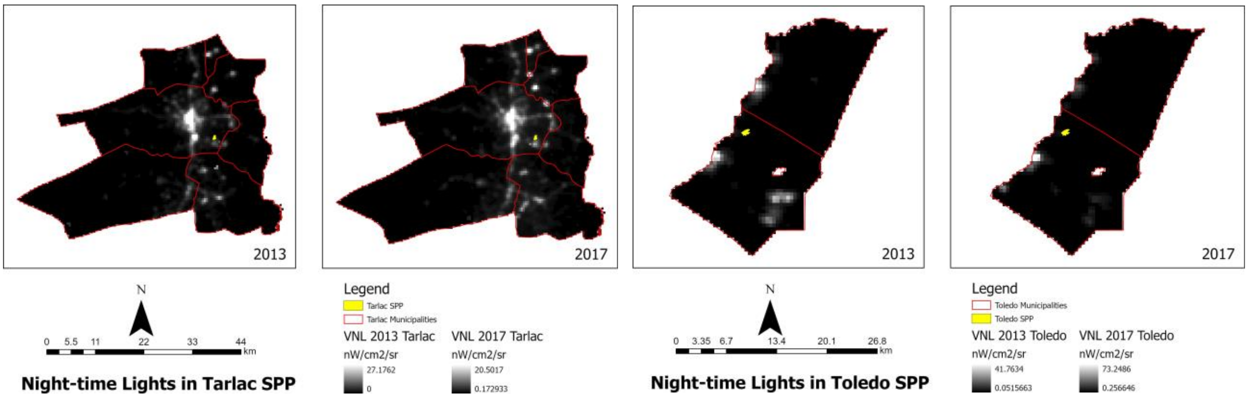


Figure 6. Transition of LC classes (majority) in Tarlac SPP and Toledo SPP. Conversion to grassland from croplands can be easily attributed to the commissioning of Tarlac SPP in January 2016. Although no clear trend for Toledo SPP, the LC change to lesser canopy cover from 2015 to 2016 may also suggest conversion to solar farms with the start of its construction in October 2015.

4.2. Impact on Night-Time Lights

Night-time lights using VIIRS data for years 2013 (pre-construction) and 2017 (after construction) for the two solar power plants are shown in Fig. 7. The legend shows an increase and decrease in the maximum radiance value from 2013 to 2017 in the municipalities surrounding Toledo and Tarlac SPPs, respectively. However, if the sum of lights is considered, both two sites have exhibited a positive increase in night-time lights for the four-year period. The computed increase in SOL from 2013 to 2017 is about 42% and 69% for the Toledo and Tarlac SPPs, respectively. This may indicate positive socioeconomic impact in the two provinces since higher SOL may be interpreted to higher electrification rates and increased economic activity. Moreover, an increase in SOL may justify a land conversion to solar farm if the socioeconomic benefits outweigh the possible negative effects on food security in the case of agricultural land conversion.



(a) **(b)**

Figure 7. VIIRS night-time lights data (in *nW/cm^2/sr*) in Tarlac (a) and Toledo (b) SPPs for years 2013 and 2017.

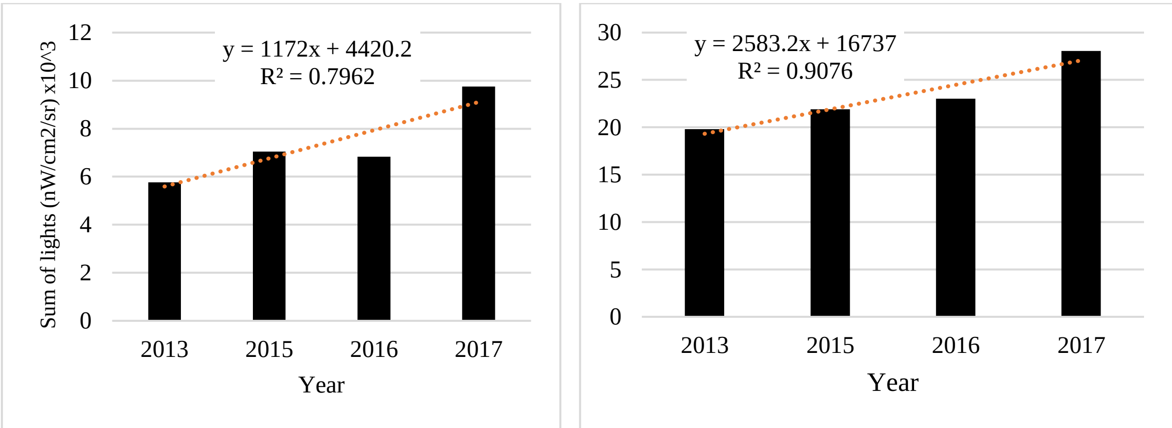


Figure 8. Sum of lights in Tarlac (a) and Toledo (b) SPPs for years 2013, 2015, 2016 and 2017.

5. CONCLUSION

This study has utilized a global land cover (LC) data (MCD12Q1) and VIIRS night-time lights (VNL) covering two of the largest solar PV farms in the Philippines in Tarlac City and Toledo City. A zonal statistical analysis was performed to extract the majority of LC class for years 2001 to 2019 (excluding 2010). Due to the relatively course spatial resolution of MCD12Q1, uncertainty in the actual LC was apparent due to the generalization of the possible mixture of classes within a 500-m pixel resolution. The said problem was noticeable in the Toledo City solar farm which produced a rather erratic LC transition. However, in the case of Tarlac City, a rather smooth and realistic LC transition was observed which showed a change from cropland to grassland at a timescale of 16 years. Nonetheless, this study has demonstrated how satellite remote sensing data can be used in the geospatial analysis of land cover changes in areas converted to solar farms. Using the VNL data, an increase of about 42% and 69% in the sum of lights (SOL) was observed in the Toledo and Tarlac SPPs, respectively. This may indicate positive socioeconomic impacts in the study areas since higher SOL may be interpreted to higher electrification rates and increased economic activity.

On one hand, outputs of this study are significant to guide relevant stakeholders in the energy industry and policymakers on where best to install solar PV systems on large tracts of land as well as the possible negative impacts of converting agricultural lands to solar farms. On the other hand, the change in the sum of lights, as proxy to socioeconomic variables, can provide a justification on whether such conversion to solar farm from agricultural lands is, to some degree, acceptable or not. For future work, a LC map can be generated from finer resolution satellite images and analysis on SOL change to specific socioeconomic variables (e.g., GDP, population, etc.) can be done.

6. ACKNOWLEDGMENTS

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