



HOKKAIDO UNIVERSITY

Title	India' s sustainable energy transitions : Analyzing agriculture land - water - solar energy nexus [an abstract of dissertation and a summary of dissertation review]
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Degree Grantor	北海道大学
Degree Name	博士(環境科学)
Dissertation Number	甲第16074号
Issue Date	2024-09-25
Doc URL	https://hdl.handle.net/2115/93505
Rights(URL)	https://creativecommons.org/licenses/by/4.0/
Type	doctoral thesis
File Information	SUPE_Hitesh_Ghanashyam_review.pdf, 審査の要旨



学 位 論 文 審 査 の 要 旨

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学 位 論 文 題 名

India's sustainable energy transitions:

Analyzing agriculture land - water - solar energy nexus

(インドの持続可能なエネルギー転換：農地・水・太陽エネルギーネクサスの分析)

India's agricultural sector, employing over 50% of the workforce and significantly contributing to GDP, faces challenges from the expanding solar energy sector. As agriculture land is converted into solar power projects, food security concerns arise, especially with 195 million people already undernourished in the country. The demand for water to clean solar panels and cool plants further strains India's water resources, with a medium-sized plant needing 165,000 liters monthly. This thesis explores the consequences of rapid solar expansion on agriculture and water. It highlights the need for careful planning and sustainable practices to balance the nation's renewable energy ambitions with food security and water resource management. As India continues its journey toward achieving the ambitious solar energy targets, addressing these challenges becomes paramount to ensure a sustainable and resilient future for the nation.

This thesis introduces an unique Solar Panel Index (SPI), an algorithm using multispectral satellite data to identify and monitor PV solar farms, reducing false positives. The study showcases the application of SPI in the Indian context, enabling accurate identification and area coverage estimation of solar plants using satellite data. This SPI's application shows 97.8% accuracy at Kamuthi solar farm. The research also introduces the concept of the Solar Energy Agriculture Water (SAW) nexus, emphasizing the interdependence of solar energy, agriculture, and water resources. This approach allows for integrated management and optimization of resources across these sectors, addressing sustainability, food security, and climate change challenges. Solar energy's role in the SAW nexus offers sustainable and clean energy solutions while positively impacting agriculture and water resources. Solar energy is able to power the irrigation system, reduce reliance on non-renewable resources, and enhance water efficiency in agriculture. Similarly, adopting water-efficient irrigation techniques can conserve water resources and reduce energy requirements, contributing to climate change mitigation. To deepen the understanding of the SAW nexus,

a case study at the Pavagadh solar power park was conducted, focusing on its impact on agriculture and water management. Geospatial Land Use Land Cover (LULC) analysis and the Pearson Correlation Coefficient were employed to uncover relationships between land use, solar energy, agriculture, and water resources, revealing strong positive correlations. Field visits to Maharashtra solar plants show significant soil microbial differences under solar panels, highlighting the need for further research. Water utilization studies reveal various sustainable cleaning methods, including self-cleaning robots. Agrivoltaics, combining solar panels and crops, is also explored for food production and water conservation, though complete land conversion to solar farms could threaten food security and water cycles.

This study emphasizes the critical role of Geographic Information Systems (GIS) in the sustainable management of the SAW nexus. This study used geospatial datasets to identify the locations of solar farms and to assess land cover changes resulting from such solar power installation. Analysis of the patterns in land cover change revealed that agricultural land was the predominant choice for solar farm installation and expansion. The analysis was supported by statistical data, highlighting the extensive transformation of land. Additionally, this study conducted the groundwater level analysis using Gravity Recovery and Climate Experiment (GRACE) to assess water resource availability in the respective region and to gauge the potential stress that solar power plants could impose on water resources. Furthermore, overlaid of the solar farm locations with Night Time Light (NTL) data was done, which serves as a reliable indicator of electrification, spanning from 2014 to 2020, a period marked by continuous growth in the solar industry since its inception. Furthermore, this study presents the development of a Land Suitability Map (LSM) for India, based on multiple parameters, including solar potential, distance from the power grid, land surface temperature, and water availability. This LSM serves as a valuable tool for decision-makers, enabling them to make well-informed choices that promote the harmonious coexistence of solar energy production, agriculture, and responsible water resource management within the SAW nexus. The study concludes by summarizing findings and recommending policies for sustainable solar energy growth while protecting agriculture and water resources, offering lessons for other countries facing similar challenges.

The examination committee recognized that this thesis develops a new algorithm to identify solar PV farms using SPI based on remote sensing data that is useful for identifying solar energy globally. This study can be useful to map solar energy globally. The SAW nexus is also well-studied and applied in the Pavagadh Solar Power Park. In addition to Mr. Supe's excellent academic knowledge, publications, and academic records throughout the Ph. D. course were outstanding. Based on this evidence, the committee concluded that Hitesh Supe is eligible for the degree of Doctor of Philosophy in Environmental Science.