論 文 の 内 容 の 要 旨

論文題目　A global assessment of solar photovoltaic resource and energy-water nexus for future sustainability
（太陽光発電資源の全球評価及び持続可能な将来に向けたエネルギー・水ネクサスに関する研究）

氏　名　ムスタジャブ　アリ

Energy and water are among the essential needs of human beings and vital for sustainable development. Both of them are strongly connected: we use water for energy and we need energy for water. Failure to consider the nexus between energy and water (E-W nexus) may give rise to improper planning and resource allocation. The energy in the shape of solar photovoltaic (PV) is linked with a part of industrial water withdrawals (IWW), the water used to cool the Thermoelectric Power Plants (TEPPs) while generating electricity. The actual solar PV resource is calculated to support the required electricity at a global scale. This will potentially result in minimizing the freshwater usage by TEPPs and overcoming the future freshwater scarcity under changing climate and socio-economic scenarios.

At first, global solar PV resource maps under different environments are produced using the solar irradiance available near the earth's surface, and all limiting factors like temperature, dust, snow, and tilt, etc. acting simultaneously and decrease the PV output. Results have revealed that a maximum annual loss of 20.1% is seen from snow covers during December-January (DJF) for the upper Northern Hemisphere. Likewise, severe dust effects causing a power output drop of 6.5% is seen for Sub-Saharan Africa for DJF. Temperature reductions are recorded lowest (5.79%) among all limiting factors for JJA. Lastly, tilt angles are also evident to limit (1~8%) the solar PV outputs. The validation of our results shows a high value for the coefficient of determination (R2= 0.787) which demonstrates the better performance of our models. Likewise, future analysis up to 2100 by considering climate changes in terms of Representative Concentration Pathways (RCP2.6, RCP4.5, and RCP6.0) and socio-economic scenarios; Shared Socioeconomic Pathways (SSP1, SSP2, and SSP3) were also carried out. It is revealed that there would be a slight difference (-4.72% to +4.23%) in the future PV

resource under such scenarios. Moreover, cost analysis for solar PV has shown that it is competitive with conventional electricity in regions like Sub-Saharan Africa and Australia.

Second, this study dealt with the freshwater scarcity and amount of water used to cool the TEPPs while generating electricity. Water scarcity index, withdrawal-to-availability has shown that China has the maximum population (0.11 billion) under severe water stress. The cooling water withdrawals (CWW) by TEPPs is adding to such stresses as most of it is not available to the downstream areas because of being polluted and raised temperatures. Country-wise electricity generation data for different sources (coal, oil, gas, nuclear, and biomass), along with cooling technologies shares for once-through and wet tower type system, and water use intensities are used to estimate CWW for global 17 regions presented in Asia-Pacific Integrated Model. Seawater shares are then subtracted to have the freshwater withdrawals. For 2015, maximum freshwater withdrawal of 218 km3 is seen for the USA. Future analyses have confirmed the changes in these withdrawals among various regions which are attributed to the technology shifts and efficiency changes.

Third, keeping in view the technology improvement and country-wise policy to limit the greenhouse gases emission, three solar PV scenarios (PVenh) namely Low, Medium, and High are established for the future, 2050 and 2100. Region-wise solar PV areas for all three scenarios are calculated and it is revealed that this area is still very small (<0.1%) as compared to the total available land area in a region. These PVenh scenarios are used to calculate the revised CWW for TEPPs for the future. Results have shown maximum savings of 289 km3 for China for 2100 under SSP3-RCP6.0 scenario, which could help to improve the anticipated number of populations under severe stress in the region. Also, solar electric footprints of world megacities have demonstrated that roof-top PV scheme is a viable solution to offset conventional electricity, and 11 out of 24 megacities can produce all electricity using this scheme.

This study has proven that solar PV has a great potential to offset a considerable amount of renewable electricity to the system and can help to minimize freshwater scarcity. Currently, there is a mere PV input (~1%) in the total system, however, due to improving technology, and decreasing costs, it is believed to have a large impact in the energy system in the near future. This eco-friendly resource, if utilized in a proper way, could lead to sustainable development in the region in terms of energy and water. In addition, it will help in achieving the United Nations Sustainable Development Goal No. 6–Water and Sanitation, Goal No. 7–Clean and Affordable Energy, Goal No. 11–Sustainable Cities and Communities and Goal No. 13–Climate Action.