Assessing Innovative and Sustainable Solar Energy Production in Agroecosystems

This paper examines the economic viability and sustainability implications of adopting transparent solar panels (TSP) in agricultural greenhouses, using an ecosystem services framework. The study addresses a pivotal challenge in agrivoltaic policy: balancing climate change mitigation through renewable energy generation with farmland preservation. The paper's main research question explores how incorporating the value of key ecosystem services into the economic evaluation of photovoltaic and agricultural greenhouse systems (PVGs) shapes their economic viability and benefits.

The study makes several important contributions to the literature and policy discussion around agrivoltaics. It provides a comprehensive economic analysis of TSP adoption that accounts for both provisioning ecosystem services (agricultural production and energy generation) and non-provisioning ecosystem services (greenhouse gas emissions and landscape aesthetics). The research evaluates how policies that internalize these non-provisioning services through taxes and subsidies affect land allocation decisions and overall sustainability. This analysis demonstrates how an ecosystem services framework can effectively guide policy decisions on optimal land use in agrivoltaic systems.

The analysis employs VALUE (Vegetative Agricultural Land Use Economics), a partial equilibrium model of Israel's vegetative agriculture sector. This model simulates farmers' optimal land allocation across 55 crops in 18 regions, subject to input constraints and market equilibrium conditions. The study examines three policy scenarios to understand the implications of TSP adoption and ecosystem service internalization. In the baseline scenario, PVGs are prohibited and farmers maximize profits from agricultural production only. The second scenario allows farmers to install TSP and maximize profits from both agriculture and energy production. The third scenario builds on this by internalizing non-provisioning ecosystem services through taxes and subsidies.

The research draws on multiple data sources to support its analysis. Agricultural production data from Israel's Ministry of Agriculture provides detailed information on crop acreage, yields, input requirements, prices, and regional resource constraints. Solar radiation mapping data enables the estimation of potential PVG electricity generation, while carbon pricing data allows the valuation of greenhouse gas emission impacts. Applying discrete choice experiment data to estimate the aesthetic value of agricultural landscapes. This experiment surveyed 508 Israeli residents, presenting them with choices between agricultural landscape scenarios with varying levels of greenhouse coverage and compensation through electricity bill discounts. This approach generated robust estimates of households' willingness to accept compensation for landscape changes due to greenhouse expansion.

The analysis reveals that TSP represents an economically viable and sustainable PVG technology, even before internalizing non-provisioning ecosystem services. The adoption of TSP is projected to convert 1.3% of Israel's cultivable land from open fields to covered crops. While modest, this land-use change could contribute approximately 7% to Israel's electricity supply.

The economic impacts are substantial when measured on a per-hectare annual basis. The total ecosystem services value increases by $864, comprising several components. Electricity generation contributes $812, while greenhouse gas emission reductions add $259.

Consumer surplus from agricultural products increases by $277. These gains are partially offset by a $441 reduction in agricultural output and a $43 decrease in landscape value. Under full internalization of ecosystem services, farmer profits increase by $605 per hectare annually.

The research finds that policy instruments effectively achieve multiple objectives. Pigouvian taxes and subsidies successfully reduce greenhouse expansion leading to less significant landscape impacts. The policy achieves an encouraging rate of welfare return, with approximately 7% return per dollar of subsidy. This demonstrates the potential to simultaneously advance renewable energy generation, climate change mitigation, and preservation of valuable agricultural landscapes.

Several key policy implications emerge from this analysis. The research demonstrates that TSP technology represents a promising approach to balancing renewable energy generation with agricultural land preservation. Policies that internalize non-provisioning ecosystem services through targeted taxes and subsidies can effectively guide development toward more sustainable outcomes. The observed spatial heterogeneity in landscape values suggests benefits from regionally differentiated policies. Additionally, the high sensitivity to efficiency improvements indicates the value of continued technological development in TSP.

The study also identifies important areas for future research. These include the evaluation of additional ecosystem services impacts such as water regulation, analysis of general equilibrium effects on electricity markets, and investigation of alternative policy instruments beyond Pigouvian taxes and subsidies. While the partial equilibrium nature of the analysis represents a limitation that may not capture all indirect effects of large-scale TSP adoption, the relatively small land area affected and the highly regulated nature of the agricultural sector suggest these effects are likely to be limited.

This paper demonstrates the value of using an ecosystem services framework to evaluate novel agricultural technologies and guide policy development. By considering multiple ecosystem services and their economic values, this approach helps ensure that decisions about agrivoltaic adoption appropriately balance important social objectives including renewable energy generation, agricultural production, climate change mitigation, and landscape preservation. The findings provide practical guidance for policymakers seeking to promote sustainable adoption of agrivoltaic systems while preserving agricultural landscapes and ecosystem services.