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The Effects of Green Energy Production on Farmland: A Case Study in Yunlin County, Taiwan

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Abstract

Taiwan enacted the *Act of Renewable Energy* in the year 2009 which promotes energy safety, green economy, and a sustainable environment, and with that the government envisages a contribution of photovoltaic energy of up to 20% by the year 2025. In this study we look into the motivation and background of this energy policy, plans for implementation and associated challenges, and its actual consequences for farmland use and farmers. In addition, we take a look into the implementation of mixed-use farmland in which agricultural activity and photovoltaic installations are planned to coexist in order to increase land value and productivity. We furthermore report on some of our findings related to a field survey conducted in Taiwan's corn chamber of Yunlin County which has been facing a number of socioeconomic challenges.

Keywords: agriculture, farmland use, rural area transformation, photovoltaic installations, green energy policy, Taiwan

1. Introduction

The shift toward a green(er) renewable energy policy has been on the agenda for most of the industrial countries and is supported by overarching programs such as the *United Nations Development Program* to mitigate effects from climate change [1]. The implementation is not undisputed due to the actual technical as well as financial feasibility and timing in particular. Be it by reducing nuclear power sources or by eliminating energy from conventional sources such as coal, gas, or oil, tools for renewable energy need to be developed, and their implementation needs to be enforced systematically in order to cover increasing national demands. Renewable energy comes, although not exclusively, either from solar energy through the means of photovoltaic and thermal installations, from wind energy through the use of wind turbines, or from hydro energy using hydroelectric generators, often connected to reservoirs (e.g., [2]).

For Taiwan's consumption in 2017, 98% of energy was imported from fossil resources such as oil (48%), coal (30%), natural gas (15%), and nuclear power (4%). Less than 2% of the indigenous 2% of energy was contributed by renewable

energy (biomass, hydroelectricity, photovoltaic, and wind). The installed national capacities, however, covered 5276 MW of energy in 2017 with 39% conventional hydroelectric energy, 34% photovoltaic energy, and 13% wind energy [3]. Due to the dependence on energy imports from other countries as well as a change of direction with respect to the implementation of a green energy policy, the government is actively encouraging and supporting developments in this domain.

The county of Yunlin in central Taiwan is one of the areas in which green energy projects are being developed leading to a successive change of the landscape with potential long-term effects on the farmers and farmland. Together with Chiayi County in the south, Yunlin County is located in the Chianan alluvial plain built by sediments connected to the Alishan mountain range in central Taiwan. As such the plains are characterized by farmland agriculture predominantly focused on rice, sugarcane, peanuts, and corn as well as sweet potato. In Yunlin County farmland covers about 68% of the total area. A high density of fish ponds are found along Yunlin's coast with aqua culture focused on, e.g., clams and tilapia. However, Yunlin County has been suffering from structural problems over the last decade which are related to anthropogenically caused subsidence of the land (likely) due to excessive groundwater pumping. Apart from potential destabilization of the high-speed rail construction (**Figure 2**), it causes structural problems on buildings and potentially a significant salinization of farmland (e.g., [4]).

Due to the gently sloping plains of the Yunlin alluvium, rivers contribute a significant amount of hydroelectric energy. Yunlin County hosts the third largest coal power plants in Taiwan, the Mailiao Power Plant (**Figure 2**), with a total capacity of 4200 MW distributed over 7 units [5]. Wind energy has become an important topic with the conceptualization of a number of on- and offshore wind turbines recently. Currently, Yunlin hosts less than 20 coastal onshore wind turbines which constitute no more than 5% of the national wind turbines in operation. With these, a capacity of about 35 MW can be estimated. However, recent investor agreements in late 2018 consolidated plans for setting up an offshore farm with a capacity of 8x80 MW [6] (cf. **Figure 2**).

2. The rise of energy-driven demand for farmland in Taiwan

Taiwan enacted the *Act of Renewable Energy* in the year 2009 which promotes energy safety, green economy, and a sustainable environment. The targeted proportion of electricity generated by renewable energy is set to be 20% by the year 2025 where solar power will account for 20 GW. Researchers rightly pointed out that one critical issue associated with renewable energy is the siting of energy-generating facilities [7]. Renewable energy such as wind turbines and photovoltaic installations cannot generate electricity 24 hours a day due to intermittent wind or total lack of sunlight in the night, respectively. As a result, the acreage of land needed for one unit of electricity generated by renewable energy tends to be larger than for conventional installations of power generation, such as nuclear plants and water reservoirs. The feasibility of renewable energy to become the dominant supply of energy in Taiwan by the year 2025 to a large extent has become an issue of land use. In spite of the land-consuming nature of solar power, the potential vertical multiple uses of land lessen the severity of mass consumption of land. It has been suggested that certain types of crops or vegetation can be grown underneath the solar panels without loss of much productivity. This way of agricultural production presents a way of inclusive instead of exclusive use of land. As far as solar power is concerned, Taiwan government has set a target for the year 2025 of 3 GW generation from solar panels on rooftops and 17 GW from solar panels on the ground (see **Figures 1 and 2**). Given the assumption of 10 m² of space needed

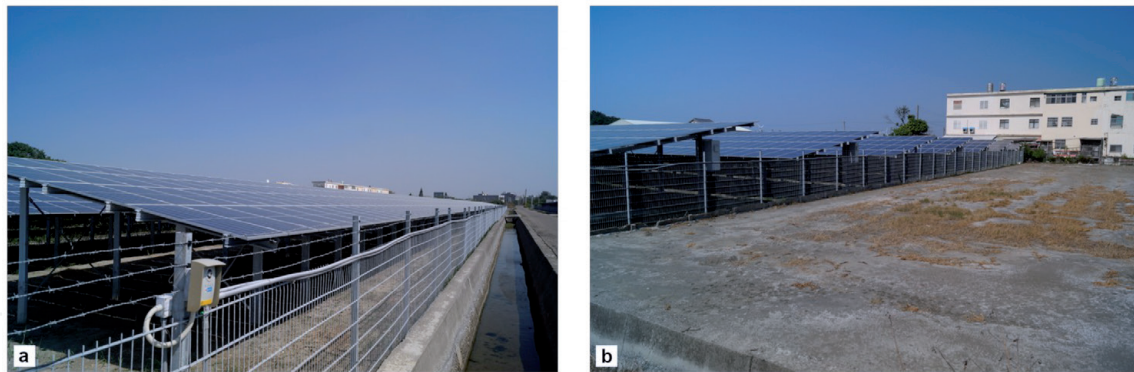


Figure 1. (a-b): Typical mounted photovoltaic arrays in central Yunlin. (a) Dense spacing of solar modules do not allow for mixed land use. (b) Inactive and probably hypersaline farmland, note irrigation channels at farmland boundaries.

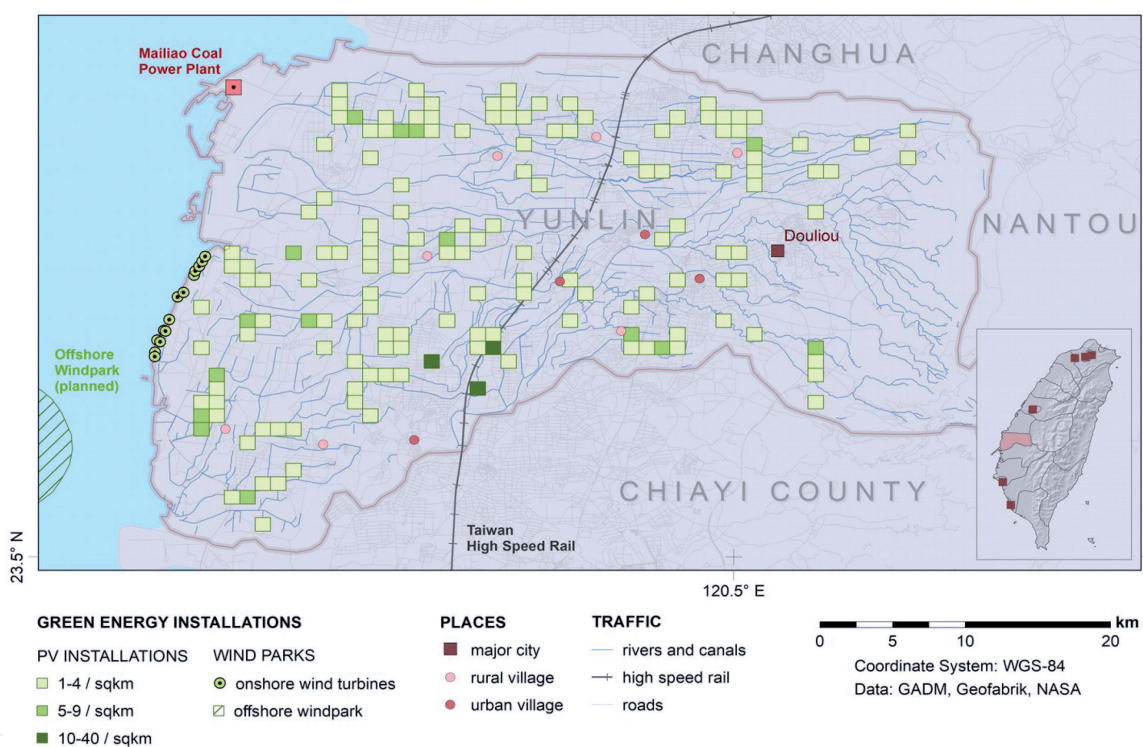


Figure 2. Sites of energy generation in the Yunlin County, locations and spatial density of rooftop and ground-based solar farms are based on a recent remote-sensing data survey and field observations.

for one rooftop solar panel and 15 m² of space for one ground solar panel, a total of 30 km² of rooftop and 255 km² of ground are, respectively, required island-wide.

In order to attain the targeted figure of energy generation, several priority sites have been identified for installation of solar panels in the 2-year initiative of solar panels proposed by the *Bureau of Energy of the Ministry of Economic Affairs*. The identified preferable location for rooftop panels are on top of state-owned buildings, factories, other buildings, and agricultural production facilities. In addition, the identified preferable sites for ground panels are sites of the salt industry, landfill and contaminated land, severe subsidence areas, and water bodies. Under a rather optimistic scenario assumed in the 2-year initiative of solar panels, 41.34 km² of space is thought to be supplied on the rooftop of all public buildings, and that could theoretically generate up to 4.1 GW of electricity. One study arrived at a potential total amount of 26.43 GW power generation contributed by solar panels on the ground surface [8]. This figure is based upon the assumption of full usage

of particular types of state-owned land (salt industry land, reservoir, detention basin, landfill, etc.) and 20% of devotion of farmland to the installation of solar panels. The authors, nevertheless, highlighted the possible conflicts between energy production and environmental protection and food security, to mention a few of them. For example, high-quality farmland that enjoys a full exposure to sunlight also tends to be well suited for solar panel installation. In this context, the counties of Changhua (彰化), Tainan (台南), Yunlin (雲林), and Chiayi (嘉義) have been promoted as priority counties for the installation of solar panels to exploit longer hours of sunlight [9] (**Figure 2**).

Besides, the lack of experience and concern over environmental issues caused by the installation of solar panels will certainly lead to impacts on the farmland market, both in terms of sales price and transaction volume. The only study so far that attempted to measure the price effect of solar panels on nearby farmland was conducted by [10]. In this case study of Tainan City, no uniform price effect has been found. The farmland price might either rise or fall with the distance from the solar panels depending on the regions they are located in. However, [10] concluded with a warning saying that the rising farmland value might harm the farming production on a longer term.

The link between energy consumption and location of solar panels on farmland is already recognized: the more the reliance on renewable energy, the more it will lead to a competition among alternative land uses. However, the discussions in Taiwan so far overly simplify the provision of farmland into sites of solar panels. Their conclusions are strongly based on the rosy assumption that a certain percentage, for example, 50%, of private land owners will soon agree to enter a long-term leasehold (of at least 20 years) with an energy company.

In the leasing of farmland for installation of solar panels, the annual rent paid by the solar power company to land owners as advertised, for example, by MOTTECH [11], is 40,000 New Taiwan dollars (approximately 1300 USD as of December 2018) for 1000 m² that will last for 20 years. Is the rent attractive enough to move the dominant use of land from farming to solar panels? The *Council of Agriculture* reports an average rent for farmland per square meter in the Tuku Township of Yunlin—famous for its garlic farming—to be 9.14 NTD, equivalent to 9140 NTD for 1000 m² of farmland [12]. That is to say, the revenue of leasing land to allow for photovoltaic installations earns 4.4 times the market rent for farming. The rent offered from solar panels is apparently alluring.

3. Designating locations for solar panel installations

Governmental criteria for designating land for solar farm use can be classified into three major categories:

1. Land characteristics suggest excluding solar farm designation due to incompatibility reasons.
2. Land characteristics suggest incorporation of solar farms in addition to or as a replacement for original use.
3. The landowner's socioeconomic status suggests incorporating solar farms is a good choice (cf. **Table 1**).

When it comes to the first case of incompatibility, a wide variety of concerns must be considered to avoid intrusion upon or damage to land resources:

environmental, agricultural, landscape, perspectives of cultural heritage, habitat, human settlement, etc. [13–15]. Solar farms are often a more efficient use for land encountering difficulty retaining its original use due to contamination, subsidence, or other deteriorating factors. In the third case, solar farms can be utilized as a tool to aid socioeconomic hardship on the part of landowners by offering a source of extra and potentially higher income, such as for financially disadvantaged or aging landowner communities.

Rooftop solar panels are allowed on agricultural land in Taiwan, but solar farms with panels set directly into the ground are restricted except in cases where the land has already been permanently contaminated and is not fit for further agricultural use. Rooftop panels are encouraged for most buildings, with the exception of greenhouses (who have a 40% maximum limit) and screenhouses, as they have minimal impact on ground-level land use and contribute to the self-sustainability of agricultural production. Ground-level solar farm use is generally not allowed for the protection of agricultural resources except when strict conditions are met, conditions that themselves correspond to the above three criteria (cf. **Table 1**). Under criterion 1, agricultural land of the highest grade (i.e., “special agricultural districts”) without actual farming activity is restricted from building solar farms [17]. Under criterion 2, agricultural land with farming activity can build solar farms within designated areas up to a 40% land use maximum. In practice, however, this type of solar farm is not encouraged as local governments fail to designate the appropriate areas. Under criterion 3, contaminated agricultural land is applicable for building solar farms

	Land use type	
	Land in general	Agricultural land
Governmental/theoretical criteria	<p>Three categories of criteria:</p> <ol style="list-style-type: none"> 1. Land characteristics that suggest excluding solar farm designation due to incompatibility, including (a) landscape and environmental concerns [13], (b) agrolological concerns [16], and (c) socioeconomic concerns [15] 2. Land characteristics that suggest incorporating solar farms in addition to or as a replacement for original use 3. Landowner’s socioeconomic status suggests incorporating solar farms is a good choice 	<p>Rooftop solar panels: Solar panels can be installed on the roof of existing buildings in agricultural land except for greenhouses (a 40% maximum) and screenhouses (The Government of Taiwan, 2018b)</p> <p>Solar farms: Criterion 1: Agricultural land of the highest grade without farming activity is restricted from building solar farms [16] Criterion 2: Agricultural land with farming activity can build solar farms within designated areas up to 40% land use maximum. In practice, however, land remains undesigned [18] Criterion 3: Agricultural land with a loss of agrolological capacity can be considered for solar farm designation up to a 70% maximum, including (a) existing permanently contaminated agricultural land and (b) subsided or salted agricultural land [18]</p>
Issues	<p>Change of land cover and landscape Potential environmental impacts on biodiversity due to land cover change from solar farm implementation [16] Potential economic impact on the original function of the land</p>	<p>Some agricultural land is overzealously replaced or abandoned altogether in lieu of solar farm upkeep by unscrupulous farm owners [19] Some tenants’ farming businesses are terminated by landlords seeking better revenues via solar farming [20]</p>

Table 1.
Compilation of designation of solar farm locations and associated issues.

(who have a 70% maximum limit) only when landowners have been devoted to decontamination, but the land has failed to recover. This condition does not apply, however, to potential future contaminated land for a variety of reasons, including to avoid cases of intentional contamination [21]. Furthermore, subsided or salted land that loses agricultural capacity can be considered for the building of solar farms [18].

4. Current challenges with respect to solar farm deployment

The deployment of solar farms may cause a series of issues from changes in land cover and landscape to impacts on environmental and economic functions of the designated land and surrounding areas (cf. **Table 1**). A change in land cover has potential environmental impacts on biodiversity as well as ecological value and function [16]. These environmental impacts are possible not only at the site of the solar farm itself but also in nearby areas whose ecological systems are inseparable. As land is taken up by solar panels, this affects the landscape and original function of the land, and economic impacts on the agricultural industry may occur due to a compromised microclimate under the panels due to a decrease solar radiation, less rain uptake, and so on [22].

In addition to these various generalizable issues, Taiwan has encountered some unique issues of its own in implementing solar farm policy; the original functioning of some agro-farms has degraded or been abandoned altogether due to insufficiently robust design of the relevant laws initiated by the then inexperienced legislature; cheating and illegal behavior of agro-solar farm owners has occurred, and high costs and intensive labor requirements for the monitoring and enforcing of these laws have been incurred (cf. **Table 1**). In 2013 the regulations for building solar panels on agricultural land were first included in the law by the central government's agricultural agency [18]. At this time, however, a considerable amount of farmland had already been replaced by solar farms due to premature laws that did not require the participation of agricultural agencies in the process of reviewing solar farm applications. Later in 2017 newly implemented laws required the agro-solar farm to maintain the agricultural function to the degree required in the review process, and failing to keep up this agricultural performance would cause termination of the solar farms in the worst case. The high financial return possible from solar power caused cheating and illegal farming practices to skirt these requirements to occur, which in turn calls for high-cost and labor-intensive monitoring on behalf of the government to enforce these laws, particularly given the enormous number of cases [19, 23]. In addition to this incentive to mismanage the agricultural side of solar-agro production, some tenants' farming businesses have been terminated altogether by landlords seeking these higher revenues from solar energy [20].

5. Land use codes and their impact on agricultural output and solar power generation on agricultural land

This section illustrates three applications of the land use code in managing solar farms on agricultural land as particularly impactful on the productivity of crop yields and solar energy generation: the mixed use of solar panel installation and original use, the distance between solar arrays, and the elevation of solar panels' aboveground level.

Firstly, incorporating a mixed-use scheme between agriculture and solar panels residing on the agricultural land (crops grown beneath solar panels, cf. **Figure 3**) can be derived from agroforestry experience where the simultaneous implementation of two types of products on the same land area can optimize its overall productivity [24].

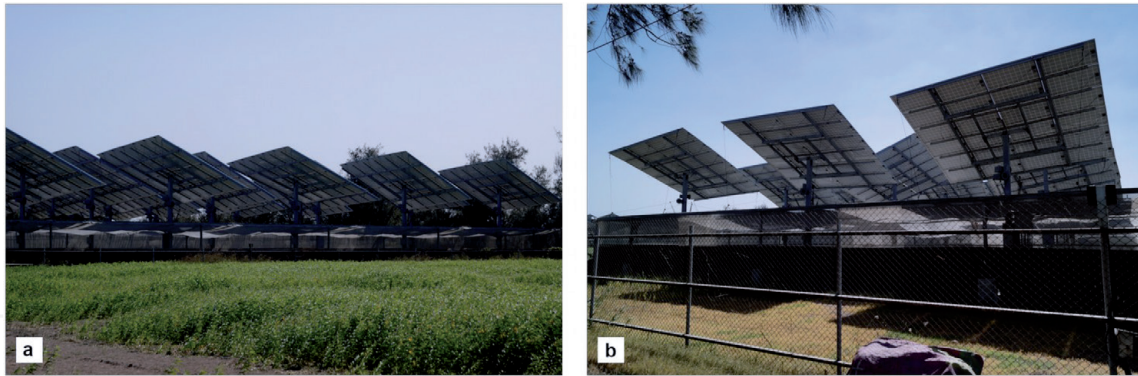


Figure 3.
(a-b): Photovoltaic arrays in central Yunlin County with solar trackers to allow for higher efficiency by tracking the direct sunlight beam. Less dense module spacing allow for mixed-land use if feasible.

Although less solar radiation is available under solar panels, potentially affecting crop productivity and types of crops suited for this type of planting, based on simulation analysis, a mixed-use scheme has higher combined productivity (solar power generation plus crop yields) than a single-use solar farm or agro-farm would on its own [25]. Additionally, a full-density solar panel pattern deploys the optimal configuration for electricity generation and can yield higher combined productivity of the land use than a half-density pattern. The higher the proportion of land dedicated to solar panels, the lower the production of crops. However, the correspondence is not one to one. An increase in solar panel land use yields a proportionally lower decrease in crop yield. In Taiwan, to meet food supply targets by keeping some portion of agricultural land for farming, 40% and 70% are set as the respective caps in the land use code for viable and nonviable (or contaminated) agricultural land that may be used for solar farm implementation [18].

The impact of the land use codes regarding the distance between solar arrays has been less studied, although too small of a distance between arrays is likely to negatively affect solar radiation. The third factor at play—solar panel elevation—likely affects the productivity of solar power generation due to dust deposition as well as the productivity of crop yields due to the influenced solar radiation on the ground, ventilation by the wind, and farming activities [24, 25]. A 4-meter elevation is generally regarded as satisfactory [25], and 4.5 meters is adopted as the cap in the codes for Taiwan [18].

These three factors, mixed-use, elevation, and distance between solar panels, can play crucial roles in achieving some of the *Sustainable Development Goals* (SDGs) of the United Nations' 2030 Agenda for Sustainable Development [26], among others, set at the national or regional level. For example, to remain at a certain level of self-sustaining food supply, a maximum level of land designated for solar farms must be adopted to allow ample room for food production. At the same time, a land use code that provides for a full density of mixed use can be adopted to achieve maximum combined productivity of solar power as well as crop yield. This takes full advantage of land and boosts maximum green energy production. Such a mixed-use scheme can be introduced and expanded to diminish poverty, reduce inequalities, and develop sustainable communities. Nonetheless, the knowledge on such potential implementations is still scarce, and further research is required.

6. Outlook

Green energy is not unequivocally met with positive feelings among the population. Reasons for this are complex and hard to pinpoint. Yunlin County is slowly over-aging facing emigration toward structurally better developed areas. In how far

this new age structure plays a role is not yet well understood. Conventional agriculture becomes challenging not only because of a changing climate but also because of anthropogenic contributions to county-wide subsidence effects leading to a deterioration of the soil quality and stability. Natural reservations against the placement of wind turbines or photovoltaic installations in the backyard due to fear against, e.g., electromagnetic radiation or ground pollution introduced by cleaning agents (e.g., [27]), respectively, can only be met by targeted information campaigns by the government, the Environmental Protection Administration (EPA), and contributing companies. Based on a local nonrepresentative survey, some of the farmers feel let down by the government regarding information exchange. Furthermore, it remains to be seen in how far the current global dispute among leading industrial countries regarding strategies of mitigating climate risk will negatively influence perception of local farmers in Taiwan as well which only increases the degree of complexity.

During the next period, the group's research will partially focus on establishing a better understanding of this complexity and the interdependence between socioeconomic, socio-technical, and socio-natural effects to be able to contribute to a better understanding and education, in order to find targeted approaches to improve the local situation.

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Conflict of interest

The authors declare no conflict of interest.

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