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Ensuring That Dual-Use Means Multi-Value: A Framework for the Co-Prioritization of Cattle Grazing and PV Energy Generation

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Abstract. Photovoltaics (PV) is the fastest growing portion of the energy sector and the lowest-cost form of renewable energy today. PV development will continue to accelerate as the world strives to meet climate goals and reduce dependence on fossil fuels. The need for open, sun-abundant landscapes puts the solar (PV) industry in competition for land with agriculture and threatens intact native rangeland, stimulating valid concerns about negative impacts to ecological processes and function, such as soil stability, nutrient cycling, water cycling, and biodiversity. The co-location of PV energy generation and agriculture, commonly referred to as agrivoltaics, and specifically livestock grazing, offers a win-win scenario. While sheep grazing is being broadly employed, there is increasing interest in cattle grazing on PV projects. Our research seeks to understand if we can co-optimize cattle grazing and PV energy generation by designing and managing *Solar Savannas,* where ecological processes, capture of solar energy, and animal health and agricultural performance are equally prioritized. This is not only a question of dual-use but of multi-value. For agrivoltaics to be a meaningful sustainability solution, we hypothesize that dual-use must provide multiple values, including ecosystem service provision, agricultural production, and PV energy generation, bolstering community relationships and social and economic viability. We are engaged in ongoing research to ensure and measure this multi-value system, building ecological, agricultural, and financial models. What we learn from the modeling of this multi-value approach to eco-agri-energy systems is intended to eliminate tradeoffs of either-or systems, reduce barriers to dual-use systems, and finally, promote holistic solutions for the integration of multi-value systems. The purpose of this paper is to present a novel foundational framework, the Solar Savanna, and establish a theoretical basis for research and agrivoltaics practices.

Keywords: Agrivoltaics, Agri Solar Grazing, Renewable Energy

1. Introduction

Photovoltaics (PV) is the fastest growing portion of the energy sector and the lowest-cost form of renewable energy today [1]. PV development will continue to accelerate as the world strives to meet climate goals and reduce dependence on fossil fuels [2]. The need for open, sun-abundant landscapes puts the solar (PV) industry in competition for land with agriculture and threatens intact native rangeland, stimulating valid concerns about negative impacts to ecological processes and function, such as soil stability, nutrient cycling, water cycling, and biodiversity [3-5]. The co-location of PV energy generation and agriculture, commonly referred to as agrivoltaics, and specifically livestock grazing, offers a win-win scenario [6]. Agrivoltaics by way of sheep grazing, has expanded in recent years in the United States (U.S.) and other countries, with little to no additional cost to solar operations. In addition to win-win successes in sheep grazing practice and according to scientific research, there is increasing interest from the agriculture and solar communities in cattle grazing on PV projects. This stems from global land dependencies of both cattle production and solar energy production. Cattle integration, primarily due to animal size and behavior, invokes new challenges for agrivoltaic visionaries, planners, and practitioners.

Our driving question is: Can we co-optimize cattle grazing and PV energy generation by designing and managing *Solar Savannas*, where ecological processes, capture of solar energy, and animal health and agricultural performance are equally prioritized? This is not only a question of dual-use. It is a question of multi-value. A savanna biome is a grassland with scattered trees and shrubs supported by symbiotic sun-plant-soil-animal relationships, a multi-value system indeed. In our Solar Savanna concept, the tree or shrub canopy is replaced by a solar panel canopy. Our collaborative science team is a partnership among government, university, technology, agriculture, and solar industry experts who seek to understand if dual-use translates to multi-value. Through our ongoing holistic approach to PV research, conducted in the southeast and central U.S., we are developing ecological, agricultural, and PV financial models to uncover a cattle-compatible design that is good for the land, good for the animal, and good for solar. This project is titled, *Integrated PV System Design and Management Platform for the Co-Optimization of Regenerative Cattle Grazing and PV Solar Generation.* We intend that results of our scientific inquiry will reduce barriers to PV energy production on grazing lands while developing procedures for measuring and monetizing the eco-agri-energy services of multi-value solar projects. The objective of this paper is to present a novel foundational framework, the Solar Savanna, and establish a theoretical basis for research and agrivoltaics practices.

2. Solar Savanna Symbiosis

Similar to a row crop farm, an aquarium, or an improved pasture, the Solar Savanna is a synthetic ecosystem, where ecological processes and relationships are supported and managed by humans. In the Solar Savanna, animals and plants are offered shade and shelter by the solar array canopy, mimicking a tree and shrub canopy. Livestock feed on diverse forages and fertilize the soil, while providing service to the solar equipment by keeping vegetation at bay and soils in place through the maintenance of living roots. All parts of this system contribute to the health and function of the whole (Figure 1. Multi-value PV concept, the “Solar Savanna,” for agrivoltaic grazing systems.).

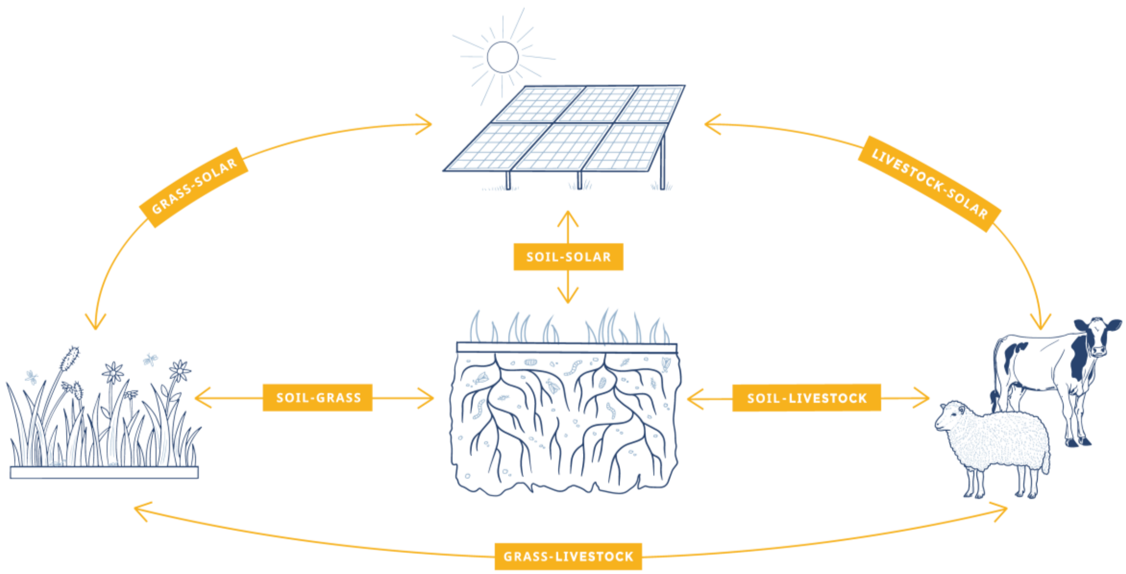

Figure 1. *Multi-value PV concept, the "Solar Savanna," for agrivoltaic grazing systems.*

In the Solar Savanna there are four primary participants: the solar array, soil, vegetation, and livestock. Each participant contributes to the ecosystem and provides a service to the other participants, creating a symbiosis and exchange of services. While peripheral to the cyclical mechanisms of the Solar Savanna, humans are also a part of this system. Humans play a significant role as managers and decision-makers and are beneficiaries of the Solar Savanna as consumers of energy and food. Therefore, the care and stewardship that humans return to the system should be reciprocal. In this way, the system functions sustainably, creating ecological, social, and economic value.

2.1 Symbiotic Relationships Among Participants

In our research, we are engaging soil and vegetation field sampling, Eddy covariance flux measures, animal science trials, and biogeochemical modeling with DAYCENT [7, 8]. With this multi-modal methodology, we are able to comprehensively analyze ecosystem dynamics among Solar Savanna participants. Characterizing the Solar Savanna means addressing six symbiotic relationships influenced by human management (Figure 1. Multi-value PV concept, the "Solar Savanna," for agrivoltaic grazing systems.).

The Solar-Soil relationship is one of structure and functionality. The solar array shades the soil, reducing evapotranspiration of critical moisture and soil temperature. Soil, in turn, provides the structural foundation for the solar array, holding it in place. Healthy soil function and stability supports solar array infrastructure and stormwater runoff prevention compliance.

The Soil-Vegetation relationship is critical for local and global processes, life on planet Earth. Soil is composed of microorganisms, organic and inorganic elements, and water, which provide nutrients to plants. Healthy soil promotes greater plant growth and deeper root systems. Vigorous above ground vegetation likewise armors the soil, protecting it from wind erosion and radiation, while sequestering carbon via photosynthesis. Robust root systems stabilize the soil, mitigating water erosion and nurturing biologic integrity.

The Vegetation-Livestock relationship is realized through the act of herbivory. Vegetation of various qualities and types provide large herbivores with a valuable fibrous and nutrient dense food source. Through the act of grazing, livestock (domestic large herbivores) maintain plant vegetative productivity, support biodiversity, and assist decomposition via trampling, bedding, and manure and urine deposition.

The Livestock-Solar relationship is a unique one, emerging from the novel ecosystem of the Solar Savanna. In this ecosystem unmanaged, overgrown vegetation is a liability for solar energy operations. Livestock graze vegetation preventing it from shading the solar array, which supports energy productivity. Meanwhile, the solar array provides shade for livestock, improving their overall health, via reduced heat stress, improved thermoregulation, and reduced water consumption [9, 10]. Livestock production on a solar project also leads to multi-value commodities, for example, wool or nutrient dense meat products, raised on land also providing clean energy to society.

The Solar-Vegetation relationship is based in sun and shade dynamics. Solar panels provide intermittent shade for vegetation, reducing water needs, improving soil moisture retention, and alleviating heat stress. This contributes to above ground vegetative growth and productivity similar to non-paneled pastures [5]. The grid-like solar array design, also creates diverse amounts of radiation reaching vegetation, which supports a variety of sun-tolerant and shade-tolerant plant species. This sun-shade pattern creates plant community niches and encourages biodiversity. In turn, live vegetation absorbs sunlight, reducing ambient temperatures below panels, therefore increasing photovoltaic energy output.

The Soil-Livestock relationship is founded in nutrient cycling. Healthy soil provides the foundation of a thriving ecosystem and abundant forage that sustains livestock needs. Livestock manure and urine serve as organic fertilizer, returning the majority of grazed offtake back into the soil. Animal hoof impacts chip and indent the soil surface, increasing water infiltration and soil aeration.

3. Multi-Value Framework

Dual-use in not enough. For agrivoltaics to be a meaningful solution to sustainable food production, renewable energy expansion, and community wellbeing, we hypothesize that dual-use must provide multiple values, including ecosystem function (e.g. soil health, carbon and nutrient cycling, biodiversity, and water cycling), agricultural production, and PV energy generation, bolstering community relationships and social and economic viability. In some agrivoltaics cases, the agricultural activity may be convenient, low risk to the PV project, and economically neutral. In other cases, the agrivoltaic PV design may be cost-prohibitive and unscalable for today’s energy markets. Each social-economic context drives relative benefits and tradeoffs. Comparatively, to press into truly integrated and diverse agrivoltaic activities, compromises must be made, while creating diversified value. In a symbiotic system, like the Solar Savanna, it is important that all uses remain in balance, an *eco-agri-energy nexus*, within a social-economic values context (Figure 2).

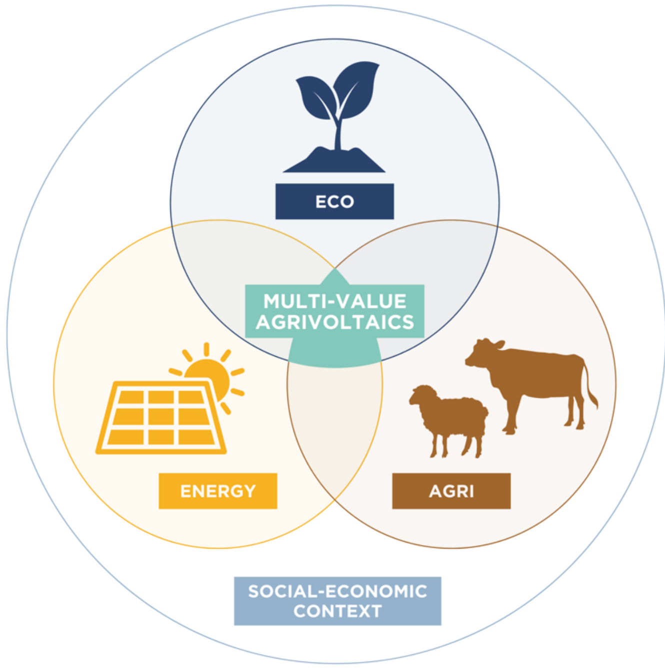

Figure 2. *The multi-value eco-agri-energy nexus concept for agrivoltaics.*

To quantify this multi-value concept, we are building financial models for the integrated agricultural and PV power generation enterprise, as well as the environmental markets business, via the modeling of biogeochemical dynamics and development of a novel carbon protocol methodology specific to agrivoltaic systems. What we learn from the modeling of this multi-value approach to eco-agri-energy systems is intended to eliminate tradeoffs of either-or systems, reduce barriers to dual-use systems, and finally, promote holistic solutions for the integration of multi-value systems.

Is cattle ranching and solar better together, enabling the stacking of multiple values? If solar energy generation detracts from the ecological health or the agricultural cultivation of the system, then the two are not better together, and the Solar Savanna model will not be replicated or scaled. Cattle have certain management and infrastructural needs. Could we design cattle-accommodating solar PV systems where capital costs are justified by multi-value returns? The social-cultural values and identities of cattle ranchers across the world are distinct and diverse. Could a niche role emerge from the Solar Savanna context? Cattle markets are dynamic, and land demand remains high. Could the needs of cattle ranchers and solar operators foster economic compatibilities? To place value on the merger of cattle ranching and PV energy generation, we turn to the established concept of *ecosystem services* in support of our multi-value approach.

3.1 Value Categories

Ecosystem services are the contributions of natural systems and their species that benefit human life and wellbeing [11]. They describe how value flows from nature to people. Mounting research of ecosystem services encourages a pluralistic approach to valuation, acknowledging sociocultural values in addition to monetary ones [12]. This approach to appraising value is especially relevant to grazing agrivoltaics, as it inherently incorporates the diverse objectives and needs of diverse industries, agriculture and PV. In fact, integrating a multi-value framework is more effective for equitable, long-term social and economic resilience [13]. For cattle grazing agrivoltaics we use our *eco-agri-energy nexus* to present a coherent, multi-value model.

3.1.1 Eco Values

As illustrated by the Solar Savanna, the ecological values of a grazing agrivoltaic system are numerous. From soil to plants to animals, the Solar Savanna transforms an energy project into an ecosystem. There is ecological value in biophysical outcomes, like reduced evapotranspiration, reduced soil surface temperature, improved soil moisture retention, improved forage quality, and biodiversity. Co-prioritizing eco values benefits nature and society through functional biogeochemical processes and effective land stewardship. In the Solar Savanna framework (Figure 1), soil is linked to every other component. Healthy, biologically-active, and functioning soils are supported by the manure and urine inputs of large herbivores [14, 15]. This cycling and recycling of biologically available nutrients are a vital part of a productive grassland or savanna ecosystem. The ecological values of the Solar Savanna are embedded in its functionality to conserve water, store carbon, and cycle essential nutrients from the sun and atmosphere to the soil via plants and animals. Stable, plant-covered soil also provides structural support and a stable foundation for solar PV infrastructure.

3.1.2 Agri Values

Converting land use from food production into energy production is not a popular or wise tradeoff when both uses can be maintained through agrivoltaics. For grazing lands, the Solar Savanna offers significant agricultural values, including animal health and welfare, sociocultural and community benefits, and economic interests. Animal science research involving sheep and cattle has shown that animals with access to shade or solar panels demonstrate reduced heat stress, improved thermoregulation, improved feed efficiency, reduced water consumption and time spent searching for water, improved average daily gain, and improved dressing percentage, compared to control groups [9, 10, 16]. Keeping livestock on solar lands preserves rural community identity and sense of place, supporting the sociocultural values of people and families. In fact 80% more survey respondents in the U.S. were more likely to accept solar development if it involved agrivoltaics [17]. In practice, the economic benefits of agrivoltaics to ranchers and farmers is a net positive scenario. On rancher-owned lands, the Solar Savanna keeps agri values in the equation, while diversified income of an energy lease reinforces agricultural commodity market variability and creates financial stability. On solar company-owned lands, where the rancher or farmer may be contracted to perform vegetation management via grazing, income is secure, lucrative, and potentially enduring. Furthermore, access to this additional land base offers established ranchers and farmers operational expansion or an entryway for landless 1st generation agrarians.

3.1.3 Energy Values

The solar PV development process requires planning, permitting, and community buy-in. Agrivoltaics provides a valuable opportunity for true community integration through agricultural partnerships with local ranchers and farmers. This results in added sociocultural value to the solar developer through social appeal and acceptance. Ranchers and farmers in a Solar Savanna become collaborators with knowledge and skills of solar project operations, who can recognize and act upon operations and management (O&M) needs or concerns. Agrivolatic design considerations start with quality construction and attention to detail, which are fundamentally beneficial for the longevity of a PV project. Panel height and row spacing are conventional levers used by solar developers to reduce vegetation management concerns, such as mowing frequency and wildfire fuel loads. It is typical for these design levers to have direct impacts to upfront construction costs and, potentially, energy costs. Therefore, design considerations (levers) for cattle integration may follow a similar logic for short and long-term decision-making. Owners of PV project must be able to recognize the multiple values that an agrivoltaic project can bring to this equation, ultimately reducing cost-benefit tradeoffs. Finally, the reputational benefits derived from an agrivoltaic approach to solar development further supports public awareness and education and may provide a marketing advantage for the sale of clean energy.

4. Implications

Agrivoltaics for grazing systems is inherently a cross-disciplinary field. Environmental components require the ecological, climate, animal, agricultural and soil sciences. Understanding PV design components requires engineering and data analytics. Our project has united these fields and brought together industry experts to uncover a cattle-compatible system design that is both ecologically and socio-economically functional. Prior to our research, no other initiative has taken the foundational steps to test comprehensive, industry-wide hypotheses for the co-location of cattle on PV projects. Through our learning, we aim to provide decision-making guidance for the economic viability of the Solar Savanna while sustaining multi-values across the nexus.

If we are going to introduce cattle to the Solar Savanna, we need to ensure that the whole ecosystem, including ecological, social, and economic dimensions, is prioritized. We must seek a balanced outcome, deliberated on multi-value benefits, to earn trust in communities and maintain integrity as an industry. The key for advancing cattle grazing agrivoltaics is to ensure that the solution is good for the land, good for the animal, and good for solar. The Solar Savanna is such a solution, a synthetic ecosystem that provides a multi-value approach to stakeholders, leveraged by an eco-agri-energy symbiosis. These values must be integrated, not only adjacent. We intend that scientifically exploring these dynamics will resolve conundrums and inquiries common across the agricultural and solar PV sectors.

Data availability statement

This article presents a theoretical framework and is not based on data.

Author contributions

Nick de Vries: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Roles/Writing – original draft, Writing – review and editing.

Anna Clare Monlezun: Conceptualization, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Roles/Writing – original draft, Writing – review and editing.

Competing interests

The authors declare the following competing interests: Silicon Ranch is a solar corporation engaged in the practice and research of agrivoltaics to uncover mutually beneficial solutions for the solar and agriculture industries.

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