# Emergence of Agrivoltaics in Rural America

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**Demari Johnson**

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On my honor as a University Student, I have neither given nor received unauthorized aid on this Assignment as defined by the Honor Guidelines for Thesis-Related A

Advisor

Kent Wayland, Department of Engineering and Society

**Introduction**

Suburbanism. An American epidemic. Cities in the United States, unlike most other countries, support the idea of expansion. Instead of building densely populated sectors, we support the idea of having our own space due to our image of freedom and solitude. However, expansion can only take place if land is readily available and is free to use commercially. This form of thinking fuels the shrinking of what is known as rural America.

When we envision rural America, we might think of a slow, one light, gas station town that is fueled by traditional thinking and core beliefs. With land development being crucial to the growth and expansion of future population and the resources for cities, it draws the question of where should America look to next. Small town communities. This growth leads to changes in prices, influx of people and businesses being brought in, and job industries for the people that already live in the area. For this paper, I would like to focus on the fuel that is driving mass populations to rural communities and incorporating a potential system that may be able to diminish social tension between the vast country and its approaching, urban neighbors . Again, this is all due to rural America being displaced by people in urban sectors because of their land/area being deemed as valuable.

As core communities are shrinking, and the job industries associated with it as well, it does bring questions about the issues of land development taking place in rural America and the issues of increased usage of energy demand, especially in areas closer to major U.S. cities. Solar panels farms have been commercially used as a way to mitigate the energy demand efforts by reducing harmful emissions released into the atmosphere, but it still has its drawbacks. They too need space to accommodate the growing populations and while they do bring down monthly utility bills, they are still pricey, most won't see the benefits until years down the road, and they

favor urban communities more than the suburban. So it draws the question of *"Is there a system out there that can accommodate both the urban communities while advocating for the rural communities?*" The solution would be yes, agrivoltaic systems.These systems utilize both agriculture and energy production by combining industries. The garden goes underneath the solar panels, which provide adequate shading and moisture retention through a water system, and optimal solar intake by having the solar panels raised at a higher height altitude closer to the sun. This system will be a key driver into communities slowly integrating together without the change of industry taking place in rural communities. Throughout this paper I will like to analyze these systems and determine if it is possible to integrate into everyday use in communities where urban sprawl is encouraged.

**Background**

To start off, the U.S. has 2.3 billion acres of total land use with green pastures and rangelands consuming the majority of it (roughly 29%) (Bigelow, 2017). This land is mainly used for commercial and residential use with cities and suburban areas taking up the majority of the space. With these large urbanized areas constructed in just this land alone, it does bring the question of where would society head next? Will it develop upward in density populated cities or will it expand out into the vast spacious land? That is the main question when demand for energy, especially as both cost and the necessity to provide a sustainable solution to combat growing populations in urban centers is continuously rising.

Drawing from these ideas and constraints, on readily available land, there have been many implementations on how solar panels provide energy that meets its population. As the population continues to increase, so will the demand that draws it in. Thus the incorporation of

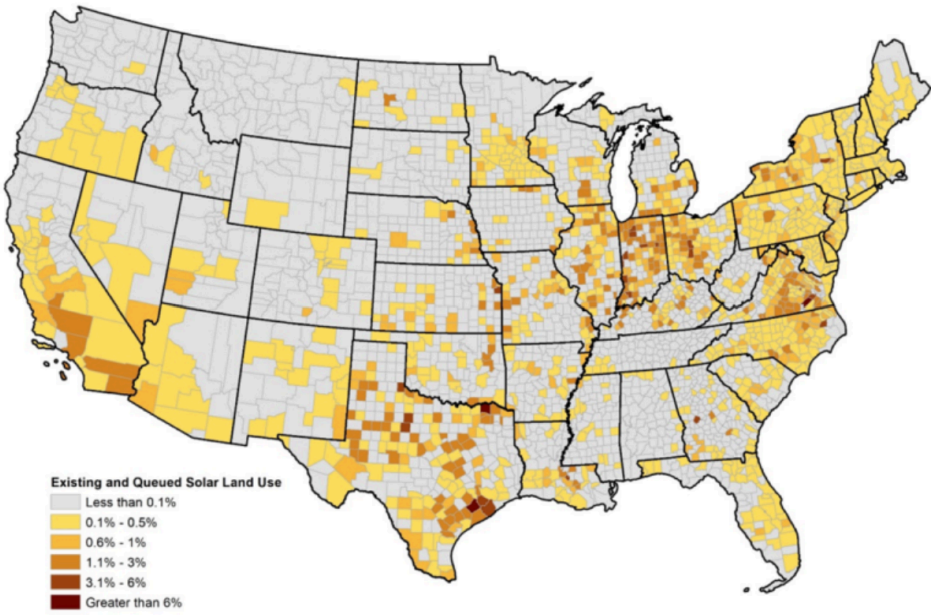
more solar panel farms emerging must be necessary in ensuring power is brought to suburban areas for both residential and commercial use.

Building on the idea of renewable energy devices also brings the problem of more land development being taken up by solar panels in addition to suburbs slowly expanding out. The construction of solar panels includes available, steady, and flat land to have them as stable and fixed in a certain position. Then a weighted surface would need to be utilized to hold down the solar panels whether it is through the use of rocks or bolted to concrete/steel surfaces. The use of a silt fence or low parameter can designate the work space and create a protective zone for construction/ Then the use of electrical engineers, with wiring and installing an inverter, to transform the electrical current, can provide power to certain communities. This would allow for a healthy solar farm to develop.

Industries and corporations also have to think about the quality of life they are bringing to the desired areas of living as locals normally do not want large plants in their proximity anyway. Thus, looking into renewable energy sources is a highly viable, feasible, and even more cost efficient option than its fossil fuel counterparts because of the qualities it possesses. As an example, the introduction of technological improvements and lowered manufacturing costs, pushed the incentives for renewable energy in the country. This goes along with the fact that the U.S. only produces less than around 1% of electrical energy for its inhabitants due to it initially being more of an investment before seeing profit gain in the later future. This leads to the emergence of the environmental plans of utilizing UV farms for production where land is available and readily accessible.

As good as this sounds, this does bring complicated issues in rural America as many of them are opposed to non-renewable energy sources due to their personal stances on N.I.M.B.Y,

which means not in my back yard (Gleason 4, 2023). This is an understandable way of thinking due to multimillion dollar corporations coming from large urban sectors, without any community engagement, and telling people that their landscape and topography will be changed by their industry. Thus for Farmers, there is a lack of adequate green space for them to carry out their roles and responsibilities which is raising livestock and producing agriculture for themselves and their community. In 2023, for example, there are 76.2 million less acres in farmland than in 1997 due to the increase in suburbanism, industrial infrastructure, and energy demand that comes with it (IER, 2024).

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Thankfully in recent years there has been better communication on the implementation of solar panels in these spaces due to lowering monthly utility bills, including electrical, and providing benefits in creating a self reliant power grid (kaya et al., 2019). This has led to the overall growth and popularity of solar panels to be more commercially displaced throughout the country. Still the issue is on the future of land development taking place. This linkage has led to

alternate solutions being utilized, agrivoltaic systems, so that farmers can keep their industry while energy demand also keeps up with the increase in population.

The biggest supporters of agrivoltaic usage comes from the idea of job industries trying to remain environmentally conscious, such as farmers. Farmers, who were once opposed to the idea of utilizing big tech in their areas came around with a 72% support rate of using agrivoltaics due to the monthly revenue that is entering their pockets as well as the savings that comes along with it (Wagner et al., 2024 ). This benefits Americans since the country is known for having biodiversity through its different climates and terrains where companies can capitalize on agrivoltaics popularity and add to their own listings of sustainability goals/net zero plan by 2050 (Toledo, 2021).

This universal tool, agrivoltaic systems, combines agricultural production by including space underneath the solar panels for crop and seeding to occur. This aligned with the idea of mass energy production to occur has made this an ideal source of renewable sustainable energy to be utilized in rural areas. This is different from solar panels as they do not sit as low to the ground and the lack of food production that can be accumulated with the lack of space. This is the combination of two industries in one.

**Methods**

For this topic, research on whether agrivoltaic systems can be integrated into American society would be taken into account. The evidence that I have collected, corresponds to the overarching theme of the progressive movement America is taking towards energy development as populations and space begin to fluctuate. Research methods I have used include using the resources presented to me by the UVA library and how to access key information. To gather information for my topic, I picked a specific location to focus on, which includes mainly the

suburban area of D.C. known as NOVA(Northern Virginia). This location allows the reader to understand the scopes of rapid development taking place in locations where the population is slowly expanding out. Through the usage of expert opinions and research, it will make it easier to see if agrivoltaics can be utilized in this region.

For my secondary sources, I based it on the development of the technological system as a whole. I am not an expert on every component on the machine, but I can utilize it to show why people in these communities can benefit and thrive from combining industry and agriculture. Thus, a new form of economy is developed and thriving. For example, I have gathered research and examples from countries, such as Japan, to demonstrate how such a densely populated island thrives on energy conservation. Using articles on how Japan have implemented agrivoltaics into their society have shown improvements in generating revenue by producing agriculture, energy, and benefiting the environment and society as a whole by utilizing land that has already been established for other farming projects.

Also including the implications of Actors Network theory, or ANT, can help break down the overall system of agrivoltaics by looking at the order at which they were placed when determining how it fits into society. This means looking at the engineers who install it to study the mechanics of how it should overall work without the addition of people/humans added. This would work more efficiently and effectively as an analysis as this includes research and studying.

**Results**

On the topic of suburbanism spreading throughout the country, the reasoning might shock you. In the United States, where the individualism agenda is being pushed, single-person housing makes up the majority of the demographic in the country due to both economic and social means (Goetz, Shortle, Bergstrom). This result highlights the fact that more space for land is being

taken up by individual people rather than by families pushing the incentive of suburbanism. As an example, Northern Virginia is experiencing this exact problem where the DC limits can not support the growing population within its bounds so it expands to the south into farm communities. In fact, this occurrence has been taking place since the 1960s which have had horrible consequences on the environment. The area is known for having irreversible environmental impacts that can cost the government up to $72 billion dollars in lost revenue being generated; traffic causing delays in production management in the suburbs (William & Mary Uni.). Rural communities surrounding this area have to live with the new influx of people entering their communities, such as Bealeton, Remington, Marshall, ect. In fact farmers have had to sell their land due to lack of predecessors to take over the farm, stress from companies buying their land, and the lack of ability to keep up with supply and demand due to both a workers shortage and a hard time deciphering when to plant because of the weather (Hollingsworth). Solar farms, which are mainly found in Northern Virginia, are simply taking up space and are only using the energy for the growing populations. This concept mixed with the increase in energy production has led analysts into looking at utilizing agrivoltaics due to solar farms ramping up production, but diminishing agriculture from increasing due to land space being taken up.

When looking at the benefits of agrivoltaic systems being implemented in society, they have positive interactions with the environment as they promote traditional farming methods while generating power for the place itself (Linda, Gobi, Meganath, Santhosh). This combines both the industrial and agricultural job industries. Agrivoltaic systems have the ability to maximize the land's potential for any means and size while providing shelter to the plants they

are covering and shielding. For the next section, looking at Japan's methods towards energy and food demand can pinpoint utilization within this nation.

Japan, a country known for its technological advancements, has this technology incorporated into their society due to high demand for energy consumption and the want of becoming an independent nation that is self reliant on food due to being an island nation. However, they still have constraints worth mentioning. While energy production in rural communities is the goal, they also have to balance the energy, which is the way of getting the best out of the agrivoltaic systems through both job industries of energy and agriculture. The Photosynthetic Photon Flux Density, or P.P.F.D., is the way the Japanese measure the production of both their stock and electricity generated in regards to recent trends to determine the rate at which the technology is working (Nasukawa, Kawabara, Tatsumi, Tajima). Rice is a main and safe source of food that can be grown in the country and must be monitored to determine the amount of food in rural areas. To aid its growth, they installed the ability of having rotating PV panels onto the agrivoltaic systems to find the best sunlit spots during time of the day while providing sunlight and adequate shading to the crops to not dry them out. Japan utilizing these systems has led it to be able to produce 107,233 kg of food in a year while producing low-fish meal feed of 13,580kg for yellowtail fish while producing little to no carbon emissions (Nakata and Ogata, 2023). The low cost of installing and preparing the site for the installations of these machines cost around $200,000 JPY (Japanese yen). This means that Japan is investing in its efforts to have both clean sources of food and energy for its large population while adhering to its limited space.

The case study on the analysis of rice being produced by agrivoltaic systems talks about shutdowns on several nuclear plants, and the ramp up demand for energy, has caused analysts to

look towards renewable energy to be curated to meet its global power standard. With these goals of energy conservation being constraints, looking into these systems as environmental damage is mitigated and electrical and food production are increased, bringing 30% of more revenue for Japan's economy, should be studied since this is implicated on an island nation (Gonocruz, 2021). This case study is easy to decipher why it is a better method of using solar panels by providing increases in Japan's economics, electrical, and food production of the nation. Thus making it more independent and self reliant.

The United States in comparison has a larger population than Japan that is spread out on more land. Another difference is that the United States has a growing population in comparison with Japan's declining population. In general, the United States is known for having good agricultural production with Tomatoes, Papayas and Peppers having a positive net growth for the country while it lags in growth through the production of Pineapples and Bananas (Nzaku et al., 2010). This means that the country needs to import a lot of the fruits and vegetables that we commonly use in the country today that rural communities that once had the space for farmland are now commercialized. In fact, The United States brings in $992 billion dollars of revenue each year from farm production, and with this number slowly diminishing, due to rural areas becoming more urbanized, it is highlighting the fact that the state of the country will depend more on imported goods rather than on traditionally grown goods (Nosowitz, 2018). This is also in correspondence with suburban areas and their solar panels stretching far into the countryside setting which ramps up energy consumption from localized sectors. Utilizing agrivoltaic systems in small towns can combine the farming industry, by bringing economic benefits to the state and overall nation, while providing more jobs for the engineers who would transport, install, and perform maintenance work on the panels.

In general these systems cost about the same as any other photovoltaic system, meaning anything solar panel related (Agostini et al., 2021). Also, the annual growth rate of solar energy is enlarging by 50% for the past 6 six years and accumulating enough power to generate homes for about 7.4 millions Americans (Pinner and Roders, 2015). As mentioned above, solar energy accumulates for less than 1 percent of global power generated, but has the ability to be utilized correctly to power millions of homes with the majority of them being single-person households. This means that as rural America is slowly turning suburban, this form of energy would be enough to power towns and bring more jobs, while also protecting jobs that are already in place. Thus, while it can be expensive with prices ranging from tens of thousands of dollars, depending on the makeup and the size of the panel, it generally is an investment and has good long term effects environmentally and economically.

Based on the ANT theory, one can understand that these agrivoltaic systems involve an entire network of people with different professions/occupations. This includes the ever progressing technological advancements made in society that need "people" to fill and cover those roles. Agrivoltaics systems require the farmers to plant, the engineers to install and maintain, and energy companies to distribute power throughout specific locations. This system will evolve as populations increase and dependency increases, but it is necessary for the growth and sustainability of rural communities and America at large.

**Discussion/Analysis**

The ANT theory was applied throughout the framework of this paper due to multiple systems essentially needing agrivoltaic systems for the future of the country. As mentioned,

Northern Virginia is a hot spot for suburbanism as D.C., and the area at large, is a popular hot zone for young employees and tourists.

In terms of food production rates, drawing articles that speak about the rate at which both the U.S. can independently produce versus the price of importation of certain fruits and vegetables is necessary when drawing metrics on being financially conscious. Meaning the inclusion of different perspectives can combat this problem. Article, such as the “Analysis of U.S. Demand for Fresh Fruit”, “Integrating Agrivoltaic Systems into Local Industries: A Case Study and Economic Analysis of Rural Japan”, “Rice yield and energy balance in an agrivoltaic system established in Shonai plain, northern Japan”, and “10 Numbers That Show How Much Farmland We’re Losing to Development - Modern Farmer.” These articles were responsible for showing the rate at which the United States imports fresh produce and by giving external examples of how other developed nations around the world added these systems into their society. Thus making the country more economically dependent.

Another important sector of this system includes the power that can be generated from it utilizing solar power and the demand that comes with it. This is important when thinking about cutting down huge carbon emissions as more companies move from concentrated cities, down into the outskirts, and slowly into rural areas where the influx of populations shifts because of these companies' transition. Articles, such as “Innovative agrivoltaic systems to produce sustainable energy: An economic and environmental assessment”, “ Agrivoltaic systems design and assessment: A critical review, and a descriptive model towards a sustainable landscape vision”, “Current status of agrivoltaic systems and their benefits to energy, food, environment , economy, and society” talk about the necessary steps towards sustainable development towards energy demand while accessing the benefits of switching to this system as a major industry in

rural America. This is important when looking at a cost-to-benefit analysis of environmental concerns and the power it can produce.

This section is mainly on how rural America would perceive this device if it was applied and incorporated into their everyday lives. This is important as more people are moving into the ever growing suburbs, which stretches out into the country land. To gather data on this, articles used included “Solar energy implications in rural America”, “Achieving renewable energy, climate, and Air Quality Policy Goals”, “Factors influencing the willingness to use agrivoltaics”, and “Major Uses of Land in the United States”. These articles talk about the people who live in the communities and how N.I.M.B.Y plays a role in the installation and usage of these systems. Not only that, the concerns of land development are also addressed as many homes, which are mainly for one personnel, continue to take up land that was once used for fresh produce. Corporations want to push the idea of progression, but farmers want to push the incentives of agriculture and a slower pace lifestyle. These combinations of people and industry can be analyzed through the installments of agrivoltaic systems in rural pockets.

Based on these findings, I think it is safe to say that the United States can integrate these technologies into American society.

**Conclusion**

Suburbanism is a product of the American ideology of freedom, space, and consumerism. As cities continue to drive the job market and expand in population, it brings the entire surrounding areas alongside it. Meaning that people in rural areas are getting the shorthand of the stick. They have to deal with the influx of people coming in, jobs being taken, and industry being changed. To combat this issue, the combination of industry through the use of agrivoltaic systems, can be implemented so that fields or fresh produce can also be used to meet energy

demand. This would boost economic growth for the area but also improve on the food available and its quality as a whole. Through the examination of Japan, we were able to see the benefits of trying to become a self-sufficient nation while coming to terms with the lack of space.

To answer the question of whether agrivoltaic systems could benefit rural america as land development diminishes due to population gain in area and the energy demand increasing.Yes, agrivoltaic systems can mitigate the problems associated inthe dwindling rural communities and bring influence to its growing diversified economy.

## Works Cited


Agostini, A., Colauzzi, M., & Amaducci, S. (2021). Innovative agrivoltaic systems to produce sustainable energy: An economic and environmental assessment. *Applied Energy, 281*, 116102. https://doi.org/10.1016/j.apenergy.2020.116102

Better Energy. (2021, September). *Existing solar installations on farmland* [Image]. https://betterenergy.org/wp-content/uploads/2021/09/existing-solar-768x526.png

Bigelow, D., & Borchers, A. (2017). *Major uses of land in the United States, 2012* (EIB-178). U.S. Department of Agriculture, Economic Research Service. https://ageconsearch.umn.edu/record/263079/

Gleason, C. (2023). *Solar energy implementation in rural America* (Undergraduate thesis). University of Nebraska–Lincoln. https://digitalcommons.unl.edu/envstudtheses/1350

Hollingsworth, B. (2022, July 26). Solar installations hasten loss of Virginia farmland. *Thomas Jefferson Institute for Public Policy.* https://www.thomasjeffersoninst.org/solar-installations-hasten-loss-of-virginia-farmland/

Institute for Energy Research. (n.d.). Solar power depletes farmlands of rich soil. *IER.* https://www.instituteforenergyresearch.org/renewable/solar-power-depletes-farmlands-of-rich-soil/

Kaya, O., Klepacka, A. M., & Florkowski, W. J. (2019). Achieving renewable energy, climate, and air quality policy goals: Rural residential investment in solar panels. *Journal of Environmental Management, 245*, 348–356. https://doi.org/10.1016/j.jenvman.2019.05.078

Kumpanalaisatit, M., Setthapun, W., Sintuya, H., Pattiya, A., & Jansri, S. N. (2022). Current status of agrivoltaic systems and their benefits to energy, food, environment, economy, and society. *Sustainable Production and Consumption, 32*, 1–12. https://doi.org/10.1016/j.spc.2022.09.005

Linda, M. M., Gobi, N., Meganath, D., & Santhosh, S. (2024, October 4). Performance analysis of normal PV array with agrovoltaics. *IEEE Xplore.* https://ieeexplore.ieee.org/document/10696149

Nakata, H., & Ogata, S. (2023). Integrating agrivoltaic systems into local industries: A case study and economic analysis of rural Japan. *Agronomy, 13*(2), 513. https://doi.org/10.3390/agronomy13020513

Nasukawa, H., Kuwabara, Y., Tatsumi, K., & Tajima, R. (2025). Rice yield and energy balance in an agrivoltaic system established in Shonai Plain, Northern Japan. *Science of the Total Environment, 900*, 1684730. https://doi.org/10.1016/j.scitotenv.2024.1684730

Nosowitz, D. (2018, May 22). 10 numbers that show how much farmland we're losing to development. *Modern Farmer.* https://modernfarmer.com/2018/05/10-numbers-that-show-how-much-farmland-were-losing-to-development/

Nzaku, K., Houston, J. E., & Fonsah, E. G. (2010). Analysis of U.S. demand for fresh fruit and vegetable imports. *AgEcon Search.* https://ageconsearch.umn.edu/record/131369/

Toledo, C., & Scognamiglio, A. (2021). Agrivoltaic systems design and assessment: A critical review, and a descriptive model towards a sustainable landscape vision (three-dimensional agrivoltaic patterns). *Sustainability, 13*(12), 6871. https://doi.org/10.3390/su13126871

Wagner, J., Bühner, C., Gölz, S., Trommsdorff, M., & Jürkenbeck, K. (2024). Factors influencing the willingness to use agrivoltaics: A quantitative study among German farmers. *Applied Energy, 353*, 120419. https://doi.org/10.1016/j.apenergy.2024.120419

Wang, Y., & Deng, Y. (2021). Environmental performance of agrivoltaics: A review. *Environments, 8*(7), 65. https://doi.org/10.3390/environments8070065