

Specialty Crop Agrivoltaics in the Southeastern USA: Profitability and the Role of Rural Energy for America Program

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Abstract

Agrivoltaic profitability in the southeastern US needs to be better understood. This study examines the profitability of tomato and strawberry agrivoltaics in Alabama. We found that reducing the Rural Energy for America Program's coverage of capital investment of agrivoltaics from 50% to 25% will make agrivoltaics unprofitable.

Keywords: Benefit-cost analysis, Climate change, Photovoltaic, Solar energy, Strawberry, Tomato

JEL Codes: C53, C63, Q48

Tweet: Lowering Rural Energy for America Program incentives make agrivoltaics unprofitable for producers in the Southeast US.

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Introduction

The production of US solar energy increased by three folds from 2017 to 2022 (Hodge, 2023) as the federal government aimed to achieve carbon-free electricity by 2035 to combat climate change (Department of Energy, 2023; Gomez-Casanovas et al., 2023; Mamun et al., 2022). Solar energy has been the fastest-growing electric power sector since 2023. The growth is expected to persist through 2025 (Hess & Tsai, 2024). Solar energy production is increasing in cropland areas due to cropland's higher solar potential, flat surface, and proximity to electrical infrastructure (Adeh et al., 2019; Department of Energy, 2023; Katkar et al., 2021). The solar future study projected that about 10.3 million acres ($41,683 \text{ km}^2$) of land is required for the large-scale electrification and decarbonization of buildings and transportation (Heath et al., 2022). This creates land-use competition between solar energy development and agricultural production, causes community opposition, and delays the development of projects. Collocating solar panels with crops—agrivoltaics (AVs)—is an innovative approach to minimize this competition (Macknick et al., 2022; Pascaris et al., 2022) and increase the efficiency of cropland use (Gomez-Casanovas et al., 2023) while reducing the community's opposition to traditional solar energy projects (Pascaris et al., 2021).

Despite the higher solar potential, solar energy production is limited in the southeastern region (Sengupta et al., 2018) because of the higher PV installation costs and lower electricity prices. When investing in AV, the southeastern region can benefit from the Rural Energy for America Program (REAP)—a policy designed to support investments in renewable energies made by agricultural producers or rural small business owners (Pascaris, 2021; Steinberg et al., 2023). AVs reduce community opposition to solar, minimize land competition between energy and food production, and facilitate solar penetration in the rural US. Thus, AVs can be a potential option for joint solar energy and food production in the southeastern US. Economic analyses of AVs in other areas in the US suggest that AVs increase revenue and profit compared to crops alone (Cuppari et al., 2021; Majumdar & Pasqualetti, 2018). However, the

profitability of AV in the Southeastern US is unclear. We aim to fill this gap.

In this article, we examine the profitability of tomato and strawberry agrivoltaics (TAV and SBAV, respectively) and the impact of REAP on AV profitability under various solar panel configurations. We focused on the effects of REAP on AV because producers could benefit from this policy by making energy-efficient improvements, such as AV project development, on their farms. Tomatoes and strawberries are popular crops in the Southeastern US, with economic, social, and cultural significance. Tomato and strawberry producers often diversify their farm operations, connecting the community through agri-tourism, revitalizing the producer's market and rural economy, creating seasonal jobs, supplying local fresh products, and hosting social events and festivals ([Sweet Grown Alabama, 2024](#); [Velasco, 2024](#)). AV adoption enhances farm diversification and generates additional revenue through agritourism, project demonstration, and social events. TAVs and SBAVs have the potential to increase farm profitability while providing access to clean energy and helping to mitigate climate change in this region. Our analysis uses Alabama as a representative state for the Southeastern US. In what follows, we will explain the AV configurations, calculation methods, and profit from TAVs and SBAVs. We will further discuss the impact of the REAP on AV farm profit and make policy recommendations.

Method

We calculated the revenue, cost, and profit of TAVs and SBAVs for a hypothetical one-acre square-shaped plot in four regions of Alabama. The parameters for the calculation are presented in Table 1. We assumed the number and size of crop plots remain unaffected by PV density—the number of solar panels per acre—because solar panels are mounted on metallic poles at 4.2 feet (ft.) or higher to accommodate cultural operations and plant maturation height. We excluded land rent, assuming that the producer owns cropland, grows crops, and operates the established AV. We calculated the direct current (DC) system size and total annual energy output at the

given PV densities using the PVWatts Calculator (Dobos, 2014; National Renewable Energy Laboratory, 2024), using the exact PV specifications specified in the calculator.

[Place Table 1 Here]

We varied tomato and strawberry yields from a 50% decrease to a 50% increase from their benchmark yields to account for crop yield uncertainty in the AVs because of crop, soil, microclimate, and PV interactions (Gomez-Casanovas et al., 2023; Mamun et al., 2022). Solar panels provide shadow to plants reducing heat, temperature, and water stresses. The interactions among increased disease resistance, improved water use efficiency, reduced sunlight, change in microbial composition, and soil disturbances may increase or decrease crop yield and fruit quality (Al-agele et al., 2021; Barron-Gafford et al., 2019; Mamun et al., 2022; Omer et al., 2022; Othman et al., 2020; Walston et al., 2018; Weselek et al., 2021; Willockx et al., 2022). The interactions among crops, PV parameters, soil, and microclimate variation are less understood for tomatoes and strawberries due to the need for more research. We varied harvest, labor, packaging, and marketing costs proportionately with the crop yield from the tomato and strawberry enterprise budgets compiled by the Alabama Cooperative Extension System (Boswell et al., 2023). The budgets do not vary across the state. Thus, we assumed that the cost of crop production and expected yield are constant across the state.

We assume that the producers receive a federal investment tax credit (ITC) and renewable energy credit (REC), and part of the initial capital investment cost (CAPEX) is compensated through REAP within six months. We calculated six months of simple interest on compensated CAPEX and summed it with the uncompensated portion of the CAPEX as a loan to repay over 25 years. We multiplied annual energy production by the electricity price and subtracted annual PV cost to estimate annual profit from energy production. The total annual cost for the PV includes loan repayment, insurance, and operational and maintenance costs. Finally, we generated all combinations of energy and crop profits and added them to estimate total AV profits. The complete analysis has 814,968 AV outcomes per crop per REAP basis for all

operational regions, considering all possible combinations, which can be accessed on [GitHub](#).

Results

Based on the parameters listed in Table 1, the annual profit from PV alone at 50% REAP and 100% PV density ranges from \$4,070 to \$16,348 per acre, depending upon electricity price, solar array types, and operation region. At 25% REAP, the loss from PV alone at 100% PV density ranges from \$1,580 to \$20,030 per acre. The annual profit from tomatoes and strawberries alone under benchmark yield and price from one acre of land are \$9,619 and \$4,176, respectively. In the remaining part of this section, we discuss the profits from TAVs and SBAVs.

Tomato agrivoltaics system (TAV)

The annual profit from 1,360 cartons of tomato alone produced on an acre and sold at \$20 per carton is \$9,619. When 50% of total PV CAPEX is compensated through the REAP (henceforth, “50% REAP”; “25% REAP” for 25% compensation), the profits from TAV at benchmark yield and crop price from an acre of land range from \$10,434 to \$25,968 depending upon PV density, panel heights, array types, and geographical regions (Table 2). At 50% REAP, benchmark yield, and crop price, TAVs are profitable in all scenarios, and the profit increases in PV density. However, at 25% REAP and benchmark yield and price, TAVs are less profitable than tomatoes alone. TAVs become unprofitable throughout the state at 25% REAP, 75% or higher PV density, and fixed panels raised above 8.2 ft. The TAV profit is reduced by 27% to 176% at the benchmark yield and price depending upon PV configuration and location if REAP is reduced from 50% to 25%.

[Place Table 2 Here]

Figure 1 shows a set of two 2,160 TAV profit scenarios under 50% REAP (Fig: 1a) and 25% REAP (Fig: 1b) respectively. At 50% REAP, most of the TAV scenarios are profitable

(Fig: 1a), but some of them are less profitable than crop alone. For example, TAV is break-even or more profitable than crop alone at benchmark yield and \$17 price when tracking panels are placed at 40% density. Under the same crop yield and price, higher profit from AV than the tomato alone can be achieved at 30% PV density with fixed panels mounted at 4.6 ft. At 50% REAP and higher PV densities, TAVs are mostly profitable even if the yield dropped by 50% and price dropped to \$17. For example, TAVs become unprofitable in the northern region at 50% REAP when yield loss is 50%, tomato price is \$17 per carton, and fixed panels with 60% PV density are mounted at 8.2 ft. TAV with the same configurations and crop prices becomes unprofitable in the black belt and southern regions at 40% PV density.

[Place Figure 1 Here]

Many TAV scenarios become unprofitable at 25% REAP (Fig: 1b). In this case, almost all TAVs become unprofitable if tomato yield is reduced to 50% of the benchmark yield across the state for all prices. The TAV profit at a \$17 per bucket of tomatoes depends upon other system parameters. TAVs are unprofitable at a \$17 tomato price and 8.2 ft. high fixed panels at 80% or above PV density. For TAVs to become profitable at 25% REAP, producers should either lower PV height to 4.2 ft., maintain benchmark or higher yield, receive \$20 or above market price, or maintain combinations of more than one of these conditions. Tomato yield must increase by 50% and receive at least \$20 per carton for TAVs to remain profitable in all four regions when 8.2 ft tall fixed solar panels cover 80% of the plot. When fixed panels are mounted at 8.2 ft. at 100% PV density, tomato yield must increase by 50% and receive a market price of \$23 per 25-lb for TAV to remain profitable in northern Alabama. The losses from TAVs generally decrease as we progress toward the south from the north due to higher solar energy production, but they are still insufficient to make a profit.

Strawberry agrivoltaic system (SBAV)

The annual profit from 3,075 buckets of strawberries produced in an acre and sold at \$6 per

bucket is \$4,176. At 50% REAP, profits from SBAV from an acre of land range from \$4,991 to \$20,524, depending upon AV configuration and geographical region (Table 3). At 50% REAP and benchmark yield and price, SBAV is profitable across all scenarios, and the profit increases with the PV density. However, at 25% REAP, the profit from the crop alone is higher than the profit from SBAV, and the profit decreases in PV density. SBAVs observe losses throughout the state at 25% REAP, benchmark yield, and price in almost all scenarios. The SBAV profit is reduced by 72% to 417% at the benchmark yield and price depending upon PV configuration and location if REAP is reduced from 50% to 25%.

[Place Table 3 Here]

Figure 2 shows 2,160 SBAV profit outcomes at 50% REAP (Fig: 2a) and 2,160 SBAV profit outcomes at 25% REAP (Fig: 2b). SBAVs are mostly profitable at 50% REAP when PV densities are higher, panel height at 6.4 ft. or lower, yields remain at benchmark or higher level, and the strawberry price is \$6/bucket or more (Fig: 2a). However, at lower prices and yield, the profitability of SBAVs depends upon panel heights, panel arrays, PV density, and geographical regions. A few unprofitable SBAV configurations in the north became profitable in the south for the same crop yield and prices because of the increase in solar energy production. For example, SBAV with 8.2 ft. tall tracking solar panels, 70% PV density, benchmark yield, and strawberry priced at \$3 per bucket become profitable except in the northern region. However, SBAV profits are smaller than crop only in several profitable scenarios. For example, SBAV profit is higher than strawberry alone at benchmark yield and \$3 strawberry price, 70% PV density, and 4.6 ft. tracking panels except in the northern region. Under the same configuration, yield, and crop prices, SBAV profit higher than strawberry profit alone across the state is achieved at 80% PV density.

[Place Figure 2 Here]

However, most SBAVs become unprofitable (Fig: 2b) at 25% REAP. SBAVs become unprofitable at \$3 per bucket even if the strawberry production increased by 50% across all scenarios. At 25% REAP, SBAVs remained profitable at the benchmark yield and \$9 strawberry price with fixed panels mounted at 6.4 ft or lower heights. SBAVs become unprofitable at 60% or above PV densities and 8.2 ft. tracking panels with the same configurations and prices as above. For SBAVs to become profitable at 25% REAP, either strawberry yield must increase by 50%, or the strawberry price must remain at the benchmark price or above in most scenarios. At 25% REAP, SBAV profit decreases in solar panel density. Only a few unprofitable scenarios at 25% REAP and lower PV densities become profitable as we progress towards the southern region from the north because of increased solar energy production.

Conclusion

We examined the profitability of TAVs and SBAVs in Alabama under two REAP scenarios varying height, array, and density of solar panels, crop yield, crop price, and geographical regions. We found that TAV and SBAV will be more attractive to producers at 50% REAP because they are mostly profitable compared to crops alone. Holding crop yield constant, the AV profits also increase in PV density at 50% REAP, which could further increase solar energy production. At 25% REAP, producing the crop alone is more profitable than AVs, even though some AV scenarios remain profitable. Reducing the REAP from 50% to 25% may make AVs less attractive because producers lose profit by allocating agricultural land to the PV. Producers further lose money by increasing PV density at 25% REAP, making AVs unattractive. It is nearly impossible to make AVs profitable without REAP or similar incentives. Decreasing the CAPEX for PV could change the outcome in the future.

Some unprofitable AV scenarios at benchmark crop yield become profitable at the higher yield for a given price and PV configuration. At a given yield, higher crop prices further make AV scenarios profitable without modifying PV configurations. Increasing crop yield under the

AV system may help maintain farm profit if REAP is reduced from 50% to 25%. Even though producers could maintain profit with 25% REAP by increasing crop yield by 50%, the current state of research is insufficient to predict a 50% increase in yield. More research is necessary to study the impact of AVs on tomato and strawberry yield and crop performance.

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Table 1: AV system parameters and model specification

System parameters	Values and units	Sources
Locational parameters		
Northern region zip code	35769	Model specification
Central region zip code	35136	Model specification
Black belt region zip code	35040	Model specification
Southern region zip code	36507	Model specification
PV costs and electricity price		
CAPEX for 4.6 ft. fixed open rack panels	\$1.59/Watt	(Horowitz et al., 2020)
CAPEX for 6.4 ft. fixed open rack panels	\$1.85/Watt	(Horowitz et al., 2020)
CAPEX for 8.2 ft. fixed open rack panels	\$2.33/Watt	(Horowitz et al., 2020)
CAPEX for 4.6 ft. single-axis rotating panels	\$1.73/Watt	(Horowitz et al., 2020)
CAPEX for 6.4 ft. single-axis rotating panels	\$1.92/Watt	(Horowitz et al., 2020)
CAPEX for 8.2 ft. single-axis rotating panels	\$2.11/Watt	(Horowitz et al., 2020)
Annual operational and maintenance cost (OPEX)	3% of annualized total CAPEX	Model specification
Annual PV insurance cost	0.5% of annualized total CAPEX	Model specification
Electricity price	\$0.04/kWh	Model specification
PV configuration		
Total solar panels at 100% PV density	885	Model specification
Panel edge-to-edge distance at 100% PV density	6 ft.	Model specification
PV density range	0% to 100%	Model specification
Solar panel length	7.75 ft.	Model specification
Solar panel width	3.5 ft.	Model specification
Total land (square-shaped)	1 Acre	Model specification
Length and width of land	417.42 ft.	Model specification
Interest/discount rate	7%	Model specification
Lifespan of PV	25 Years	Model specification
Solar panel efficiency	19%	(Dobos, 2014)
Energy policies		
Renewable energy credit (REC)	\$6.6/MWh	(Heeter & O'Shaughnessy, 2019)
Annual investment tax credit (ITC)	30% of annualized total CAPEX	(U.S. Department of Energy, 2024)
Rural Energy for America Program (REAP)	25% and 50% of total CAPEX	(U.S. Department of Agriculture, 2024)
Specialty crop parameters		
Tomato production at benchmark yield	1,360 25-lb cartons/acre	(Boswell et al., 2023)
Tomato production cost at benchmark yield	\$7,580.62	(Boswell et al., 2023)
Tomato harvest labor cost at benchmark yield *	\$1,760	(Boswell et al., 2023)
Tomato harvest boxes cost at benchmark yield *	\$1,700	(Boswell et al., 2023)
Tomato marketing cost at benchmark yield *	\$2,720	(Boswell et al., 2023)
Tomato prices	\$17, \$20, and \$23 /carton	(Boswell et al., 2023)
Strawberry production at benchmark yield	3,075 4-quart buckets/acre	(Boswell et al., 2023)
Strawberry production cost at benchmark yield	\$14274.34	(Boswell et al., 2023)
Strawberry harvest labor cost at benchmark yield *	\$996	(Boswell et al., 2023)
Strawberry harvest bucket cost at benchmark yield *	\$2,460	(Boswell et al., 2023)
Strawberry prices	\$3, \$6, and \$9 /bucket	(Boswell et al., 2023)
Tomato and strawberry yield range	-50%, 0%, +50% of benchmark yield	Model specification

Notes: * indicate that these costs are part of the total production cost of the respective crop. Carton means 25-pound (lb) carton, and bucket means 4-quart bucket, henceforth referred to as “carton” and “bucket”, respectively.

Table 2: Profit from TAVs at benchmark tomato yield and price.

Solar Proportion →			25% Solar (177 Panels)			50% Solar (413 Panels)			75% Solar (590 Panels)			100% Solar (885 Panels)		
Solar Panel Height (ft.) →			4.6	6.4	8.2	4.6	6.4	8.2	4.6	6.4	8.2	4.6	6.4	8.2
REAP	Regions	Array	Profit from TAVs											
50%	North	Fixed	11,869	11,369	10,434	14,865	13,699	11,519	17,862	16,030	12,604	20,860	18,362	13,690
50%	Central	Fixed	12,063	11,563	10,628	15,317	14,151	11,971	18,573	16,741	13,315	21,829	19,331	14,659
50%	Black Belt	Fixed	12,189	11,690	10,755	15,612	14,447	12,266	19,037	17,205	13,779	22,462	19,964	15,292
50%	South	Fixed	12,235	11,736	10,801	15,720	14,554	12,374	19,206	17,374	13,948	22,692	20,194	15,522
50%	North	Tracking	12,368	12,001	11,635	16,031	15,176	14,320	19,695	18,351	17,006	23,359	21,526	19,693
50%	Central	Tracking	12,658	12,292	11,925	16,709	15,853	14,998	20,760	19,415	18,071	24,810	22,977	21,144
50%	Black Belt	Tracking	12,802	12,435	12,068	17,043	16,187	15,332	21,284	19,940	18,596	25,526	23,693	21,860
50%	South	Tracking	12,890	12,523	12,157	17,249	16,393	15,538	21,608	20,264	18,920	25,968	24,135	22,301
25%	North	Fixed	8,572	7,542	5,614	7,174	4,769	272	5,777	1,998	-5,070	4,379	-774	-10,411
25%	Central	Fixed	8,766	7,736	5,808	7,626	5,221	724	6,487	2,709	-4,359	5,349	196	-9,441
25%	Black Belt	Fixed	8,893	7,863	5,935	7,921	5,517	1,019	6,951	3,173	-3,895	5,981	828	-8,809
25%	South	Fixed	8,939	7,909	5,981	8,029	5,624	1,127	7,120	3,341	-3,726	6,212	1,059	-8,578
25%	North	Tracking	8,782	8,026	7,270	7,665	5,900	4,135	6,547	3,774	1,002	5,430	1,649	-2,132
25%	Central	Tracking	9,073	8,316	7,560	8,342	6,577	4,813	7,612	4,839	2,066	6,882	3,100	-681
25%	Black Belt	Tracking	9,216	8,460	7,703	8,676	6,911	5,147	8,137	5,364	2,591	7,597	3,816	35
25%	South	Tracking	9,304	8,548	7,792	8,882	7,118	5,353	8,461	5,688	2,915	8,039	4,258	477

Notes: Profits from TAVs producing 1,360 cartons of tomato per acre (benchmark yield) assuming no yield penalty or benefit from solar-crop interactions. Electricity and tomato carton prices are \$0.04/kWh and \$20 (benchmark price) respectively.

Table 3: Profits from SBAVs at benchmark yield and price

Solar Proportion →			25% Solar (177 Panels)			50% Solar (413 Panels)			75% Solar (590 Panels)			100% Solar (885 Panels)		
Solar Panel Height (ft.) →			4.6	6.4	8.2	4.6	6.4	8.2	4.6	6.4	8.2	4.6	6.4	8.2
REAP	Regions	Array	Profit from SBAVs											
50%	North	Fixed	6,425	5,925	4,991	9,421	8,255	6,075	12,419	10,587	7,160	15,416	12,918	8,246
50%	Central	Fixed	6,619	6,119	5,185	9,873	8,708	6,527	13,130	11,298	7,871	16,386	13,887	9,215
50%	Black Belt	Fixed	6,746	6,246	5,312	10,169	9,003	6,823	13,594	11,762	8,335	17,018	14,520	9,848
50%	South	Fixed	6,792	6,292	5,357	10,276	9,110	6,930	13,762	11,930	8,504	17,249	14,750	10,078
50%	North	Tracking	6,924	6,558	6,191	10,588	9,732	8,877	14,251	12,907	11,563	17,915	16,082	14,249
50%	Central	Tracking	7,215	6,848	6,481	11,265	10,410	9,554	15,316	13,972	12,627	19,367	17,534	15,700
50%	Black Belt	Tracking	7,358	6,991	6,625	11,599	10,743	9,888	15,841	14,496	13,152	20,082	18,249	16,416
50%	South	Tracking	7,446	7,080	6,713	11,805	10,950	10,094	16,165	14,820	13,476	20,524	18,691	16,858
25%	North	Fixed	3,129	2,098	171	1,730	-675	-5,172	333	-3,446	-10,513	-1,064	-6,218	-15,855
25%	Central	Fixed	3,323	2,292	365	2,183	-222	-4,720	1,044	-2,735	-9,802	-95	-5,248	-14,885
25%	Black Belt	Fixed	3,450	2,419	492	2,478	73	-4,424	1,508	-2,271	-9,338	538	-4,615	-14,252
25%	South	Fixed	3,495	2,465	537	2,585	180	-4,317	1,677	-2,102	-9,169	768	-4,385	-14,022
25%	North	Tracking	3,339	2,582	1,826	2,221	456	-1,308	1,104	-1,669	-4,442	-14	-3,795	-7,576
25%	Central	Tracking	3,629	2,873	2,116	2,898	1,134	-631	2,168	-605	-3,378	1,438	-2,343	-6,124
25%	Black Belt	Tracking	3,772	3,016	2,260	3,232	1,468	-297	2,693	-80	-2,853	2,154	-1,628	-5,409
25%	South	Tracking	3,860	3,104	2,348	3,438	1,674	-91	3,017	244	-2,529	2,595	-1,186	-4,967

Note: Profit from SBAV producing 3,075 buckets of strawberries per acre (benchmark yield) assuming no yield penalty or benefit from solar-crop interactions. Electricity and strawberry bucket prices are \$0.04/kWh and \$6 (benchmark price) respectively.

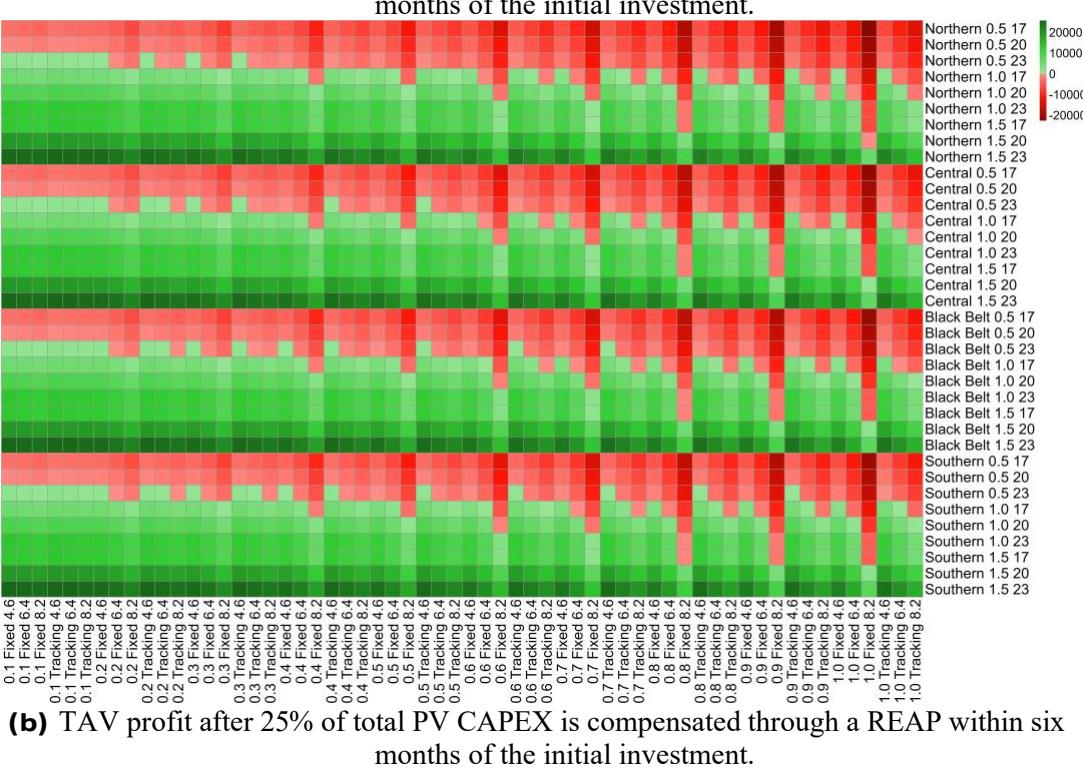
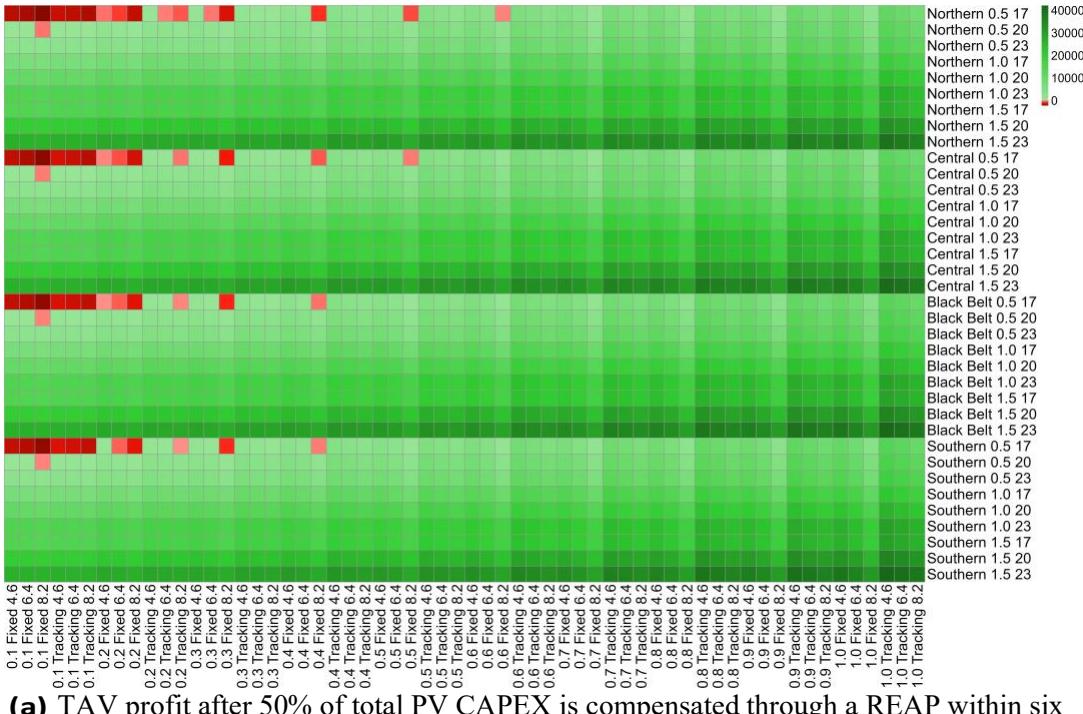
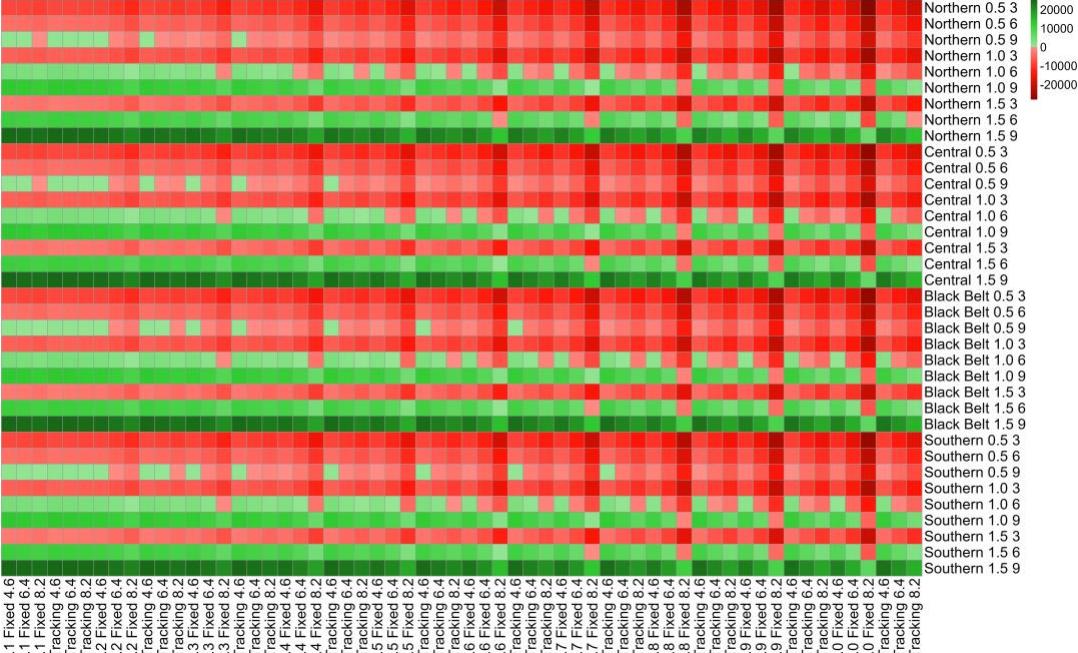


Figure 1: TAV profits in the four regions of Alabama under various PV configurations. The vertical axis indicates electricity price, tomato price, tomato yield, and regions of Alabama. For example, the label “Northern 0.5 17” on the first row means the northern region of Alabama, 50% yield of 1,360 cartons of tomatoes, and \$17 per carton of tomato. The horizontal axis has PV density, solar array types, and solar panel ground clearance height (ft.). For example, “0.10 Fixed 4.6” on the first column means 10% PV density, fixed-tilt solar panels mounted 4.6 ft. above the ground. Green and red colored blocks represent profits and losses from TAVs, respectively. Profits and losses increase as blocks turn darker in color. Source: Authors.



(a) SBAV profit after 50% of the total PV CAPEX is compensated through a REAP within six months of the initial investment.



(b) SBAV profit after 25% of the total PV CAPEX is compensated through a REAP within six months of the initial investment.

Figure 2: SBAV profits in the four regions of Alabama under various solar energy system configurations. The vertical axis has electricity prices, strawberry prices, strawberry yield, and regions of Alabama. For example, “Northern 0.5 3” on the first row represents the northern region of Alabama, with a strawberry yield of 50% of 3,075 buckets and \$3 per bucket strawberry. The horizontal axis has PV density, solar panel array types, and solar panel ground clearance height (ft.). For example, the label “0.10 Fixed 4.6” on the first column represents 10% PV density, fixed-tilt solar panels mounted 4.6 ft. above the ground. Green and red colored blocks represent profits and losses from TAVs, respectively. Profits and losses increase as blocks turn darker in color. Source: Authors.