

# Choice Paper

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Techno-economic analysis of agrivoltaic systems in Alabama. A paper for [Choice Magazine](#) by AAEEA.

## 1 Setting Up

### 1.1 Housekeeping

```
# #| echo: TRUE
rm(list = ls()) # Clean the environment.
options(
  warn=0, # Warnings. options(warn=-1) / options(warn=0)
  scipen=999 # No scientific notations.
)
```

### 1.2 Working directory

Codes and output are suppressed. Errors and warnings are visible. No warning and no error means code is working as it should.

### 1.3 Load libraries

```
library(tidyverse, warn.conflicts = FALSE, quietly = TRUE)
```

```
-- Attaching core tidyverse packages ----- tidyverse 2.0.0 --
v dplyr      1.1.4      v readr      2.1.5
v forcats    1.0.0      v stringr    1.5.1
v ggplot2    3.5.1      v tibble     3.2.1
v lubridate  1.9.3      v tidyr      1.3.1
v purrr      1.0.2
```

```
-- Conflicts ----- tidyverse_conflicts() --
```

```
x dplyr::filter() masks stats::filter()
```

```
x dplyr::lag()     masks stats::lag()
```

```
i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become
```

```
library(psych, warn.conflicts = FALSE, quietly = TRUE)
library(likert, warn.conflicts = FALSE, quietly = TRUE) # Likert Items
library(mice, warn.conflicts = FALSE, quietly = TRUE)
library(openxlsx2, warn.conflicts = FALSE, quietly = TRUE)
library(ggpubr, warn.conflicts = FALSE, quietly = TRUE) # Scatter plot
library(gmodels, warn.conflicts = FALSE, quietly = TRUE) # Crosstab
library(reshape2, warn.conflicts = FALSE, quietly = TRUE) # Reshape data
library(pacman, warn.conflicts = FALSE, quietly = TRUE) # Package Management
library(progress, warn.conflicts = FALSE, quietly = TRUE) #progress bar
library(arrow, warn.conflicts = FALSE, quietly = TRUE) #progress bar
```

Some features are not enabled in this build of Arrow. Run ``arrow_info()`` for more information.  
The repository you retrieved Arrow from did not include all of Arrow's features.  
You can install a fully-featured version by running:  
``install.packages('arrow', repos = 'https://apache.r-universe.dev')``.

```
pacman::p_loaded()
```

```
[1] "arrow"      "progress"   "pacman"     "reshape2"   "gmodels"    "ggpubr"
[7] "openxlsx2"  "mice"       "likert"     "xtable"     "psych"      "lubridate"
[13] "forcats"    "stringr"    "dplyr"      "purrr"      "readr"      "tidyr"
[19] "tibble"     "ggplot2"    "tidyverse"
```

## 1.4 Progress Bar

Tracking data processing progress.

```
##### Progress Bar #####
pb = progress_bar$new(
  format = "Processing data at :rate. Processed :bytes in :elapsed.",
  clear = TRUE,
  total = NA,
  width = 80)
f = function() {
  for (i in 1:100) {
    pb$tick(sample(1:100 * 1000, 1))
    Sys.sleep(2/100)
  }
  pb$tick(1e7)
  #invisible()
}
```

## 1.5 Theme for plots

Setting theme for plots:

```
##### Plotting Data: #####
# Map Theme:
plottheme <- ggplot() +
  theme_void() +
  # Mapping theme:
  theme(axis.title = element_blank(),
        axis.ticks = element_blank(),
        axis.text = element_blank(),
        panel.border = element_blank(),
        plot.margin = margin(t = 0,
                              r = 0,
                              b = 0,
                              l = 0,
                              unit = "cm"),
        plot.title = element_text(hjust = 0.5),
        plot.background = element_rect(fill = "white",
                                         color = "black",
                                         linewidth = 0),
        panel.background = element_rect(fill = "white",
```

```

        color = "black",
        linewidth = 0),
panel.grid.major.x = element_line(color = "lightgrey",
        linetype = 2,
        linewidth = 0),
panel.grid.minor.x = element_line(color = "lightgrey",
        linetype = 2,
        linewidth = 0),
panel.grid.major.y = element_line(color = "grey",
        linetype = 2,
        linewidth = 0),
panel.grid.minor.y = element_line(color = "grey",
        linetype = 2,
        linewidth = 0),
axis.line.x.top = element_line(color = "white",
        linetype = 2,
        linewidth = 0),
axis.line.y.right = element_line(color = "white",
        linetype = 2,
        linewidth = 0),
axis.line.x.bottom = element_line(color = "black",
        linetype = 1,
        linewidth = 0),
axis.line.y.left = element_line(color = "black",
        linetype = 1,
        linewidth = 0),

# Text formatting:
text = element_text(family = "serif", # font
        size = 12, # font size
        colour = "black"# font color
),
legend.position = c(0.95, -0.05),
legend.key = element_rect(color = "black",
        fill = NA,
        linewidth = 0.05,
        linetype = 1),
legend.justification = "right",
legend.direction = "horizontal")

```

## 2 Import data

Import necessary data.

### 2.1 Tomato

- Yield = Total tomato production (total bucket of 25 lb) from 1 acres of land which varies from 10% to 200% of total production (100%). The range was simulated by multiplying 100% yield by yldvar.
- yldvar = Yield variation parameter ranges from 10% to 200%.
- Rev17 to Rev23 = Revenue for price ranges of \$17 to \$23 per bucket of tomato.
- Total cost = Total cost of production for the given yield.
- rolac17 to rolac23= Return to operator, labor and capital for price range of \$17 to \$23.
- operator Cost = Operator labor cost at \$15/hour for given yield. For 100% yield, total hours = 90.
- rlc17 to 23 = Return to land and capital after subtracting operator cost from total revenue.

```
tomato <- read_xlsx("Parameters.xlsx",
  sheet = "Tomato",
  start_row = 2,
  start_col = 9,
  skip_empty_rows = TRUE,
  skip_empty_cols = TRUE,
  col_names = TRUE) %>%
  rename(yield = Yield,
    yldvar = `Yield Variation (%)`)
dim(tomato)
```

```
[1] 20 25
```

```
head(tomato)
```

	yldvar	yield	Rev17	Rev18	Rev19	Rev20	Rev21	Rev22	Rev23	Total Cost	rolac17
3	2.0	2720	46240	48960	51680	54400	57120	59840	62560	24560.62	21679.38
4	1.9	2584	43928	46512	49096	51680	54264	56848	59432	23862.62	20065.38
5	1.8	2448	41616	44064	46512	48960	51408	53856	56304	23164.62	18451.38

6	1.7	2312	39304	41616	43928	46240	48552	50864	53176	22466.62	16837.38
7	1.6	2176	36992	39168	41344	43520	45696	47872	50048	21768.62	15223.38
8	1.5	2040	34680	36720	38760	40800	42840	44880	46920	21070.62	13609.38
	rolac18	rolac19	rolac20	rolac21	rolac22	rolac23	Operator	Cost		rlc17	
3	24399.38	27119.38	29839.38	32559.38	35279.38	37999.38		2700		18979.38	
4	22649.38	25233.38	27817.38	30401.38	32985.38	35569.38		2565		17500.38	
5	20899.38	23347.38	25795.38	28243.38	30691.38	33139.38		2430		16021.38	
6	19149.38	21461.38	23773.38	26085.38	28397.38	30709.38		2295		14542.38	
7	17399.38	19575.38	21751.38	23927.38	26103.38	28279.38		2160		13063.38	
8	15649.38	17689.38	19729.38	21769.38	23809.38	25849.38		2025		11584.38	
	rlc18	rlc19	rlc20	rlc21	rlc22	rlc223					
3	21699.38	24419.38	27139.38	29859.38	32579.38	35299.38					
4	20084.38	22668.38	25252.38	27836.38	30420.38	33004.38					
5	18469.38	20917.38	23365.38	25813.38	28261.38	30709.38					
6	16854.38	19166.38	21478.38	23790.38	26102.38	28414.38					
7	15239.38	17415.38	19591.38	21767.38	23943.38	26119.38					
8	13624.38	15664.38	17704.38	19744.38	21784.38	23824.38					

tail(tomato)

	yldvar	yield	Rev17	Rev18	Rev19	Rev20	Rev21	Rev22	Rev23	Total	Cost	rolac17
17	0.6	816	13872	14688	15504	16320	17136	17952	18768	14788.62		-916.6174
18	0.5	680	11560	12240	12920	13600	14280	14960	15640	14090.62		-2530.6174
19	0.4	544	9248	9792	10336	10880	11424	11968	12512	13392.62		-4144.6174
20	0.3	408	6936	7344	7752	8160	8568	8976	9384	12694.62		-5758.6174
21	0.2	272	4624	4896	5168	5440	5712	5984	6256	11996.62		-7372.6174
22	0.1	136	2312	2448	2584	2720	2856	2992	3128	11298.62		-8986.6174
	rolac18	rolac19	rolac20	rolac21	rolac22	rolac23						
17	-100.6174	715.3826	1531.3826	2347.3826	3163.3826	3979.3826						
18	-1850.6174	-1170.6174	-490.6174	189.3826	869.3826	1549.3826						
19	-3600.6174	-3056.6174	-2512.6174	-1968.6174	-1424.6174	-880.6174						
20	-5350.6174	-4942.6174	-4534.6174	-4126.6174	-3718.6174	-3310.6174						
21	-7100.6174	-6828.6174	-6556.6174	-6284.6174	-6012.6174	-5740.6174						
22	-8850.6174	-8714.6174	-8578.6174	-8442.6174	-8306.6174	-8170.6174						
	Operator	Cost	rlc17	rlc18	rlc19	rlc20	rlc21					
17		810	-1726.617	-910.6174	-94.61736	721.3826	1537.3826					
18		675	-3205.617	-2525.6174	-1845.61736	-1165.6174	-485.6174					
19		540	-4684.617	-4140.6174	-3596.61736	-3052.6174	-2508.6174					
20		405	-6163.617	-5755.6174	-5347.61736	-4939.6174	-4531.6174					
21		270	-7642.617	-7370.6174	-7098.61736	-6826.6174	-6554.6174					
22		135	-9121.617	-8985.6174	-8849.61736	-8713.6174	-8577.6174					
	rlc22	rlc223										

```

17 2353.3826 3169.3826
18 194.3826 874.3826
19 -1964.6174 -1420.6174
20 -4123.6174 -3715.6174
21 -6282.6174 -6010.6174
22 -8441.6174 -8305.6174

```

## 2.2 Strawberry

- Everything same as tomato.
- Numbers 3 to 9 in names are price ranges for strawberry.

```

strawberry <- read_xlsx("Parameters.xlsx",
                        sheet = "Strawberry",
                        start_row = 2,
                        start_col = 7,
                        skip_empty_rows = TRUE,
                        skip_empty_cols = TRUE,
                        col_names = TRUE) %>%
  rename(yield = Yield,
         yldvar = `Yield Variation (%)`)
dim(strawberry)

```

```
[1] 20 25
```

```
head(strawberry)
```

	yldvar	yield	Rev3	Rev4	Rev5	Rev6	Rev7	Rev8	Rev9	Total Cost
3	2.0	6150.0	18450.0	24600	30750.0	36900	43050.0	49200	55350.0	20190.49
4	1.9	5842.5	17527.5	23370	29212.5	35055	40897.5	46740	52582.5	19844.85
5	1.8	5535.0	16605.0	22140	27675.0	33210	38745.0	44280	49815.0	19499.20
6	1.7	5227.5	15682.5	20910	26137.5	31365	36592.5	41820	47047.5	19153.56
7	1.6	4920.0	14760.0	19680	24600.0	29520	34440.0	39360	44280.0	18807.91
8	1.5	4612.5	13837.5	18450	23062.5	27675	32287.5	36900	41512.5	18462.27
	rolac3	rolac4	rolac5	rolac6	rolac7	rolac8	rolac9			
3	-1740.495	4409.50503	10559.505	16709.51	22859.51	29009.51	35159.51			
4	-2317.350	3525.15003	9367.650	15210.15	21052.65	26895.15	32737.65			
5	-2894.205	2640.79503	8175.795	13710.80	19245.80	24780.80	30315.80			
6	-3471.060	1756.44003	6983.940	12211.44	17438.94	22666.44	27893.94			
7	-4047.915	872.08503	5792.085	10712.09	15632.09	20552.09	25472.09			



```

8 -4624.770 -12.26997 4600.230 9212.73 13825.23 18437.73 23050.23
Operator Cost      rlc3      rlc4      rlc5      rlc6      rlc7      rlc8
3      2700 -4440.495  1709.505 7859.505 14009.505 20159.51 26309.51
4      2565 -4882.350   960.150 6802.650 12645.150 18487.65 24330.15
5      2430 -5324.205   210.795 5745.795 11280.795 16815.80 22350.80
6      2295 -5766.060  -538.560 4688.940  9916.440 15143.94 20371.44
7      2160 -6207.915 -1287.915 3632.085  8552.085 13472.09 18392.09
8      2025 -6649.770 -2037.270 2575.230  7187.730 11800.23 16412.73
      rlc9
3 32459.51
4 30172.65
5 27885.80
6 25598.94
7 23312.09
8 21025.23

```

```
tail(strawberry)
```

```

      yldvar  yield   Rev3 Rev4   Rev5 Rev6   Rev7 Rev8   Rev9 Total Cost
17    0.6 1845.0 5535.0 7380 9225.0 11070 12915.0 14760 16605.0   15351.46
18    0.5 1537.5 4612.5 6150 7687.5  9225 10762.5 12300 13837.5   15005.82
19    0.4 1230.0 3690.0 4920 6150.0  7380  8610.0  9840 11070.0   14660.17
20    0.3  922.5 2767.5 3690 4612.5  5535  6457.5  7380  8302.5   14314.53
21    0.2  615.0 1845.0 2460 3075.0  3690  4305.0  4920  5535.0   13968.88
22    0.1  307.5  922.5 1230 1537.5  1845  2152.5  2460  2767.5   13623.24
      rolac3   rolac4   rolac5   rolac6   rolac7   rolac8   rolac9
17 -9816.465 -7971.465 -6126.465 -4281.465 -2436.465 -591.465  1253.535
18 -10393.320 -8855.820 -7318.320 -5780.820 -4243.320 -2705.820 -1168.320
19 -10970.175 -9740.175 -8510.175 -7280.175 -6050.175 -4820.175 -3590.175
20 -11547.030 -10624.530 -9702.030 -8779.530 -7857.030 -6934.530 -6012.030
21 -12123.885 -11508.885 -10893.885 -10278.885 -9663.885 -9048.885 -8433.885
22 -12700.740 -12393.240 -12085.740 -11778.240 -11470.740 -11163.240 -10855.740
Operator Cost      rlc3      rlc4      rlc5      rlc6      rlc7
17      810 -10626.46 -8781.465 -6936.465 -5091.465 -3246.465
18      675 -11068.32 -9530.820 -7993.320 -6455.820 -4918.320
19      540 -11510.17 -10280.175 -9050.175 -7820.175 -6590.175
20      405 -11952.03 -11029.530 -10107.030 -9184.530 -8262.030
21      270 -12393.88 -11778.885 -11163.885 -10548.885 -9933.885
22      135 -12835.74 -12528.240 -12220.740 -11913.240 -11605.740
      rlc8      rlc9
17 -1401.465  443.535
18 -3380.820 -1843.320

```

```

19 -5360.175 -4130.175
20 -7339.530 -6417.030
21 -9318.885 -8703.885
22 -11298.240 -10990.740

```

## 2.3 Squash

- Everything same as tomato and strawberry.
- Numbers 11 to 17 in names are price ranges for squash.

```

squash <- read_xlsx("Parameters.xlsx",
  sheet = "Squash",
  start_row = 2,
  start_col = 8,
  skip_empty_rows = TRUE,
  skip_empty_cols = TRUE,
  col_names = TRUE) %>%
  rename(yield = Yield,
    yldvar = `Yield Variation (%)`)
dim(squash)

```

```
[1] 20 25
```

```
head(squash)
```

	yldvar	yield	Rev11	Rev12	Rev13	Rev14	Rev15	Rev16	Rev17	Total	Cost	rolac11
3	2.0	2180	23980	26160	28340	30520	32700	34880	37060	13670.88		10309.117
4	1.9	2071	22781	24852	26923	28994	31065	33136	35207	13173.63		9607.367
5	1.8	1962	21582	23544	25506	27468	29430	31392	33354	12676.38		8905.617
6	1.7	1853	20383	22236	24089	25942	27795	29648	31501	12179.13		8203.867
7	1.6	1744	19184	20928	22672	24416	26160	27904	29648	11681.88		7502.117
8	1.5	1635	17985	19620	21255	22890	24525	26160	27795	11184.63		6800.367
	rolac12	rolac13	rolac14	rolac15	rolac16	rolac17	Operator	Cost	rlc11			
3	12489.117	14669.12	16849.12	19029.12	21209.12	23389.12		2700	7609.117			
4	11678.367	13749.37	15820.37	17891.37	19962.37	22033.37		2565	7042.367			
5	10867.617	12829.62	14791.62	16753.62	18715.62	20677.62		2430	6475.617			
6	10056.867	11909.87	13762.87	15615.87	17468.87	19321.87		2295	5908.867			
7	9246.117	10990.12	12734.12	14478.12	16222.12	17966.12		2160	5342.117			
8	8435.367	10070.37	11705.37	13340.37	14975.37	16610.37		2025	4775.367			
	rlc12	rlc13	rlc14	rlc15	rlc16	rlc17						

```

3 9789.117 11969.117 14149.117 16329.12 18509.12 20689.12
4 9113.367 11184.367 13255.367 15326.37 17397.37 19468.37
5 8437.617 10399.617 12361.617 14323.62 16285.62 18247.62
6 7761.867 9614.867 11467.867 13320.87 15173.87 17026.87
7 7086.117 8830.117 10574.117 12318.12 14062.12 15806.12
8 6410.367 8045.367 9680.367 11315.37 12950.37 14585.37

```

```
tail(squash)
```

```

      yldvar yield Rev11 Rev12 Rev13 Rev14 Rev15 Rev16 Rev17 Total Cost   rolac11
17    0.6   654   7194   7848   8502   9156   9810  10464  11118   6709.383   484.617
18    0.5   545   5995   6540   7085   7630   8175   8720   9265   6212.133  -217.133
19    0.4   436   4796   5232   5668   6104   6540   6976   7412   5714.883  -918.883
20    0.3   327   3597   3924   4251   4578   4905   5232   5559   5217.633 -1620.633
21    0.2   218   2398   2616   2834   3052   3270   3488   3706   4720.383 -2322.383
22    0.1   109   1199   1308   1417   1526   1635   1744   1853   4223.133 -3024.133
      rolac12   rolac13   rolac14   rolac15   rolac16   rolac17
17  1138.617  1792.61702  2446.617   3100.617   3754.61702  4408.617
18   327.867   872.86702  1417.867   1962.867   2507.86702  3052.867
19  -482.883  -46.88298   389.117    825.117   1261.11702  1697.117
20 -1293.633 -966.63298  -639.633  -312.633    14.36702   341.367
21 -2104.383 -1886.38298 -1668.383 -1450.383 -1232.38298 -1014.383
22 -2915.133 -2806.13298 -2697.133 -2588.133 -2479.13298 -2370.133
      Operator Cost      rlc11      rlc12      rlc13      rlc14      rlc15      rlc16
17           810  -325.383    328.617    982.617   1636.617   2290.617   2944.617
18           675  -892.133   -347.133    197.867    742.867   1287.867   1832.867
19           540 -1458.883 -1022.883   -586.883   -150.883    285.117    721.117
20           405 -2025.633 -1698.633 -1371.633 -1044.633   -717.633   -390.633
21           270 -2592.383 -2374.383 -2156.383 -1938.383 -1720.383 -1502.383
22           135 -3159.133 -3050.133 -2941.133 -2832.133 -2723.133 -2614.133
      rlc17
17  3598.61702
18  2377.86702
19  1157.11702
20   -63.63298
21 -1284.38298
22 -2505.13298

```

## 2.4 Electricity price

Electricity price ranges from 1 cents to 6 cents in 0.5 cent increment. Previously, I used AL retail electricity price as described below. It's no longer in use but I description below here

for the record.

Electricity price (\$/kWh) was retail electricity price range for Alabama based on retail electricity price in April 2023 and April 2024 taken from [DOE Database](#). Retail electricity price range in Alabama was from 6.44 to 15.85 cents/kWh in April 2023 and April 2024 which represents industry, commercial, and residential prices.

```
elec_price <- read_xlsx("Parameters.xlsx",  
                        sheet = "Electricity Price") %>%  
  rename(epr_kwh = `Electricity Price ($/kWh)`)  
dim(elec_price)
```

```
[1] 11  1
```

```
elec_price
```

	epr_kwh
2	0.010
3	0.015
4	0.020
5	0.025
6	0.030
7	0.035
8	0.040
9	0.045
10	0.050
11	0.055
12	0.060

## 2.5 PV system cost

- Data taken from “[Capital Costs for Dual-Use Photovoltaic Installations: 2020 Benchmark](#)” Table 1 and Figure 3.
- This data was used to estimate CAPEX.
- avtypes = agrivoltaic types.
- item = itemized component of system.
- cost = cost of each item.
- height = ground to panel clearance height (ft.)
- tcost = Total cost is the sum of all itemized cost for AV system. See figure 3 and table 1 in above document for more detail.

```
pvsc <- wb_read(file = "Parameters.xlsx",
               sheet = "PV system Cost (NREL)",
               rows = c(1:109),
               cols = c(1:5),
               col_names = TRUE) %>%
  rename(avtyps = `AV Types`,
         item = Item,
         cost = `Cost ($/W)`,
         height = `Panel Height (ft.)`,
         tcost = `Total Cost ($/W)`)
dim(pvsc)
```

```
[1] 108 5
```

```
head(pvsc)
```

	avtyps	item	cost	height	tcost
2	Typical Fixed PV	EPC/Developer Net Profit	0.11	4.6	1.53
3	Typical Fixed PV	Developer Overhead	0.15	4.6	1.53
4	Typical Fixed PV	Contingency(3%)	0.05	4.6	1.53
5	Typical Fixed PV	Interconnection Fee	0.03	4.6	1.53
6	Typical Fixed PV	Permitting Fee (if any)	0.02	4.6	1.53
7	Typical Fixed PV	Sale Tax (if any)	0.05	4.6	1.53

```
tail(pvsc)
```

	avtyps	item	cost
104	PV + Crops (Reinforced Regular Mount)	EPC Overhead	0.25
105	PV + Crops (Reinforced Regular Mount)	Installation and Labor Cost	0.32
106	PV + Crops (Reinforced Regular Mount)	Electrical BOS	0.38
107	PV + Crops (Reinforced Regular Mount)	Structural BOS	0.32
108	PV + Crops (Reinforced Regular Mount)	Inverter Only	0.08
109	PV + Crops (Reinforced Regular Mount)	Module	0.40
	height	tcost	
104	8.2	2.33	
105	8.2	2.33	
106	8.2	2.33	
107	8.2	2.33	
108	8.2	2.33	
109	8.2	2.33	

## 2.6 Capex (NREL)

Variable Descriptions:

- Capex: Capital investment cost (\$/W) to develop solar energy system. Capex includes cost of physical structure, developer's overhead and EPC/Developer's net profit.
- capex estimated as  $f(\text{height}, \text{tracker})$  using OLS for 6.4 ft Tracking system.
- Height = ground to panel clearance in ft.
- array: Solar array. Tracker = Single axis sun tracking panels; Fixed = Non-tracking panels.

```
capex <- read.table(file = "CAPEX.txt",  
                    header = TRUE,  
                    sep = "\t") %>%  
  rename(capex = cost,  
         height = pheight,  
         array = tracker)  
dim(capex)
```

```
[1] 6 3
```

```
capex
```

	height	capex	array
1	4.6	1.593333	Fixed
2	4.6	1.733333	Tracking
3	6.4	1.850000	Fixed
4	8.2	2.330000	Fixed
5	8.2	2.110000	Tracking
6	6.4	1.921667	Tracking

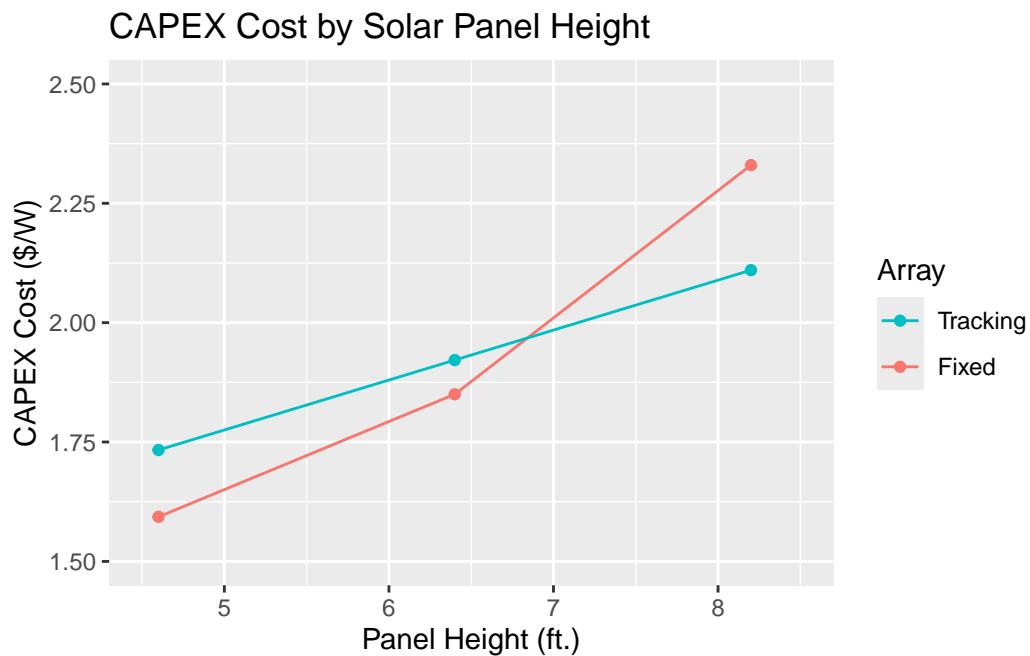
### 2.6.1 Plotting capex

```
plottheme %>% ggplot(data = capex,  
                     mapping = (aes(  
                       x = height,  
                       y = capex,  
                       color = array,                     )
```

```

                                group = array))) +
geom_point() +
geom_line() +
# geom_text(aes(label = "Tracker"),
#           nudge_x = 0.05,
#           nudge_y = 0.05,
#           size = 6) +
labs(
  title = "CAPEX Cost by Solar Panel Height",
  x = "Panel Height (ft.)",
  y = "CAPEX Cost ($/W)",
  color = "Array"
) +
scale_x_continuous(limits = c(4.5, 8.5)) +
scale_y_continuous(limits = c(1.5, 2.5)) +
guides(color = guide_legend(reverse = TRUE))

```



## 2.7 Panel Configuration

- Panel configuration and DV system output (W).

```

panconf <- wb_read(file = "Parameters.xlsx",
  sheet = "Panel Spacing",
  start_row = 2,
  start_col = 1,
  skip_empty_rows = TRUE,
  skip_empty_cols = TRUE,
  col_names = TRUE)
# rename(avtyps = `AV Types`,
#       item = Item,
#       cost = `Cost ($/W)`,
#       height = `Panel Height (ft.)`,
#       tcost = `Total Cost ($/W)`)
dim(panconf)

```

```
[1] 21 21
```

```
head(panconf)
```

	Total Area (Acre)	Total Area (Sq. Ft.)	Solar Proportion	
3	1	43560	1.00	
4	1	43560	0.95	
5	1	43560	0.90	
6	1	43560	0.85	
7	1	43560	0.80	
8	1	43560	0.75	
	Solar Proportion Area (Sq. Ft.)	Solar Proportion Area (Sq.M.)		
3	43560	4046.856		
4	41382	3844.513		
5	39204	3642.170		
6	37026	3439.828		
7	34848	3237.485		
8	32670	3035.142		
	Side Length (ft.)	YSide Length (ft.)	XSide length (ft.)	Panel Length (ft.)
3	208.7103	208.7103	208.7103	7.75
4	208.7103	208.7103	198.2748	7.75
5	208.7103	208.7103	187.8393	7.75
6	208.7103	208.7103	177.4038	7.75
7	208.7103	208.7103	166.9683	7.75
8	208.7103	208.7103	156.5327	7.75
	Row Seperator (ft.)	Panel Width(ft.)	Panel Area (Sq. ft.)	Panels/Row
3	6	3.5	27.125	59



4	6	3.5	27.125	59
5	6	3.5	27.125	59
6	6	3.5	27.125	59
7	6	3.5	27.125	59
8	6	3.5	27.125	59
Total Rows Total Panels Array Area (Sq. Ft.) Array Area (Sq. M.)				
3	15	885	24005.62	2230.195
4	14	826	22405.25	2081.516
5	13	767	20804.88	1932.836
6	12	708	19204.50	1784.156
7	12	708	19204.50	1784.156
8	11	649	17604.12	1635.477
XSide Open Length (ft) Inter Panel Spacing (ft) Panel Efficiency				
3		92	6	0.19
4		100	7	0.19
5		107	8	0.19
6		115	10	0.19
7		115	10	0.19
8		123	12	0.19
DC System Size (kW)				
3		423.7371		
4		395.4880		
5		367.2388		
6		338.9897		
7		338.9897		
8		310.7405		

```
tail(panconf)
```

Total Area (Acre) Total Area (Sq. Ft.) Solar Proportion			
18	1	43560	0.25
19	1	43560	0.20
20	1	43560	0.15
21	1	43560	0.10
22	1	43560	0.05
23	1	43560	0.00
Solar Proportion Area (Sq. Ft.) Solar Proportion Area (Sq.M.)			
18		10890	1011.7140
19		8712	809.3712
20		6534	607.0284
21		4356	404.6856
22		2178	202.3428

23		0	0.0000	
	Side Length (ft.)	YSide Length (ft.)	XSide length (ft.)	Panel Length (ft.)
18	208.7103	208.7103	52.17758	7.75
19	208.7103	208.7103	41.74207	7.75
20	208.7103	208.7103	31.30655	7.75
21	208.7103	208.7103	20.87103	7.75
22	208.7103	208.7103	10.43552	7.75
23	208.7103	208.7103	0.00000	7.75
	Row Seperator (ft.)	Panel Width(ft.)	Panel Area (Sq. ft.)	Panels/Row
18	6	3.5	27.125	59
19	6	3.5	27.125	59
20	6	3.5	27.125	59
21	6	3.5	27.125	59
22	6	3.5	27.125	59
23	6	3.5	27.125	59
	Total Rows	Total Panels	Array Area (Sq. Ft.)	Array Area (Sq. M.)
18	3	177	4801.125	446.0391
19	3	177	4801.125	446.0391
20	2	118	3200.750	297.3594
21	1	59	1600.375	148.6797
22	0	0	0.000	0.0000
23	0	0	0.000	0.0000
	XSide Open Length (ft)	Inter Panel Spacing (ft)	Panel Efficienfy	
18	185	92	0.19	
19	185	92	0.19	
20	193	193	0.19	
21	200	NA	0.19	
22	208	NA	0.19	
23	208	NA	0.19	
	DC System Size (kW)			
18	84.74742			
19	84.74742			
20	56.49828			
21	28.24914			
22	0.00000			
23	0.00000			

## 2.8 Energy output

Energy output was simulated using NREL [PV Watts Calculator](#).

- sprop = land proportion covered by solar in 1 acres. Value ranges from 0 to 1.

- Panels = Total number of panels in 1 acres of land.
- datalot: 1 = first simulation done for four regions of AL; 2 = second simulation done for four regions of AL. Two simulations have two unique zipcodes for each simulated region.
- al\_regs = regions of Alabama
- zips = zipcodes selected from each region of AL for simulation.
- array = Fixed (open rack); 1AxisRot = 1 Axis Tracking. See above NREL tool for more detail.
- dc\_kw = DC system size, calculated for each solar panel heights considering solar panels efficiency and area covered by solar panels.
- energy = total energy output ( kWh/Year) considering system parameters. Total hours considered by the model is 8,760 (See [PV Watts Calculator](#) Results > help (below the result) > results > download monthly or hourly results).

```
energy_output <- read_xlsx("Parameters.xlsx",
                          sheet = "Energy Output",
                          start_row = 1,
                          start_col = 1,
                          skip_empty_rows = TRUE,
                          skip_empty_cols = TRUE,
                          col_names = TRUE) %>%
  rename(sprop = `Solar Proportion`,
         panels = `Total Panels`,
         datalot = DataLot,
         al_regs = `Region of AL`,
         zips = ZIPCODE,
         array = `Array Type`,
         dc_kw = `DC System Size (kW)`,
         energy = `Energy (kWh/Year)`) %>%
  mutate(dc_kw = round(dc_kw, 2),
         array = case_when(
           array == "1AxisRot" ~ "Tracking",
           array == "FixedOpen" ~ "Fixed",
           TRUE ~ array))

dim(energy_output)
```

```
[1] 336    8
```

```
head(energy_output)
```

	sprop	panels	datalot	al_regs	zip	array	dc_kw	energy
2	1.00	885	1	Northern	35801	Tracking	423.74	672887
3	0.95	826	1	Northern	35801	Tracking	395.49	628029
4	0.90	767	1	Northern	35801	Tracking	367.24	583171
5	0.75	649	1	Black Belt	36117	Tracking	310.74	534002
6	0.75	649	2	Black Belt	36040	Tracking	310.74	515824
7	0.80	708	1	Black Belt	36117	Tracking	338.99	582547

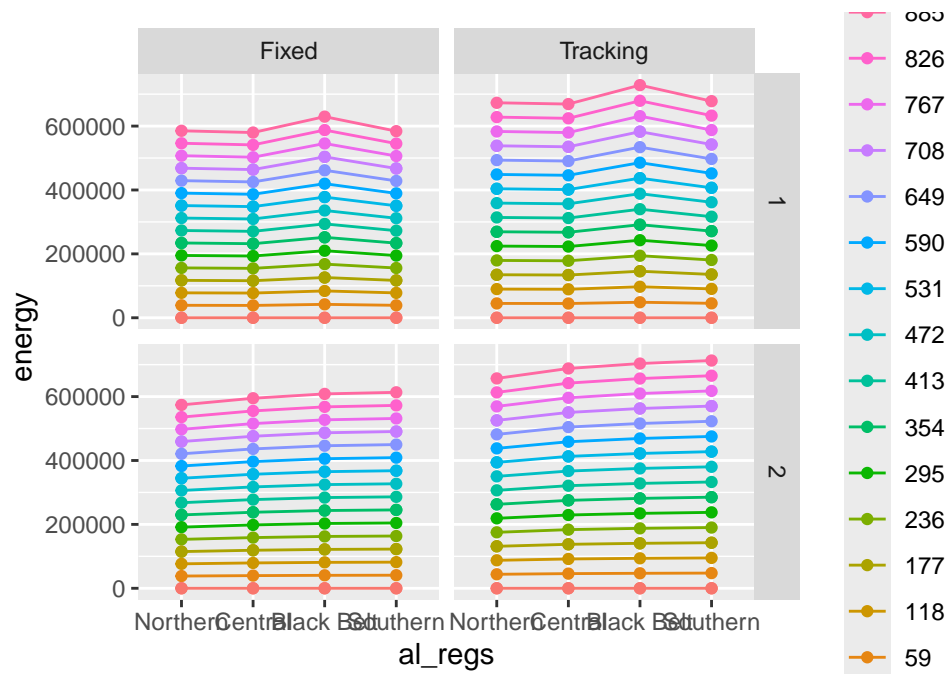
```
tail(energy_output)
```

	sprop	panels	datalot	al_regs	zip	array	dc_kw	energy
332	0.25	177	2	Southern	36507	Fixed	84.75	122697
333	0.20	177	2	Southern	36507	Fixed	84.75	122697
334	0.15	118	2	Southern	36507	Fixed	56.50	81800
335	0.10	59	2	Southern	36507	Fixed	28.25	40902
336	0.05	0	2	Southern	36507	Fixed	0.00	0
337	0.00	0	2	Southern	36507	Fixed	0.00	0

### 2.8.1 Energy output by solar panels counts

Plotting Energy output by number of solar panels in one acres of AV system from fixed and single axis rotation system for two zipcodes (1, 2) within each of the four regions of AL.

```
lox <- c("Northern", "Central", "Black Belt", "Southern")
array_levs = c("Single Axis Rotation", "Fixed Open Rack")
datalot_levs = c("Location 1", "Location 2")
ggplot(data = energy_output,
        mapping = aes(x = al_regs,
                      y = energy,
                      #fill = energy,
                      color = factor(panels),
                      group = factor(panels))) +
  geom_line()+
  geom_point() +
  facet_grid(datalot~array) +
  scale_x_discrete(limits = lox) +
  guides(color = guide_legend(reverse = TRUE))
```

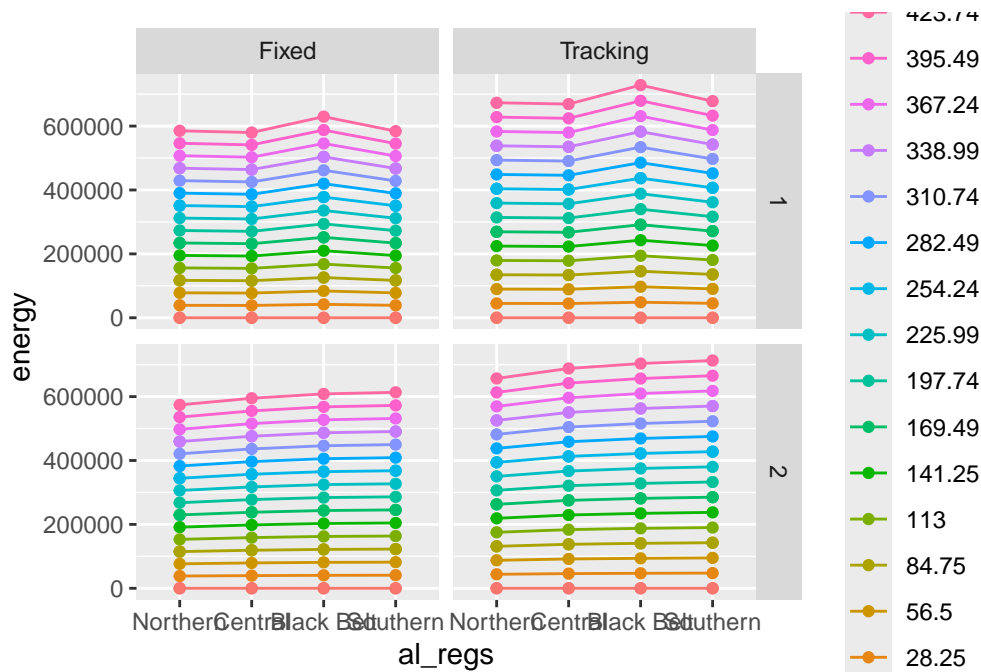


## 2.8.2 Energy output by DC System Size

Plotting Energy output by DC System Size from fixed and single axis rotation system for two zipcodes (1, 2) within each of the four regions of AL.

```
ggplot(data = energy_output,
       mapping = aes(x = al_regs,
                     y = energy,
                     #fill = energy,
                     color = factor(dc_kw),
                     group = factor(dc_kw))) +

  geom_line()+
  geom_point() +
  facet_grid(datalot~array) +
  scale_x_discrete(limits = lox) +
  guides(color = guide_legend(reverse = TRUE))
```



### 3 Revenue from energy

#### 3.1 Simulation 1

- elcprc = electricity price. See Electricity price data for more detail.
- elcrev = Revenue from electricity for given electricity prices. See “energy output” and “electricity price” dataset for more details.
- I took average of “energy” from datalot 1 and datalot 2 to minimize computation time.

```
# Convert to data frames if they are not already
matrix1 <- energy_output %>%
  group_by(sprop, al_regs, array, dc_kw, panels) %>%
  #filter(datalot == 2) %>%
  # Compute mean of datalot 1 and datalot 2:
  summarise(
    energy = mean(energy),
    .groups = 'drop'
  ) # dimension of matrix is 168*6
matrix2 <- elec_price # dimension of matrix is 11*1
```

```

# Initialize the result data frame
# energy_revenue <- data.frame(matrix(nrow = 1848, ncol = 9))
energy_revenue <- data.frame(
  matrix(nrow = nrow(matrix2)*nrow(matrix1),
        ncol = ncol(matrix2)+ncol(matrix1)+1))

# Variable to keep track of the row index in the result matrix
row_index <- 1

# Loop through each value of the second matrix
for (i in 1:nrow(matrix2)) {
  # Loop through each value of the second matrix
  for (j in 1:nrow(matrix1)) {
    # First matrix, second matrix, combined two matrices.
    new_row <- c(matrix1[j, ],
                 matrix2[i, ],
                 matrix1$energy[j] * matrix2$epr_kwh[i])
    # Assign the new row to the result matrix
    energy_revenue[row_index, ] <- new_row
    # Increment the row index
    row_index <- row_index + 1
  }
}

# Name the columns
colnames(energy_revenue) <- c(colnames(matrix1), "elcprc", "elcrev")

# Display the result
dim(energy_revenue)

```

```
[1] 1848    8
```

```
head(energy_revenue); tail(energy_revenue)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev
1	0	Black Belt	Fixed	0	0	0	0.01	0
2	0	Black Belt	Tracking	0	0	0	0.01	0
3	0	Central	Fixed	0	0	0	0.01	0
4	0	Central	Tracking	0	0	0	0.01	0
5	0	Northern	Fixed	0	0	0	0.01	0
6	0	Northern	Tracking	0	0	0	0.01	0

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev
1843	1	Central	Fixed	423.74	885	587291.0	0.06	35237.46
1844	1	Central	Tracking	423.74	885	678466.0	0.06	40707.96
1845	1	Northern	Fixed	423.74	885	579622.5	0.06	34777.35
1846	1	Northern	Tracking	423.74	885	664888.0	0.06	39893.28
1847	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23
1848	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90

```
# Check for any NAs in the result
if(any(is.na(energy_revenue))) {
  na_indices <- which(is.na(energy_revenue), arr.ind = TRUE)
  print(paste("NAs found at rows:", unique(na_indices[, 1])))
} else {
  print("No NAs found in the result data frame.")
}
```

```
[1] "No NAs found in the result data frame."
```

## 3.2 Simulation 2

This simulation has same result as above (Cross checking above code and output). Results are suppressed but errors and warnings are not. No error and no warnings means code is working as it should.

```
## | results='hide'
# Sample data
set.seed(123)
matrix1 <- energy_output # dimension of matrix is 176*7
matrix2 <- elec_price # dimension of matrix is 11*1

# Initializing the result matrix
result_matrix <- data.frame(matrix(ncol = nrow(matrix2),
                                   nrow = 0))
colnames(result_matrix) <- c(colnames(matrix1), "elcrev", "elcprc")

# Loop to multiply first and second matrices
for (i in 1:nrow(matrix2)) {
  temp_matrix <- matrix1
  temp_matrix$E_Prc <- matrix2[i, ]
  temp_matrix$E_Rev <- matrix1$energy[j] * matrix2$epr_kwh[i]
  result_matrix <- rbind(result_matrix, temp_matrix)
```



```

}

# Display the resulting matrix
dim(result_matrix)
head(result_matrix)
tail(result_matrix)

```

### 3.3 Plotting revenue from energy production

#### 3.3.1 Breakdown by number of solar panels

I am using data from simulation 1 for this visualization. This code plots one chart per electricity cost. There are 11 electricity cost resulting into 11 charts.

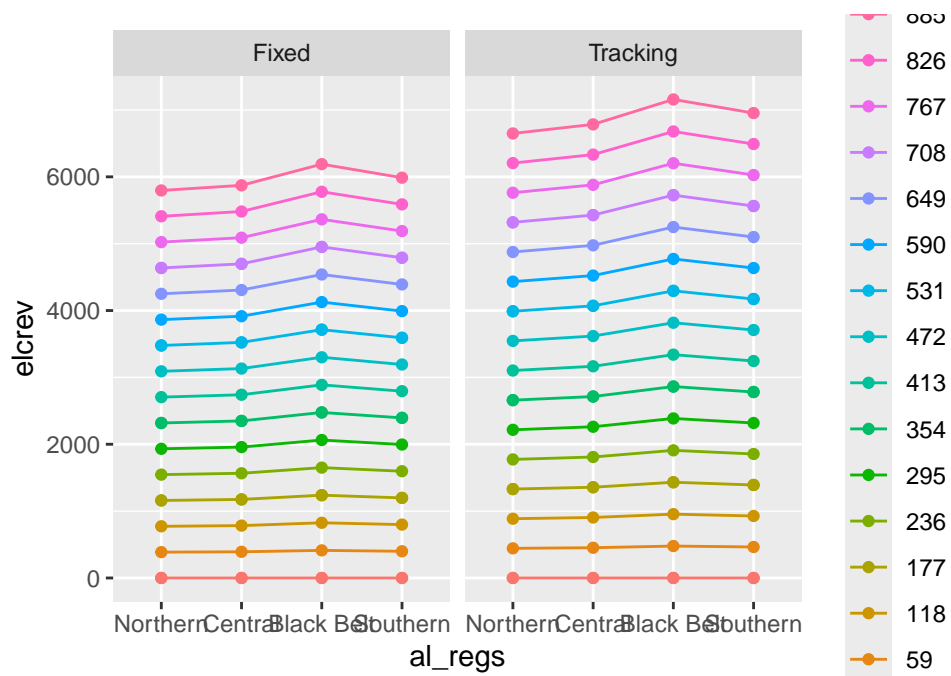
```

lox <- c("Northern", "Central", "Black Belt", "Southern")
array_levs = c("Single Axis Rotation", "Fixed Open Rack")
datalot_levs = c("Location 1", "Location 2")
for (i in unique(energy_revenue$elcprc)) {
  a = ggplot(data = (energy_revenue %>%
    filter(elcprc == i)),
    mapping = aes(x = al_regs,
                  y = elcrev,
                  #fill = energy,
                  color = factor(panels),
                  group = factor(panels))) +

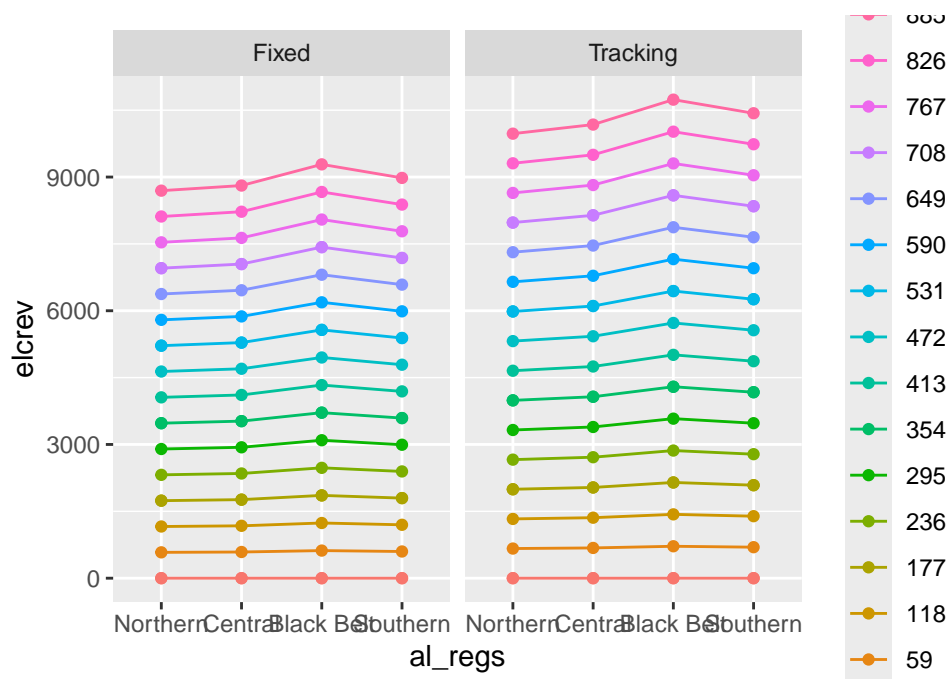
  geom_line() +
  geom_point() +
  facet_grid(.~array) +
  scale_x_discrete(limits = lox) +
  guides(color = guide_legend(reverse = TRUE))
  cat("Electricity Price = ", i)
  print(a)
}

```

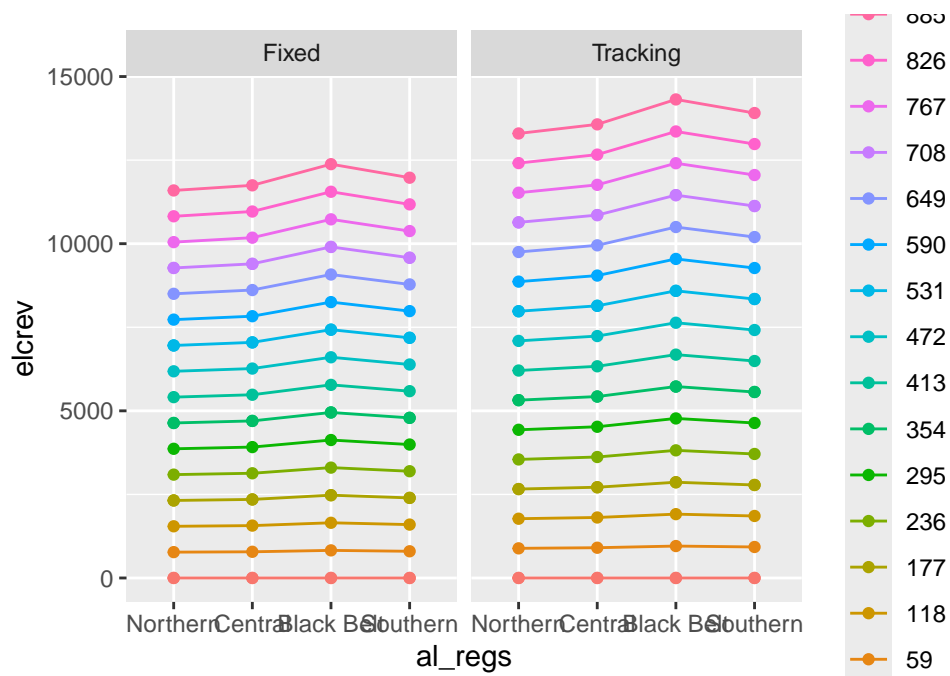
Electricity Price = 0.01



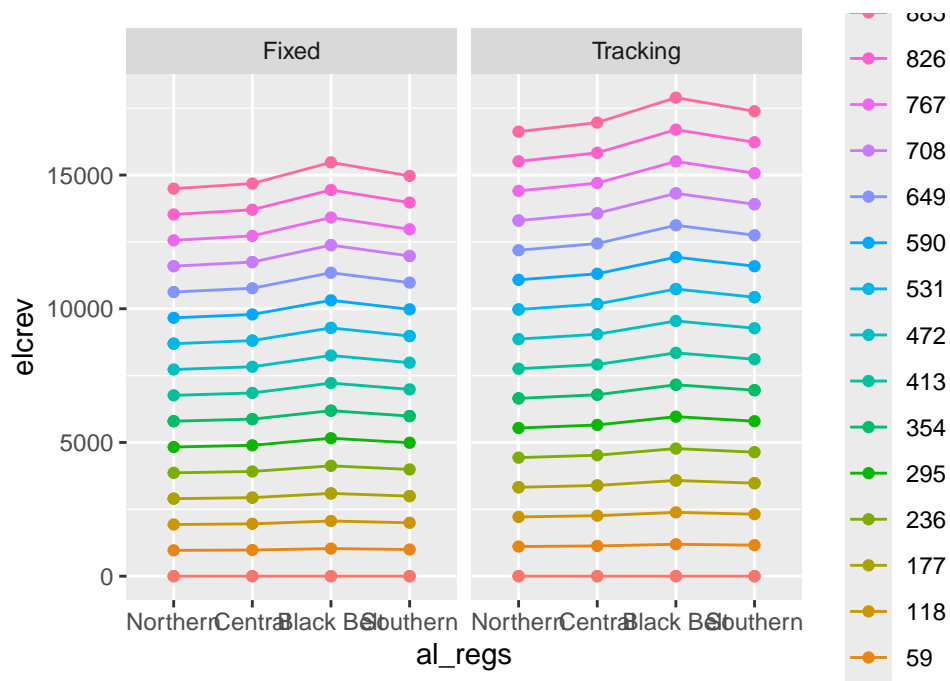
Electricity Price = 0.015



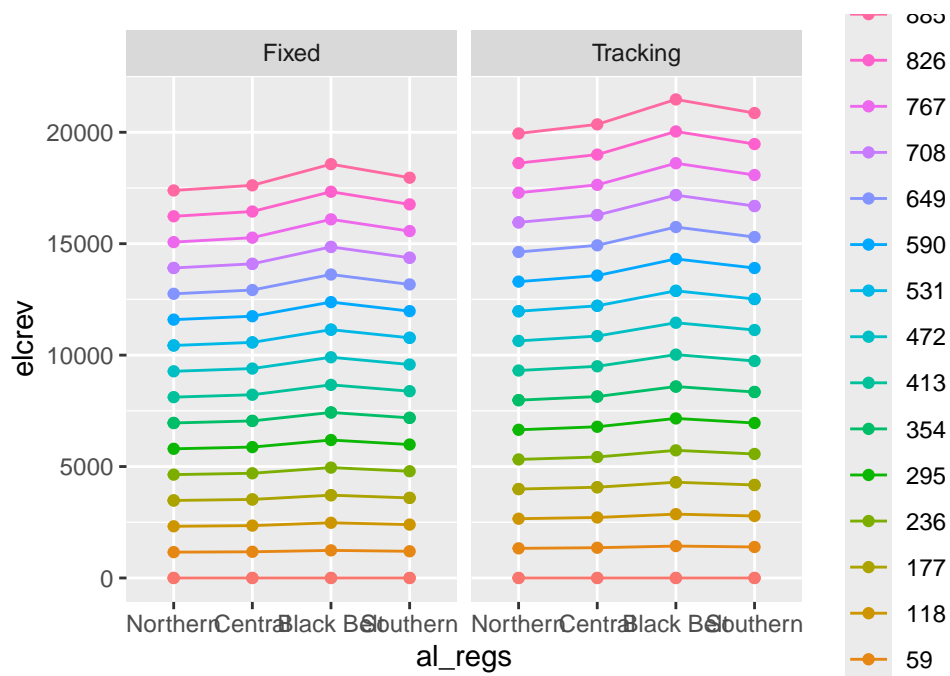
Electricity Price = 0.02



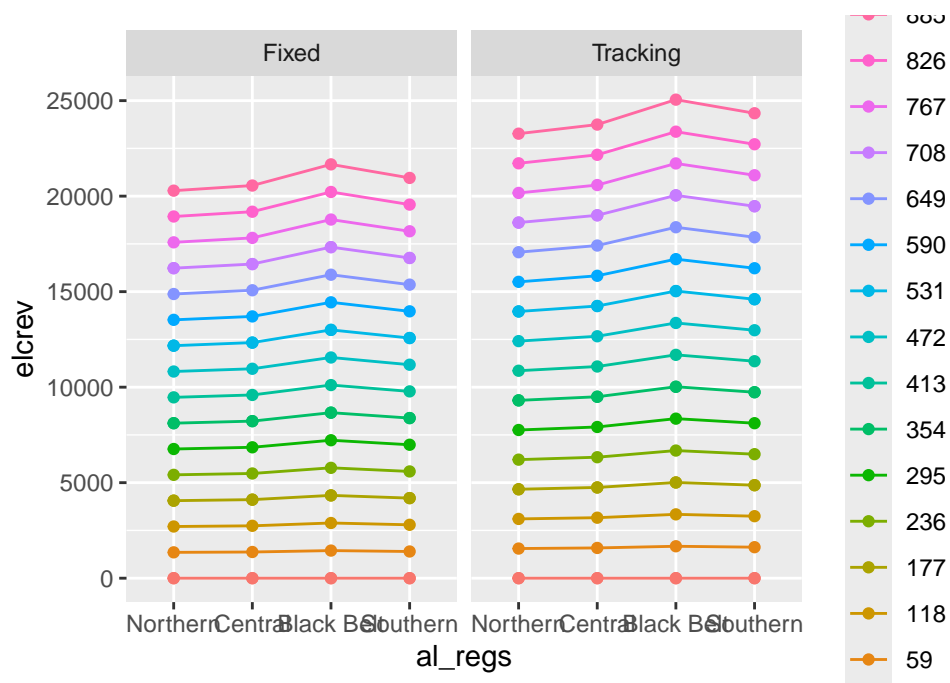
Electricity Price = 0.025



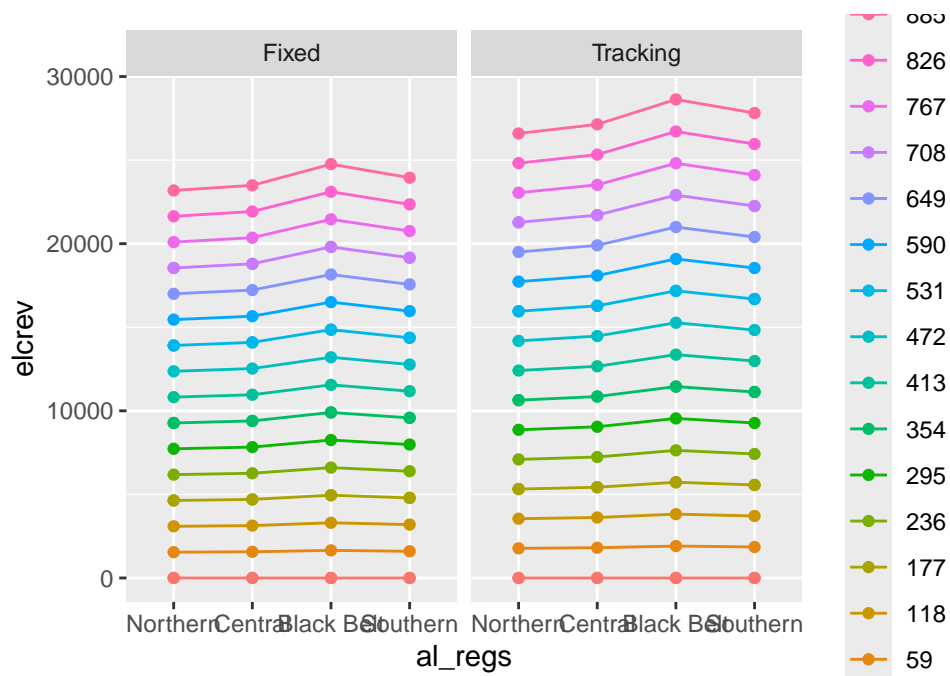
Electricity Price = 0.03



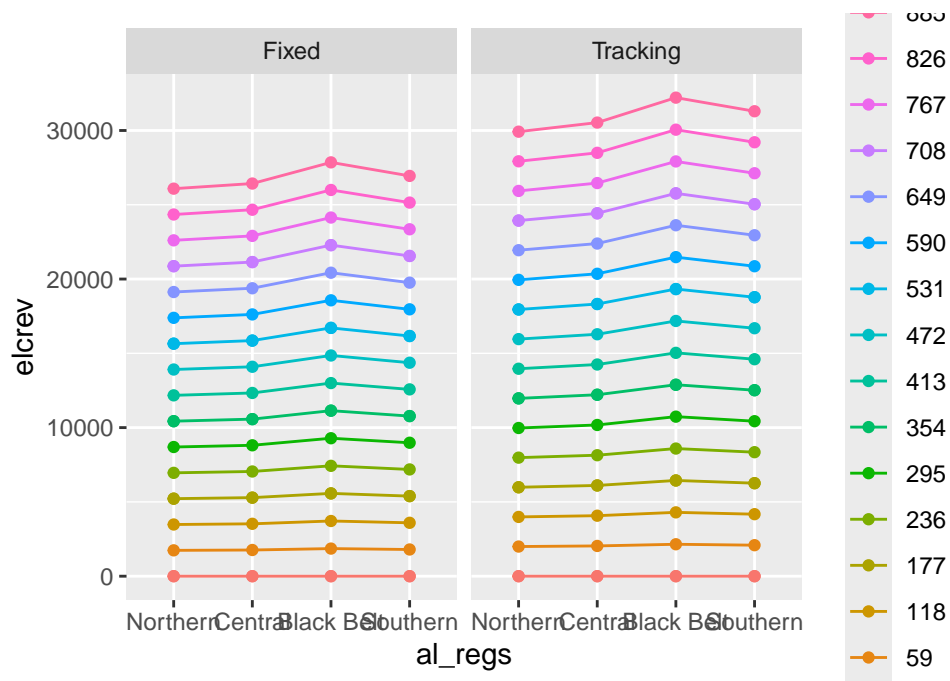
Electricity Price = 0.035



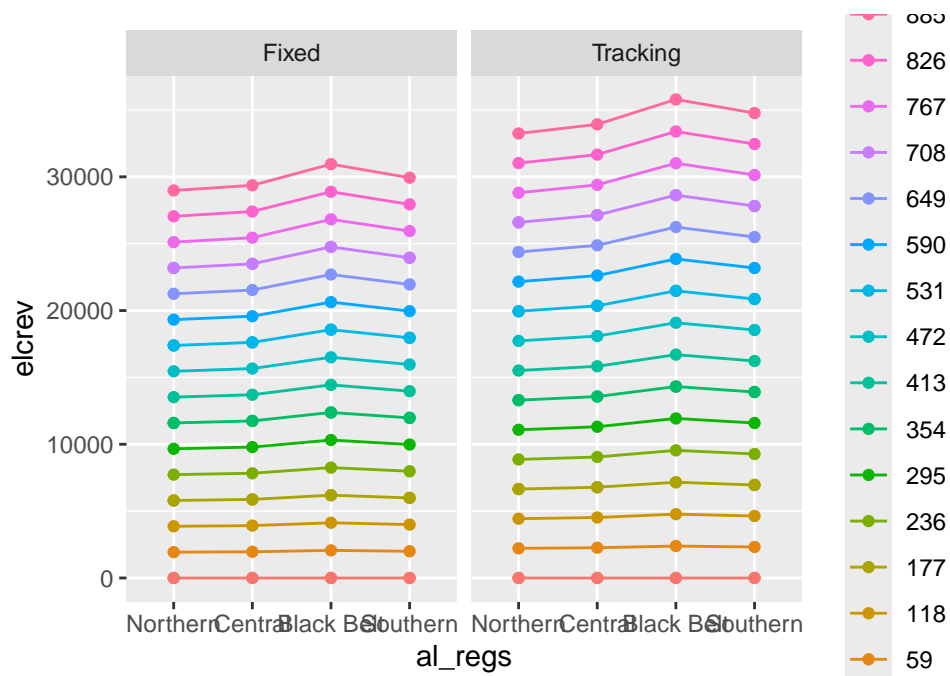
Electricity Price = 0.04



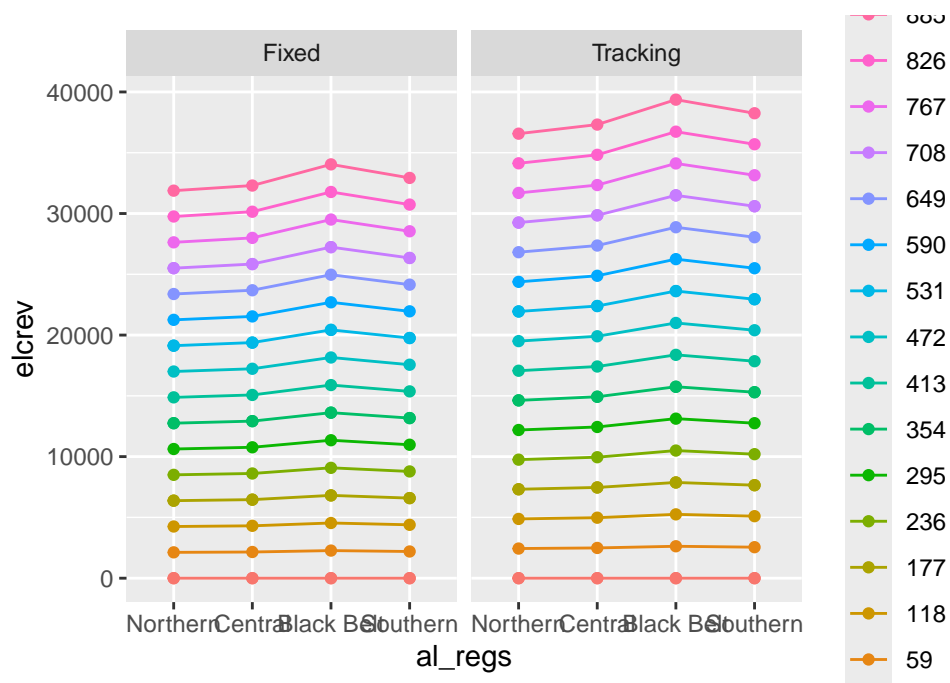
Electricity Price = 0.045



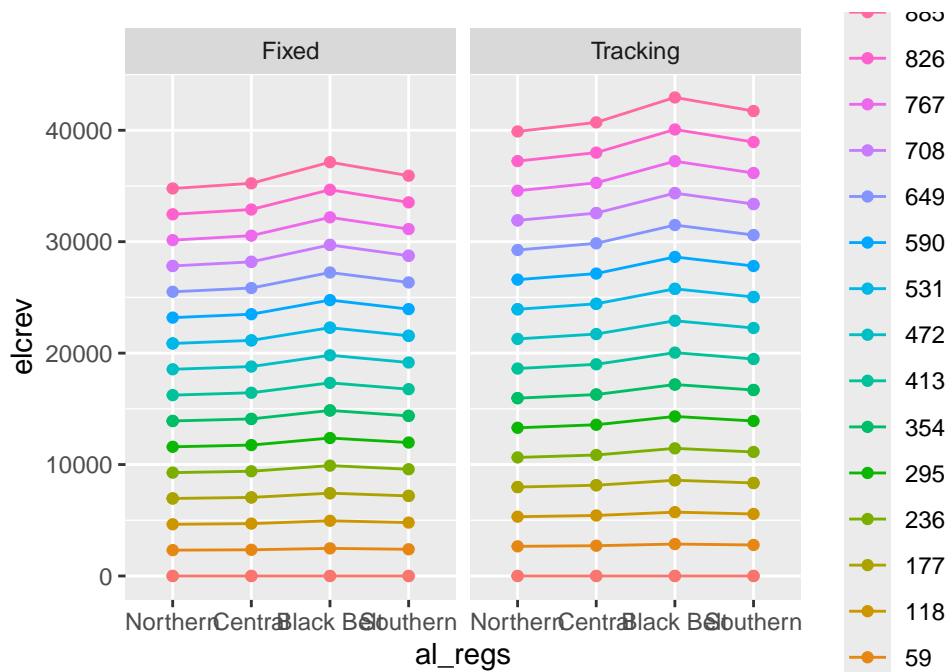
Electricity Price = 0.05



Electricity Price = 0.055



Electricity Price = 0.06



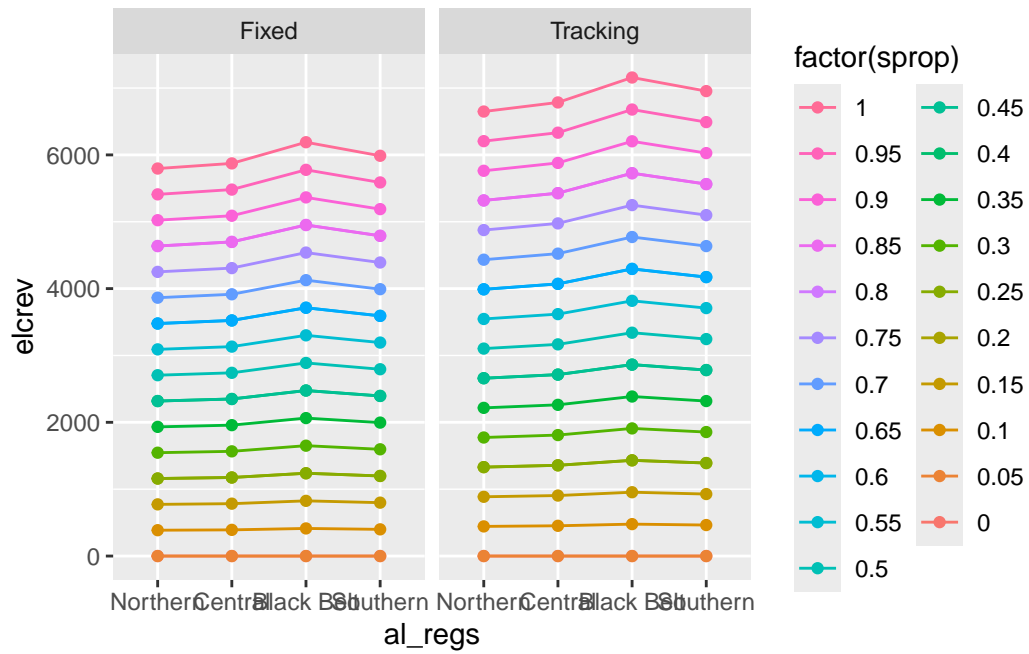
### 3.3.2 Breakdown by proportion of land under solar panels

- Two proportions may have same number of solar panels (Eg. 0.80 and 0.85, 0.20 and 0.25). So, total lines in the chart may not match with total number of legend levels. Some proportions are overlapping in the chart. See panel configuration for more detail.

```
lox <- c("Northern", "Central", "Black Belt", "Southern")
array_levs = c("Single Axis Rotation", "Fixed Open Rack")
datalot_levs = c("Location 1", "Location 2")
for (i in unique(energy_revenue$elcprc)) {
  a = ggplot(data = (energy_revenue %>%
    filter(elcprc == i)),
    mapping = aes(x = al_regs,
                  y = elcrev,
                  #fill = energy,
                  color = factor(sprop),
                  group = factor(sprop)))+
    geom_line()+
    geom_point()+
    facet_grid(.~array) +
    scale_x_discrete(limits = lox) +
    guides(color = guide_legend(reverse = TRUE))
}
```

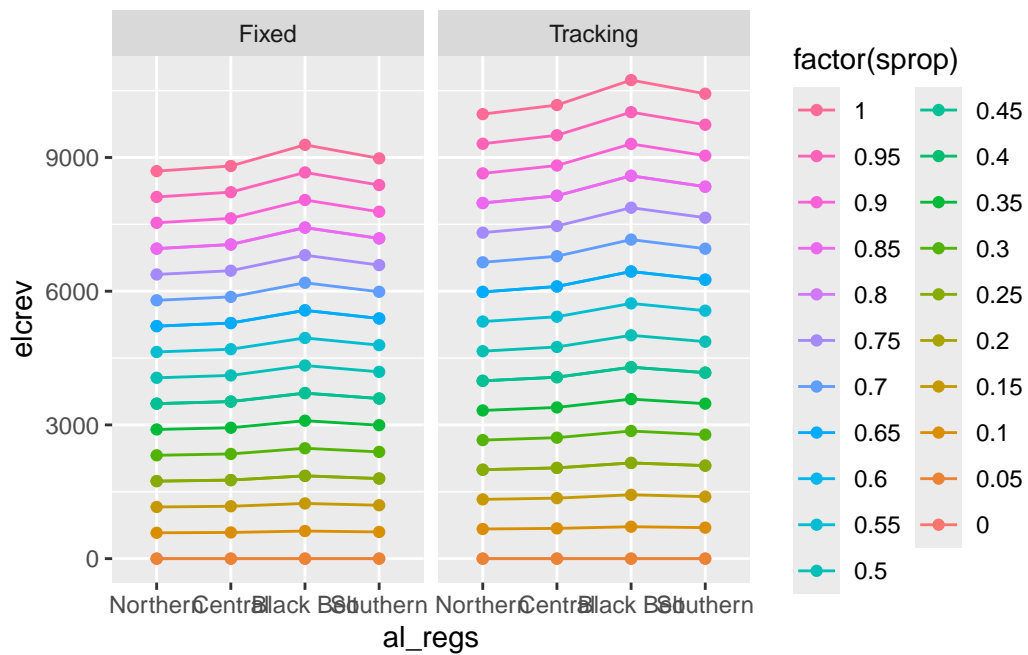
```
cat("Electricity Price = ", i)
print(a)
}
```

Electricity Price = 0.01

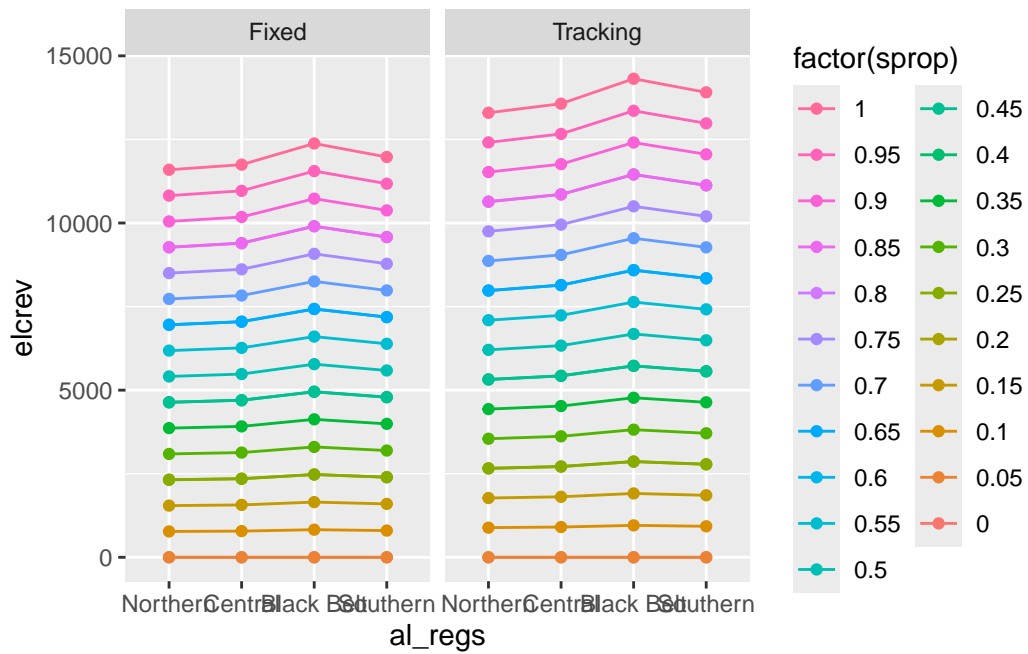


Electricity Price = 0.015

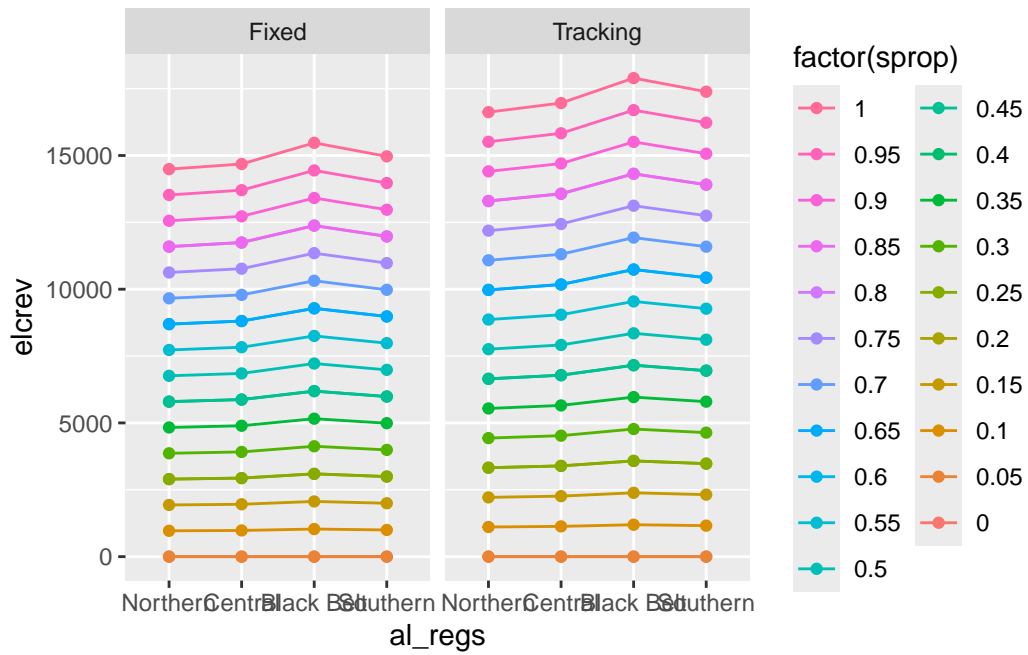




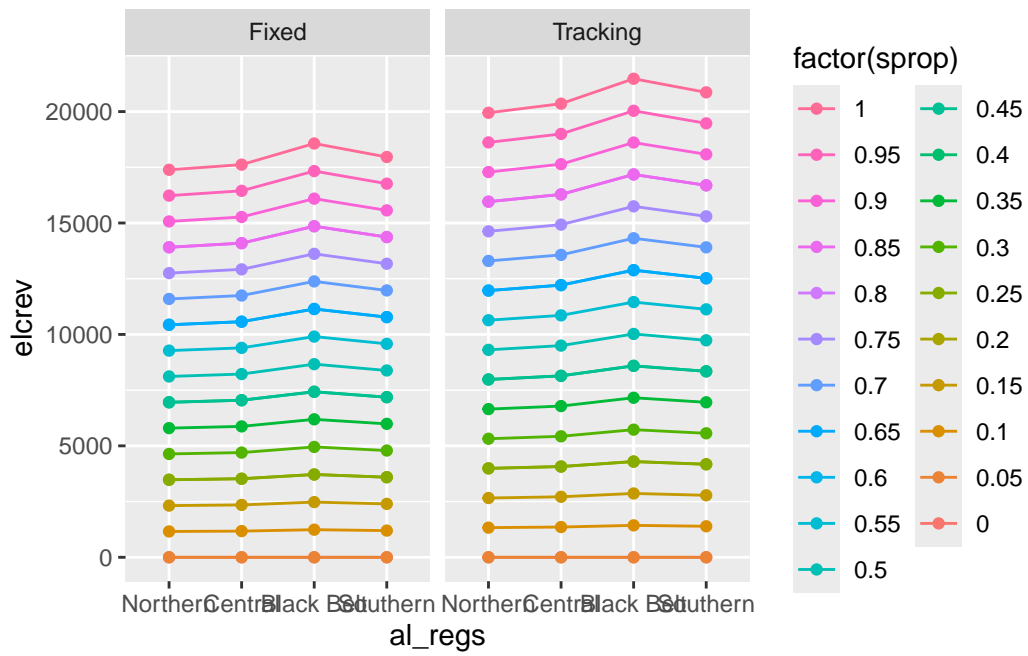
Electricity Price = 0.02



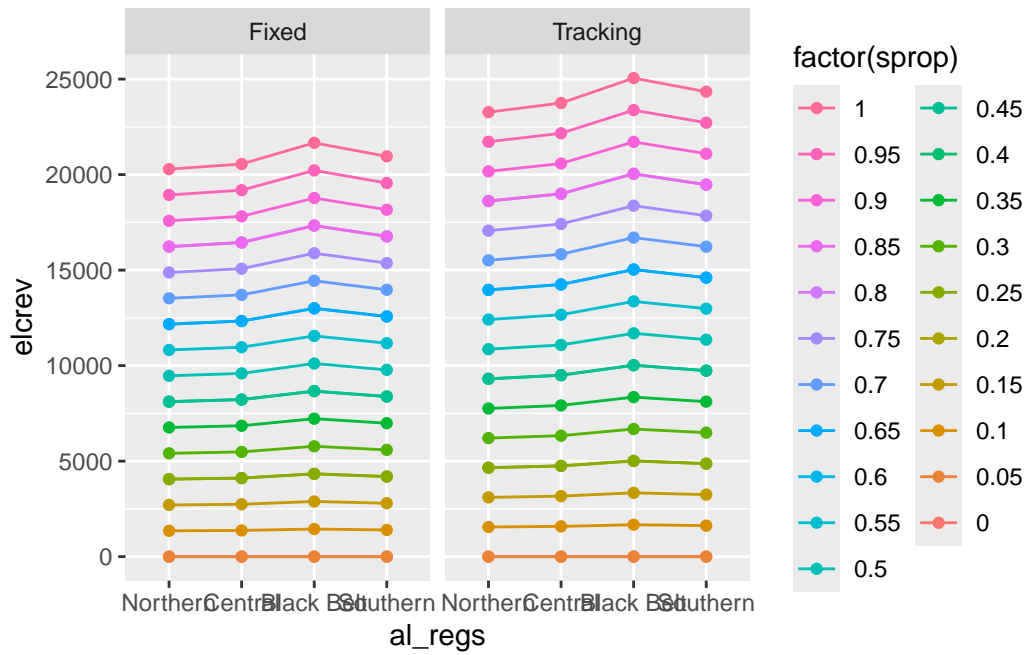
Electricity Price = 0.025



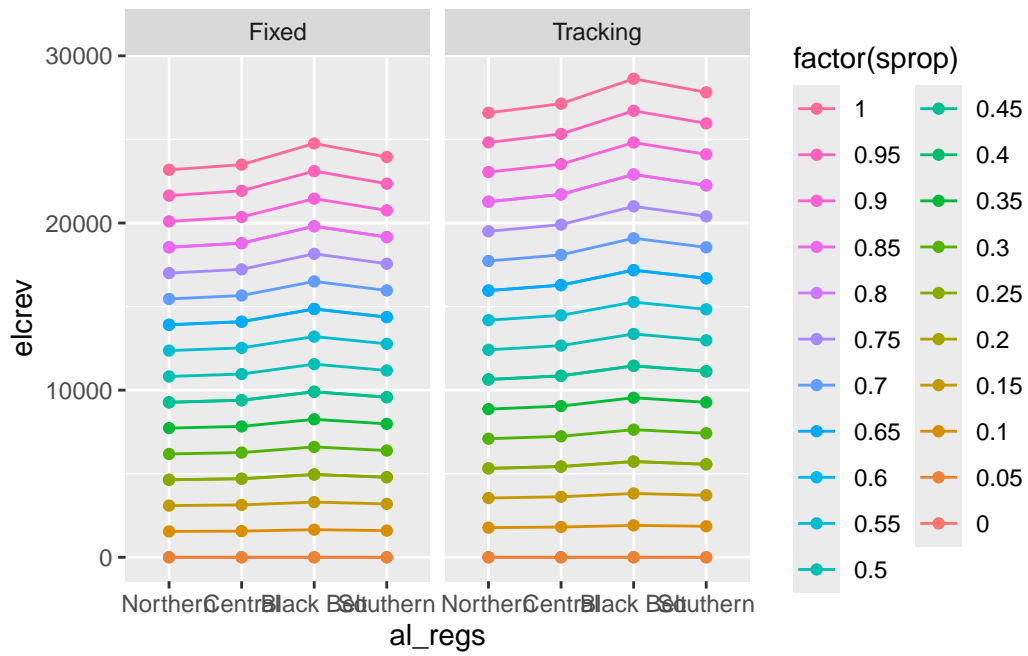
Electricity Price = 0.03



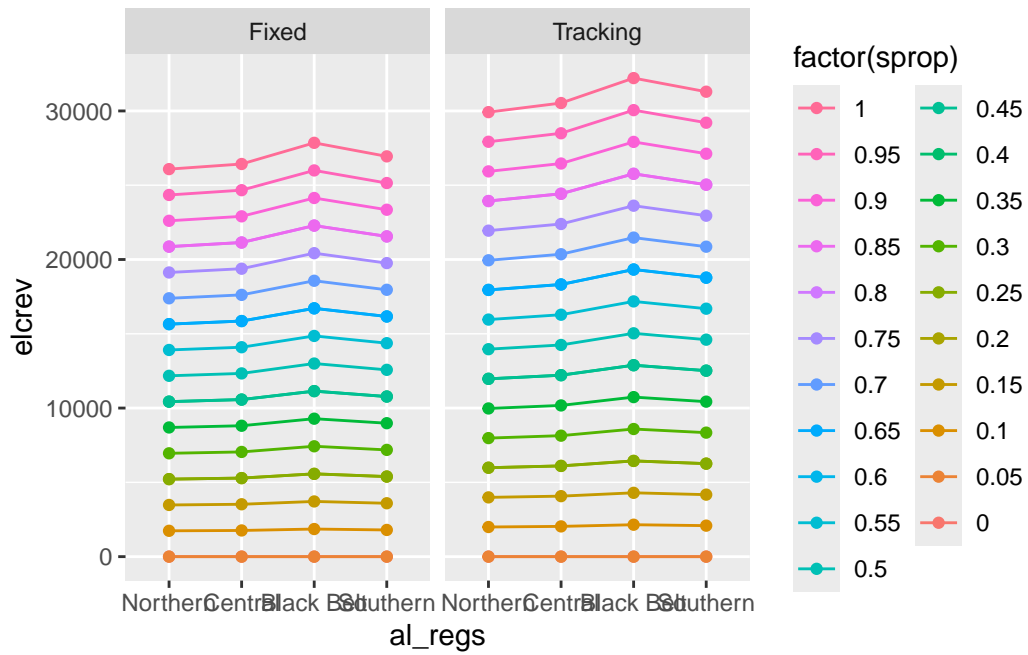
Electricity Price = 0.035



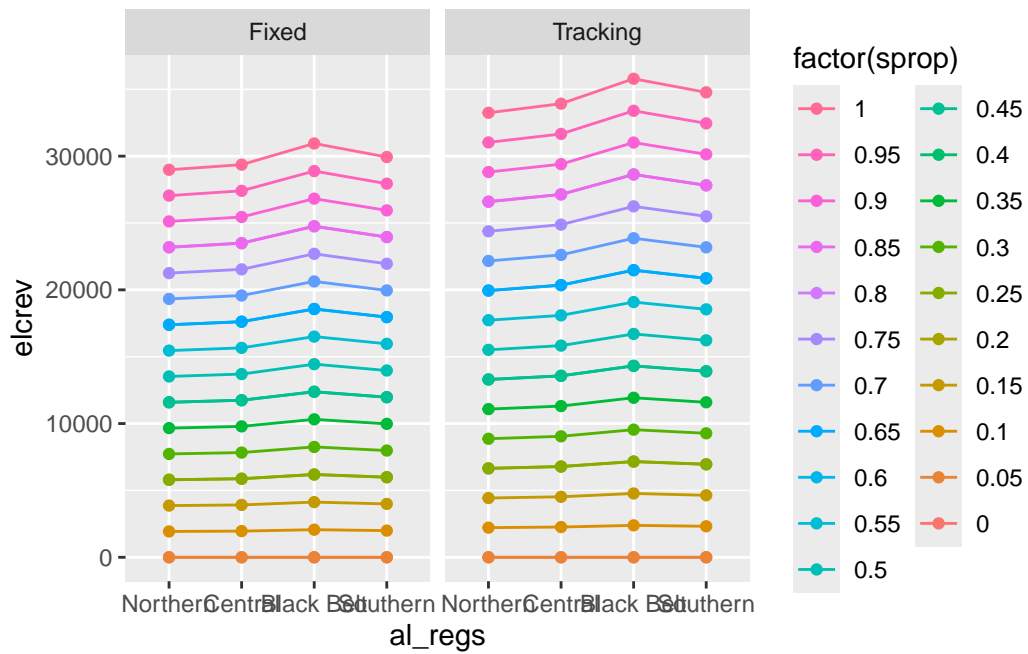
Electricity Price = 0.04



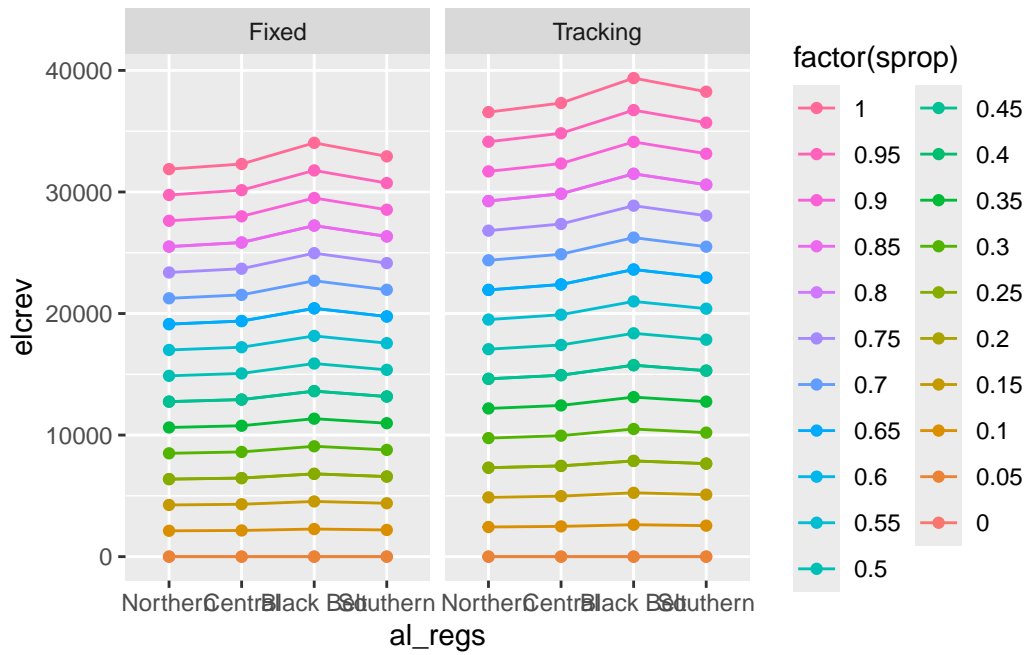
Electricity Price = 0.045



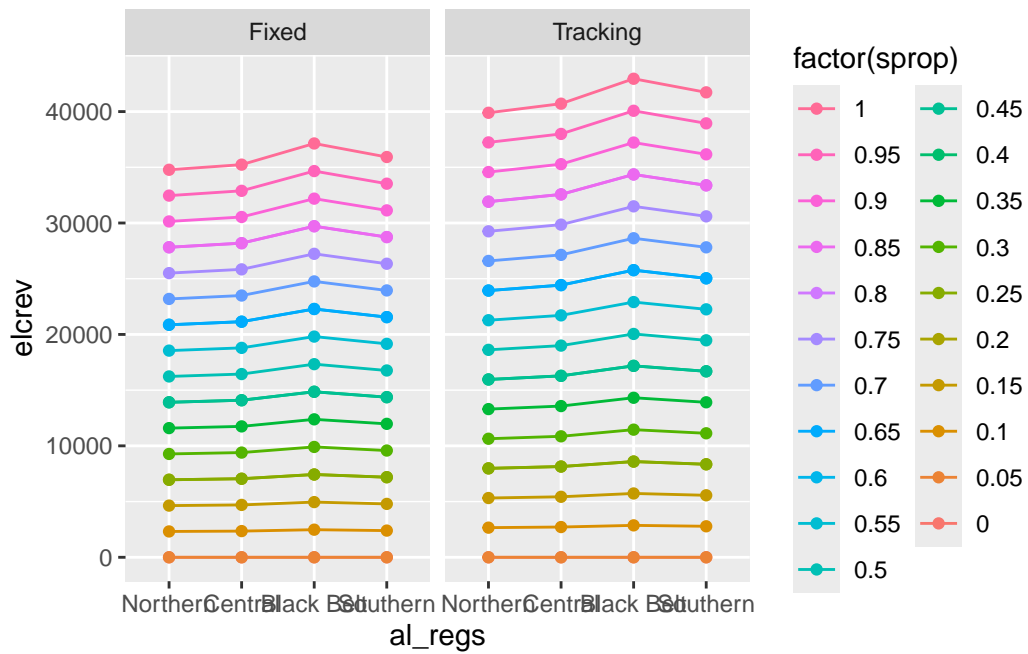
Electricity Price = 0.05



Electricity Price = 0.055



Electricity Price = 0.06



## 4 Solar system cost

- Cost of solar energy system in agrivoltaic setting.
- I used DC system size (dc\_kw) and capex (\$/W) to get total cost for each height and panel tracking system.
- 1 kw dc system size costs x\$ CAPEX for given height and tracking system.
- y kw dc system size costs \$x\*y for given height and tracking system.
- Use simulation 1 data and capex data to get solar system cost.
- There should be  $1936*3 = 5808$  rows in this dataset.
- height = height of solar panels; see capex dataset for details.
- capex = capex from capex table; see capex dataset for details.
- ttlcost = Total cost for given DC system size.
- anncost = Annual payment to repay loan ( $P_{ann} = \frac{P_o(i(1+i)^t)}{(1+i)^t - 1}$ ), where  $P_o$  = CAPEX loan borrowed to repay in  $t$  years;  $t = 25$ , and  $i$  = annual interest rate at 5%.
- moncost = Monthly payment to repay loan ( $P_{mon} = \frac{P_o((i/12)(1+(i/12))^{t*12})}{(1+(i/12))^{t*12} - 1}$ ), where  $P_o$  = CAPEX loan borrowed to repay in  $t$  years;  $t = 25$ , and  $i$  = annual interest rate at 5%.

```
expanded_data <- energy_revenue %>%
  slice(rep(1:n(),
           each = 3))
capex_height <- rep(unique(capex$height),
                   length.out = nrow(energy_revenue))
energy_cost = cbind(expanded_data, capex_height) %>%
  rename(height = capex_height)

energy_cost <- left_join(energy_cost,
                        capex,
                        by = c("array", "height")) %>%
  mutate(ttlcost = capex*dc_kw,
         anncost = ttlcost*(0.05*(1 + 0.05)^25)/((1 + 0.05)^25 - 1),
         moncost = ttlcost*((0.05/12)*(1 + (0.05/12))^(25*12))/((1 + (0.05/12))^(25*12) - 1))

dim(energy_cost)
```

```
[1] 5544    13
```

```
head(energy_cost)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height	capex
1	0	Black Belt	Fixed	0	0	0	0.01	0	4.6	1.593333
2	0	Black Belt	Fixed	0	0	0	0.01	0	6.4	1.850000
3	0	Black Belt	Fixed	0	0	0	0.01	0	8.2	2.330000
4	0	Black Belt	Tracking	0	0	0	0.01	0	4.6	1.733333
5	0	Black Belt	Tracking	0	0	0	0.01	0	6.4	1.921667
6	0	Black Belt	Tracking	0	0	0	0.01	0	8.2	2.110000
	ttlcost	anncost	moncost							
1	0	0	0							
2	0	0	0							
3	0	0	0							
4	0	0	0							
5	0	0	0							
6	0	0	0							

```
tail(energy_cost)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height	
5539	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	4.6	
5540	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	6.4	
5541	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	8.2	
5542	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	4.6	
5543	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	6.4	
5544	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	8.2	
	capex	ttlcost	anncost	moncost						
5539	1.593333	675.1591	47.90419	3.946913						
5540	1.850000	783.9190	55.62098	4.582712						
5541	2.330000	987.3142	70.05237	5.771740						
5542	1.733333	734.4827	52.11335	4.293713						
5543	1.921667	814.2870	57.77567	4.760241						
5544	2.110000	894.0914	63.43798	5.226769						

## 5 Profit from solar

Profit from solar energy system in agrivoltaic setting

- eprofit = profit from electricity after subtracting total cost (ttlcost) from total revenue (elcrev).

- eannprof = annual profit from solar after subtracting annual loan repayment distributed over 25 years.
- emonprof = monthly profit from solar after subtracting monthly loan repayment distributed over 25 years.

```
solar_profit <- energy_cost %>%
  mutate(eprofit = elcrev - ttlcost,
         eannprof = elcrev - anncost,
         emonprof = (elcrev/12) - moncost)
dim(solar_profit)
```

```
[1] 5544    16
```

```
head(solar_profit)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height	capex
1	0	Black Belt	Fixed	0	0	0	0.01	0	4.6	1.593333
2	0	Black Belt	Fixed	0	0	0	0.01	0	6.4	1.850000
3	0	Black Belt	Fixed	0	0	0	0.01	0	8.2	2.330000
4	0	Black Belt	Tracking	0	0	0	0.01	0	4.6	1.733333
5	0	Black Belt	Tracking	0	0	0	0.01	0	6.4	1.921667
6	0	Black Belt	Tracking	0	0	0	0.01	0	8.2	2.110000
	ttlcost	anncost	moncost	eprofit	eannprof	emonprof				
1	0	0	0	0	0	0				
2	0	0	0	0	0	0				
3	0	0	0	0	0	0				
4	0	0	0	0	0	0				
5	0	0	0	0	0	0				
6	0	0	0	0	0	0				

```
tail(solar_profit)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height
5539	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	4.6
5540	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	6.4
5541	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	8.2
5542	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	4.6
5543	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	6.4
5544	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	8.2
	capex	ttlcost	anncost	moncost	eprofit	eannprof	emonprof		



```

5539 1.593333 675.1591 47.90419 3.946913 35248.07 35875.33 2989.656
5540 1.850000 783.9190 55.62098 4.582712 35139.31 35867.61 2989.020
5541 2.330000 987.3142 70.05237 5.771740 34935.92 35853.18 2987.831
5542 1.733333 734.4827 52.11335 4.293713 40990.42 41672.79 3472.781
5543 1.921667 814.2870 57.77567 4.760241 40910.61 41667.12 3472.315
5544 2.110000 894.0914 63.43798 5.226769 40830.81 41661.46 3471.848

```

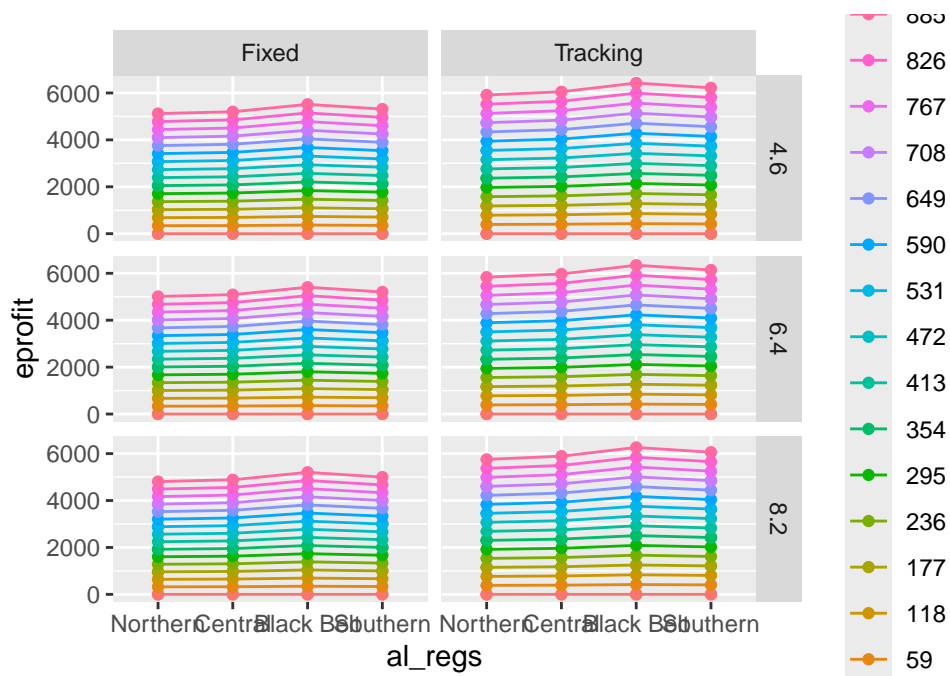
## 5.1 Plot profit from solar

```

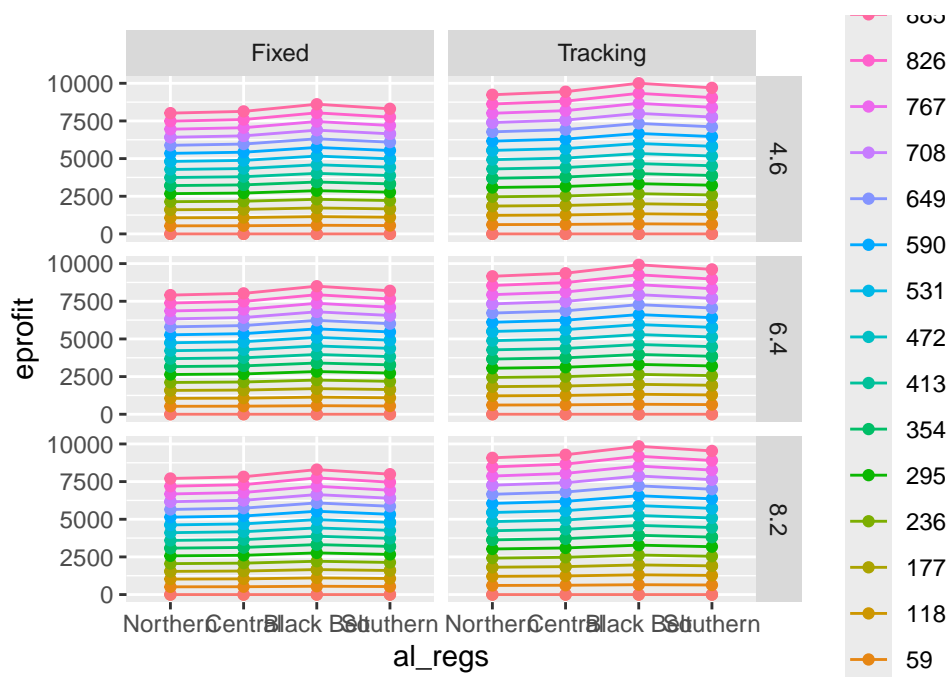
lox <- c("Northern", "Central", "Black Belt", "Southern")
array_levs = c("Single Axis Rotation", "Fixed Open Rack")
datalot_levs = c("Location 1", "Location 2")
for (i in unique(solar_profit$elcprc)) {
  b = ggplot(
    data = (solar_profit %>%
      filter(elcprc == i)),
    mapping = aes(
      x = al_regs,
      y = eprofit,
      #fill = energy,
      color = factor(panels),
      group = factor(panels)
    )
  ) +
  geom_line() +
  geom_point() +
  facet_grid(height ~ array) +
  scale_x_discrete(limits = lox) +
  guides(color = guide_legend(reverse = TRUE))
  cat("Electricity Price = ", i)
  print(b)
}

```

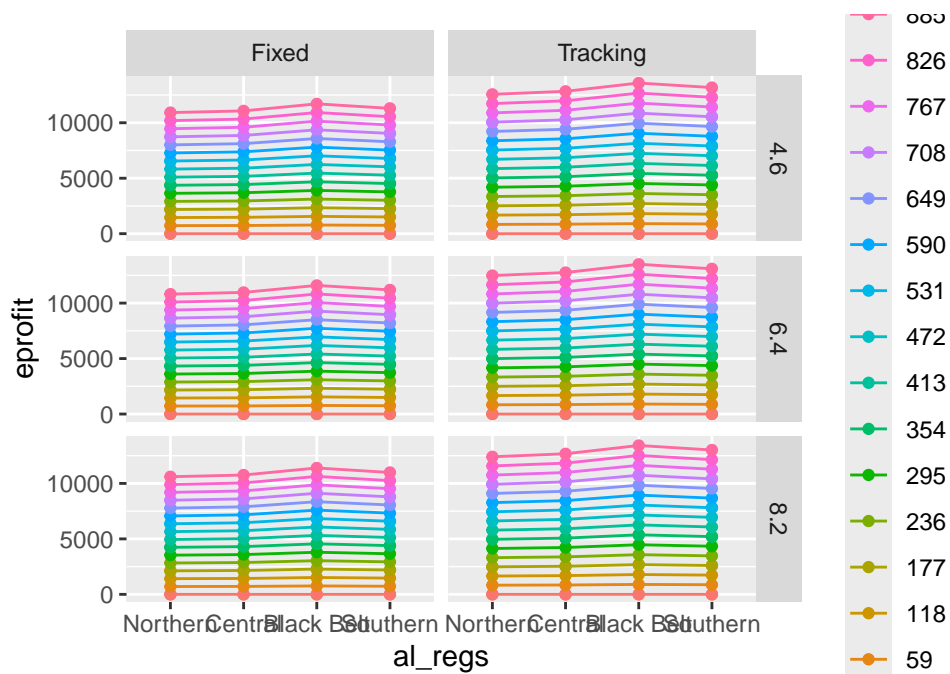
Electricity Price = 0.01



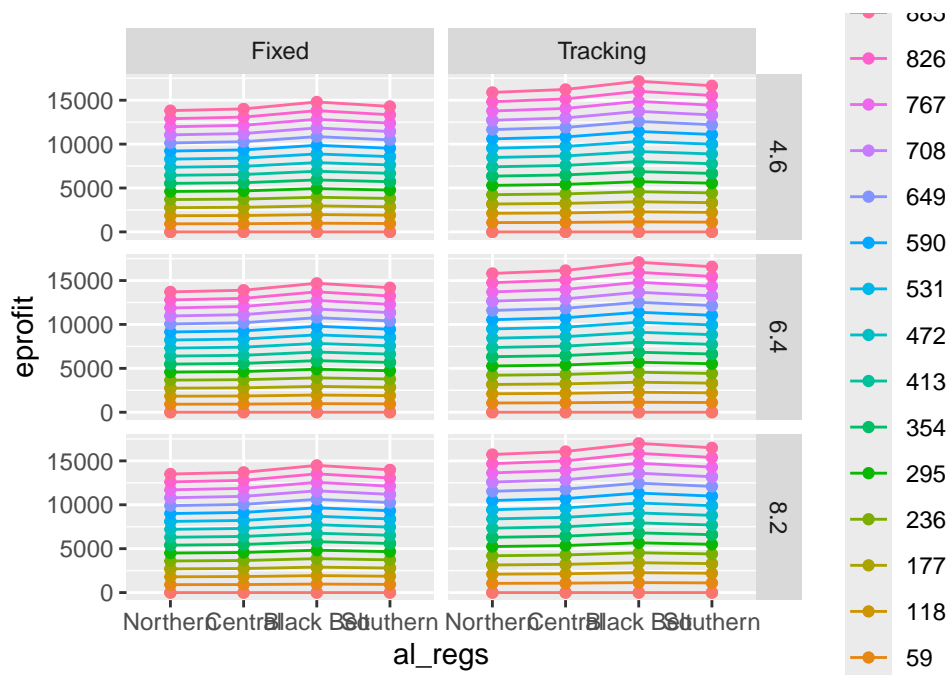
Electricity Price = 0.015



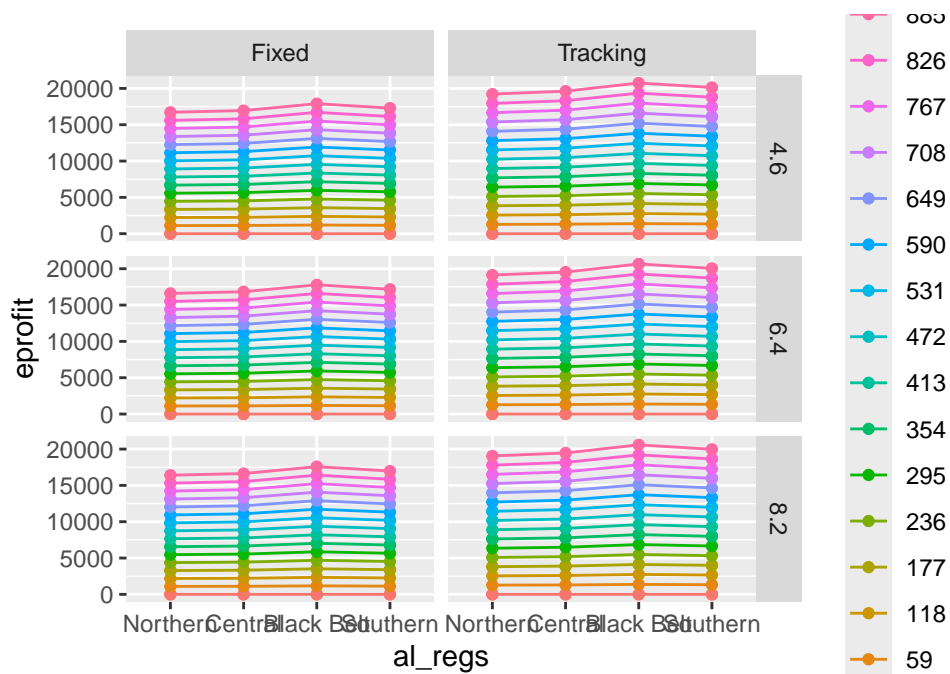
Electricity Price = 0.02



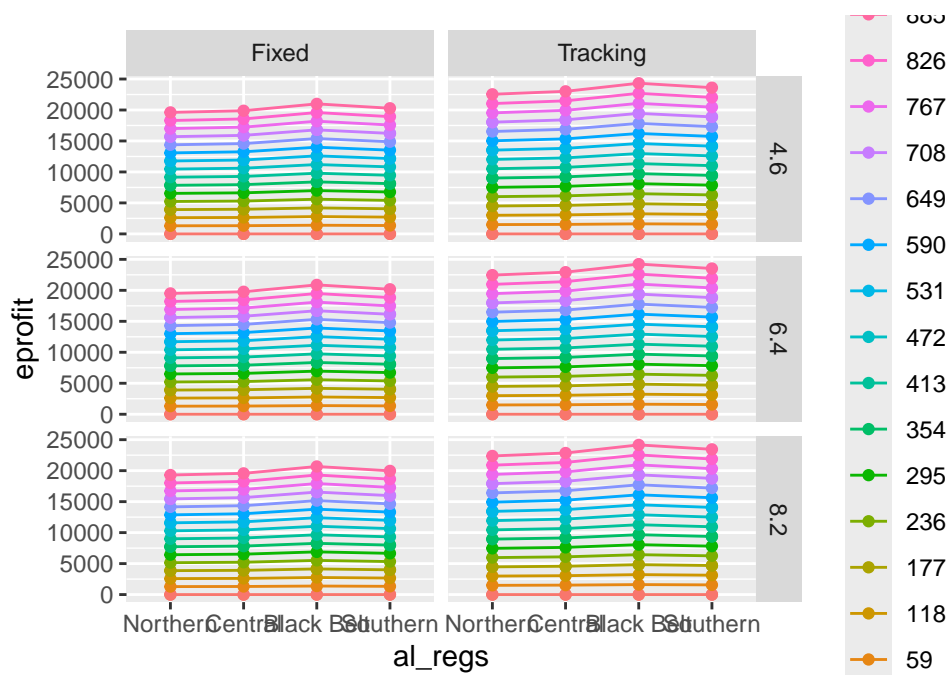
Electricity Price = 0.025



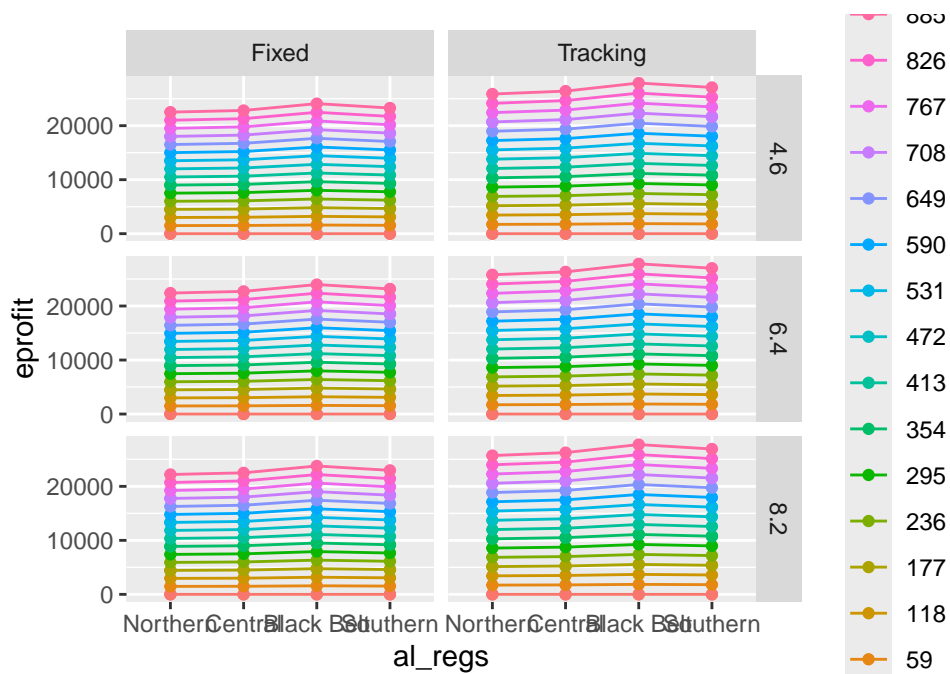
Electricity Price = 0.03



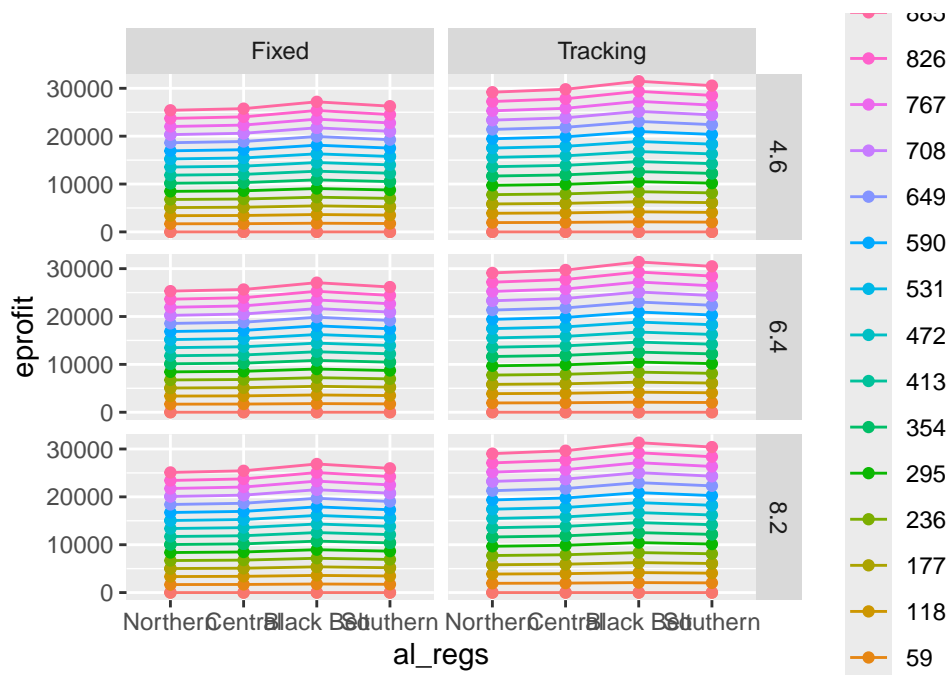
Electricity Price = 0.035



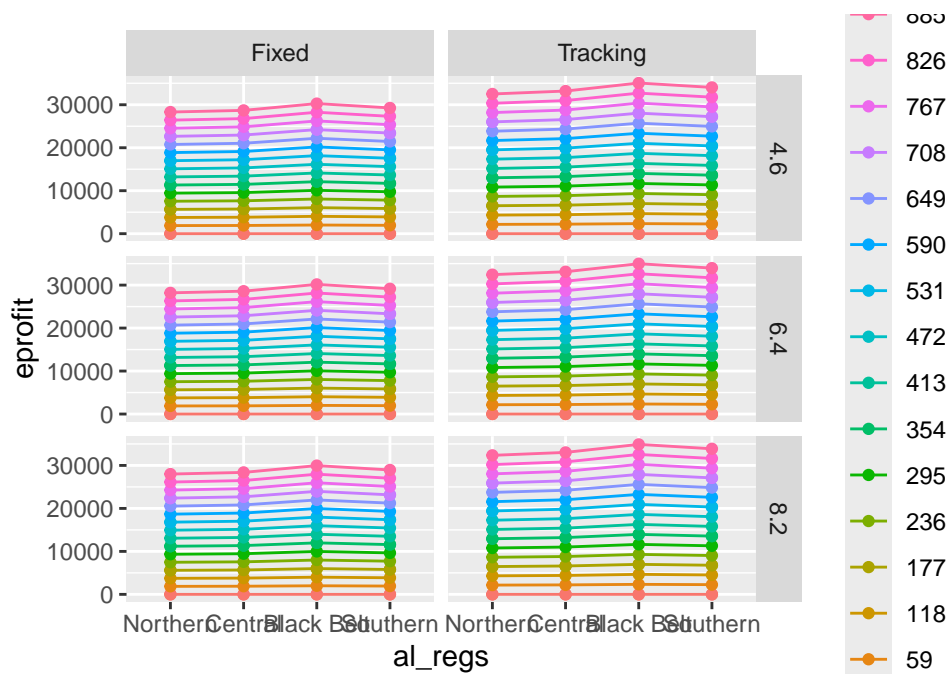
Electricity Price = 0.04



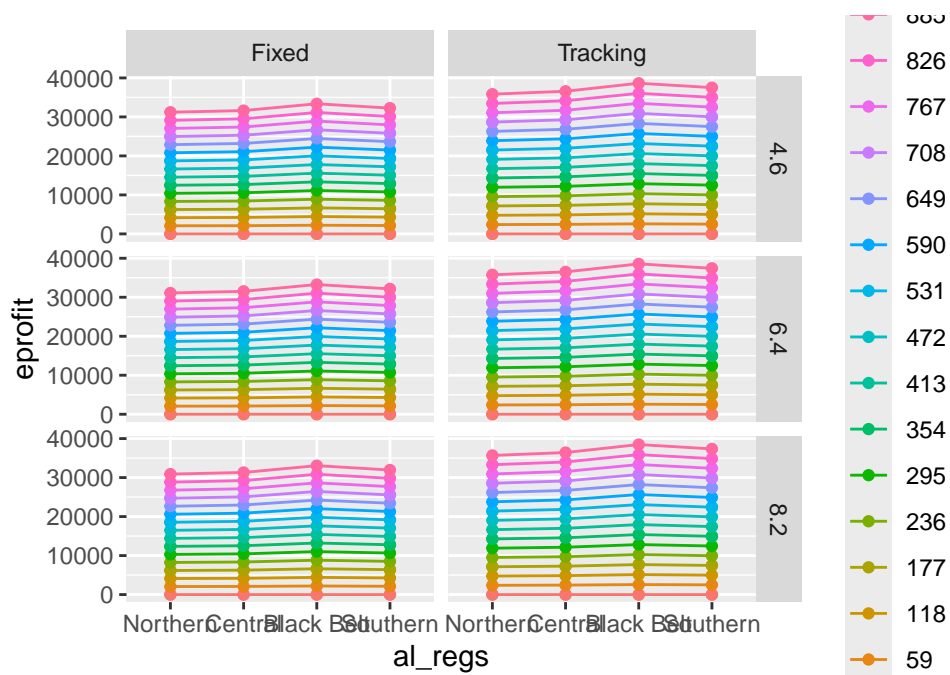
Electricity Price = 0.045



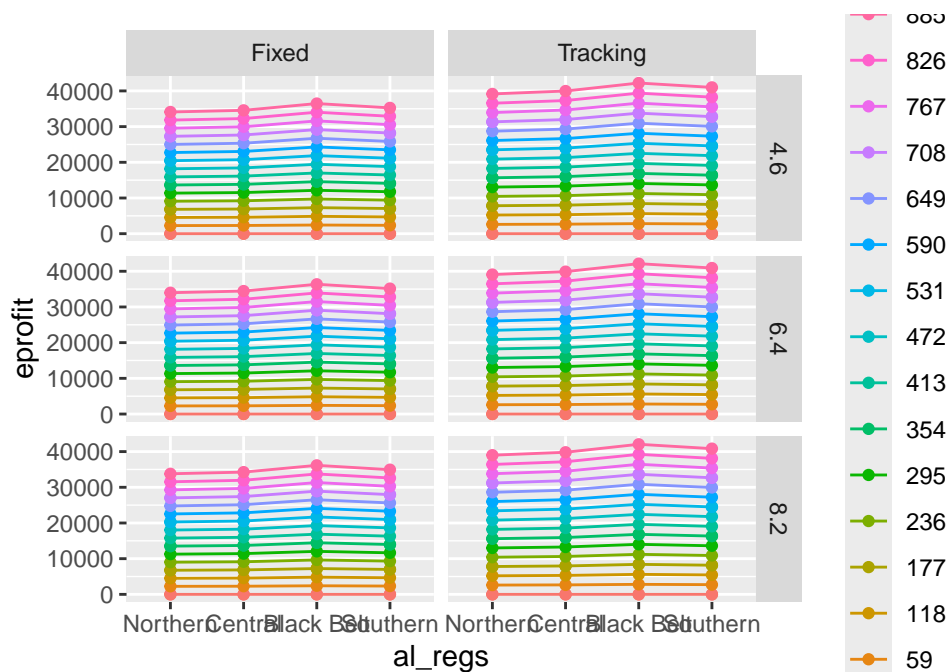
Electricity Price = 0.05



Electricity Price = 0.055



Electricity Price = 0.06



## 6 Profit from crops

### 6.1 Tomato

Filter return to operator, land and capital profit from Tomato:

```
tomato_profit = tomato %>%
  select(yldvar, yield,
         rolac17, rolac18, rolac19, rolac20,
         rolac21, rolac22, rolac23)
dim(tomato_profit)
```

```
[1] 20  9
```

```
tomato_profit
```

	yldvar	yield	rolac17	rolac18	rolac19	rolac20	rolac21
3	2.0	2720	21679.3826	24399.3826	27119.3826	29839.3826	32559.3826
4	1.9	2584	20065.3826	22649.3826	25233.3826	27817.3826	30401.3826
5	1.8	2448	18451.3826	20899.3826	23347.3826	25795.3826	28243.3826

6	1.7	2312	16837.3826	19149.3826	21461.3826	23773.3826	26085.3826
7	1.6	2176	15223.3826	17399.3826	19575.3826	21751.3826	23927.3826
8	1.5	2040	13609.3826	15649.3826	17689.3826	19729.3826	21769.3826
9	1.4	1904	11995.3826	13899.3826	15803.3826	17707.3826	19611.3826
10	1.3	1768	10381.3826	12149.3826	13917.3826	15685.3826	17453.3826
11	1.2	1632	8767.3826	10399.3826	12031.3826	13663.3826	15295.3826
12	1.1	1496	7153.3826	8649.3826	10145.3826	11641.3826	13137.3826
13	1.0	1360	5539.3826	6899.3826	8259.3826	9619.3826	10979.3826
14	0.9	1224	3925.3826	5149.3826	6373.3826	7597.3826	8821.3826
15	0.8	1088	2311.3826	3399.3826	4487.3826	5575.3826	6663.3826
16	0.7	952	697.3826	1649.3826	2601.3826	3553.3826	4505.3826
17	0.6	816	-916.6174	-100.6174	715.3826	1531.3826	2347.3826
18	0.5	680	-2530.6174	-1850.6174	-1170.6174	-490.6174	189.3826
19	0.4	544	-4144.6174	-3600.6174	-3056.6174	-2512.6174	-1968.6174
20	0.3	408	-5758.6174	-5350.6174	-4942.6174	-4534.6174	-4126.6174
21	0.2	272	-7372.6174	-7100.6174	-6828.6174	-6556.6174	-6284.6174
22	0.1	136	-8986.6174	-8850.6174	-8714.6174	-8578.6174	-8442.6174
		rolac22	rolac23				
3		35279.3826	37999.3826				
4		32985.3826	35569.3826				
5		30691.3826	33139.3826				
6		28397.3826	30709.3826				
7		26103.3826	28279.3826				
8		23809.3826	25849.3826				
9		21515.3826	23419.3826				
10		19221.3826	20989.3826				
11		16927.3826	18559.3826				
12		14633.3826	16129.3826				
13		12339.3826	13699.3826				
14		10045.3826	11269.3826				
15		7751.3826	8839.3826				
16		5457.3826	6409.3826				
17		3163.3826	3979.3826				
18		869.3826	1549.3826				
19		-1424.6174	-880.6174				
20		-3718.6174	-3310.6174				
21		-6012.6174	-5740.6174				
22		-8306.6174	-8170.6174				

Convert data to long format:



```

# Assign column names for clarity
colnames(tomato_profit) <- c("yldvar", "yield",
                             "rolac17", "rolac18", "rolac19",
                             "rolac20", "rolac21", "rolac22",
                             "rolac23")

# Reshape the data frame from wide to long format
tomato_long <- melt(tomato_profit,
                    id.vars = c("yldvar", "yield"),
                    measure.vars = c("rolac17", "rolac18", "rolac19",
                                      "rolac20", "rolac21", "rolac22",
                                      "rolac23"),
                    variable.name = "price",
                    value.name = "profit")

# Convert the 'Price' column to numeric by extracting the number
tomato_long$price <- as.numeric(gsub("rolac", "", tomato_long$price))

# View the resulting data frame
dim(tomato_long)

```

```
[1] 140  4
```

```
head(tomato_long)
```

	yldvar	yield	price	profit
1	2.0	2720	17	21679.38
2	1.9	2584	17	20065.38
3	1.8	2448	17	18451.38
4	1.7	2312	17	16837.38
5	1.6	2176	17	15223.38
6	1.5	2040	17	13609.38

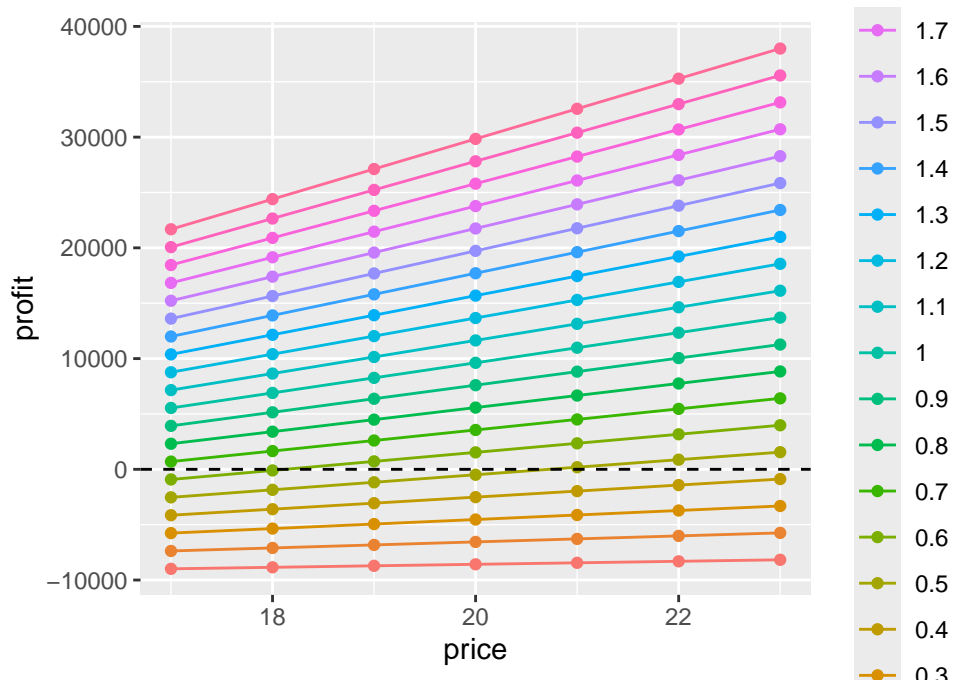
```
tail(tomato_long)
```

	yldvar	yield	price	profit
135	0.6	816	23	3979.3826
136	0.5	680	23	1549.3826
137	0.4	544	23	-880.6174
138	0.3	408	23	-3310.6174
139	0.2	272	23	-5740.6174
140	0.1	136	23	-8170.6174

### 6.1.1 Profit from tomato

```
ggplot(data = tomato_long,
       mapping = aes(x = price,
                     y = profit,
                     color = factor(yldvar),
                     group = factor(yield))) +

  geom_line() +
  geom_point() +
  geom_hline(yintercept = 0,
            linetype = "dashed",
            color = "black") +
  guides(color = guide_legend(reverse = TRUE))
```



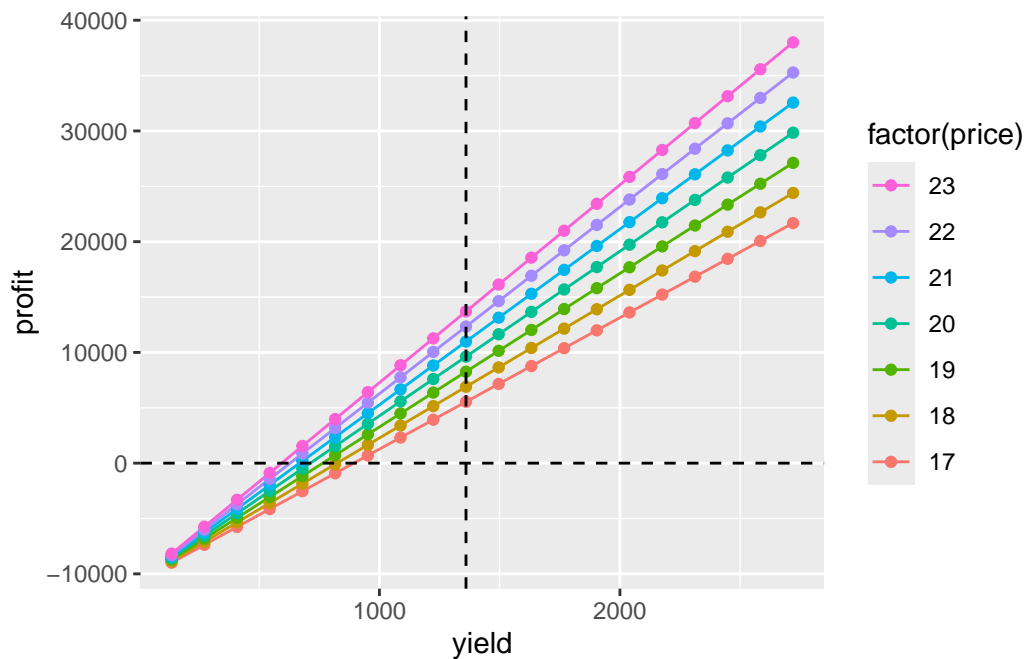
```
ggplot(data = tomato_long,
       mapping = aes(x = yield,
                     y = profit,
                     #fill = yield,
                     color = factor(price),
                     group = factor(price))) +

  geom_line() +
```

```

geom_point() +
geom_hline(yintercept = 0,
           linetype = "dashed",
           color = "black") +
# Vertical dashed line is 100% yield
geom_vline(xintercept = tomato_long$yield[11],
           linetype = "dashed",
           color = "black") +
guides(color = guide_legend(reverse = TRUE))

```



## 6.2 Strawberry

Filter return to operator, land and capital profit from strawberry

```

strawberry_profit = strawberry %>%
  select(yldvar, yield,
         rolac3, rolac4, rolac5, rolac6, rolac7, rolac8, rolac9)
dim(strawberry_profit)

```

```
[1] 20 9
```

# strawberry\_profit

	yldvar	yield	rolac3	rolac4	rolac5	rolac6	rolac7
3	2.0	6150.0	-1740.495	4409.50503	10559.505	16709.505	22859.505
4	1.9	5842.5	-2317.350	3525.15003	9367.650	15210.150	21052.650
5	1.8	5535.0	-2894.205	2640.79503	8175.795	13710.795	19245.795
6	1.7	5227.5	-3471.060	1756.44003	6983.940	12211.440	17438.940
7	1.6	4920.0	-4047.915	872.08503	5792.085	10712.085	15632.085
8	1.5	4612.5	-4624.770	-12.26997	4600.230	9212.730	13825.230
9	1.4	4305.0	-5201.625	-896.62497	3408.375	7713.375	12018.375
10	1.3	3997.5	-5778.480	-1780.97997	2216.520	6214.020	10211.520
11	1.2	3690.0	-6355.335	-2665.33497	1024.665	4714.665	8404.665
12	1.1	3382.5	-6932.190	-3549.68997	-167.190	3215.310	6597.810
13	1.0	3075.0	-7509.045	-4434.04497	-1359.045	1715.955	4790.955
14	0.9	2767.5	-8085.900	-5318.39997	-2550.900	216.600	2984.100
15	0.8	2460.0	-8662.755	-6202.75497	-3742.755	-1282.755	1177.245
16	0.7	2152.5	-9239.610	-7087.10997	-4934.610	-2782.110	-629.610
17	0.6	1845.0	-9816.465	-7971.46497	-6126.465	-4281.465	-2436.465
18	0.5	1537.5	-10393.320	-8855.81997	-7318.320	-5780.820	-4243.320
19	0.4	1230.0	-10970.175	-9740.17497	-8510.175	-7280.175	-6050.175
20	0.3	922.5	-11547.030	-10624.52997	-9702.030	-8779.530	-7857.030
21	0.2	615.0	-12123.885	-11508.88497	-10893.885	-10278.885	-9663.885
22	0.1	307.5	-12700.740	-12393.23997	-12085.740	-11778.240	-11470.740
	rolac8	rolac9					
3	29009.505	35159.505					
4	26895.150	32737.650					
5	24780.795	30315.795					
6	22666.440	27893.940					
7	20552.085	25472.085					
8	18437.730	23050.230					
9	16323.375	20628.375					
10	14209.020	18206.520					
11	12094.665	15784.665					
12	9980.310	13362.810					
13	7865.955	10940.955					
14	5751.600	8519.100					
15	3637.245	6097.245					
16	1522.890	3675.390					
17	-591.465	1253.535					
18	-2705.820	-1168.320					
19	-4820.175	-3590.175					
20	-6934.530	-6012.030					

```
21 -9048.885 -8433.885
22 -11163.240 -10855.740
```

Convert data to long format:

```
# Assign column names for clarity
colnames(strawberry_profit) <- c("yldvar", "yield",
                                "rolac3", "rolac4", "rolac5",
                                "rolac6", "rolac7", "rolac8",
                                "rolac9")
# Reshape the data frame from wide to long format
stberry_long <- melt(strawberry_profit,
                    id.vars = c("yldvar", "yield"),
                    measure.vars = c("rolac3", "rolac4", "rolac5",
                                     "rolac6", "rolac7", "rolac8",
                                     "rolac9"),
                    variable.name = "price",
                    value.name = "profit")

# Convert the 'Price' column to numeric by extracting the number
stberry_long$price <- as.numeric(gsub("rolac", "", stberry_long$price))

# View the resulting data frame
dim(stberry_long)
```

```
[1] 140    4
```

```
head(stberry_long)
```

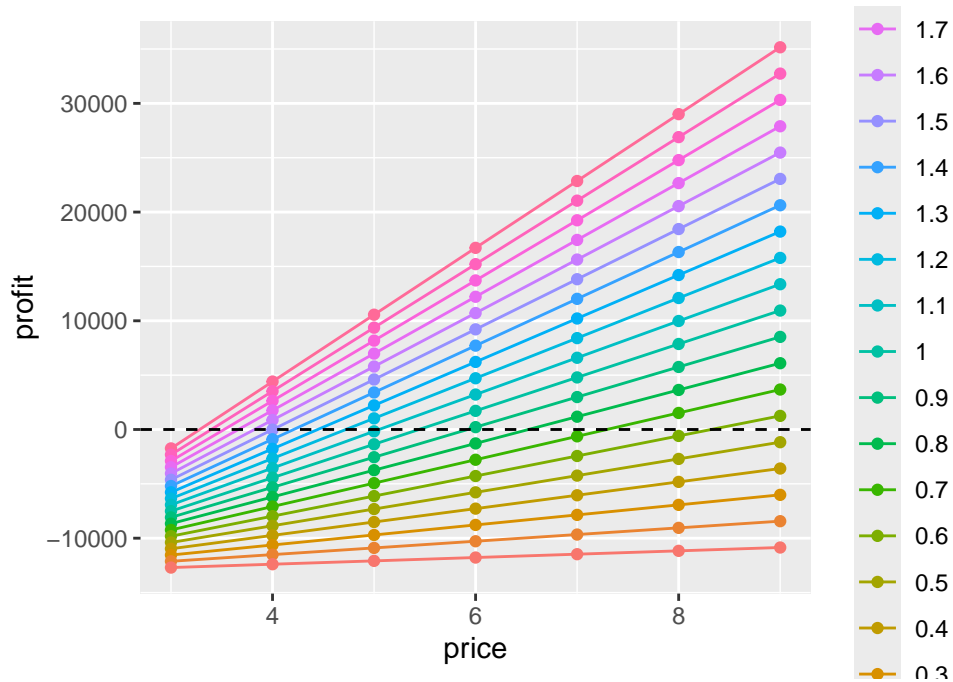
	yldvar	yield	price	profit
1	2.0	6150.0	3	-1740.495
2	1.9	5842.5	3	-2317.350
3	1.8	5535.0	3	-2894.205
4	1.7	5227.5	3	-3471.060
5	1.6	4920.0	3	-4047.915
6	1.5	4612.5	3	-4624.770

```
tail(stberry_long)
```

	yldvar	yield	price	profit
135	0.6	1845.0	9	1253.535
136	0.5	1537.5	9	-1168.320
137	0.4	1230.0	9	-3590.175
138	0.3	922.5	9	-6012.030
139	0.2	615.0	9	-8433.885
140	0.1	307.5	9	-10855.740

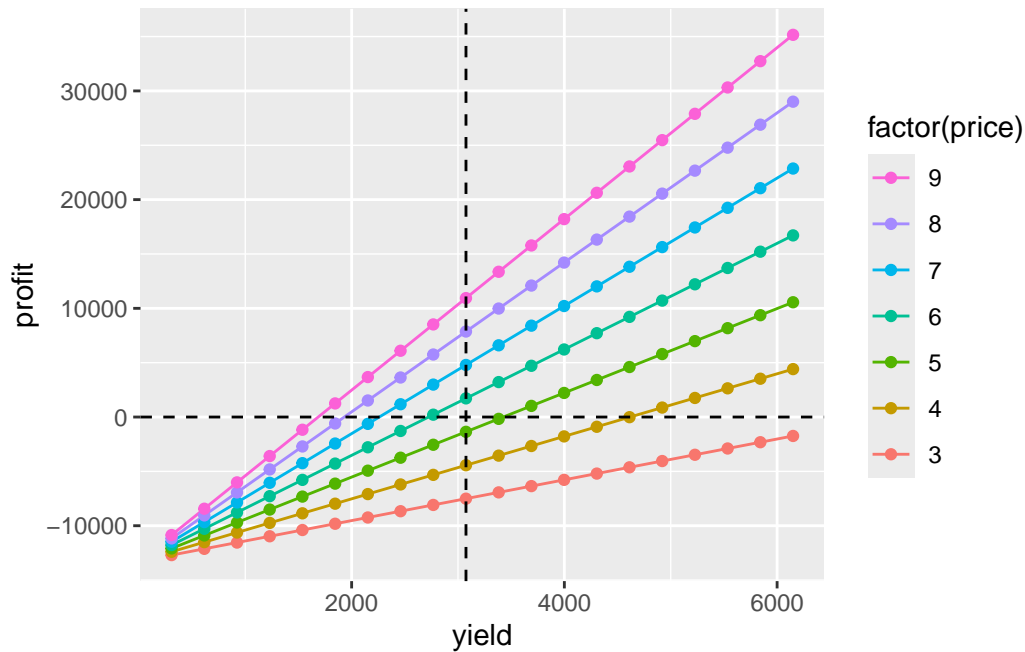
### 6.2.1 Plot Strawberry Profit

```
ggplot(data = stberry_long,
       mapping = aes(x = price,
                     y = profit,
                     color = factor(yldvar),
                     group = factor(yield))) +
  geom_line() +
  geom_point() +
  geom_hline(yintercept = 0,
            linetype = "dashed",
            color = "black") +
  guides(color = guide_legend(reverse = TRUE))
```



```
ggplot(data = stberrry_long,
       mapping = aes(x = yield,
                     y = profit,
                     color = factor(price),
                     group = factor(price))) +

  geom_line() +
  geom_point() +
  geom_hline(yintercept = 0,
            linetype = "dashed",
            color = "black") +
  #Vertical dashed line is 100% yield
  geom_vline(xintercept = stberrry_long$yield[11],
            linetype = "dashed",
            color = "black") +
  guides(color = guide_legend(reverse = TRUE))
```



### 6.3 Squash

Filter return to operator, land and capital profit from squash

```
squash_profit = squash %>%
  select(yldvar, yield,
```

```

        rolac11, rolac12, rolac13, rolac14,
        rolac15, rolac16, rolac17)
squash_profit

```

	yldvar	yield	rolac11	rolac12	rolac13	rolac14	rolac15	rolac16
3	2.0	2180	10309.117	12489.117	14669.11702	16849.117	19029.117	21209.11702
4	1.9	2071	9607.367	11678.367	13749.36702	15820.367	17891.367	19962.36702
5	1.8	1962	8905.617	10867.617	12829.61702	14791.617	16753.617	18715.61702
6	1.7	1853	8203.867	10056.867	11909.86702	13762.867	15615.867	17468.86702
7	1.6	1744	7502.117	9246.117	10990.11702	12734.117	14478.117	16222.11702
8	1.5	1635	6800.367	8435.367	10070.36702	11705.367	13340.367	14975.36702
9	1.4	1526	6098.617	7624.617	9150.61702	10676.617	12202.617	13728.61702
10	1.3	1417	5396.867	6813.867	8230.86702	9647.867	11064.867	12481.86702
11	1.2	1308	4695.117	6003.117	7311.11702	8619.117	9927.117	11235.11702
12	1.1	1199	3993.367	5192.367	6391.36702	7590.367	8789.367	9988.36702
13	1.0	1090	3291.617	4381.617	5471.61702	6561.617	7651.617	8741.61702
14	0.9	981	2589.867	3570.867	4551.86702	5532.867	6513.867	7494.86702
15	0.8	872	1888.117	2760.117	3632.11702	4504.117	5376.117	6248.11702
16	0.7	763	1186.367	1949.367	2712.36702	3475.367	4238.367	5001.36702
17	0.6	654	484.617	1138.617	1792.61702	2446.617	3100.617	3754.61702
18	0.5	545	-217.133	327.867	872.86702	1417.867	1962.867	2507.86702
19	0.4	436	-918.883	-482.883	-46.88298	389.117	825.117	1261.11702
20	0.3	327	-1620.633	-1293.633	-966.63298	-639.633	-312.633	14.36702
21	0.2	218	-2322.383	-2104.383	-1886.38298	-1668.383	-1450.383	-1232.38298
22	0.1	109	-3024.133	-2915.133	-2806.13298	-2697.133	-2588.133	-2479.13298
			rolac17					
3			23389.117					
4			22033.367					
5			20677.617					
6			19321.867					
7			17966.117					
8			16610.367					
9			15254.617					
10			13898.867					
11			12543.117					
12			11187.367					
13			9831.617					
14			8475.867					
15			7120.117					
16			5764.367					
17			4408.617					
18			3052.867					



```
19 1697.117
20 341.367
21 -1014.383
22 -2370.133
```

Convert data to long format:

```
# Assign column names for clarity
colnames(squash_profit) <- c("yldvar", "yield",
                             "rolac11", "rolac12", "rolac13",
                             "rolac14", "rolac15", "rolac16",
                             "rolac17")

# Reshape the data frame from wide to long format
squash_long <- melt(squash_profit,
                    id.vars = c("yldvar", "yield"),
                    measure.vars = c("rolac11", "rolac12", "rolac13",
                                      "rolac14", "rolac15", "rolac16",
                                      "rolac17"),
                    variable.name = "price",
                    value.name = "profit")

# Convert the 'Price' column to numeric by extracting the number
squash_long$price <- as.numeric(gsub("rolac", "", squash_long$price))

# View the resulting data frame
dim(squash_long)
```

```
[1] 140 4
```

```
head(squash_long)
```

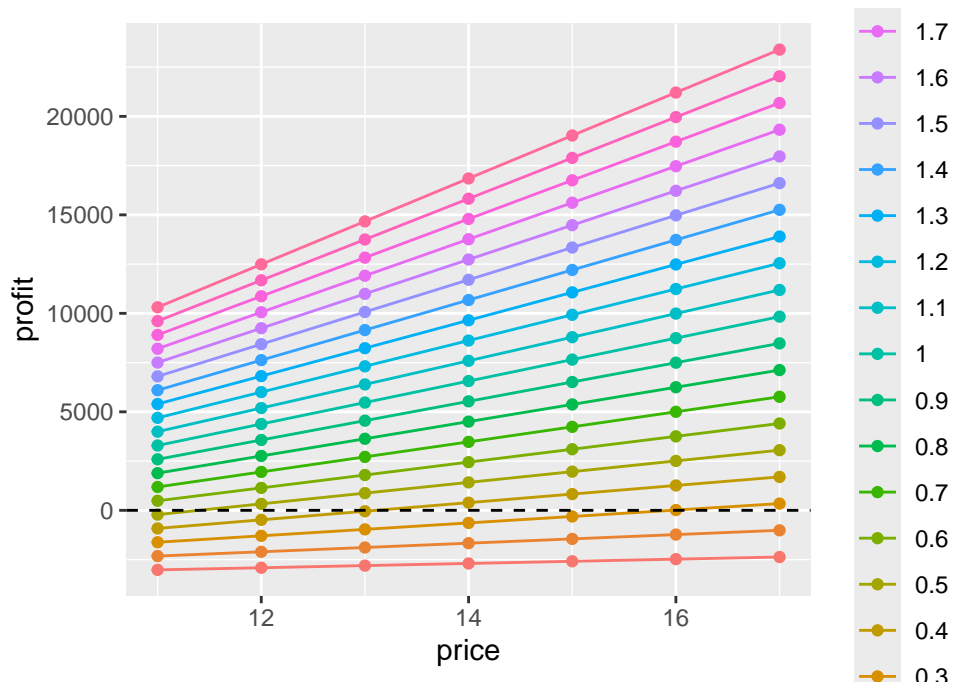
	yldvar	yield	price	profit
1	2.0	2180	11	10309.117
2	1.9	2071	11	9607.367
3	1.8	1962	11	8905.617
4	1.7	1853	11	8203.867
5	1.6	1744	11	7502.117
6	1.5	1635	11	6800.367

```
tail(squash_long)
```

	yldvar	yield	price	profit
135	0.6	654	17	4408.617
136	0.5	545	17	3052.867
137	0.4	436	17	1697.117
138	0.3	327	17	341.367
139	0.2	218	17	-1014.383
140	0.1	109	17	-2370.133

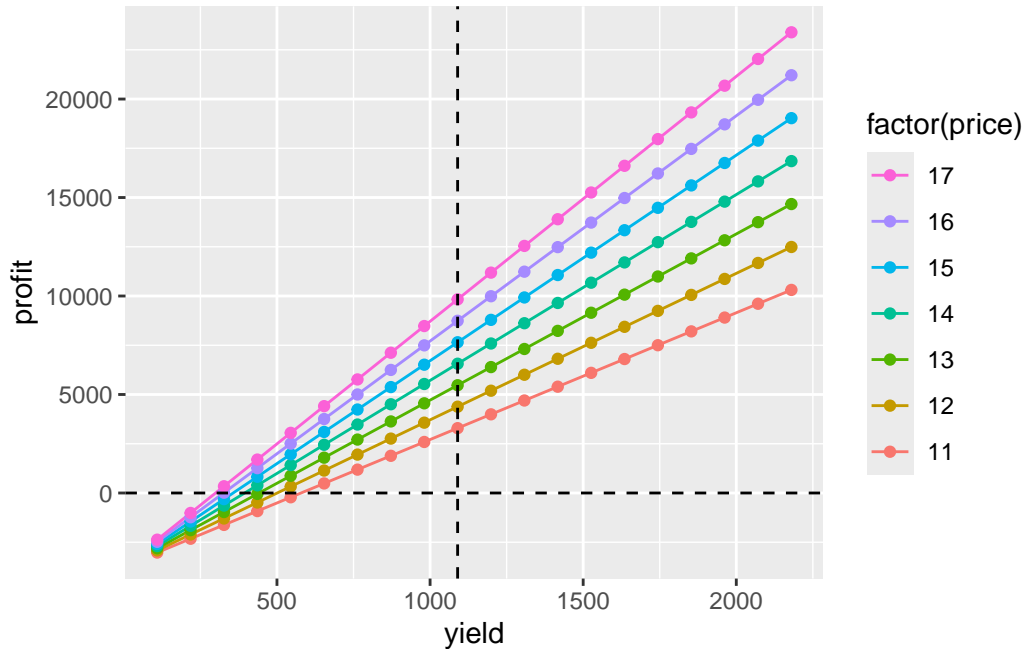
### 6.3.1 Profit from squash:

```
ggplot(data = squash_long,  
       mapping = aes(x = price,  
                     y = profit,  
                     color = factor(yldvar),  
                     group = factor(yield))) +  
  geom_line() +  
  geom_point() +  
  geom_hline(yintercept = 0,  
            linetype = "dashed",  
            color = "black") +  
  guides(color = guide_legend(reverse = TRUE))
```



```
ggplot(data = squash_long,
       mapping = aes(x = yield,
                     y = profit,
                     color = factor(price),
                     group = factor(price))) +

  geom_line() +
  geom_point() +
  geom_hline(yintercept = 0,
            linetype = "dashed",
            color = "black") +
  # Vertical dashed line is 100% yield
  geom_vline(xintercept = squash_long$yield[11],
            linetype = "dashed",
            color = "black") +
  guides(color = guide_legend(reverse = TRUE))
```



## 7 Profit from agrivoltaics

Total profit from solar and crops for all combinations of AVs simulated.

### 7.1 Profit from tomato agrivoltaic system

- Joint profit from tomato (tomato\_long) and solar energy production (solar\_profit) from 1 acre of land.
- The last variable (tav\_profit) is the final profit from tomato agrivoltaic system which is the result of our interest.

```
# Generate all combinations of row indices from both matrices
index_combinations <- expand.grid(1:nrow(solar_profit),
                                   1:nrow(tomato_long))

# Define a function to process each combination of indices
process_combination <- function(indices) {
  i <- indices[1]
  j <- indices[2]
  new_row <- c(solar_profit[i, ],
               tomato_long[j, ],
```

```

        #solar_profit[i, 14] = eannprof
        solar_profit$eannprof[i] + tomato_long$profit[j])
    return(new_row)
}

# Apply the function to each combination of indices and combine the results into a matrix
tav_profit <- do.call(rbind,
                      lapply(
                        seq_len(nrow(index_combinations)),
                        function(k) {
                          indices <- as.integer(
                            index_combinations[k, ])
                          process_combination(indices)
                        })
                      )

# Optionally, you can convert the result back to a data frame if needed
tav_profit <- as.data.frame(tav_profit) %>%
  rename(tav_profit = V21)
tav_profit <- data.frame(lapply(tav_profit, unlist))
str(tav_profit)

```

```

'data.frame':  776160 obs. of  21 variables:
 $ sprop      : num  0 0 0 0 0 0 0 0 0 0 ...
 $ al_regs    : chr   "Black Belt" "Black Belt" "Black Belt" "Black Belt" ...
 $ array      : chr   "Fixed" "Fixed" "Fixed" "Tracking" ...
 $ dc_kw      : num  0 0 0 0 0 0 0 0 0 0 ...
 $ panels     : num  0 0 0 0 0 0 0 0 0 0 ...
 $ energy     : num  0 0 0 0 0 0 0 0 0 0 ...
 $ elcprc     : num  0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 ...
 $ elcrev     : num  0 0 0 0 0 0 0 0 0 0 ...
 $ height     : num  4.6 6.4 8.2 4.6 6.4 8.2 4.6 6.4 8.2 4.6 ...
 $ capex      : num  1.59 1.85 2.33 1.73 1.92 ...
 $ ttlcost    : num  0 0 0 0 0 0 0 0 0 0 ...
 $ anncost    : num  0 0 0 0 0 0 0 0 0 0 ...
 $ moncost    : num  0 0 0 0 0 0 0 0 0 0 ...
 $ eprofit    : num  0 0 0 0 0 0 0 0 0 0 ...
 $ eannprof   : num  0 0 0 0 0 0 0 0 0 0 ...
 $ emonprof   : num  0 0 0 0 0 0 0 0 0 0 ...
 $ yldvar     : num  2 2 2 2 2 2 2 2 2 2 ...
 $ yield      : num  2720 2720 2720 2720 2720 2720 2720 2720 2720 2720 ...
 $ price      : num  17 17 17 17 17 17 17 17 17 17 ...
 $ profit     : num  21679 21679 21679 21679 21679 ...

```

```
$ tav_profit: num 21679 21679 21679 21679 21679 ...
```

```
head(tav_profit)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height	capex
1	0	Black Belt	Fixed	0	0	0	0.01	0	4.6	1.593333
2	0	Black Belt	Fixed	0	0	0	0.01	0	6.4	1.850000
3	0	Black Belt	Fixed	0	0	0	0.01	0	8.2	2.330000
4	0	Black Belt	Tracking	0	0	0	0.01	0	4.6	1.733333
5	0	Black Belt	Tracking	0	0	0	0.01	0	6.4	1.921667
6	0	Black Belt	Tracking	0	0	0	0.01	0	8.2	2.110000
	ttlcost	anncost	moncost	eprofit	eannprof	emonprof	yldvar	yield	price	profit
1	0	0	0	0	0	0	2	2720	17	21679.38
2	0	0	0	0	0	0	2	2720	17	21679.38
3	0	0	0	0	0	0	2	2720	17	21679.38
4	0	0	0	0	0	0	2	2720	17	21679.38
5	0	0	0	0	0	0	2	2720	17	21679.38
6	0	0	0	0	0	0	2	2720	17	21679.38
	tav_profit									
1	21679.38									
2	21679.38									
3	21679.38									
4	21679.38									
5	21679.38									
6	21679.38									

```
tail(tav_profit)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height
776155	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	4.6
776156	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	6.4
776157	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	8.2
776158	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	4.6
776159	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	6.4
776160	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	8.2
	capex	ttlcost	anncost	moncost	eprofit	eannprof	emonprof	yldvar	
776155	1.593333	675.1591	47.90419	3.946913	35248.07	35875.33	2989.656	0.1	
776156	1.850000	783.9190	55.62098	4.582712	35139.31	35867.61	2989.020	0.1	
776157	2.330000	987.3142	70.05237	5.771740	34935.92	35853.18	2987.831	0.1	
776158	1.733333	734.4827	52.11335	4.293713	40990.42	41672.79	3472.781	0.1	
776159	1.921667	814.2870	57.77567	4.760241	40910.61	41667.12	3472.315	0.1	

776160	2.110000	894.0914	63.43798	5.226769	40830.81	41661.46	3471.848	0.1
	yield	price	profit	tav_profit				
776155	136	23	-8170.617	27704.71				
776156	136	23	-8170.617	27696.99				
776157	136	23	-8170.617	27682.56				
776158	136	23	-8170.617	33502.17				
776159	136	23	-8170.617	33496.51				
776160	136	23	-8170.617	33490.84				

### 7.1.1 Saving results locally

```
#write_csv(tav_profit, "tav_profit.csv")
write_feather(tav_profit,
  sink = "tav_profit.feather",
  version = 2,
  chunk_size = 65536L,
  compression = c("default"),
  #compression = c("default", "lz4", "lz4_frame", "uncompressed", "zstd"),
  compression_level = NULL
)
```

## 7.2 Profit from strawberry agrivoltaic system

- Joint profit from strawberry (stberry\_long) and solar energy production (solar\_profit) from 1 acre of land.
- The last variable (sbav\_profit) is the final profit from strawberry agrivoltaic system which is the result of our interest.

```
# Generate all combinations of row indices from both matrices
index_combinations <- expand.grid(1:nrow(solar_profit),
  1:nrow(stberry_long))

# Define a function to process each combination of indices
process_combination <- function(indices) {
  i <- indices[1]
  j <- indices[2]
  new_row <- c(solar_profit[i, ],
    stberry_long[j, ],
    #solar_profit[i, 14] = eannprof
    solar_profit$eannprof[i] + stberry_long$profit[j])
}
```

```

    return(new_row)
}

# Apply the function to each combination of indices and combine the results into a matrix
sbav_profit <- do.call(rbind,
                      lapply(
                        seq_len(nrow(index_combinations)),
                        function(k) {
                          indices <- as.integer(
                            index_combinations[k, ])
                          process_combination(indices)
                        })
                      )

# Optionally, you can convert the result back to a data frame if needed
sbav_profit <- as.data.frame(sbav_profit) %>%
  rename(sbav_profit = V21)
sbav_profit <- data.frame(lapply(sbav_profit, unlist))
str(sbav_profit)

```

```

'data.frame':  776160 obs. of  21 variables:
 $ sprop      : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ al_regs    : chr   "Black Belt" "Black Belt" "Black Belt" "Black Belt" ...
 $ array      : chr   "Fixed" "Fixed" "Fixed" "Tracking" ...
 $ dc_kw      : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ panels     : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ energy     : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ elcprc     : num  0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 ...
 $ elcrev     : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ height     : num  4.6 6.4 8.2 4.6 6.4 8.2 4.6 6.4 8.2 4.6 ...
 $ capex      : num  1.59 1.85 2.33 1.73 1.92 ...
 $ ttlcost    : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ anncost    : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ moncost    : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ eprofit    : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ eannprof   : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ emonprof   : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ yldvar     : num  2 2 2 2 2 2 2 2 2 2 2 ...
 $ yield      : num  6150 6150 6150 6150 6150 6150 6150 6150 6150 6150 ...
 $ price      : num  3 3 3 3 3 3 3 3 3 3 3 ...
 $ profit     : num  -1740 -1740 -1740 -1740 -1740 ...
 $ sbav_profit: num  -1740 -1740 -1740 -1740 -1740 ...

```



```
head(sbav_profit)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height	capex
1	0	Black Belt	Fixed	0	0	0	0.01	0	4.6	1.593333
2	0	Black Belt	Fixed	0	0	0	0.01	0	6.4	1.850000
3	0	Black Belt	Fixed	0	0	0	0.01	0	8.2	2.330000
4	0	Black Belt	Tracking	0	0	0	0.01	0	4.6	1.733333
5	0	Black Belt	Tracking	0	0	0	0.01	0	6.4	1.921667
6	0	Black Belt	Tracking	0	0	0	0.01	0	8.2	2.110000
	ttlcost	anncost	moncost	eprofit	eannprof	emonprof	yldvar	yield	price	
1	0	0	0	0	0	0	2	6150	3	
2	0	0	0	0	0	0	2	6150	3	
3	0	0	0	0	0	0	2	6150	3	
4	0	0	0	0	0	0	2	6150	3	
5	0	0	0	0	0	0	2	6150	3	
6	0	0	0	0	0	0	2	6150	3	
	profit	sbav_profit								
1	-1740.495	-1740.495								
2	-1740.495	-1740.495								
3	-1740.495	-1740.495								
4	-1740.495	-1740.495								
5	-1740.495	-1740.495								
6	-1740.495	-1740.495								

```
tail(sbav_profit)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height	
776155	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	4.6	
776156	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	6.4	
776157	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	8.2	
776158	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	4.6	
776159	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	6.4	
776160	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	8.2	
	capex	ttlcost	anncost	moncost	eprofit	eannprof	emonprof	yldvar		
776155	1.593333	675.1591	47.90419	3.946913	35248.07	35875.33	2989.656	0.1		
776156	1.850000	783.9190	55.62098	4.582712	35139.31	35867.61	2989.020	0.1		
776157	2.330000	987.3142	70.05237	5.771740	34935.92	35853.18	2987.831	0.1		
776158	1.733333	734.4827	52.11335	4.293713	40990.42	41672.79	3472.781	0.1		
776159	1.921667	814.2870	57.77567	4.760241	40910.61	41667.12	3472.315	0.1		
776160	2.110000	894.0914	63.43798	5.226769	40830.81	41661.46	3471.848	0.1		
	yield	price	profit	sbav_profit						

776155	307.5	9	-10855.74	25019.59
776156	307.5	9	-10855.74	25011.87
776157	307.5	9	-10855.74	24997.44
776158	307.5	9	-10855.74	30817.05
776159	307.5	9	-10855.74	30811.38
776160	307.5	9	-10855.74	30805.72

### 7.2.1 Saving results locally

```
#write_csv(sbav_profit, "tav_profit.csv")
write_feather(sbav_profit,
  sink = "sbav_profit.feather",
  version = 2,
  chunk_size = 65536L,
  compression = c("default"),
  #compression = c("default", "lz4", "lz4_frame", "uncompressed", "zstd"),
  compression_level = NULL
)
```

## 7.3 Profit from squash agrivoltaic system

- Joint profit from squash (squash\_long) and solar energy production (solar\_profit) from 1 acre of land.
- The last variable (sqav\_profit) is the final profit from squash agrivoltaic system which is the result of our interest.

```
# Generate all combinations of row indices from both matrices
index_combinations <- expand_grid(1:nrow(solar_profit),
  1:nrow(squash_long))

# Define a function to process each combination of indices
process_combination <- function(indices) {
  i <- indices[1]
  j <- indices[2]
  new_row <- c(solar_profit[i, ],
    squash_long[j, ],
    #solar_profit[i, 14] = eannprof
    solar_profit$eannprof[i] + squash_long$profit[j])
  return(new_row)
}
```

```
# Apply the function to each combination of indices and combine the results into a matrix
sqav_profit <- do.call(rbind,
                      lapply(
                        seq_len(nrow(index_combinations)),
                        function(k) {
                          indices <- as.integer(
                            index_combinations[k, ])
                          process_combination(indices)
                        })
                      )

# Optionally, you can convert the result back to a data frame if needed
sqav_profit <- as.data.frame(sqav_profit) %>%
  rename(sqav_profit = V21)
sqav_profit <- data.frame(lapply(sqav_profit, unlist))
str(sqav_profit)
```

```
'data.frame':  776160 obs. of  21 variables:
 $ sprop      : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ al_regs    : chr  "Black Belt" "Black Belt" "Black Belt" "Black Belt" ...
 $ array      : chr  "Fixed" "Fixed" "Fixed" "Tracking" ...
 $ dc_kw      : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ panels     : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ energy     : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ elcprc     : num  0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 ...
 $ elcrev     : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ height     : num  4.6 6.4 8.2 4.6 6.4 8.2 4.6 6.4 8.2 4.6 ...
 $ capex      : num  1.59 1.85 2.33 1.73 1.92 ...
 $ ttlcost    : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ anncost    : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ moncost    : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ eprofit    : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ eannprof   : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ emonprof   : num  0 0 0 0 0 0 0 0 0 0 0 ...
 $ yldvar     : num  2 2 2 2 2 2 2 2 2 2 2 ...
 $ yield      : num  2180 2180 2180 2180 2180 2180 2180 2180 2180 2180 ...
 $ price      : num  11 11 11 11 11 11 11 11 11 11 ...
 $ profit     : num  10309 10309 10309 10309 10309 ...
 $ sqav_profit: num  10309 10309 10309 10309 10309 ...
```

```
head(sqav_profit)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height	capex
1	0	Black Belt	Fixed	0	0	0	0.01	0	4.6	1.593333
2	0	Black Belt	Fixed	0	0	0	0.01	0	6.4	1.850000
3	0	Black Belt	Fixed	0	0	0	0.01	0	8.2	2.330000
4	0	Black Belt	Tracking	0	0	0	0.01	0	4.6	1.733333
5	0	Black Belt	Tracking	0	0	0	0.01	0	6.4	1.921667
6	0	Black Belt	Tracking	0	0	0	0.01	0	8.2	2.110000
	ttlcost	anncost	moncost	eprofit	eannprof	emonprof	yldvar	yield	price	profit
1	0	0	0	0	0	0	2	2180	11	10309.12
2	0	0	0	0	0	0	2	2180	11	10309.12
3	0	0	0	0	0	0	2	2180	11	10309.12
4	0	0	0	0	0	0	2	2180	11	10309.12
5	0	0	0	0	0	0	2	2180	11	10309.12
6	0	0	0	0	0	0	2	2180	11	10309.12
	sqav_profit									
1	10309.12									
2	10309.12									
3	10309.12									
4	10309.12									
5	10309.12									
6	10309.12									

```
tail(sqav_profit)
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height	
776155	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	4.6	
776156	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	6.4	
776157	1	Southern	Fixed	423.74	885	598720.5	0.06	35923.23	8.2	
776158	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	4.6	
776159	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	6.4	
776160	1	Southern	Tracking	423.74	885	695415.0	0.06	41724.90	8.2	
	capex	ttlcost	anncost	moncost	eprofit	eannprof	emonprof	yldvar		
776155	1.593333	675.1591	47.90419	3.946913	35248.07	35875.33	2989.656	0.1		
776156	1.850000	783.9190	55.62098	4.582712	35139.31	35867.61	2989.020	0.1		
776157	2.330000	987.3142	70.05237	5.771740	34935.92	35853.18	2987.831	0.1		
776158	1.733333	734.4827	52.11335	4.293713	40990.42	41672.79	3472.781	0.1		
776159	1.921667	814.2870	57.77567	4.760241	40910.61	41667.12	3472.315	0.1		
776160	2.110000	894.0914	63.43798	5.226769	40830.81	41661.46	3471.848	0.1		
	yield	price	profit	sqav_profit						

776155	109	17	-2370.133	33505.19
776156	109	17	-2370.133	33497.48
776157	109	17	-2370.133	33483.04
776158	109	17	-2370.133	39302.65
776159	109	17	-2370.133	39296.99
776160	109	17	-2370.133	39291.33

### 7.3.1 Saving results locally

```
#write_csv(sqav_profit, "tav_profit.csv")
write_feather(sqav_profit,
  sink = "sqav_profit.feather",
  version = 2,
  chunk_size = 65536L,
  compression = c("default"),
  #compression = c("default", "lz4", "lz4_frame", "uncompressed", "zstd"),
  compression_level = NULL
)
```