Analysis

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Cost-benefit analysis of charger

It is necessary to analyze how much would it benefit from installation of one charger. The benefit could be estimated by the fuel cost reduction as EV uses electricity. Assumping electricity price and gas price keep changing annually and annual discount factor is 6%, the cost - benefit analyses were constructed based on 4 cases. 1) onwer takes the installation cost of 1 charger and uses it, 2) owner takes the installation cost for the whole chargers (5 renters) and uses one of them, 3) owner doesn't live in the building, but pays the cost of all chargers (6 chargers) and get commission of 20% of the benefit generated from the chargers, and 4) with the case 3, there are additional 6 more EVs are using by sharing the 6 installed chargers. Net present value (NPV) and discounted payback period (DPP) are measured for each scenario.

To assess how rebates can be applied in the proposed policies, it needed to be analyzed how the expected benefits through the installation of a charger compare to their cost and calculate a break-even point. This analysis assumes EV-ready buildings and will be based on the outcome of the previous sections and the fuel cost reduction achieved by using EVs, plus the installation cost of the chargers. This break-even point heavily depends on the individual situation (condos, apartments, owner-renter relationships, etc.). Assuming annual changes of gasoline and energy prices and an annual discount factor of 6%, four different example cases were provided:

- Case 1: Condo - Owner invests into the installation of one charger for personal use
- Case 2: Mixed Condo / Rental apartments (condo owner owns 5 additional units in the building and rents them out to tenants) - Owner invests into multiple chargers and uses one of them
- Case 3: Rental apartments - Landlord invests into a set of chargers (in this case we assume 6 chargers), while not using any of them for personal use and receiving a commission of 20% of the benefits generated through the chargers
- Case 4: Rental apartments - Sharing chargers with case 3 above - 12 renters are sharing 6 installed chargers (2 renters share 1 charger)

These cases all assume that the installed chargers will be used such that the upfront cost for a charger (level 2 stands alone) is $2,050 for charger ready sites. The net present value (NPV) and discounted payback period (DPP) were measured for each scenario. We assume the annual vehicle miles travelled to be 10,230 miles per vehicle and an average MPG of 33 according to the standard applied to the year 2017. Thus, an internal combustion engine (ICE) vehicle requires 310 gallons of fuel on average per year. The total cost was calculated to be $772 per year based in a fuel price of $2.49 / gallon. For EVs we assume the same mileage and a fuel economy of 30 kWh / 100 miles (34 kWh/ 100 miles for Tesla models S - 90D, 30 kWh/ 100 miles for Nissan Leaf, 32 kWh/ 100 miles for Kia Soul). Thus, the annual energy requirement is 3069 kWh. Based on a price of $0.077/kWh the annual cost is calculated as $236.30, which results in an annual benefit in operational cost of $535.70 per EV. For case 1, we achieve break-even within less than 6 years, which is reasonable as the investor directly receives their Return-On-Investment (ROI). In each case, Net present value (NPV), present value (PV) and future value (FV) would be measured. This is a case comparable to single family housing EVSE.

Benefits

Conventional vehicle

- VMT 10,230 miles

- MPG 33 miles/ gallon
- Gas required 310 gallons
- Gas unit price \$2.49/ gallon
- Total cost \$772

EV

- Fuel economy 30 kWh/100 mile
- Elec. need per year 3069 kWh
- Elec. unit cost \$0.077/ kWh
- Elec. cost \$236.3

Annual benefit for one car \$535.7

Cost

- Installation \$2,050 (based on Megan's table)

After 100 times Monte Carlo simulations, it shows that case 1 takes less than 6 years to reach the break-even point, while case 2, over 20 years and case 3, about 18 years. This analysis indicates that government supports are necessary to benefit buiding owners for the same impact as the single family households.

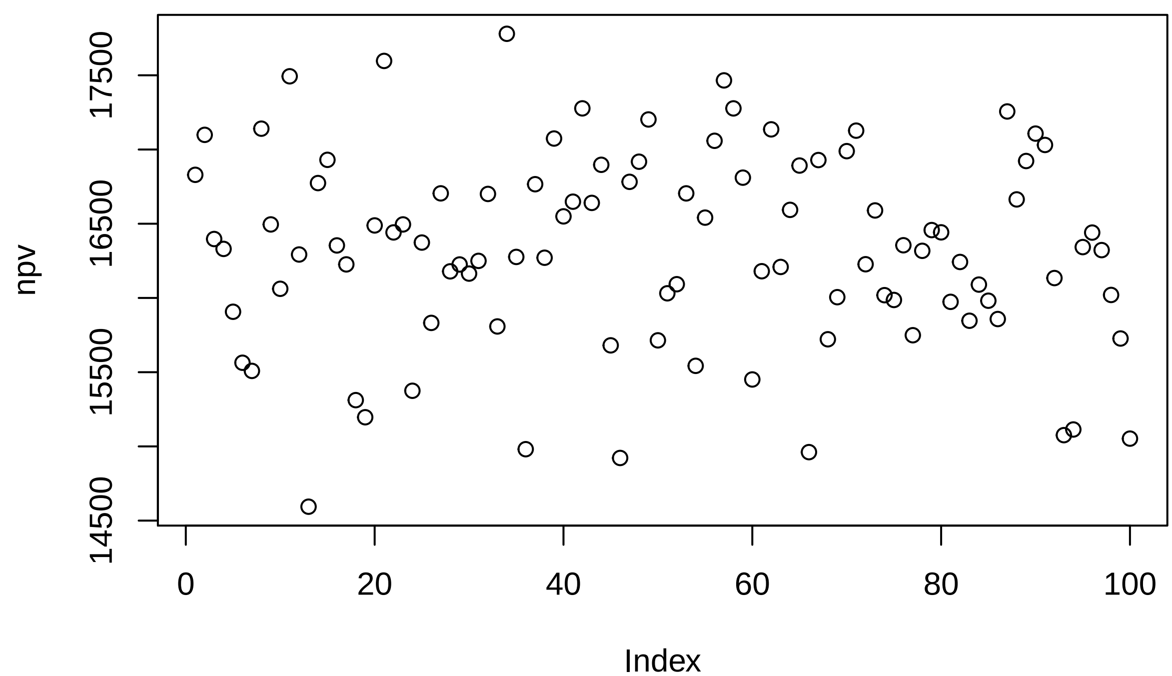
Moreover, MUD charger has potential as one charger could serve muliple EVs. The case 4 shows that it only takes about 10 years to reach the break-even point. Government support could be lessen compared to the case 3.

```
vmt=10230
mpg=33
gas=vmt/mpg
gas_c=2.49
c_cost=gas_c*gas

kw=3069
u_cost=0.077
e_cost=kw*u_cost

ben=c_cost-e_cost

inst=2050

rt=0.06
```

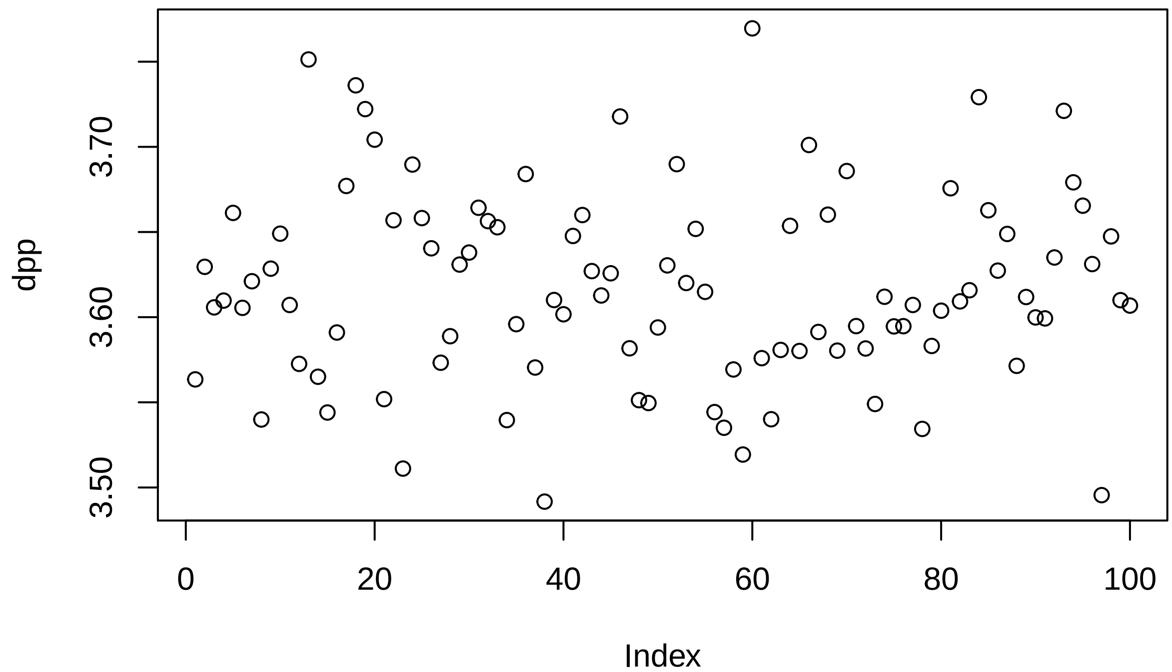
case1, single owner - single user

```
npv = c()
dpp = c()

for(j in 1:100){
  rgs=gas_c
  rei=u_cost
```

```r
  cf=-inst
  q=data.frame(matrix(NA,25,6))
  for(i in 1:25){
    rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
    rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
    fv=rgs*gas - kw*rei
    pv= fv/(1+rt)^i
    old=cf
    cf=cf+pv
    dp=ifelse(cf>0,i-1+abs(old/pv),0)
    q[i,]=c(rgs,rei,fv,pv,cf,dp)
  }
  npv[j]=sum(q[,4])-inst #net present value
  dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
plot(npv)
```




```r
plot(dpp)
```




```r
colnames(q) = c("Gas price($/gallon)","Elec.price($/kWh)","FV($)","PV($)","NPV($)","DPP(year)")
q
```

```
##    Gas price($/gallon) Elec.price($/kWh)     FV($)    PV($)      NPV($)
## 1             2.732461        0.08309209  592.0532 558.5407 -1491.4593
## 2             2.936700        0.08893685  637.4300 567.3104  -924.1489
## 3             3.164740        0.09755118  681.6850 572.3558  -351.7931
## 4             3.416425        0.10660911  731.9085 579.7401   227.9470
## 5             3.670945        0.11622823  781.2886 583.8243   811.7713
## 6             3.929271        0.12492764  834.6711 588.4102  1400.1815
## 7             4.243783        0.13679551  895.7474 595.7232  1995.9047
## 8             4.612833        0.14995492  969.7667 608.4436  2604.3483
## 9             4.942054        0.16402887 1028.6320 608.8457  3213.1940
## 10            5.294421        0.17891744 1092.1728 609.8636  3823.0576
## 11            5.777950        0.19180236 1202.5232 633.4742  4456.5318
## 12            6.313253        0.20582934 1325.4182 658.6922  5115.2240
## 13            6.932114        0.22535019 1457.3557 683.2652  5798.4892
## 14            7.607726        0.24782174 1597.8303 706.7219  6505.2111
## 15            8.197672        0.27001985 1712.5874 714.6029  7219.8139
## 16            8.844882        0.29502043 1836.4959 722.9298  7942.7437
## 17            9.504850        0.31598523 1976.7449 734.0927  8676.8364
## 18           10.445629        0.34334157 2184.4298 765.3014  9442.1379
## 19           11.187322        0.37504634 2317.0526 765.8160 10207.9539
## 20           11.973546        0.40635025 2464.7103 768.5083 10976.4622
## 21           12.886971        0.44235226 2637.3818 775.8001 11752.2623
```

```
## 22           13.886422        0.48538793 2815.1354 781.2144 12533.4768
## 23           15.261172        0.53391637 3092.3739 809.5750 13343.0518
## 24           16.722753        0.57492068 3419.6217 844.5732 14187.6250
## 25           18.079931        0.61688504 3711.5586 864.7881 15052.4130
##    DPP(year)
## 1   0.000000
## 2   0.000000
## 3   0.000000
## 4   3.606812
## 5   4.390438
## 6   6.379601
## 7   8.350390
## 8  10.280345
## 9  12.277518
## 10 14.268710
## 11 16.035064
## 12 17.765727
## 13 19.486440
## 14 21.204768
## 15 23.103253
## 16 24.986881
## 17 26.819810
## 18 28.337802
## 19 30.329512
## 20 32.282815
## 21 34.148570
## 22 36.043581
## 23 37.481551
## 24 38.798573
## 25 40.405898
```

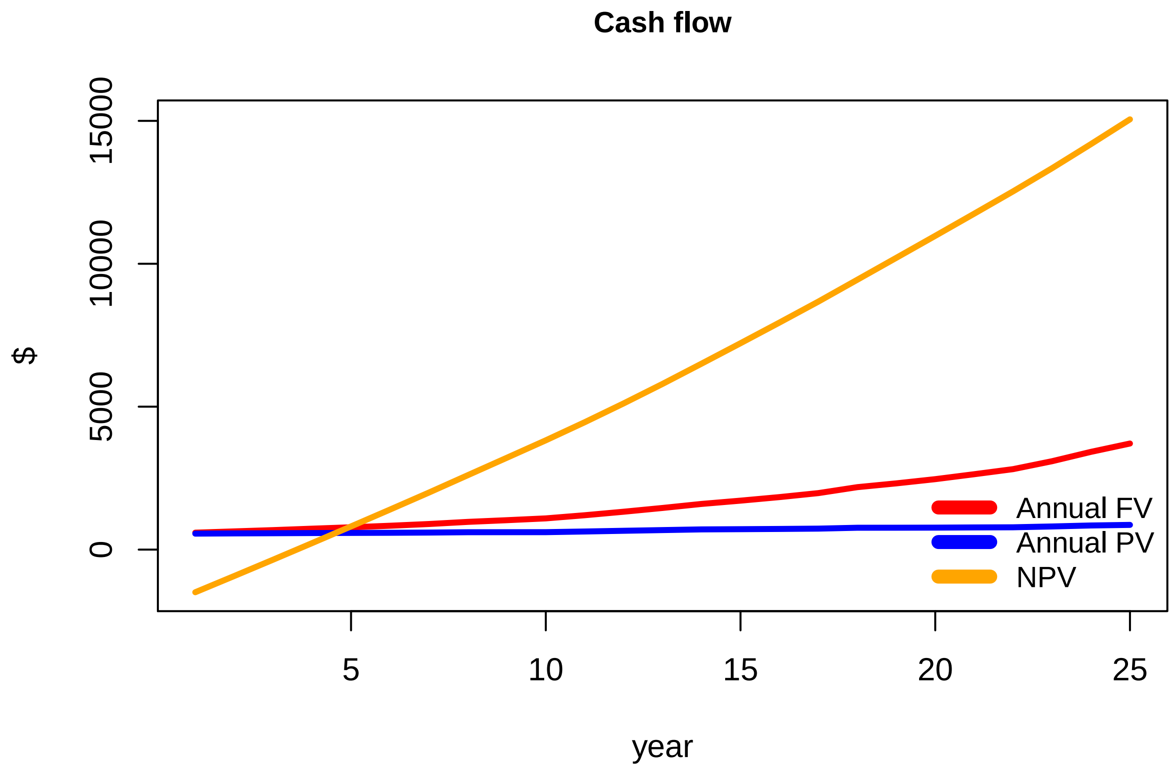
```r
mean(npv)
```

```
## [1] 16325.83
```

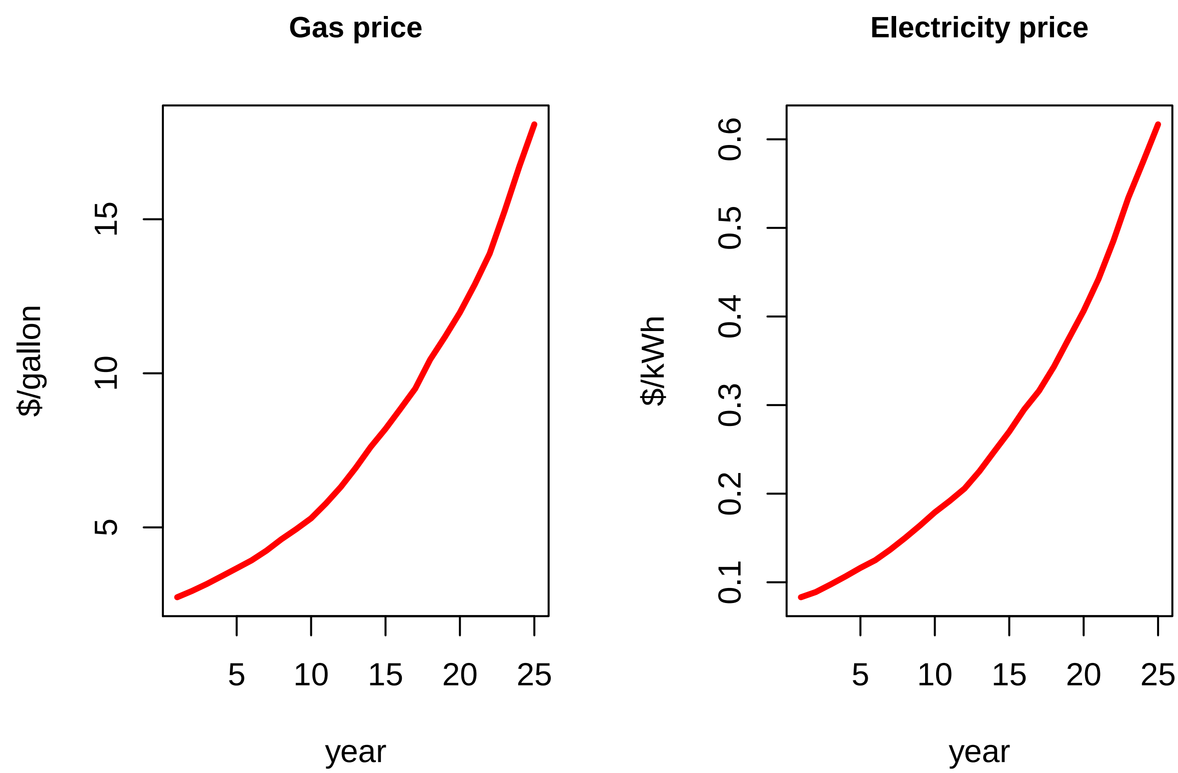
```r
mean(dpp)
```

```
## [1] 3.617498
```

```r
par(mfrow= c(1,1))
plot(q[,3], main = "Cash flow", ylab="$", xlab="year",
     type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3,cex.main=0.9)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("bottomright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.l
```

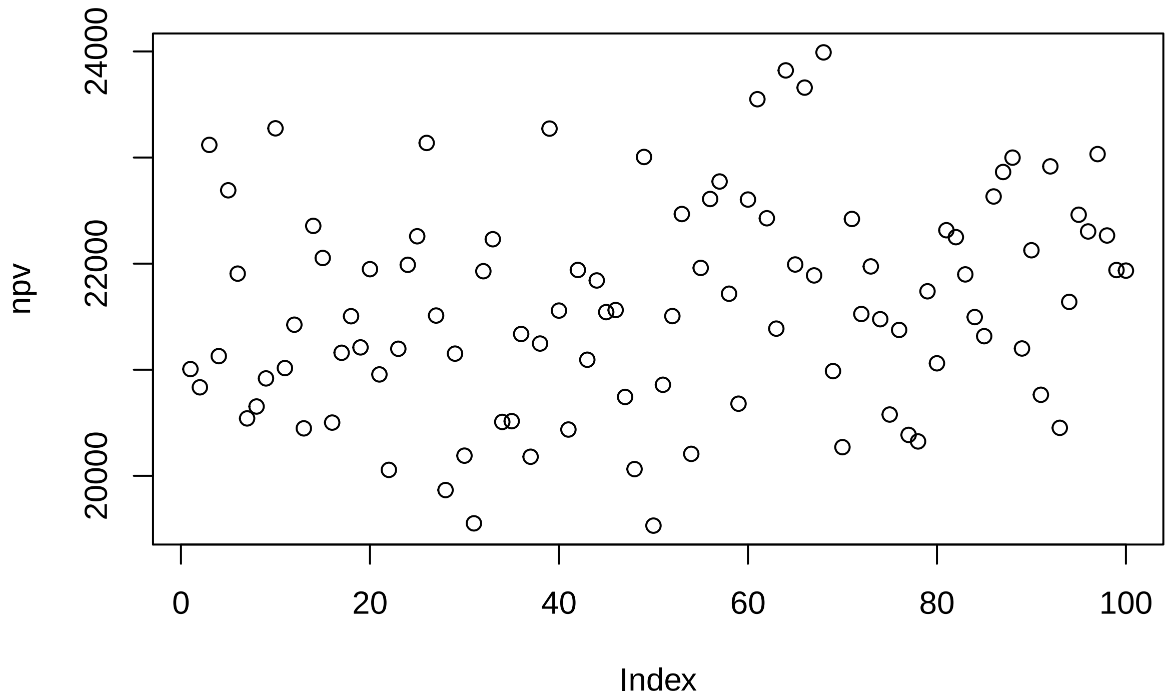



```r
par(mfrow= c(1,2))
plot(q[,1], main = "Gas price", ylab="$/gallon", xlab="year",
     type = 'l', ylim = c(min(q[,1]),max(q[,1])), col = 'red',lwd=3,cex.main=0.9)

plot(q[,2], main = "Electricity price", ylab="$/kWh", xlab="year",
     type = 'l', ylim = c(min(q[,2]),max(q[,2])), col = 'red',lwd=3,cex.main=0.9)
```

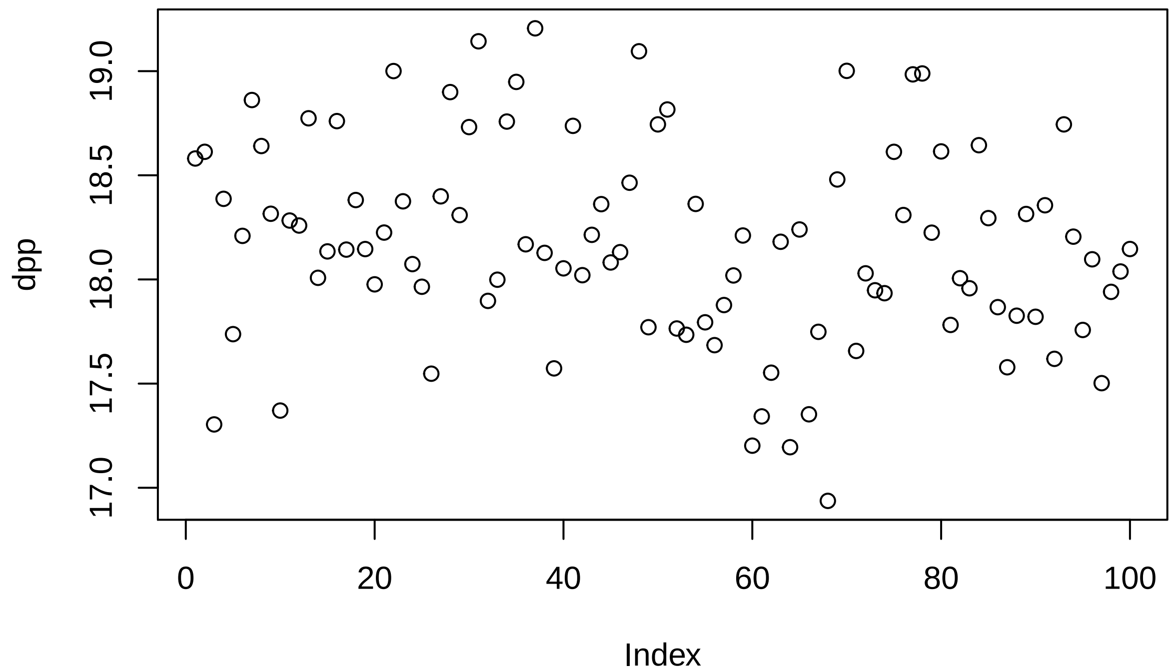


case2, one owner - 5 renters

```
npv = c()
dpp = c()

for(j in 1:100){
  rgs=gas_c
  rei=u_cost
  cf=-inst * 6
  q=data.frame(matrix(NA,30,6))
  for(i in 1:30){
    rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
    rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
    fv=rgs*gas - kw*rei
    pv= fv/(1+rt)^i
    old=cf
    cf=cf+pv
    dp=ifelse(cf>0,i-1+abs(old/pv),0)
    q[i,]=c(rgs,rei,fv,pv,cf,dp)
  }
  npv[j]=sum(q[,4])-inst #net present value
  dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
plot(npv)
```




```
plot(dpp)
```




```r
colnames(q) = c("Gas price($/gallon)","Elec.price($/kWh)","FV($)","PV($)","NPV($)","DPP(year)")
q
```

```
##    Gas price($/gallon) Elec.price($/kWh)     FV($)    PV($)      NPV($)
## 1             2.709813        0.08460279  580.3960 547.5434 -11752.4566
## 2             2.929040        0.09090240  629.0228 559.8281 -11192.6285
## 3             3.183395        0.09779199  686.7289 576.5908 -10616.0377
## 4             3.454573        0.10560917  746.8029 591.5379 -10024.4998
## 5             3.731361        0.11604758  800.5719 598.2339  -9426.2659
## 6             4.103153        0.12665390  883.2765 622.6751  -8803.5908
## 7             4.407012        0.13918320  939.0204 624.5022  -8179.0886
## 8             4.837568        0.15224060 1032.4198 647.7529  -7531.3357
## 9             5.305444        0.16362591 1142.5196 676.2556  -6855.0801
## 10            5.730664        0.17706467 1233.0944 688.5535  -6166.5266
## 11            6.151329        0.19009351 1323.5150 697.2112  -5469.3154
## 12            6.623787        0.20449227 1425.7872 708.5726  -4760.7429
## 13            7.143358        0.22282569 1530.5890 717.5999  -4043.1430
## 14            7.792819        0.24044483 1677.8486 742.1140  -3301.0290
## 15            8.473573        0.26099880 1825.8022 761.8435  -2539.1855
## 16            9.158269        0.28336694 1969.4103 775.2510  -1763.9344
## 17            9.998102        0.30467204 2164.3733 803.7712   -960.1632
## 18           10.953365        0.33062727 2380.8480 834.1153   -126.0479
## 19           11.942425        0.35545993 2611.2452 863.0505    737.0026
## 20           12.782622        0.38138061 2792.1556 870.6073   1607.6099
## 21           13.992463        0.41413059 3066.6967 902.0854   2509.6954
```

```
## 22           15.374145        0.44853306 3389.4371  940.5861   3450.2814
## 23           16.625500        0.49068184 3648.0023  955.0370   4405.3184
## 24           18.097348        0.53111799 3980.1769  983.0183   5388.3367
## 25           19.458161        0.57426997 4269.5954  994.8099   6383.1466
## 26           21.002053        0.62264668 4599.7337 1011.0676   7394.2142
## 27           22.641964        0.68403649 4919.7010 1020.1883   8414.4025
## 28           24.764845        0.73889372 5409.4370 1058.2489   9472.6515
## 29           27.194607        0.81054941 5942.7521 1096.7749  10569.4264
## 30           29.351105        0.87901129 6401.1568 1114.5063  11683.9327
##    DPP(year)
## 1    0.00000
## 2    0.00000
## 3    0.00000
## 4    0.00000
## 5    0.00000
## 6    0.00000
## 7    0.00000
## 8    0.00000
## 9    0.00000
## 10   0.00000
## 11   0.00000
## 12   0.00000
## 13   0.00000
## 14   0.00000
## 15   0.00000
## 16   0.00000
## 17   0.00000
## 18   0.00000
## 19  18.14605
## 20  19.84654
## 21  21.78210
## 22  23.66823
## 23  25.61272
## 24  27.48142
## 25  29.41645
## 26  31.31327
## 27  33.24789
## 28  34.95125
## 29  36.63682
## 30  38.48351
```

```r
mean(npv)
```

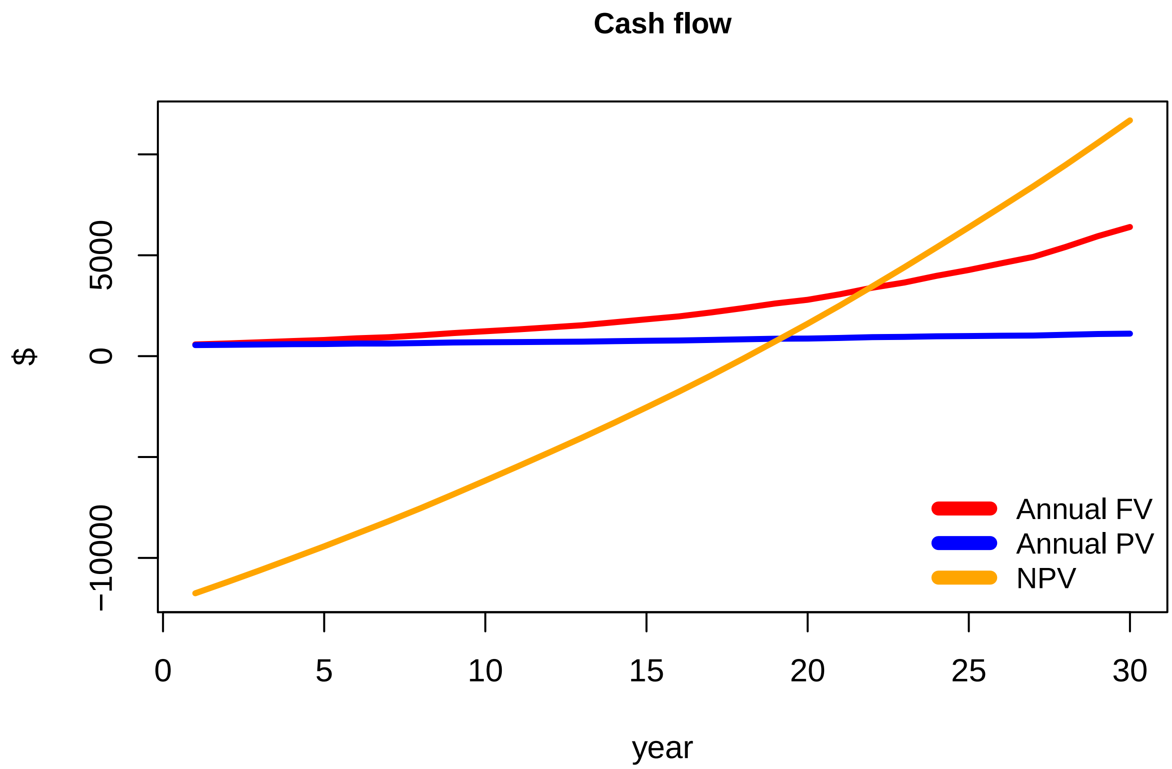
```
## [1] 21610.93
```

```r
mean(dpp)
```

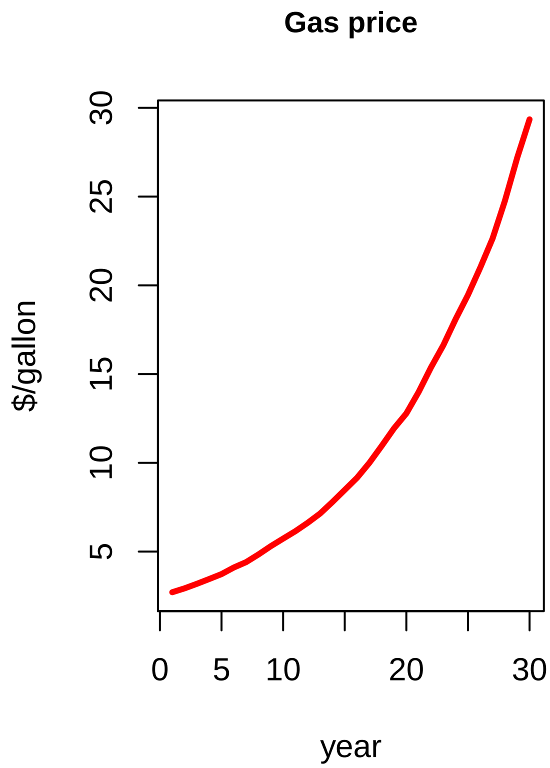
```
## [1] 18.17197
```

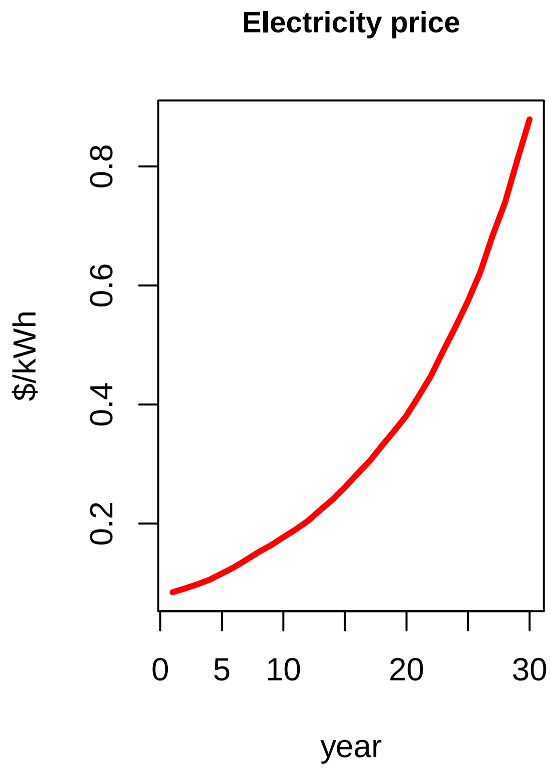
```r
par(mfrow= c(1,1))
plot(q[,3], main = "Cash flow", ylab="$", xlab="year",
     type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3,cex.main=0.9)
```

```r
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("bottomright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.l
```




```r
par(mfrow= c(1,2))
plot(q[,1], main = "Gas price", ylab="$/gallon", xlab="year",
     type = 'l', ylim = c(min(q[,1]),max(q[,1])), col = 'red',lwd=3,cex.main=0.9)

plot(q[,2], main = "Electricity price", ylab="$/kWh", xlab="year",
     type = 'l', ylim = c(min(q[,2]),max(q[,2])), col = 'red',lwd=3,cex.main=0.9)
```



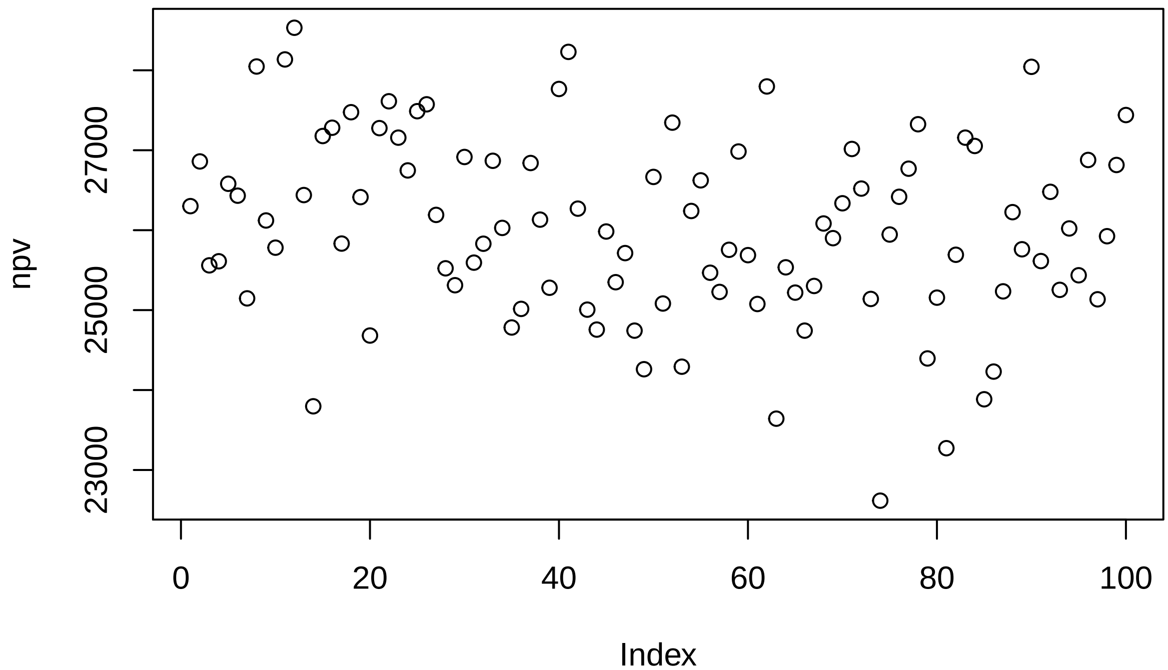


case3, no onwer but only 6 renters living

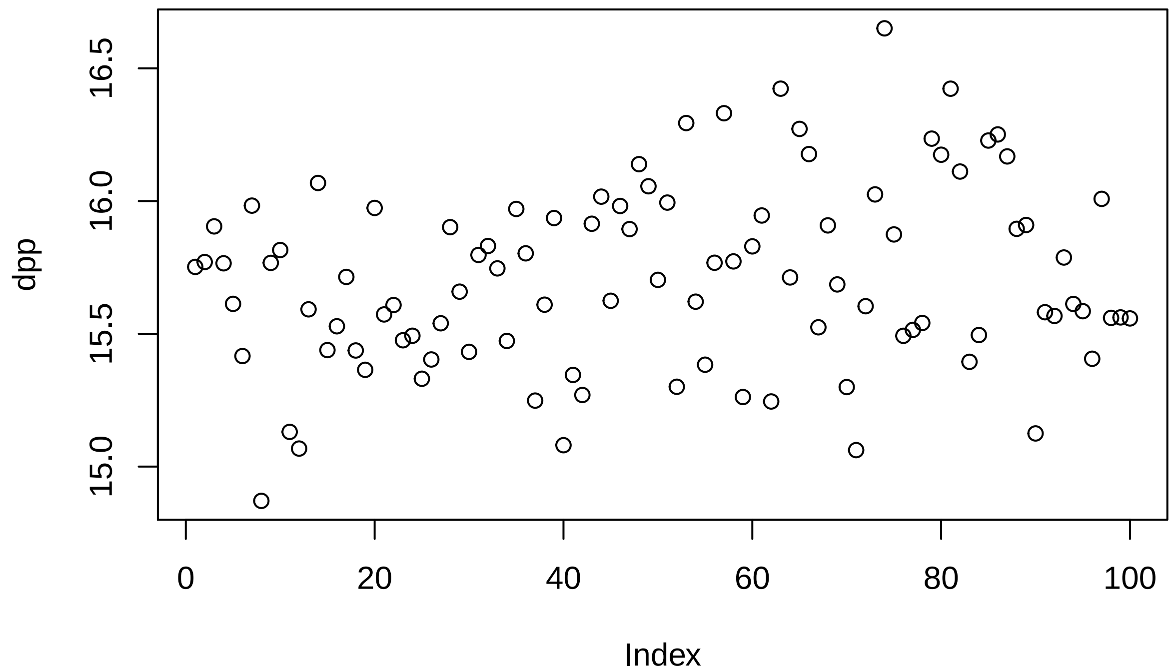
Here it is assumed that the owner doesn't live in the building while collecting a commission of 20% of profit generated from the charger installation. This commission could be interpreted as the increased rental or tax credits if government supports.

```
npv = c()
dpp = c()
com = 0.2

for(j in 1:100){
  rgs=gas_c
  rei=u_cost
  cf=-inst * 6
  q=data.frame(matrix(NA,30,6))
  for(i in 1:30){
    rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
    rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
    fv=com*6*(rgs*gas - kw*rei)
    pv= fv/(1+rt)^i
    old=cf
    cf=cf+pv
    dp=ifelse(cf>0,i-1+abs(old/pv),0)
    q[i,]=c(rgs,rei,fv,pv,cf,dp)
  }
```

```r
  npv[j]=sum(q[,4])-inst #net present value
  dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
plot(npv)
```




```r
plot(dpp)
```




```r
colnames(q) = c("Gas price($/gallon)","Elec.price($/kWh)","FV($)","PV($)","NPV($)","DPP(year)")
q
```

```
##    Gas price($/gallon) Elec.price($/kWh)      FV($)     PV($)       NPV($)
## 1             2.664600        0.08395083  682.0571  643.4501 -11656.5499
## 2             2.875413        0.09109286  734.1768  653.4147 -11003.1352
## 3             3.156391        0.09782335  813.9136  683.3775 -10319.7576
## 4             3.392096        0.10754809  865.7816  685.7801  -9633.9775
## 5             3.692336        0.11547432  948.2803  708.6102  -8925.3673
## 6             4.040928        0.12379276 1047.3213  738.3202  -8187.0472
## 7             4.440701        0.13437111 1157.0787  769.5234  -7417.5237
## 8             4.883283        0.14759140 1273.0315  798.7157  -6618.8080
## 9             5.348716        0.16064209 1398.1095  827.5389  -5791.2691
## 10            5.738693        0.17452775 1492.0431  833.1491  -4958.1200
## 11            6.280439        0.19175931 1630.1119  858.7226  -4099.3974
## 12            6.731391        0.20577185 1746.2608  867.8381  -3231.5593
## 13            7.242831        0.22380932 1870.0882  876.7703  -2354.7890
## 14            7.842439        0.24160069 2027.6202  896.8184  -1457.9706
## 15            8.618037        0.26203031 2240.9046  935.0512   -522.9194
## 16            9.231956        0.28611687 2380.5766  937.1051    414.1857
## 17           10.112311        0.31215546 2612.1737  970.0684   1384.2541
## 18           11.076854        0.34095531 2864.9194 1003.7067   2387.9608
## 19           12.091738        0.36512327 3153.4504 1042.2564   3430.2172
## 20           13.263979        0.39852092 3466.5274 1080.8796   4511.0968
## 21           14.409117        0.42861245 3781.6976 1112.4068   5623.5036
```

```
## 22           15.768183        0.46580380 4150.3020 1151.7300   6775.2335
## 23           17.147023        0.49956139 4538.9078 1188.2736   7963.5072
## 24           18.693905        0.54318480 4953.6918 1223.4556   9186.9628
## 25           20.543730        0.58716613 5479.8520 1276.7980  10463.7608
## 26           22.141002        0.63299635 5905.2536 1298.0340  11761.7947
## 27           23.833098        0.68290996 6350.8918 1316.9714  13078.7662
## 28           25.510417        0.73544213 6781.3890 1326.6441  14405.4103
## 29           27.638977        0.78863515 7377.3140 1361.5330  15766.9433
## 30           30.329885        0.84425690 8173.4879 1423.0870  17190.0303
##    DPP(year)
## 1    0.00000
## 2    0.00000
## 3    0.00000
## 4    0.00000
## 5    0.00000
## 6    0.00000
## 7    0.00000
## 8    0.00000
## 9    0.00000
## 10   0.00000
## 11   0.00000
## 12   0.00000
## 13   0.00000
## 14   0.00000
## 15   0.00000
## 16  15.55802
## 17  16.42697
## 18  18.37914
## 19  20.29115
## 20  22.17354
## 21  24.05526
## 22  25.88266
## 23  27.70175
## 24  29.50903
## 25  31.19531
## 26  33.06124
## 27  34.93094
## 28  36.85853
## 29  38.58029
## 30  40.07939
```

```r
mean(npv)
```

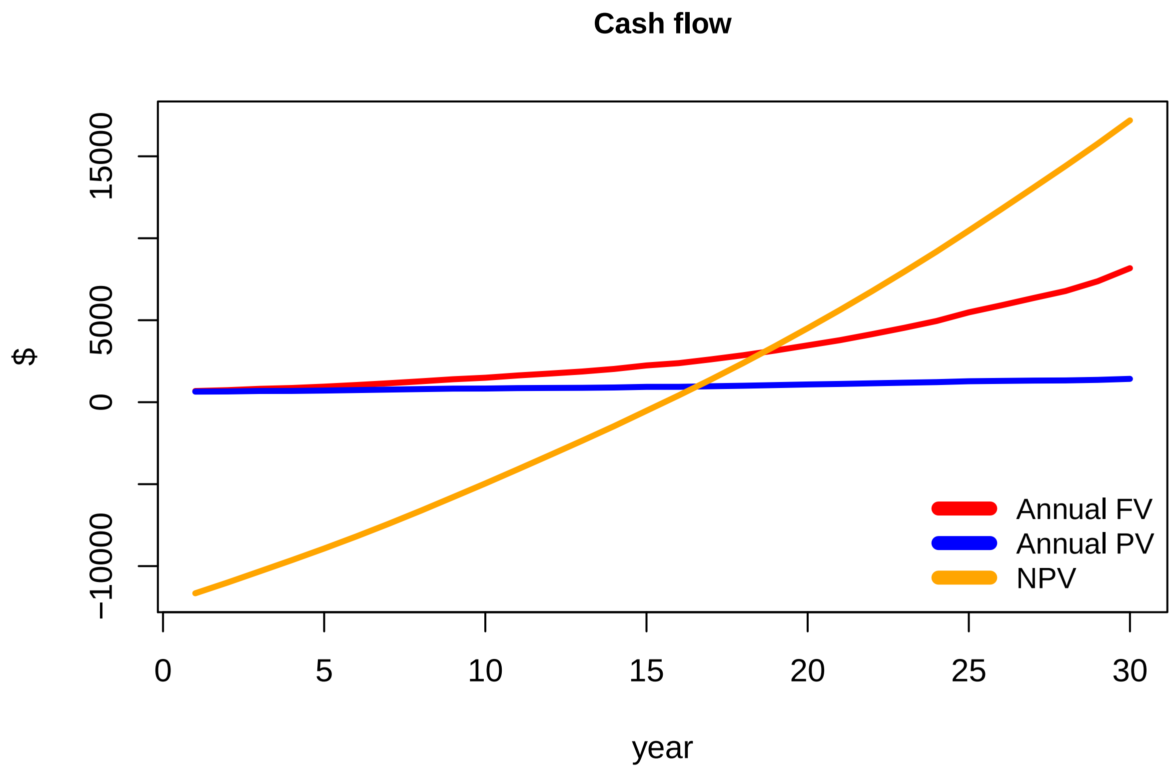
```
## [1] 26023.07
```

```r
mean(dpp)
```

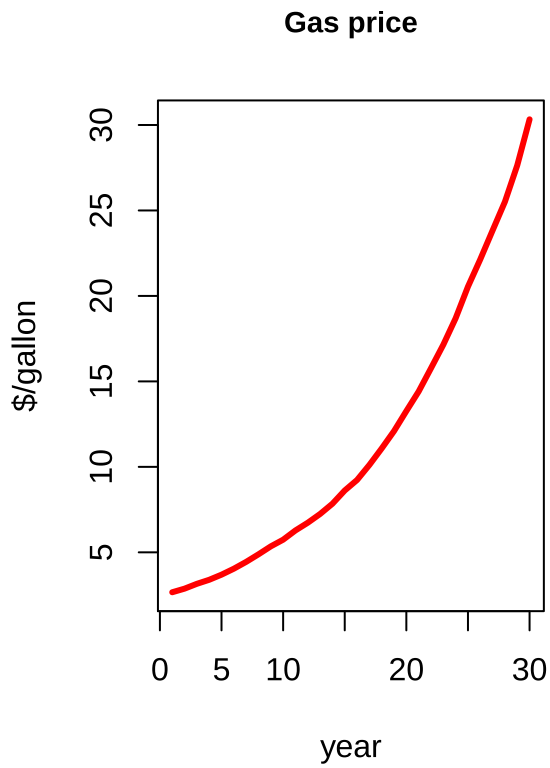
```
## [1] 15.70981
```

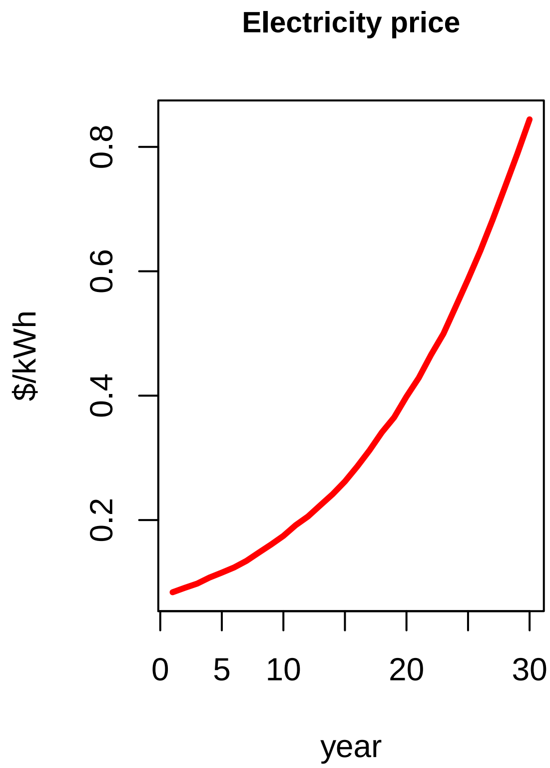
```r
par(mfrow= c(1,1))
plot(q[,3], main = "Cash flow", ylab="$", xlab="year",
     type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3,cex.main=0.9)
```

```r
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("bottomright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.l
```




```r
par(mfrow= c(1,2))
plot(q[,1], main = "Gas price", ylab="$/gallon", xlab="year",
     type = 'l', ylim = c(min(q[,1]),max(q[,1])), col = 'red',lwd=3,cex.main=0.9)

plot(q[,2], main = "Electricity price", ylab="$/kWh", xlab="year",
     type = 'l', ylim = c(min(q[,2]),max(q[,2])), col = 'red',lwd=3,cex.main=0.9)
```



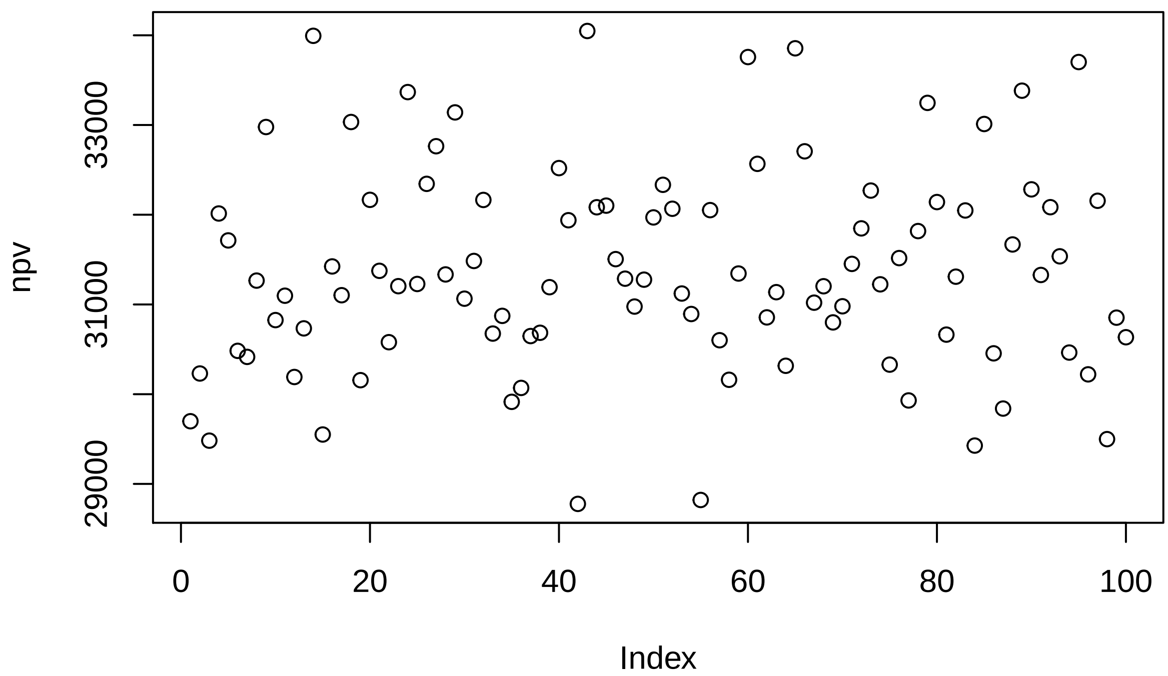


case4, 12 renters (sharing chargers) but rest conditions are the same as case3.

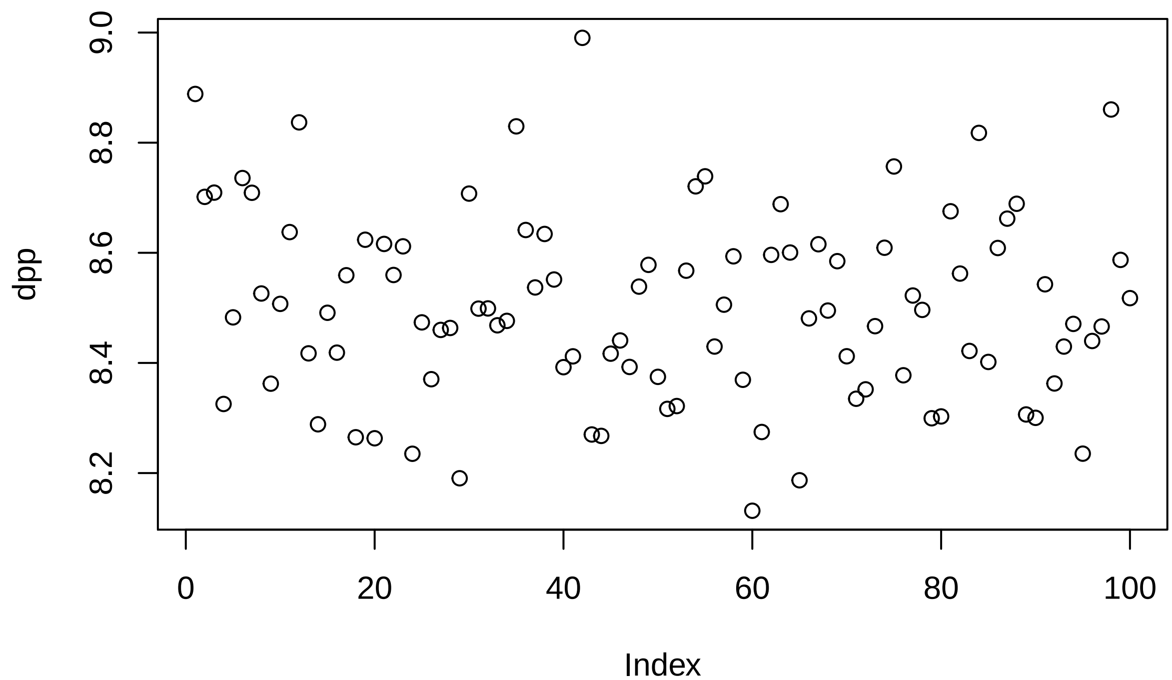
This case, 2 EV owners are using one charger by sharing it given the same utilization rate as the case3.

```
npv = c()
dpp = c()
com = 0.2

for(j in 1:100){
  rgs=gas_c
  rei=u_cost
  cf=-inst * 6
  q=data.frame(matrix(NA,20,6))
  for(i in 1:20){
    rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
    rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
    fv=com*12*(rgs*gas - kw*rei)
    pv= fv/(1+rt)^i
    old=cf
    cf=cf+pv
    dp=ifelse(cf>0,i-1+abs(old/pv),0)
    q[i,]=c(rgs,rei,fv,pv,cf,dp)
  }
  npv[j]=sum(q[,4])-inst #net present value
  dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
```

```r
}
plot(npv)
```




```r
plot(dpp)
```




```r
colnames(q) = c("Gas price($/gallon)","Elec.price($/kWh)","FV($)","PV($)","NPV($)","DPP(year)")
q
```

```
##    Gas price($/gallon) Elec.price($/kWh)    FV($)    PV($)       NPV($)
## 1             2.706283        0.08450986 1391.008 1312.272 -10987.7279
## 2             2.915482        0.09102395 1498.673 1333.813  -9653.9147
## 3             3.176138        0.09768851 1643.512 1379.924  -8273.9904
## 4             3.471187        0.10705028 1794.073 1421.074  -6852.9162
## 5             3.797732        0.11616935 1969.855 1471.991  -5380.9256
## 6             4.096544        0.12511529 2126.279 1498.943  -3881.9826
## 7             4.394474        0.13701068 2260.323 1503.244  -2378.7388
## 8             4.774191        0.14761424 2464.731 1546.403   -832.3361
## 9             5.216291        0.15810662 2716.370 1607.815    775.4793
## 10            5.653401        0.17284709 2933.008 1637.776   2413.2557
## 11            6.079949        0.19001936 3123.875 1645.619   4058.8743
## 12            6.596063        0.20841865 3372.343 1675.951   5734.8252
## 13            7.216211        0.22746542 3693.442 1731.630   7466.4549
## 14            7.739265        0.24422543 3959.147 1751.134   9217.5892
## 15            8.410986        0.26311026 4319.809 1802.505  11020.0946
## 16            9.001886        0.28700203 4583.461 1804.262  12824.3571
## 17            9.646623        0.31074356 4888.275 1815.331  14639.6884
## 18           10.410610        0.33594178 5271.081 1846.691  16486.3789
## 19           11.356601        0.36097844 5790.488 1913.832  18400.2106
## 20           12.467170        0.39528929 6364.032 1984.335  20384.5457
##    DPP(year)
```

```
## 1   0.000000
## 2   0.000000
## 3   0.000000
## 4   0.000000
## 5   0.000000
## 6   0.000000
## 7   0.000000
## 8   0.000000
## 9   8.517681
## 10  9.473495
## 11 11.466473
## 12 13.421834
## 13 15.311808
## 14 17.263782
## 15 19.113765
## 16 21.107811
## 17 23.064472
## 18 24.927527
## 19 26.614331
## 20 28.272733
```

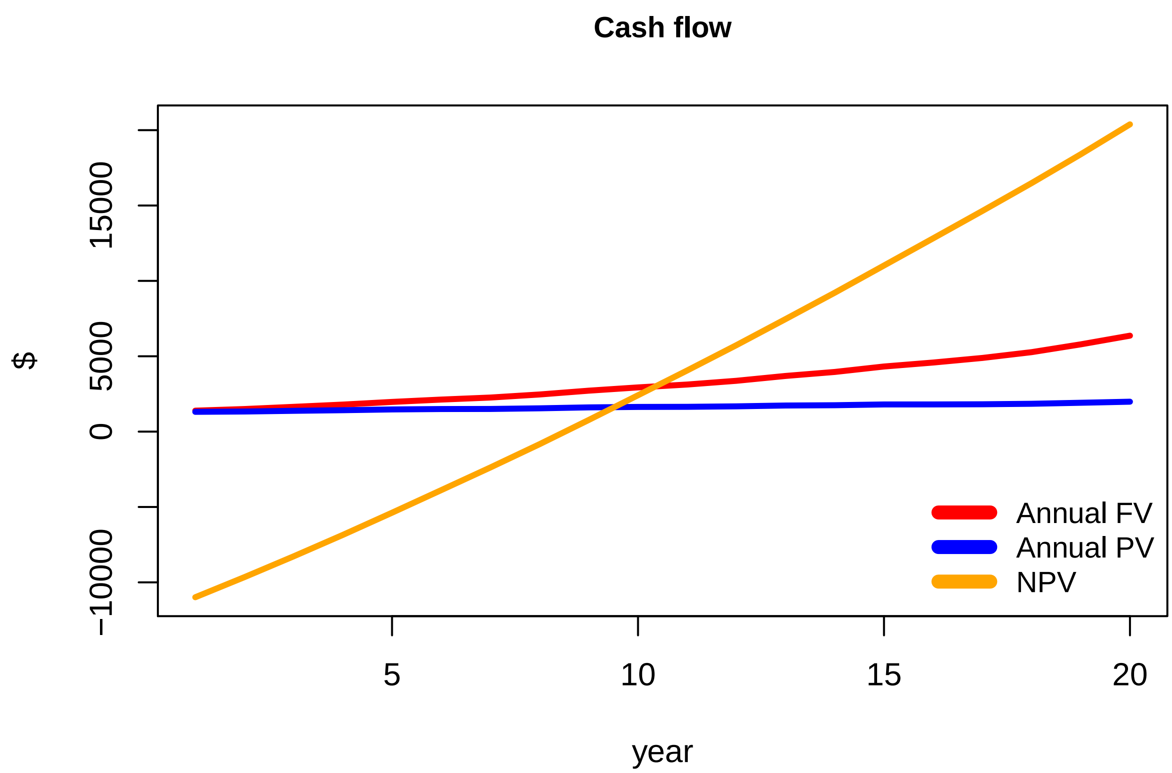
```
mean(npv)
```

```
## [1] 31380.76
```

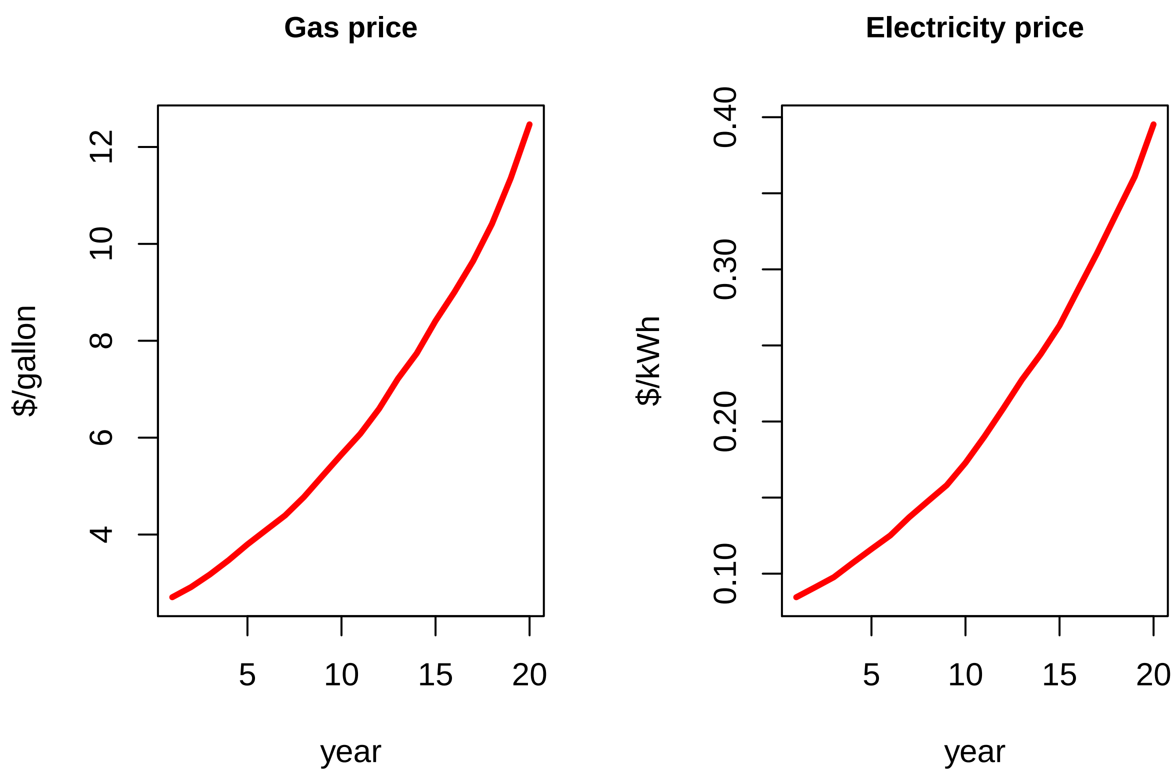
```
mean(dpp)
```

```
## [1] 8.501556
```

```
par(mfrow= c(1,1))
plot(q[,3], main = "Cash flow", ylab="$", xlab="year",
     type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3,cex.main=0.9)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("bottomright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.
```




```r
par(mfrow= c(1,2))
plot(q[,1], main = "Gas price", ylab="$/gallon", xlab="year",
     type = 'l', ylim = c(min(q[,1]),max(q[,1])), col = 'red',lwd=3,cex.main=0.9)

plot(q[,2], main = "Electricity price", ylab="$/kWh", xlab="year",
     type = 'l', ylim = c(min(q[,2]),max(q[,2])), col = 'red',lwd=3,cex.main=0.9)
```



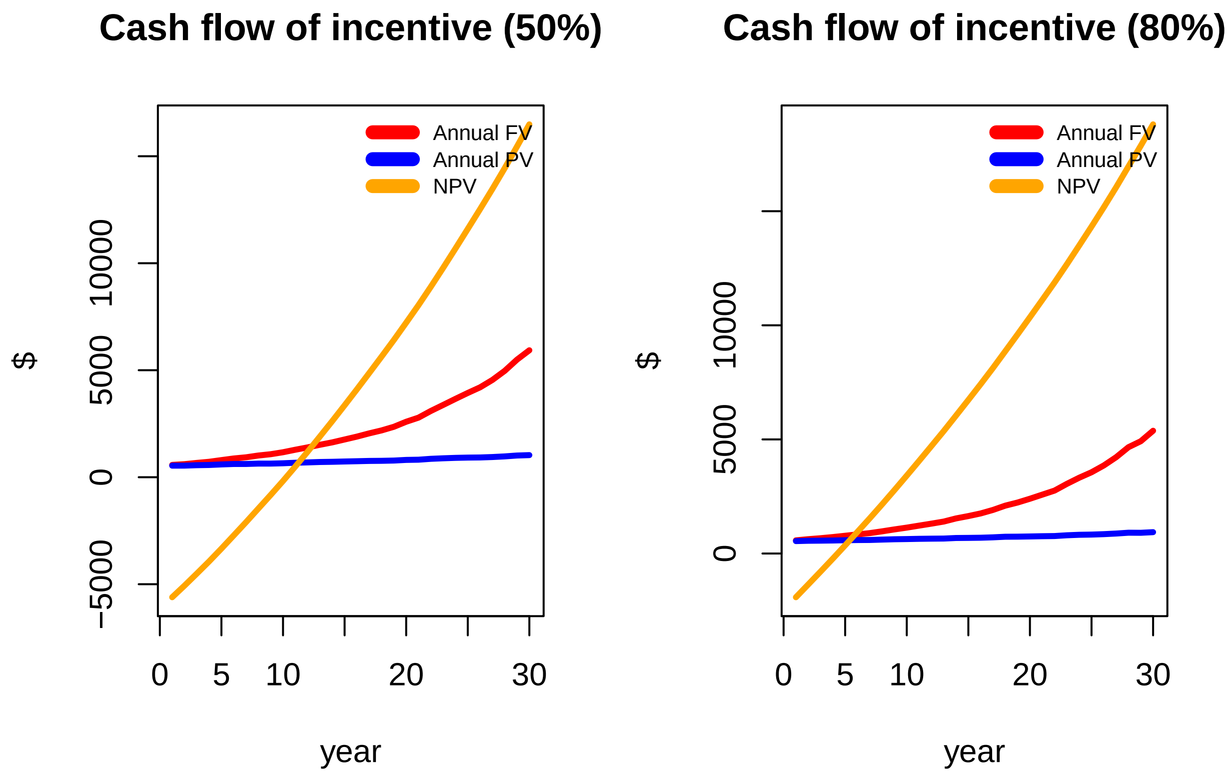
Commission vs. Incentive

As the previous cost benefit analysis shows, in order to make the investment of chargers as effective as for single family households, there should be support to MUD owners who need to invest their private funds for the installation of chargers. Taking into account the previous case analysis, a DPP of 5 years should be targeted if we aim at achieving a similar benefit as for case 1. This section investigates how high the incentives would have to be to achieve this goal for case 2, case 3 and case 4.

For case 2, the incentive would have to be at least 80% of the upfront cost. A figure below shows that an incentive of 50% would still not be enough.

```
npv = c()
dpp = c()
for(j in 1:100){
rgs=gas_c
rei=u_cost
cf=-inst *6*0.5
q=data.frame(matrix(NA,30,6))
for(i in 1:30){
rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
fv=(rgs*gas - kw*rei)
pv= fv/(1+rt)^i
old=cf
cf=cf+pv
```

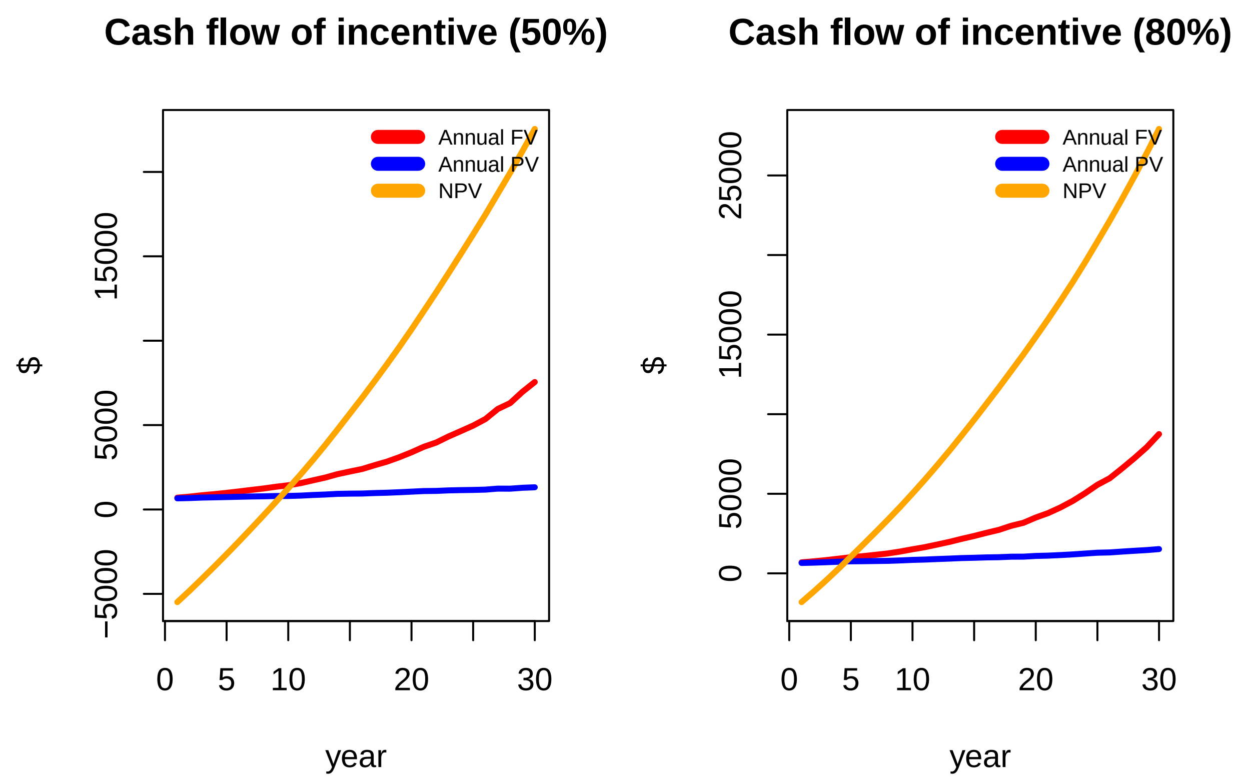
```
dp=ifelse(cf>0,i-1+abs(old/pv),0)
q[i,]=c(rgs,rei,fv,pv,cf,dp)
}
npv[j]=sum(q[,4])-inst #net present value
dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
par(mfrow= c(1,2))
plot(q[,3], main = "Cash flow of incentive (50%)", ylab="$", xlab="year",
type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("topright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.lty


npv = c()
dpp = c()
com = 0.5
for(j in 1:100){
rgs=gas_c
rei=u_cost
cf=-inst * 6 * 0.2
q=data.frame(matrix(NA,30,6))
for(i in 1:30){
rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
fv=(rgs*gas - kw*rei)
pv= fv/(1+rt)^i
old=cf
cf=cf+pv
dp=ifelse(cf>0,i-1+abs(old/pv),0)
q[i,]=c(rgs,rei,fv,pv,cf,dp)
}
npv[j]=sum(q[,4])-inst #net present value
dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
plot(q[,3], main = "Cash flow of incentive (80%)", ylab="$", xlab="year",
type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("topright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.lty
```



For case 3, the results are very similar. Hence, both case 2 and case 3 would require an incentive to cover around 80% to receive a comparable DPP as single-family household or condo owners receive.

```
npv = c()
dpp = c()
com=0.2
for(j in 1:100){
rgs=gas_c
rei=u_cost
cf=-inst *6*0.5
q=data.frame(matrix(NA,30,6))
for(i in 1:30){
rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
fv=com*6*(rgs*gas - kw*rei)
pv= fv/(1+rt)^i
old=cf
cf=cf+pv
dp=ifelse(cf>0,i-1+abs(old/pv),0)
q[i,]=c(rgs,rei,fv,pv,cf,dp)
}
npv[j]=sum(q[,4])-inst #net present value
dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
par(mfrow= c(1,2))
plot(q[,3], main = "Cash flow of incentive (50%)", ylab="$", xlab="year",
```

```
type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("topright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.lty


npv = c()
dpp = c()
com = 0.2
for(j in 1:100){
rgs=gas_c
rei=u_cost
cf=-inst * 6 * 0.2
q=data.frame(matrix(NA,30,6))
for(i in 1:30){
rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
fv=com*6*(rgs*gas - kw*rei)
pv= fv/(1+rt)^i
old=cf
cf=cf+pv
dp=ifelse(cf>0,i-1+abs(old/pv),0)
q[i,]=c(rgs,rei,fv,pv,cf,dp)
}
npv[j]=sum(q[,4])-inst #net present value
dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
plot(q[,3], main = "Cash flow of incentive (80%)", ylab="$", xlab="year",
type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("topright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.lty
```



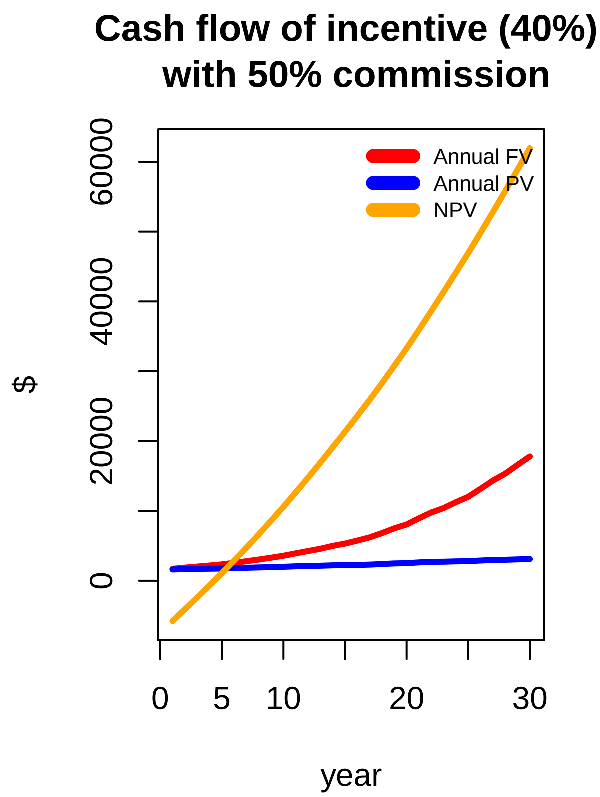
To achieve the DPP of 5 years like the case 1, 1 owner single family, commission rate and incentive rate were estimated for each scenario: case 3, rental apartment (no owner living) and case 4, rental apartment (sharing chargers in addition to the case 3 above - 12 renters are sharing 6 installed chargers).

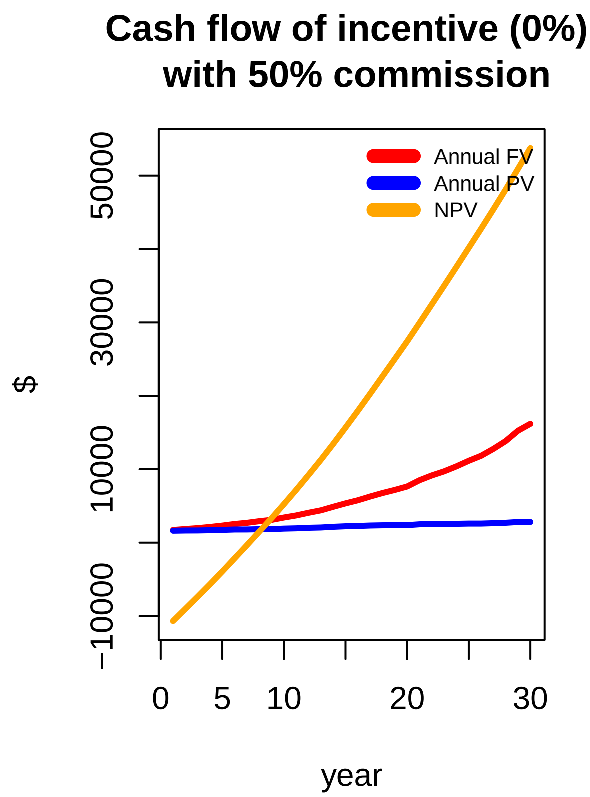
Incentive comparison (case 3)

For the case 3, rental apartment, with the commission rate, 50%, it is estimated that about 40% incentive is required to meet the 5 year's DPP. It also shows there is not much improvement of shortening the DPP even if there is no incentive (in this case, the DPP is 8 years). We can see incentive supports a little from the investment perspectives.

```
par(mfrow = c(1,2))

npv = c()
dpp = c()
com = 0.5
for(j in 1:100){
  rgs=gas_c
  rei=u_cost
  cf=-inst *6*0.6
  q=data.frame(matrix(NA,30,6))
  for(i in 1:30){
    rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
    rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
    fv=com*6*(rgs*gas - kw*rei)
```

```
    pv= fv/(1+rt)^i
    old=cf
    cf=cf+pv
    dp=ifelse(cf>0,i-1+abs(old/pv),0)
    q[i,]=c(rgs,rei,fv,pv,cf,dp)
  }
  npv[j]=sum(q[,4])-inst #net present value
  dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}

plot(q[,3], main = "Cash flow of incentive (40%) \n with 50% commission", ylab="$", xlab="year",
     type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("topright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.lty


npv = c()
dpp = c()
com = 0.5
for(j in 1:100){
  rgs=gas_c
  rei=u_cost
  cf=-inst * 6
  q=data.frame(matrix(NA,30,6))
  for(i in 1:30){
    rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
    rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
    fv=com*6*(rgs*gas - kw*rei)
    pv= fv/(1+rt)^i
    old=cf
    cf=cf+pv
    dp=ifelse(cf>0,i-1+abs(old/pv),0)
    q[i,]=c(rgs,rei,fv,pv,cf,dp)
  }
  npv[j]=sum(q[,4])-inst #net present value
  dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
plot(q[,3], main = "Cash flow of incentive (0%) \n with 50% commission", ylab="$", xlab="year",
     type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("topright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.lty
```



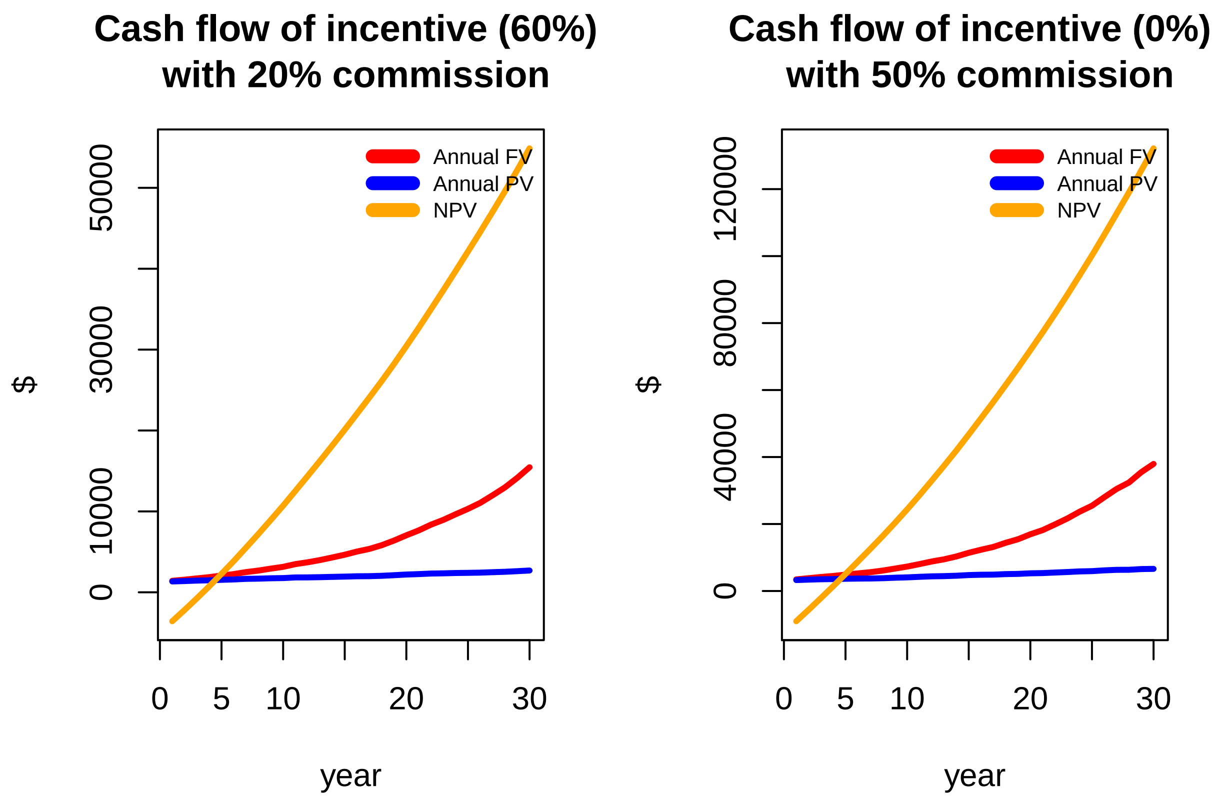


Commission comparison (case 4)

In case 4, rental apartment with the sharing chargers, a scenario of 50% commission rate and no incentive is estimated to have the same DPP of 5 years of the scenario of 20% commission rate and 60% incentive rate, which confirms that the impact of commission rate change is more than the incentive rate change on DPP. Policy makers can take this account to support investment of chargers.

```
npv = c()
dpp = c()
com = 0.2
for(j in 1:100){
  rgs=gas_c
  rei=u_cost
  cf=-inst *6*0.4
  q=data.frame(matrix(NA,30,6))
  for(i in 1:30){
    rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
    rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
    fv=com*12*(rgs*gas - kw*rei)
    pv= fv/(1+rt)^i
    old=cf
    cf=cf+pv
    dp=ifelse(cf>0,i-1+abs(old/pv),0)
    q[i,]=c(rgs,rei,fv,pv,cf,dp)
  }
```

```r
  npv[j]=sum(q[,4])-inst #net present value
  dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
par(mfrow= c(1,2))
plot(q[,3], main = "Cash flow of incentive (60%) \n with 20% commission", ylab="$", xlab="year",
     type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("topright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.lty


npv = c()
dpp = c()
com = 0.5
for(j in 1:100){
  rgs=gas_c
  rei=u_cost
  cf=-inst * 6
  q=data.frame(matrix(NA,30,6))
  for(i in 1:30){
    rgs = rgs*(1+runif(1,0.07,0.1)) #annual gas price increase
    rei = rei*(1+runif(1,0.07,0.1)) #annual elec. price increase
    fv=com*12*(rgs*gas - kw*rei)
    pv= fv/(1+rt)^i
    old=cf
    cf=cf+pv
    dp=ifelse(cf>0,i-1+abs(old/pv),0)
    q[i,]=c(rgs,rei,fv,pv,cf,dp)
  }
  npv[j]=sum(q[,4])-inst #net present value
  dpp[j]=min(q[,6][q[,6]>0]) #discounted payback period
}
plot(q[,3], main = "Cash flow of incentive (0%) \n with 50% commission", ylab="$", xlab="year",
     type = 'l', ylim = c(min(q[,5]),max(q[,5])), col = 'red',lwd=3)
lines(q[,4], type = 'l', col='blue',lwd=3)
lines(q[,5], type = 'l', col='orange',lwd=3)
legend("topright", legend=c("Annual FV","Annual PV","NPV"),col=c("red","blue","orange"), lty=1, box.lty
```



Adding a 60% incentive of upfront cost to case 4, shows a DPP of 5 years, which can also be achieved through changing the commission fee to 50%. It also confirms that commissions are more effective to reach the goal of a shorter DPP than incentivizing the upfront cost.

Furthermore, it was found that sharing chargers by two, is as effective as collecting commissions. By increasing the number of users for a given charger we can enhance the mechanism for owners to reach shorter DPP. By optimizing the utilization rate of chargers depending upon the local conditions, it can reduce the commissioning rate while getting the same result and thus deliver added value to both the renter and the landlord.

Policy optimization

We start our policy effect analysis based on a case that assumes the installation of stand-alone level 2 chargers ($2,050 installation cost) with a budget limited to 100 chargers (i.e. $205,000), For the eleven MUD block groups that were defined in the cluster analysis for Tacoma we find three of them related to the higher income cluster (1) while cluster 2 is more related to the characteristics of the remaining 8 block groups. To keep this analysis within simple bounds, we only consider the ownership structure cases 1 and 2 from the cost benefit analysis.

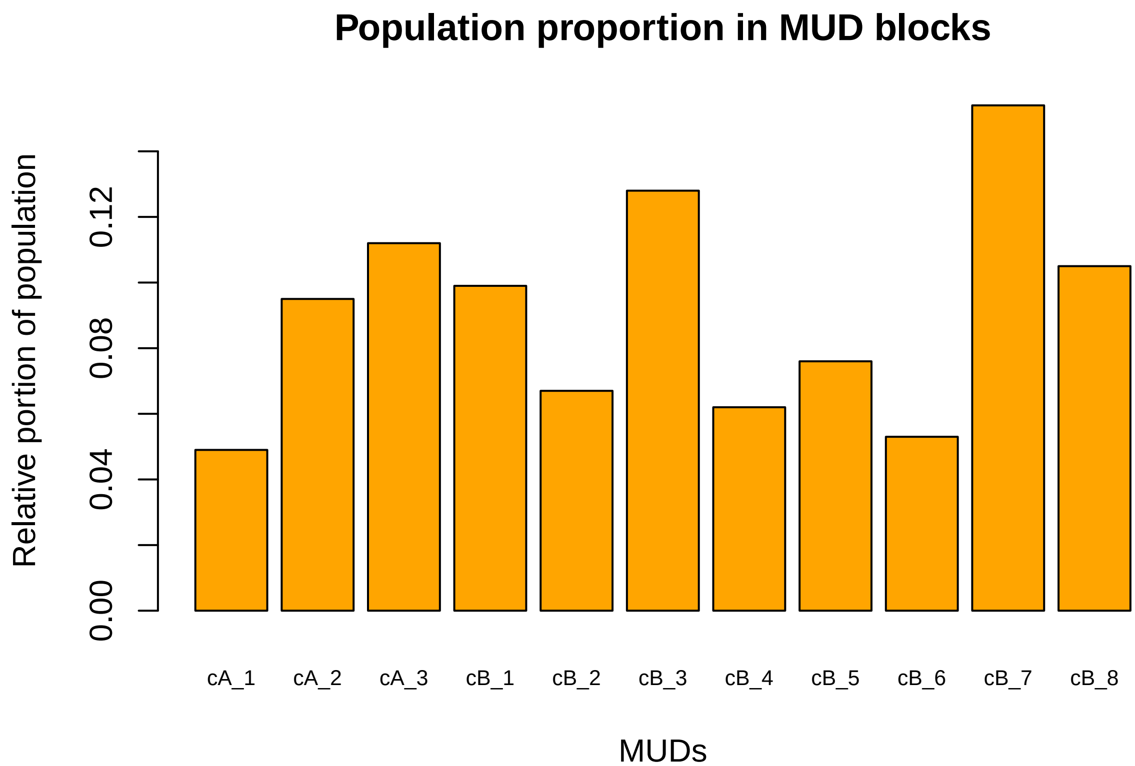
Based on the identified renter and owner distribution structure of the MUD block clusters 1 and 2, the cluster 1 (i.e. 3 block groups) are assumed to include 30% of MUDs with the case 1 structure and 70% of the case 2 structure; cluster 2 (8 block groups) is assumed to have 10% of the case 1 structure and 90% of the case 2 structure.

The aim of the following analysis is to check how different social or rent household structures in MUDs affect the outcome of the selected policy application in terms of efficiency and equity. We considered a cash flow time horizon of 20 years to receive an average expected NPV per unit charger. Furthermore, based on the population of each block group, each of them was weighted in proportion to its population assuming that the EVSE demand is proportional to the population.

These benefit weights were added to the objective functions of the maximization problem. The policy parameter α was set to different values depending on the policy goals. The efficiency-oriented policy seeks to maximize the benefit by focusing more on efficiency. By concentrating on cA__1, cA__2 and cA__3, which happen to be all cluster 1, the maximized benefit in terms of saved energy turns out to be $446,695 for a 20-year time horizon. This is the maximum benefit from installing 100 chargers. Thus, focusing on these block groups would maximize the efficiency.

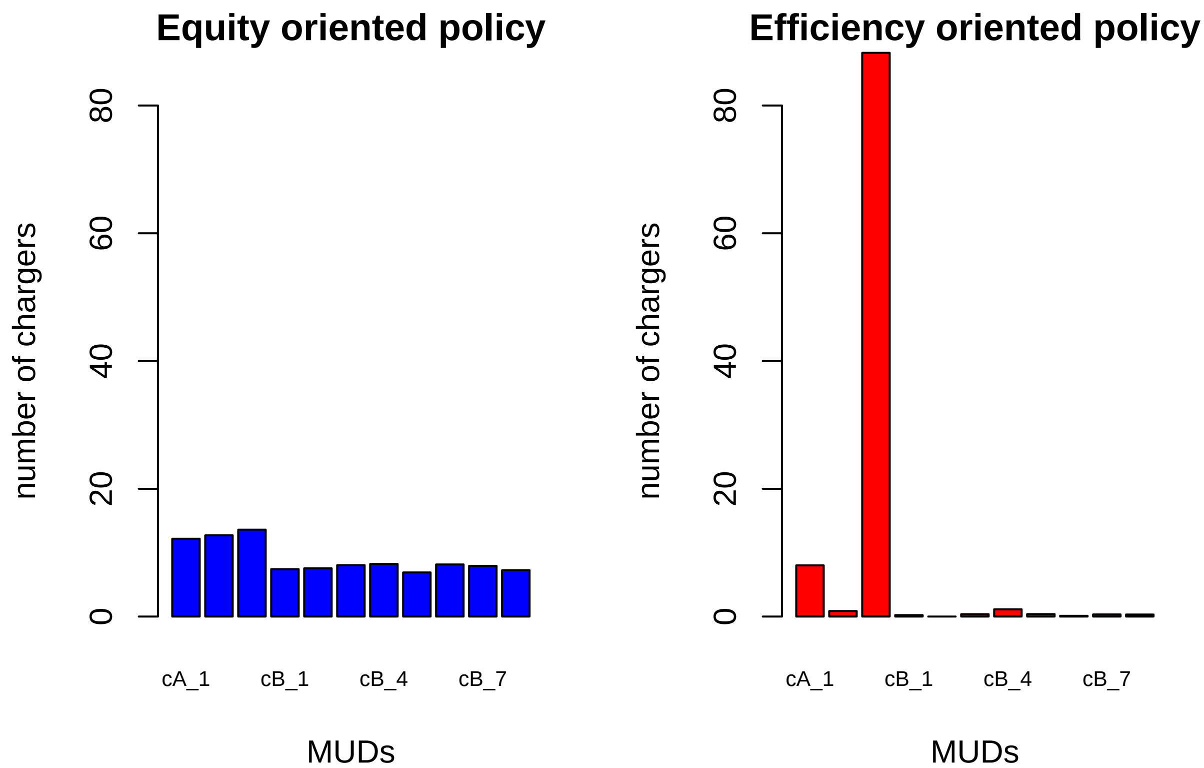
On the other hand, the equity policy seeks to maximize the benefit while focusing more on equity. The optimal solution was found and the expected benefit in terms of saved energy is estimated to $78,191 over a 20-year time horizon. This benefit is far lower than for the efficiency policy while it improves the equal resource allocation for all MUD block groups regardless of which cluster they are belong to.

```r
library(nloptr)
c = 2050 #cost for one charger
m = 100*c #capacity
n = 11 #number of places for demand
npv = c(11741.5,1601) # (-5000,1500) #single,
c1 = c(0.3,0.7)
c2 = c(0.1,0.9)
cc1= t(c1)%*%npv
cc2= t(c2)%*%npv
b = c(rep(cc1,3),rep(cc2,8)) #benefit per cluster
pop=c(0.049,0.095,0.112,0.099,0.067,0.128,0.062,0.076,0.053,0.154,0.105) #population weight
bp=pop*b #total benefit

names(pop) = c("cA_1","cA_2","cA_3","cB_1","cB_2","cB_3","cB_4","cB_5","cB_6","cB_7","cB_8")
barplot(pop, col = "orange", main = "Population proportion in MUD blocks",
        xlab="MUDs", ylab="Relative portion of population",cex.names = 0.7)
```




```r
# Objective function EQUITY
alpha = 1 # fair
eval.f <- function(x) {return(-sum(b*log(x)))} #max

# Constraint function
# to be of the form g(x) <= 0
eval.g <- function(x) {
  return(sum(c*x) - m)
}

x0 <- rep(9,11)

opts <- list('algorithm' = 'NLOPT_GN_ISRES', 'xtol_rel' = 1.0e-8, 'maxeval' = 100000)

eq = nloptr(
  x0 = x0,
  eval_f = eval.f,
  lb = rep(0,11),
  ub = rep(100,11),
  eval_g_eq = eval.g,
  opts = opts
)

par(mfrow=c(1,2))
bar1 = eq$solution
names(bar1) = c("cA_1","cA_2","cA_3","cB_1","cB_2","cB_3","cB_4","cB_5","cB_6","cB_7","cB_8")
```

```r
barplot(bar1, col = "blue", main = "Equity oriented policy",
        xlab="MUDs", ylim = c(0,80),ylab="number of chargers",cex.names = 0.7)


# Objective function Efficiency
alpha = 0
eval.f <- function(x) {return (-sum(b*x^(1-alpha)/(1-alpha)))} #max



# Constraint function
# to be of the form g(x) <= 0
eval.g <- function(x) {
  return(sum(c*x) - m)
}

x0 <- rep(9,11)

opts <- list('algorithm' = 'NLOPT_GN_ISRES', 'xtol_rel' = 1.0e-8, 'maxeval' = 100000)

ef = nloptr(
  x0 = x0,
  eval_f = eval.f,
  lb = rep(0,11),
  ub = rep(100,11),
  eval_g_eq = eval.g,
  opts = opts
)

bar = ef$solution
names(bar) = c("cA_1","cA_2","cA_3","cB_1","cB_2","cB_3","cB_4","cB_5","cB_6","cB_7","cB_8")
barplot(bar, col = "red", main = "Efficiency oriented policy",
        xlab="MUDs", ylim = c(0,80), ylab="number of chargers",cex.names = 0.7)
```



Equity oriented policy
number of chargers
0
20
40
60
80
cA_1
cB_1
cB_4
cB_7
MUDs
Efficiency oriented policy
number of chargers
0
20
40
60
80
cA_1
cB_1
cB_4
cB_7
MUDs