SV2414 and vrp2113 Energy Storage Options in Sao Vicente Note: This RMD does not contain setpoint calculation. Setpoint calculation, along with question 5 of 'Storage Capacity Effects on Capacity Factor' section (which uses setpoints) is included in another RMD following this one.

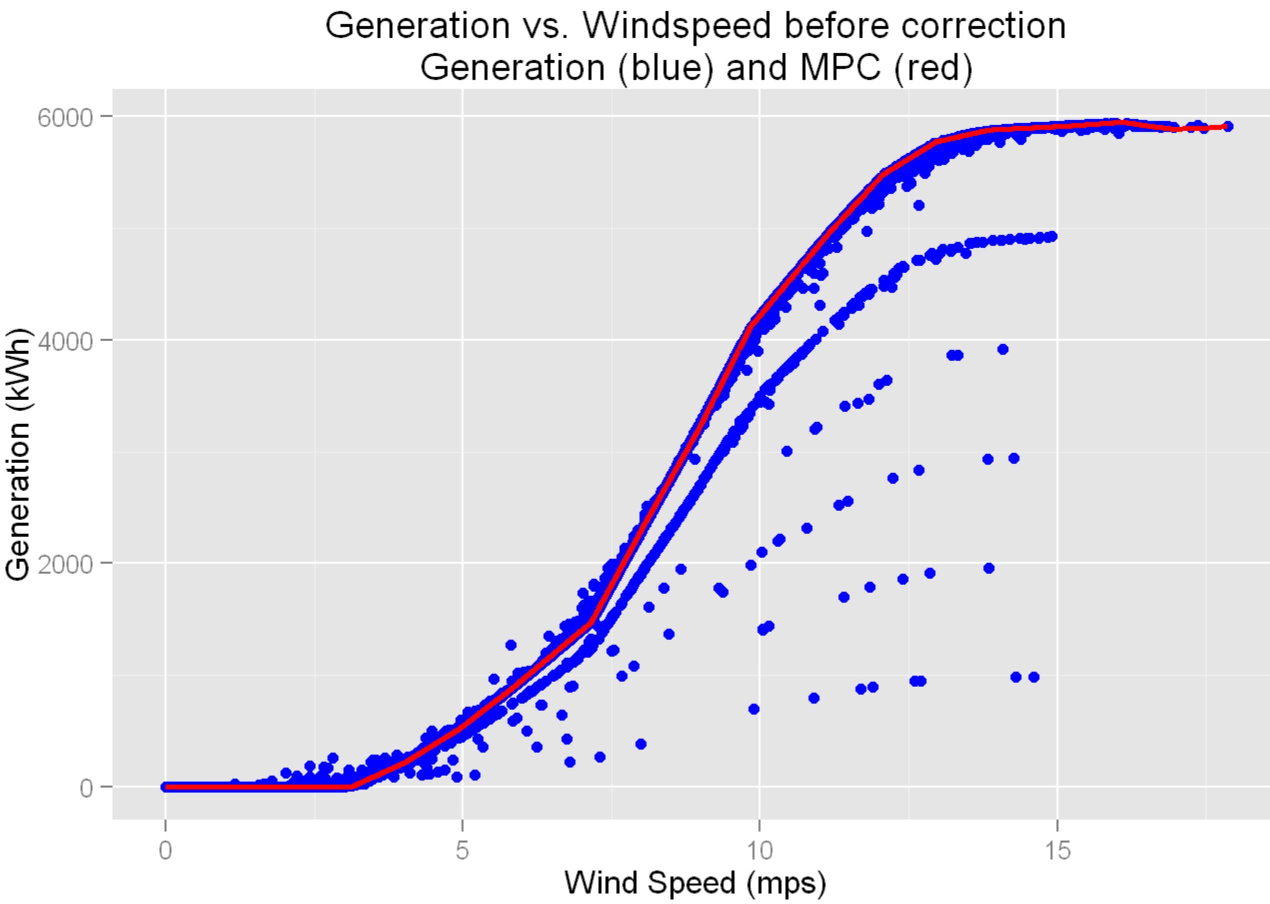
ANALYSIS OF ORIGINAL DISPATCH DATA

Import data required and rename columns for ease.

```
## Loading required package: plyr
## Loading required package: ggplot2
```

Plot to check if imported data adheres to the Manufacturer's Power Curve.

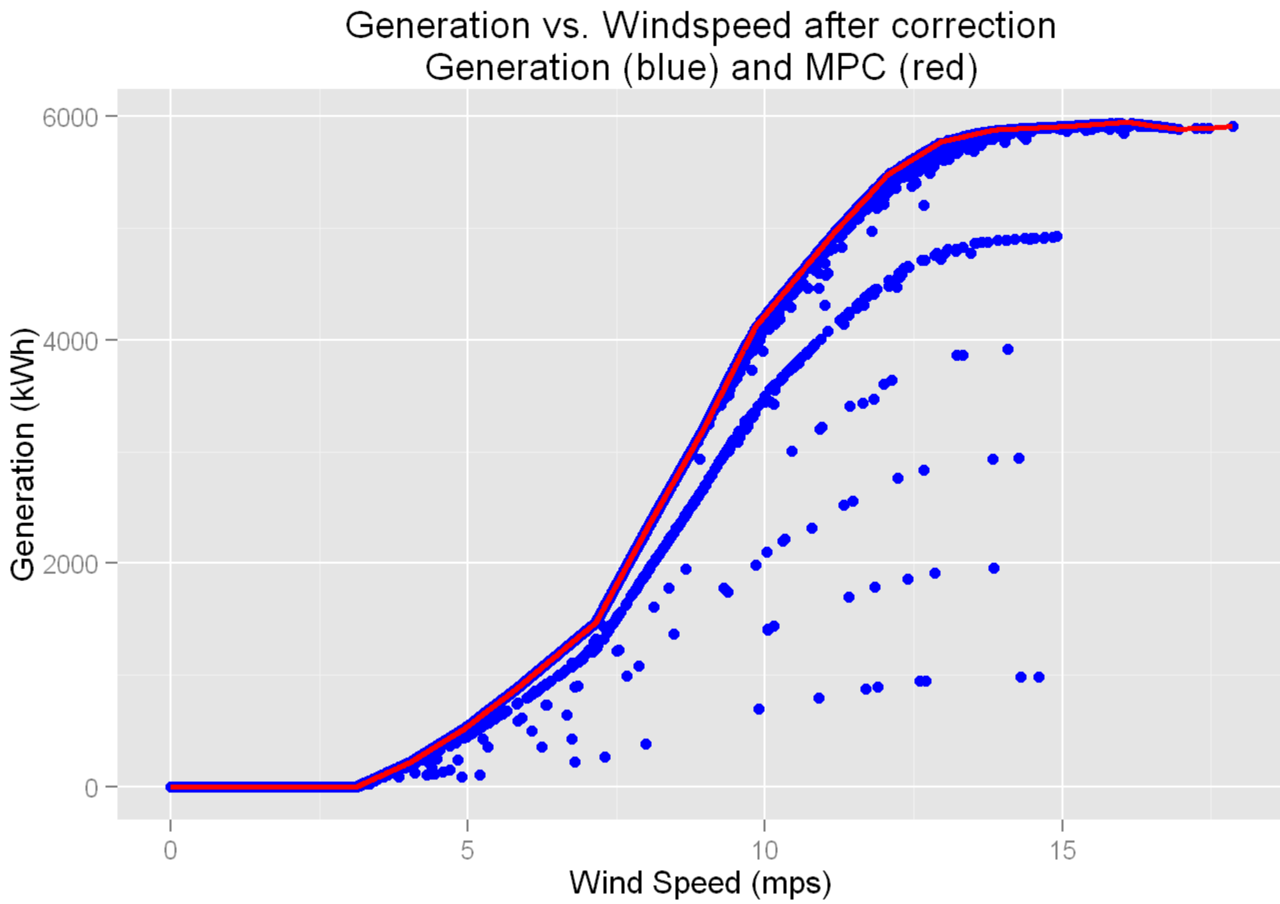
```
#Interpolate for MPC power
interp=splinefun(mpc$windspeed_mps, mpc$power_kW,method = "natural")
#Find equivalent MPC power for the windspeeds we have
wind$mpc_power<-interp(wind$windspeed)*7

#Plot to check data
plot0<-ggplot(wind, aes(x=wind$windspeed))
plot0+geom_point(aes(y=wind$windgen),colour="blue",size=2)+geom_line(aes(y=wind$mpc_power),colour="red",size=1)+xlab("Wind Speed (mps)")+ylab("Generation (kWh)")+ggtitle("Generation vs. Windspeed before correction\nGeneration (blue) and MPC (red)")
```




```
#Reassign values that are greater than MPC power equivalents to MPC power equivalents
for (j in 1:nrow(wind)){
  if(wind$windgen[j]>wind$mpc_power[j])
    wind$windgen[j]<-wind$mpc_power[j]
}
```

Plot to check if data has been corrected to MPC.

```
#Plot to check if data has been corrected
plot1<-ggplot(wind, aes(x=wind$windspeed))
plot1+geom_point(aes(y=wind$windgen),colour="blue",size=2)+geom_line(aes(y=wind$mpc_power),colour="red",size=1)+xlab("Wind Speed (mps)")+ylab("Generation (kWh)")+ggtitle("Generation vs. Windspeed after correction\nGeneration (blue) and MPC (red)")
```



Organize and clean data.

```
#Convert date to date format
wind$date<-as.Date(wind$date,format="%Y-%m-%d")
#Create new column for datetime using date and hour
wind$datetime=as.POSIXct(wind$date+wind$hour*(1/24)+(1/3), format="%Y-%m-%d %H:%M:%S", origin="2013-0
1-01 00:00:00")

#Convert date and time to datetime format for demand data
dem$data.pt2.date.time<-as.POSIXct(dem$data.pt2.date.time,format="%Y-%m-%d %H:%M:%S")
#Rename columns
names(dem)[3]<-"datetime"
names(dem)[4]<-"demand"

#Remove columns we don'tneed
wind<-wind[-c(1,2,3,7)]
dem<-dem[-c(1,2)]

#Merge generation and demand data
ad<-merge(x = dem,y = wind,by="datetime",all.x=TRUE)

#Check summary of wind speed and generation data
summary(ad$windspeed)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
##    0.00    7.07    9.02    8.84   11.00   17.90     179 
```

```
summary(ad$windgen)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
##      -1    1410    3200    3100    4780    5940     179 
```

```
#Fill missing generation data
ad$windspeed[is.na(ad$windspeed)]<-summary(wind$windspeed)[4]
ad$del_hourly[is.na(ad$del_hourly)]<-0
for (i in 1:nrow(ad)){
  if(is.na(ad$windgen[i])){
    ad$windgen[i]<-interp(wind$windspeed[i])*7
    }
}

#Convert negative generation values to 0
ad$del_hourly[ad$del_hourly<0]<-0
ad$windgen[ad$windgen<0]<-0

#Check summary of wind speed and generation data after correction
summary(ad$windspeed)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
##    0.00    7.14    8.95    8.84   10.90   17.90 
```

```
summary(ad$windgen)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
##       0    1400    3190    3100    4780    5950 
```

```
#Check summary of demand data
summary(ad$demand)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
##       0    6720    7880    7930    9170   11800 
```

```
#Correct small demand values to mean demand
ad$demand[ad$demand<quantile(ad$demand,0.005)]<-summary(ad$demand)[4]
```

```
#Check summary of demand data after correction
summary(ad$demand)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    2440    6740    7920    7960    9170   11800
```

1. Calculate the uncurtailed capacity factor of the wind farm over the course of this year in the absence of any energy storage options, as per the turbine power curve and wind speed.

```
#Calculate uncurtailed capacity factor
cf_unc<-sum(ad$windgen)*100/(850*8760*7)
sprintf("Before any baseload is applied, uncurtailed CF is %.2f percent",cf_unc)
```

```
## [1] "Before any baseload is applied, uncurtailed CF is 52.04 percent"
```

2. Calculate the curtailed capacity factor of the wind farm over the course of the year in the absence of energy storage, using dispatched power values. How much energy is lost over the course of the year due to curtailment?

```
#Find wind generation utilized
for (j in 1:nrow(ad)){
  ad$wind_utilized[j]=min(ad$windgen[j],ad$demand[j])
}
#Find curtailment
ad$curtailment=ad$windgen-ad$wind_utilized
ad$deficit=ad$demand-ad$wind_utilized
sprintf("Before any baseload is applied, curtailment is %.2f kWh",sum(ad$curtailment))
```

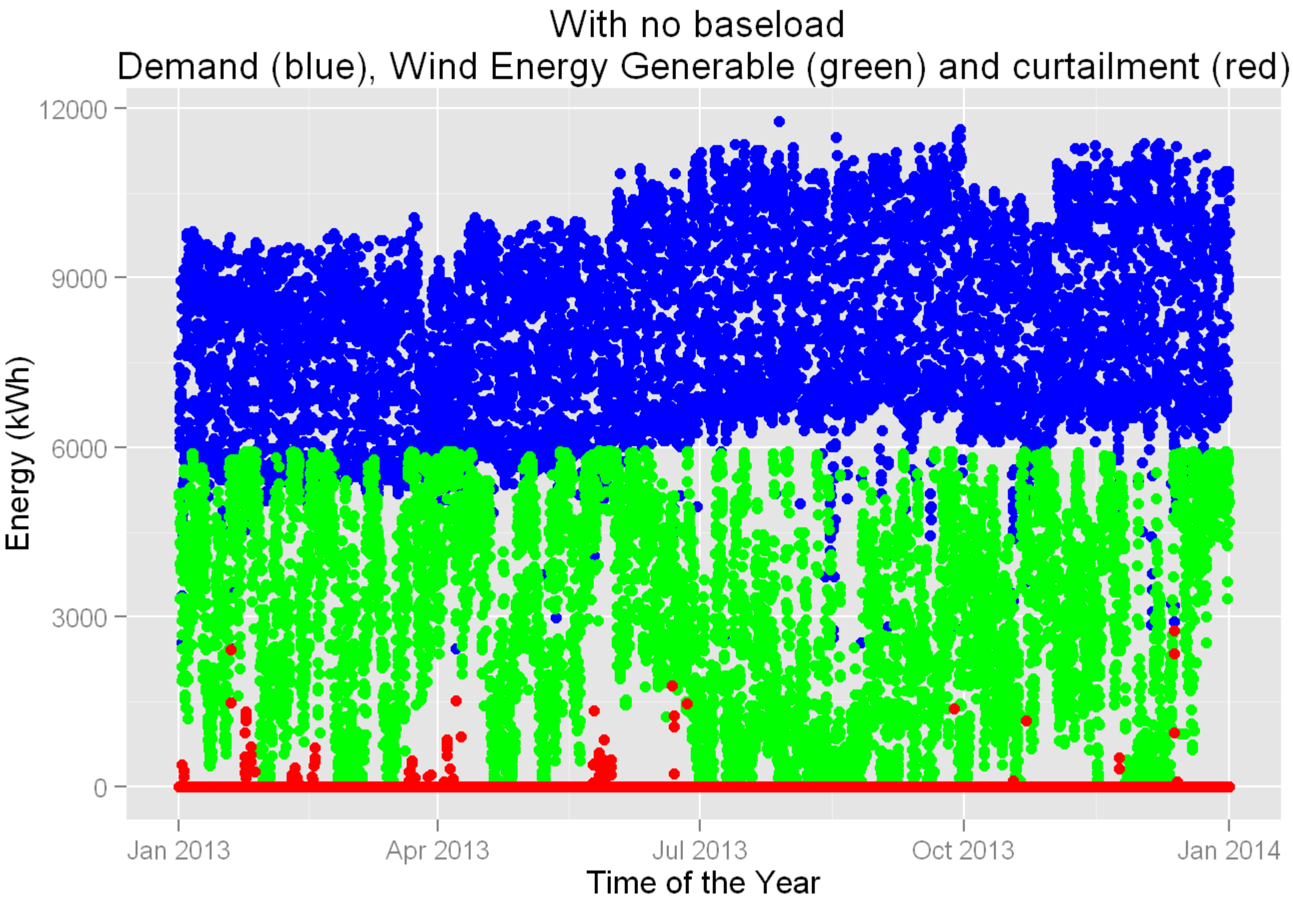
```
## [1] "Before any baseload is applied, curtailment is 52442.29 kWh"
```

```
#Calculate curtailed capacity factor
cf_c<-sum(ad$wind_utilized)*100/(850*8760*7)
sprintf("Before any baseload is applied, curtailed CF is %.2f percent",cf_c)
```

```
## [1] "Before any baseload is applied, curtailed CF is 51.94 percent"
```

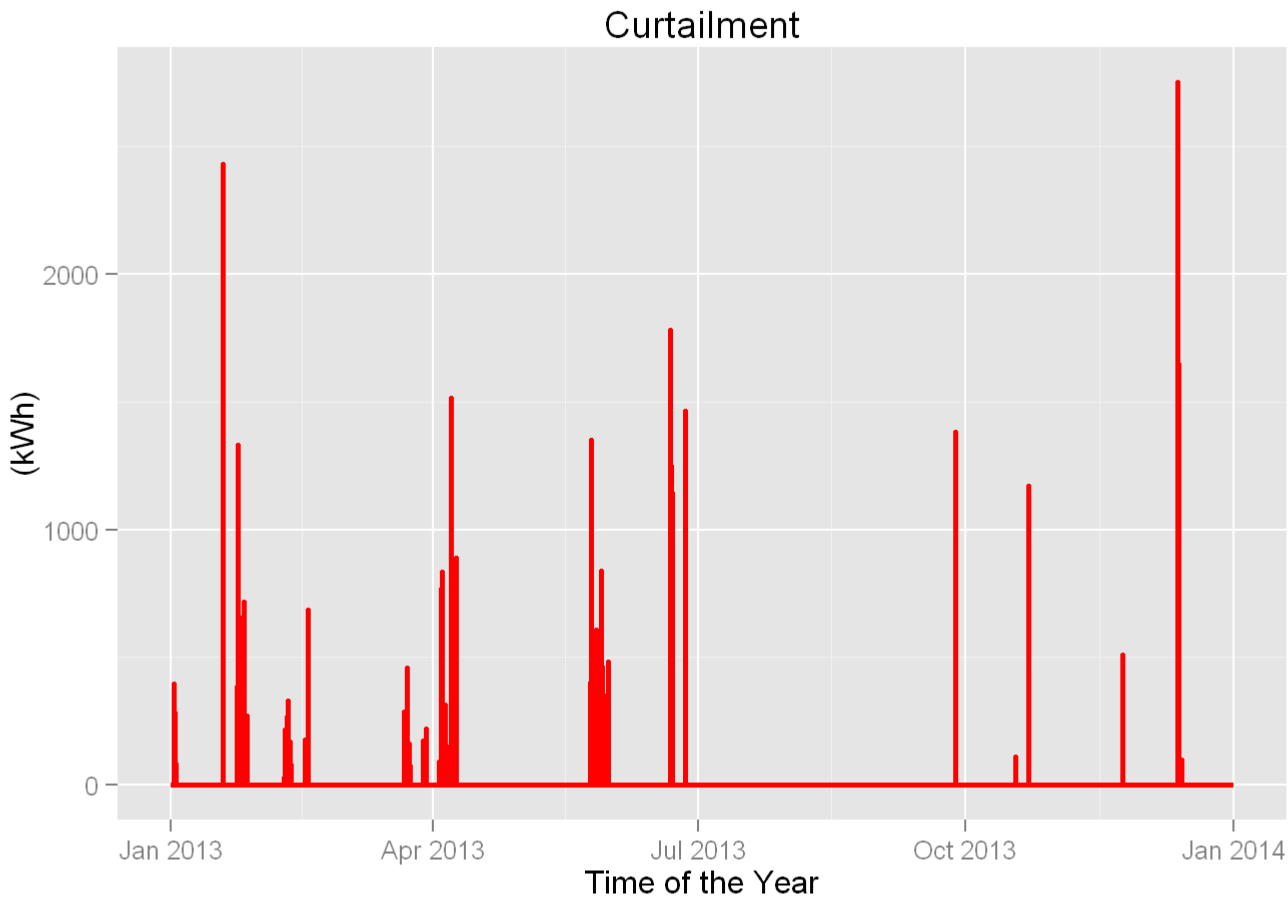
Plot for this scenario:

```
#Plot demand, generation and curtailment across the year
plot2<-ggplot(ad, aes(x=ad$datetime))
plot2+geom_point(aes(y=ad$demand),colour="blue",size=2)+geom_point(aes(y=ad$windgen),colour="green",s
ize=2)+geom_point(aes(y=ad$curtailment),colour="red",size=2)+ylab("Energy (kWh)")+xlab("Time of the Y
ear")+ggtitle("With no baseload \nDemand (blue), Wind Energy Generable (green) and curtailment (red)"
)
```

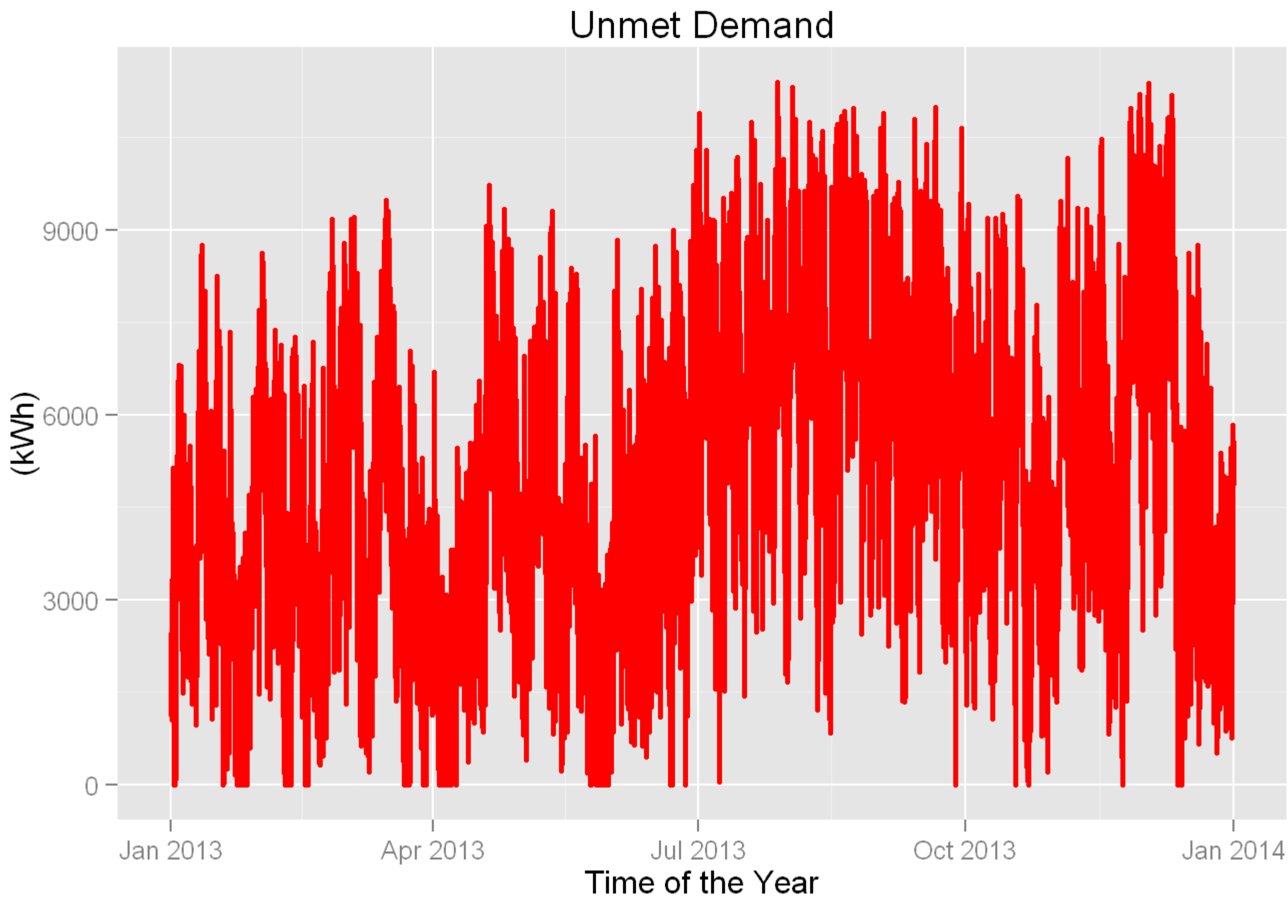


3. What periods of the year have the greatest amount of curtailment over the year? What parts of the year have the highest amount of unmet demand?

```
plot2+geom_line(aes(y=ad$curtailment),colour="red",size=1)+ylab("(kWh)")+xlab("Time of the Year")+ggt
itle("Curtailment")
```




```
plot2+geom_line(aes(y=ad$deficit),colour="red",size=1)+ylab("(kWh)")+xlab("Time of the Year")+ggtitle
("Unmet Demand")
```



APPLICATION OF CONSTANT BASELOAD GENERATION

1. Consider the overall range of demand values over the course of the year. What would be a reasonable value for baseload generation? Why? 2. Given this baseload value, calculate the new curtailment and capacity factor of the wind farm.

```
#Find optimum baseload
ad$baseload=5320
ad$totalsupply=ad$baseload+ad$windgen
for (j in 1:nrow(ad)){
    ad$ts_utilized[j]=min(ad$demand[j],ad$totalsupply[j])
  }
ad$ts_curtailment=ad$totalsupply-ad$ts_utilized
ad$ts_deficit=ad$demand-ad$ts_utilized

sprintf("Optimum baseload is found to be %.2f kWh",summary(ad$baseload)[4])
```

```
## [1] "Optimum baseload is found to be 5320.00 kWh"
```

```
sprintf("This is optimum because deficit is %.2f percent of curtailment, and therefore, curtailment c
an completely meet deficit with a large enough storage",100*(sum(ad$ts_deficit)/sum(ad$ts_curtailment
)))
```

```
## [1] "This is optimum because deficit is 64.09 percent of curtailment, and therefore, curtailment c
an completely meet deficit with a large enough storage"
```

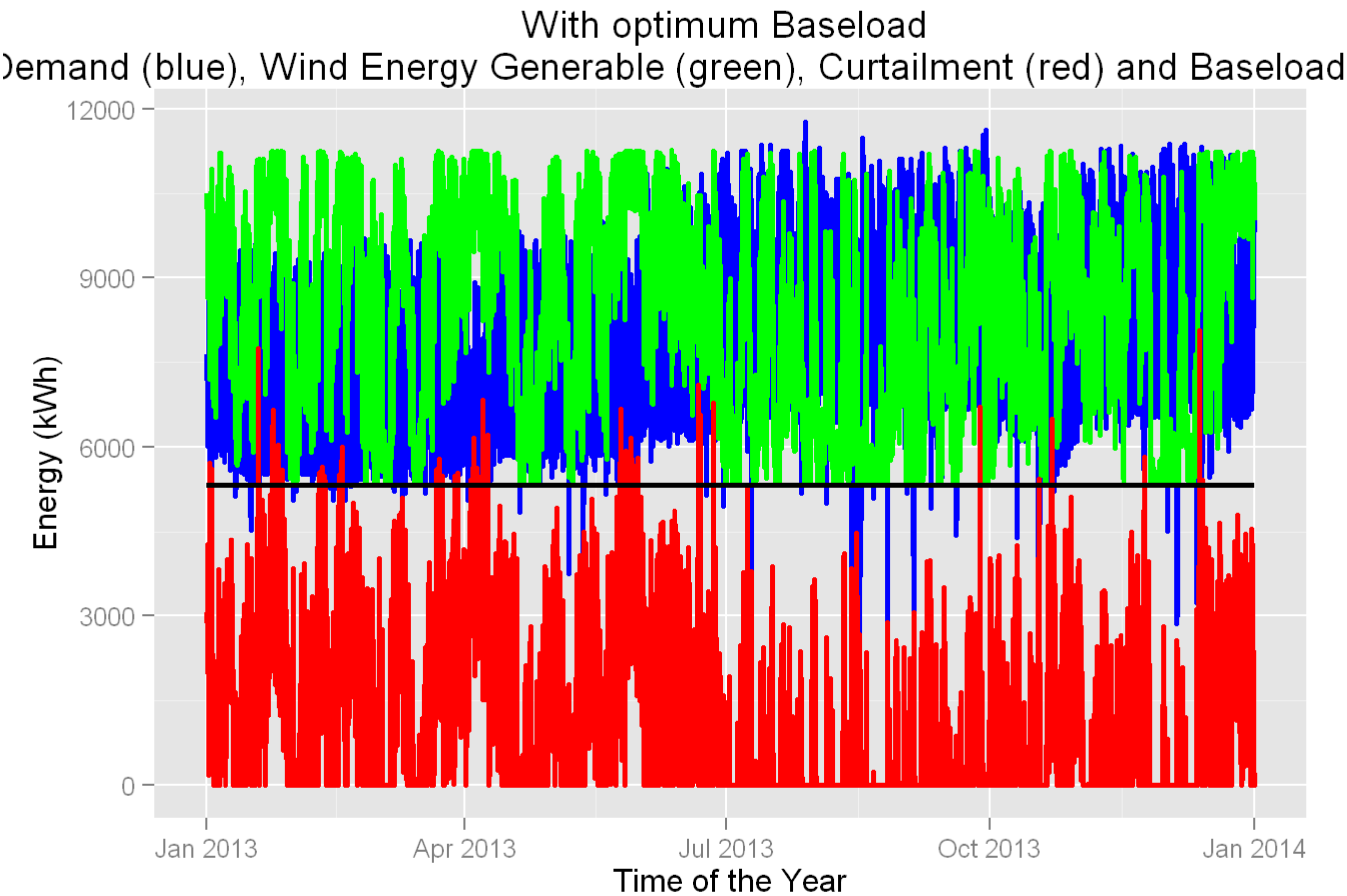
```
sprintf("For optimum baseload, non-baseload energy not met by wind farm over the year is %.2f kWh",su
m(ad$ts_deficit))
```

```
## [1] "For optimum baseload, non-baseload energy not met by wind farm over the year is 7088891.11 kW
h"
```

```
sprintf("For optimum baseload, curtailment over the year is %.2f kWh",sum(ad$ts_curtailment))
```

```
## [1] "For optimum baseload, curtailment over the year is 11061662.99 kWh"
```

```
#Plot to show demand and generation lines for this optimum baseload
plot3<-ggplot(ad, aes(x=ad$datetime))
plot3+geom_line(aes(y=ad$demand),colour="blue",size=1)+geom_line(aes(y=ad$totalsupply),colour="green"
,size=1)+geom_line(aes(y=ad$ts_curtailment),colour="red",size=1)+geom_line(aes(y=ad$baseload),colour=
"black",size=1)+ylab("Energy (kWh)")+xlab("Time of the Year")+ggtitle("With optimum Baseload \nDemand
 (blue), Wind Energy Generable (green), Curtailment (red) and Baseload (black)")
```




```
#Find capacity factor with optimum baseload
sum=0.0
for (i in 1:nrow(ad)){
sum=sum+max(ad$ts_utilized[i]-ad$baseload[i],0.0)
}
cf_c_bl=sum*100/(850*8760*7)
sprintf("For this baseload, curtailed CF is %.2f percent",cf_c_bl)
```

```
## [1] "For this baseload, curtailed CF is 31.04 percent"
```

STORAGE CAPACITY EFFECTS ON CAPACITY FACTOR

1. Perform an energy balance on the system over the entire year, assuming no energy storage. How much non-baseload energy is not met by the wind farm (and must be met by extra diesel energy) over the course of the year? How much energy is lost over the year due to excess generation (i.e. what is the curtailment over the year?)

```
#With 3MW baseload
ad$baseload2=3000.0
ad$totalsupply2=ad$baseload2+ad$windgen
for (j in 1:nrow(ad)){
    ad$ts_utilized2[j]=min(ad$demand[j],ad$totalsupply2[j])
```

```
  }
ad$ts_curtailment2=ad$totalsupply2-ad$ts_utilized2
ad$ts_deficit2=ad$demand-ad$ts_utilized2
sprintf("New baseload is %.2f kWh",summary(ad$baseload2)[4])
```

```
## [1] "New baseload is 3000.00 kWh"
```

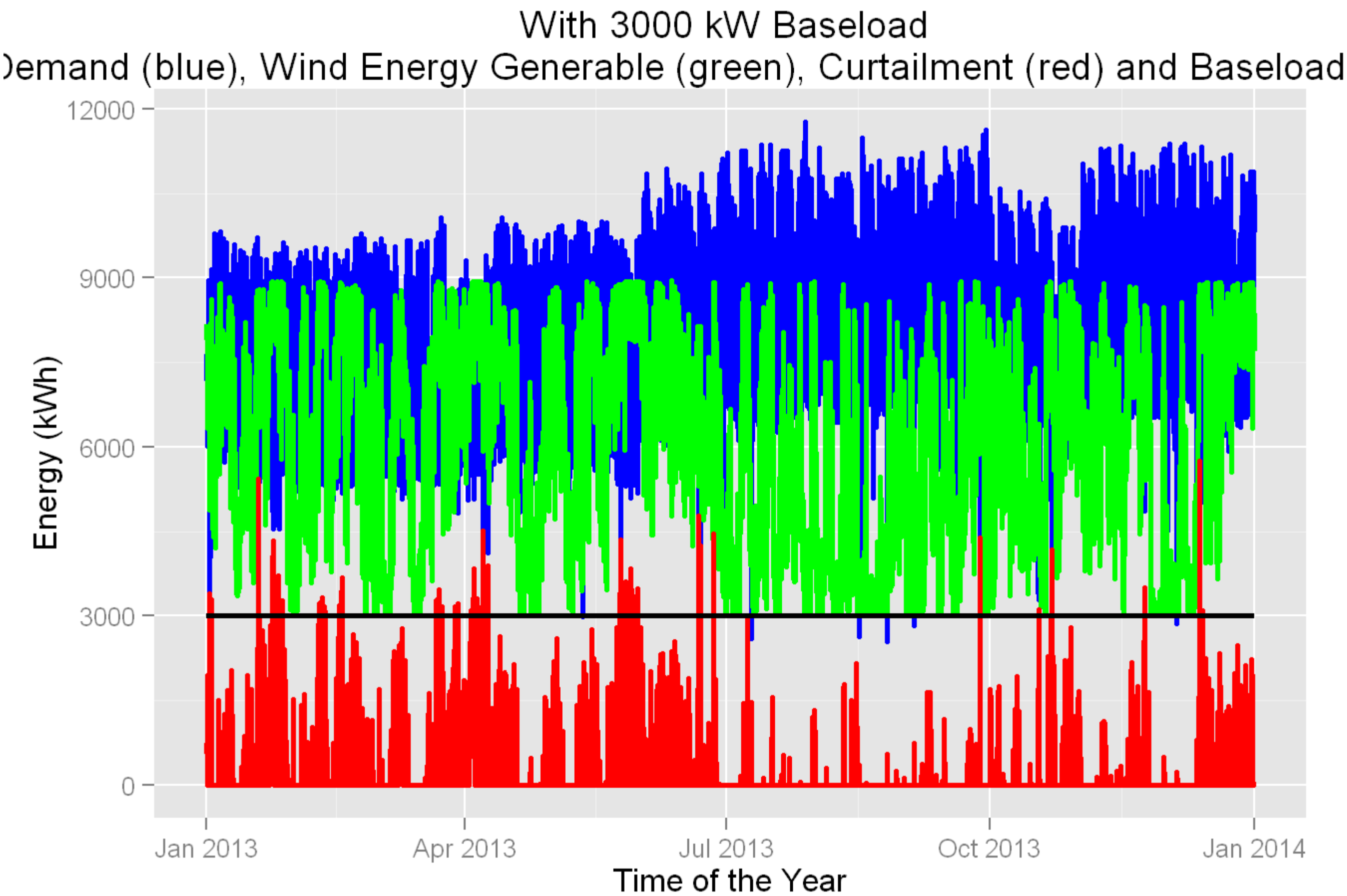
```
sprintf("For this baseload, non-baseload energy not met by wind farm over the year is %.2fkWh",sum(ad
$ts_deficit2))
```

```
## [1] "For this baseload, non-baseload energy not met by wind farm over the year is 18987679.14kWh"
```

```
sprintf("For this baseload, curtailment over the year is %.2fkWh",sum(ad$ts_curtailment2))
```

```
## [1] "For this baseload, curtailment over the year is 2637251.01kWh"
```

```
#Plot to show demand and generation lines for this baseload
plot4<-ggplot(ad, aes(x=ad$datetime))
plot4+geom_line(aes(y=ad$demand),colour="blue",size=1)+geom_line(aes(y=ad$totalsupply2),colour="green
",size=1)+geom_line(aes(y=ad$ts_curtailment2),colour="red",size=1)+geom_line(aes(y=ad$baseload2),colo
ur="black",size=1)+ylab("Energy (kWh)")+xlab("Time of the Year")+ggtitle("With 3000 kW Baseload \nDem
and (blue), Wind Energy Generable (green), Curtailment (red) and Baseload (black)")
```




```
#Find capacity factor
sum2=0.0
for (i in 1:nrow(ad)){
sum2=sum2+max(ad$ts_utilized2[i]-ad$baseload2[i],0.0)
}
cf_c_bl2=sum2*100/(850*8760*7)
sprintf("For this baseload, curtailed CF is %.2f percent",cf_c_bl2)
```

```
## [1] "For this baseload, curtailed CF is 46.99 percent"
```

2. Now, using a simple loop (see the previous projects) and creating a running capacity total over each hour of the year, estimate the amount of recoverable energy possible by implementing this 10MWh storage. How much energy is recovered compared to the amount of non-baseload energy not met by wind over the course of the year? What is the new effective capacity factor of the wind farm? 3. Perform analogous calculations for a variety of different storage capacities for 3MW constant baseload power or the proposed setpoint-defined baseload generation curve. What point would be considered optimum, to deliver the highest fraction of unmet non-baseload capacity with storage discharged energy? Explain your reasoning.

```
#Run 3MW baseload scenario for various storage options
storagecap<-data.frame("Storage_Cap"=c(1,2,3,4,5,6,7,8,9,10,12,14,16,18,20,22.5,25,27.5,30))
storagecap$Storage_Cap<-storagecap$Storage_Cap*10000.0
```

```
for (j in 1:nrow(storagecap)){
  #Calculate state of  storage at each hour
  ad$storage[1]=min(0.8*ad$ts_curtailment2[1],storagecap$Storage_Cap[j])
  for (i in 2:nrow(ad)){
    #with curtailment
    if (ad$ts_deficit2[i]==0){
      ad$storage[i]=min((ad$storage[i-1]+0.8*ad$ts_curtailment2[i]),storagecap$Storage_Cap[j])
      }
    #With deficit
    else if (ad$ts_curtailment2[i]==0){
      ad$storage[i]=max(ad$storage[i-1]-((ad$ts_deficit2[i])/0.8),0.0)
      }
  }

  #Calculate net WE used in each hour
  ad$we_used[1]=max(ad$ts_utilized2[1]-ad$baseload2[1],0.0)
  #Find total wind energy supplied (including from storage) at each hour
  for (i in 2:nrow(ad)){
    if (ad$ts_deficit2[i]==0){
      ad$we_used[i]=max(ad$ts_utilized2[i]-ad$baseload2[i],0.0)
      }
    else if (ad$ts_curtailment2[i]==0){
    ad$we_used[i]=max(ad$ts_utilized2[i]-ad$baseload2[i],0.0)+(ad$storage[i-1]-ad$storage[i])*0.8
    }
  }

  #Print storage capacity
  sprintf("Storage Capacity: %.2f kWh",storagecap$Storage_Cap[j])

  #Print previous useful WE
  sprintf("Without storage, net useful wind energy is %.2f kWh",sum2)

  #Print new useful WE
  sprintf("With storage, net useful wind energy is % .2fkWh",sum(ad$we_used))
  storagecap$WE_useful[j]=sum(ad$we_used)

  #Print additional useful WE
  sprintf("Therefore additional useful wind energy due to storage is %.2f kWh",sum(ad$we_used)-sum2)
  storagecap$benefit[j]=sum(ad$we_used)-sum2

  #Print fraction of previous curtailment saved
  sprintf("This is %.2f percent of the curtailment that would have occured without storage, %.2f kWh"
,(sum(ad$we_used)-sum2)*100/sum(ad$ts_curtailment2),sum(ad$ts_curtailment2))
  storagecap$frac.c.saved[j]=(sum(ad$we_used)-sum2)*100/sum(ad$ts_curtailment2)

  #Print fraction of previous unmet demand now met
```

```
  sprintf("Therefore, %.2f kWh (%.2f percent) of non-baseload energy not met by the wind farm earlier, %.2f kWh, can be met by adding storage",sum(ad$we_used)-sum2,(sum(ad$we_used)-sum2)*100/sum(ad$ts_deficit2),sum(ad$ts_deficit2))
  storagecap$frac.d.met[j]=(sum(ad$we_used)-sum2)*100/sum(ad$ts_deficit2)

  #Print new capacity factor
  cf_c_bl2_st=sum(ad$we_used)*100/(850*8760*7)
  sprintf("Capacity factor with storage is %.2f percent",cf_c_bl2_st)
  storagecap$newCF[j]=cf_c_bl2_st
}

#Print for 10MWh storage capacity scenario
#Print storage capacity
sprintf("Storage Capacity: %.2f kWh",storagecap$Storage_Cap[1])
```

```
## [1] "Storage Capacity: 10000.00 kWh"
```

```
#Print previous useful WE
sprintf("Without storage, net useful wind energy is %.2f kWh",sum2)
```

```
## [1] "Without storage, net useful wind energy is 24490312.86 kWh"
```

```
#Print new useful WE
sprintf("With storage, net useful wind energy is % .2fkWh",storagecap$WE_useful[1])
```

```
## [1] "With storage, net useful wind energy is  25403868.59kWh"
```

```
#Print additional useful WE
sprintf("Therefore additional useful wind energy due to storage is %.2f kWh",storagecap$benefit[1])
```

```
## [1] "Therefore additional useful wind energy due to storage is 913555.73 kWh"
```

```
#Print fraction of previous curtailment saved
sprintf("This is %.2f percent of the curtailment that would have occured without storage.",storagecap$frac.c.saved[1])
```

```
## [1] "This is 34.64 percent of the curtailment that would have occured without storage."
```

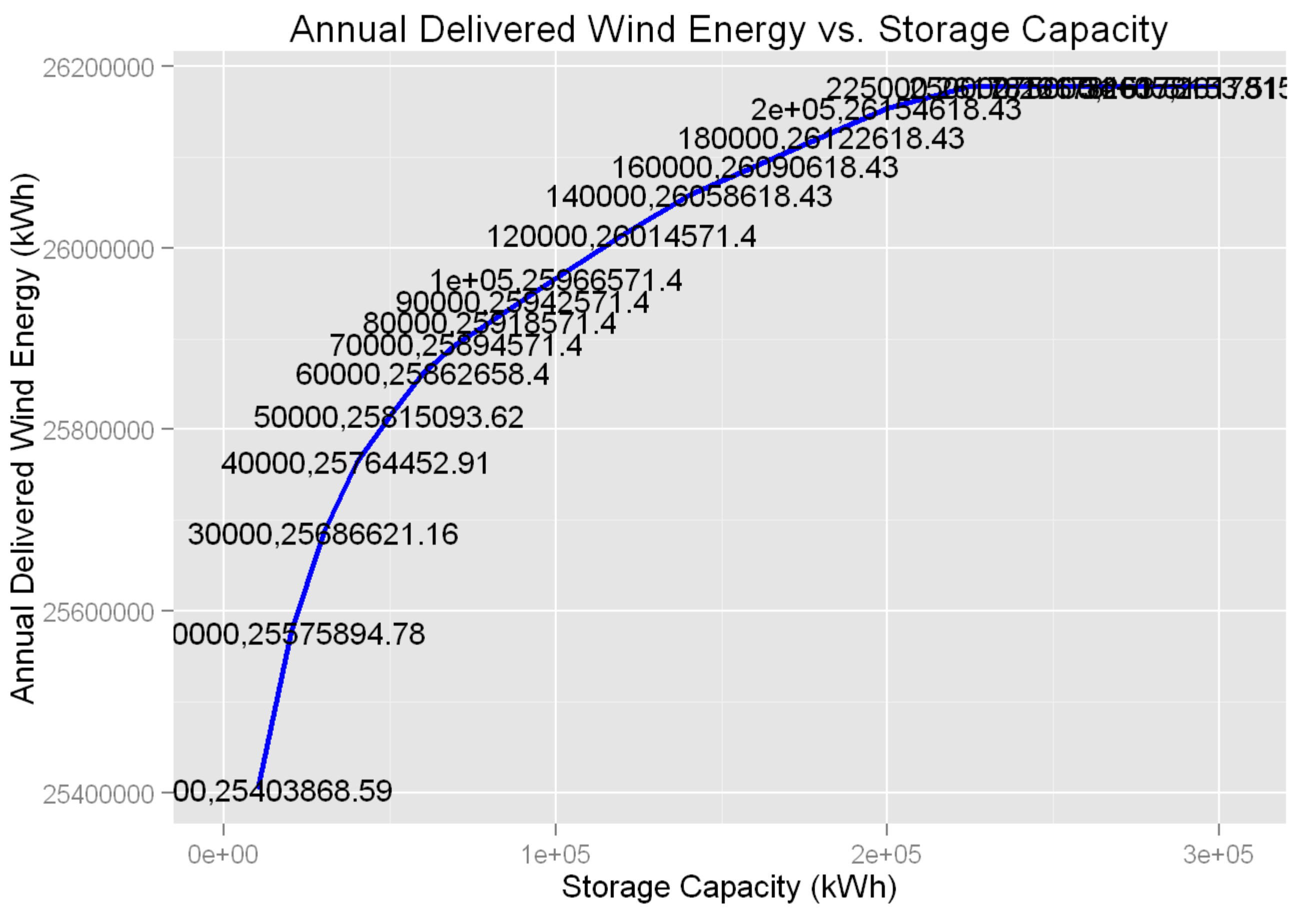
```
#Print fraction of previous unmet demand now met
sprintf("Therefore, %.2f kWh (%.2f percent) of non-baseload energy not met by the wind farm earlier, %.2f kWh, can be met by adding storage",storagecap$benefit[1],storagecap$frac.d.met[1],(100/4.81)*storagecap$benefit[1])
```

```
## [1] "Therefore, 913555.73 kWh (4.81 percent) of non-baseload energy not met by the wind farm earli
er, 18992842.52 kWh, can be met by adding storage"
```

```
#Print new capacity factor
sprintf("Capacity factor with storage is %.2f percent",storagecap$newCF[1])
```

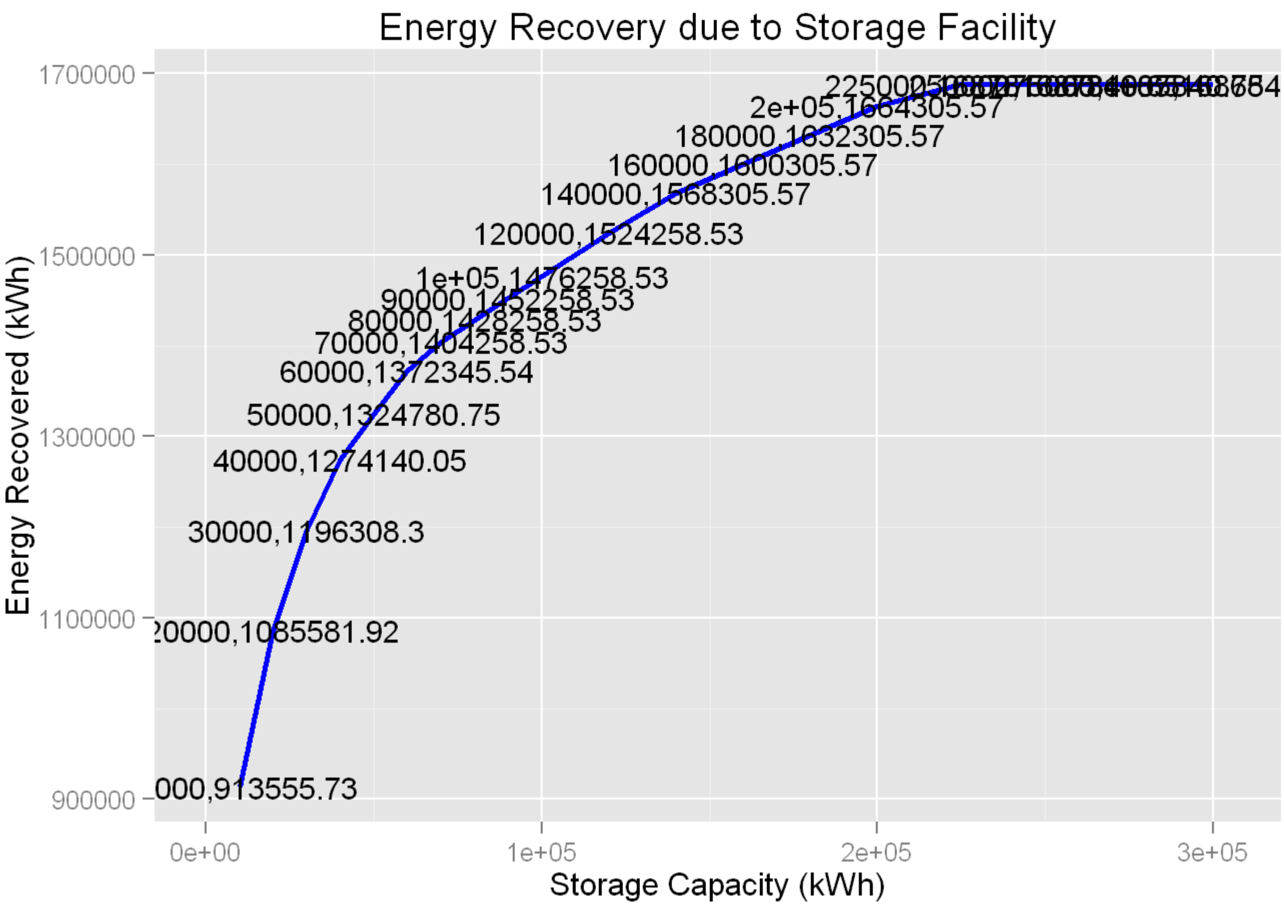
```
## [1] "Capacity factor with storage is 48.74 percent"
```

```
#Plot useful WE for each storage scenario
plot5<-ggplot(storagecap, aes(x=storagecap$Storage_Cap,y=storagecap$WE_useful))
plot5+geom_line(colour="blue",size=1)+geom_text(size=4, label=paste(round(storagecap$Storage_Cap, 2),
 round(storagecap$WE_useful, 2), sep=","))+xlim(0,5000+storagecap$Storage_Cap[nrow(storagecap)])+ylab
("Annual Delivered Wind Energy (kWh)")+xlab("Storage Capacity (kWh)")+ggtitle("Annual Delivered Wind
Energy vs. Storage Capacity")
```

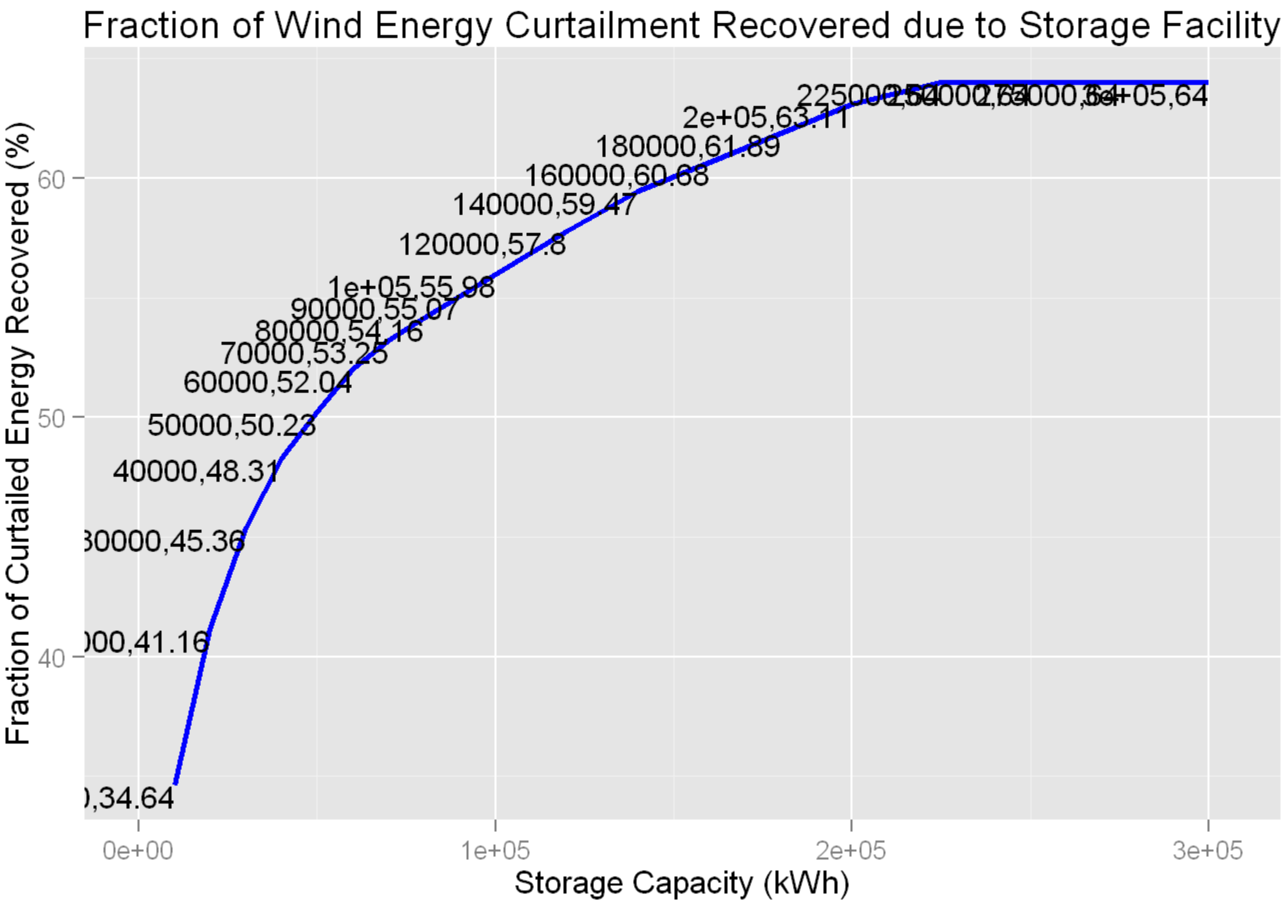



```
#Plot additional useful WE due to storage, for each storage scenario
plot6<-ggplot(storagecap, aes(x=storagecap$Storage_Cap,y=storagecap$benefit))
plot6+geom_line(colour="blue",size=1)+geom_text(size=4, label=paste(round(storagecap$Storage_Cap, 2),
 round(storagecap$benefit, 2), sep=","))+xlim(0,5000+storagecap$Storage_Cap[nrow(storagecap)])+ylab("
Energy Recovered (kWh)")+xlab("Storage Capacity (kWh)")+ggtitle("Energy Recovery due to Storage Facil
```

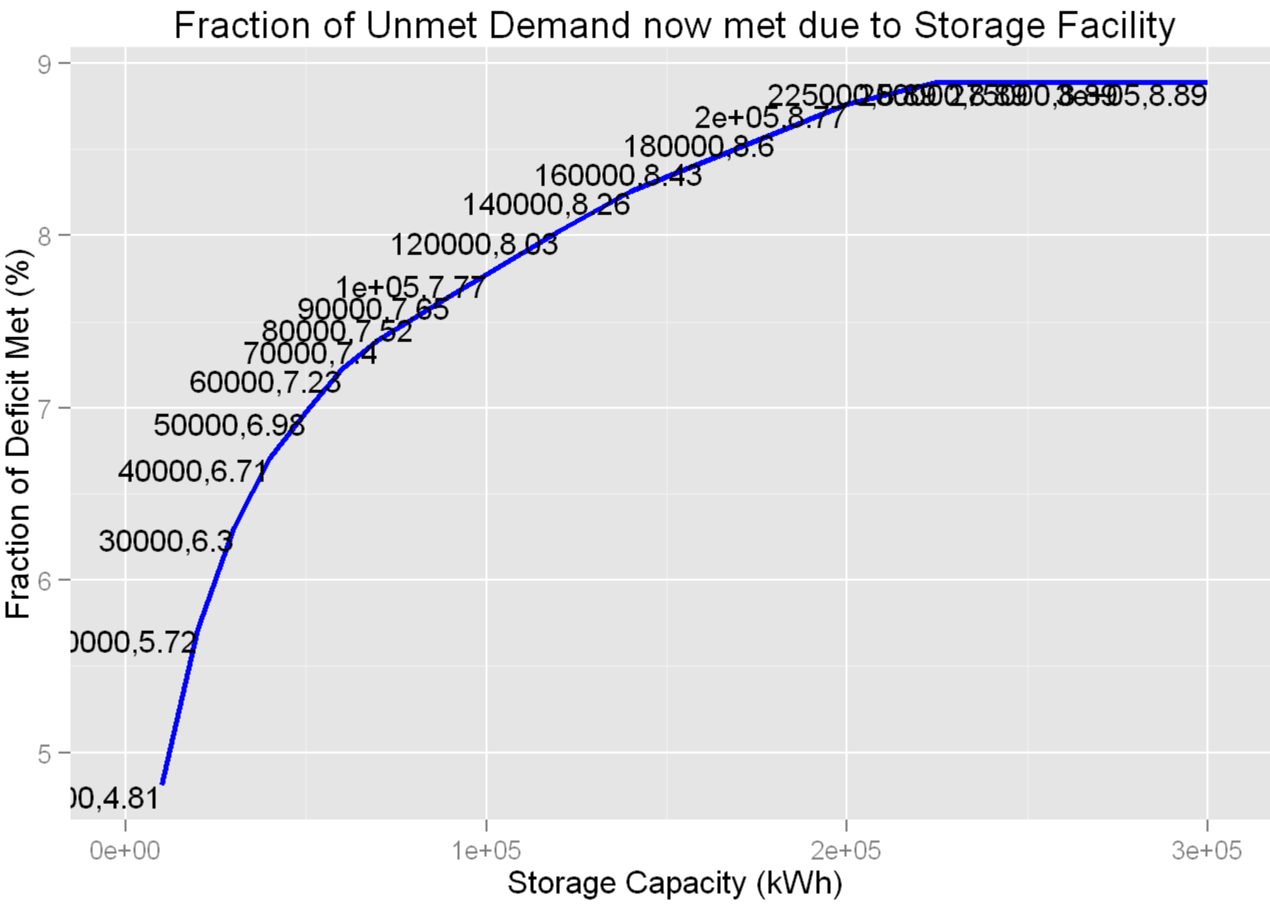
```
ity")
```



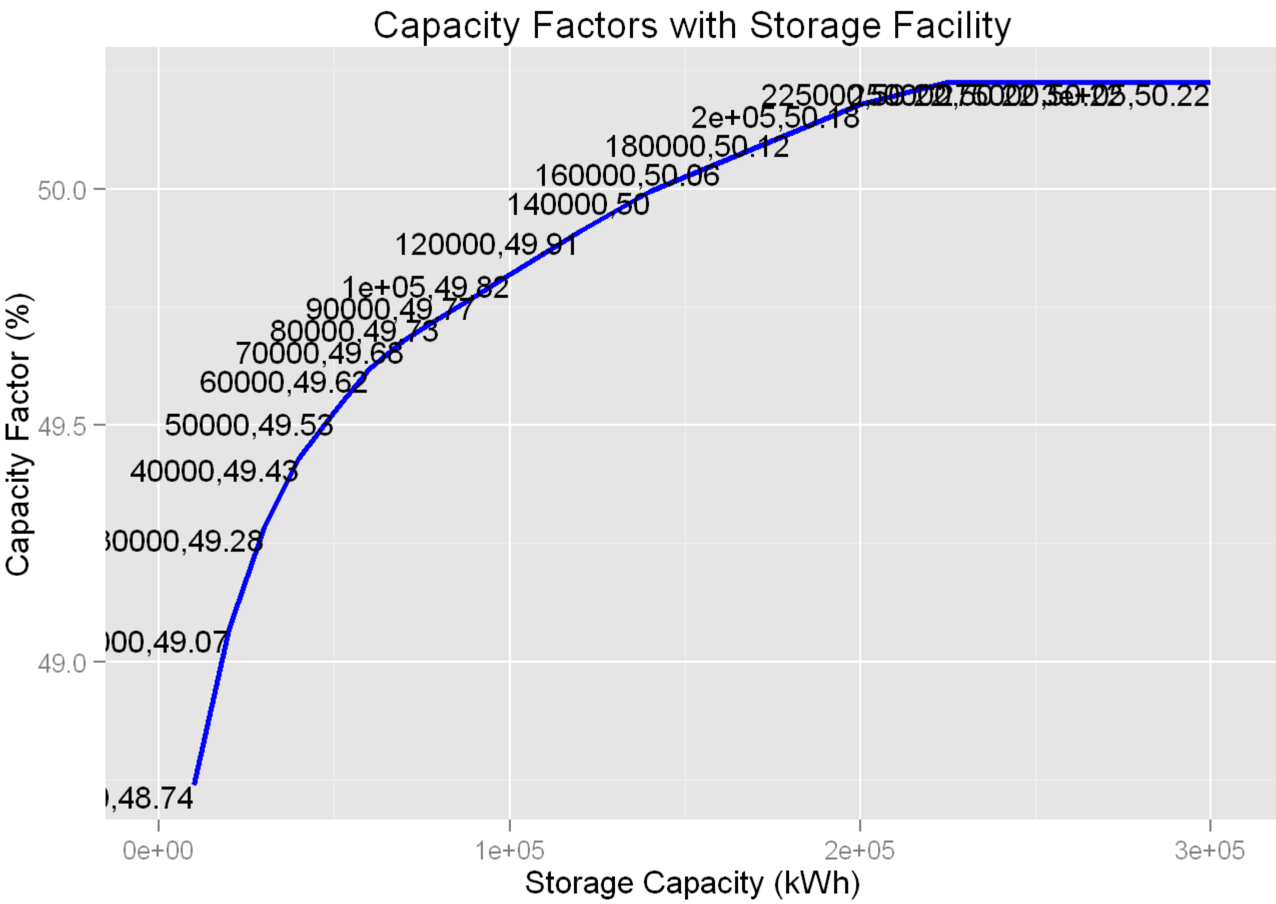

```
#Plot fraction of curtailed energy recovered, for each storage scenario
plot7<-ggplot(storagecap, aes(x=storagecap$Storage_Cap,y=storagecap$frac.c.saved))
plot7+geom_line(colour="blue",size=1)+geom_text(size=4, label=paste(round(storagecap$Storage_Cap, 2),
 round(storagecap$frac.c.saved, 2), sep=","),hjust = 1, vjust = 1)+ylab("Fraction of Curtailed Energy
 Recovered (%)")+xlim(0,5000+storagecap$Storage_Cap[nrow(storagecap)])+xlab("Storage Capacity (kWh)")
+ggtitle("Fraction of Wind Energy Curtailment Recovered due to Storage Facility")
```




```
#Plot fraction of unmet demand now met, for each storage scenario
plot8<-ggplot(storagecap, aes(x=storagecap$Storage_Cap,y=storagecap$frac.d.met))
plot8+geom_line(colour="blue",size=1)+geom_text(size=4, label=paste(round(storagecap$Storage_Cap, 2),
 round(storagecap$frac.d.met, 2), sep=","),hjust = 1, vjust = 1)+xlim(0,5000+storagecap$Storage_Cap[n
row(storagecap)])+ylab("Fraction of Deficit Met (%)")+xlab("Storage Capacity (kWh)")+ggtitle("Fractio
n of Unmet Demand now met due to Storage Facility")
```




```
#Plot CFs with storage, for each storage scenario
plot9<-ggplot(storagecap, aes(x=storagecap$Storage_Cap,y=storagecap$newCF), label=text)
plot9+geom_line(colour="blue",size=1)+geom_text(size=4, label=paste(round(storagecap$Storage_Cap, 2),
 round(storagecap$newCF, 2), sep=","),hjust = 1, vjust = 1)+ylab("Capacity Factor (%)")+xlab("Storage
 Capacity (kWh)")+xlim(0,5000+storagecap$Storage_Cap[nrow(storagecap)])+ggtitle("Capacity Factors wit
h Storage Facility")
```

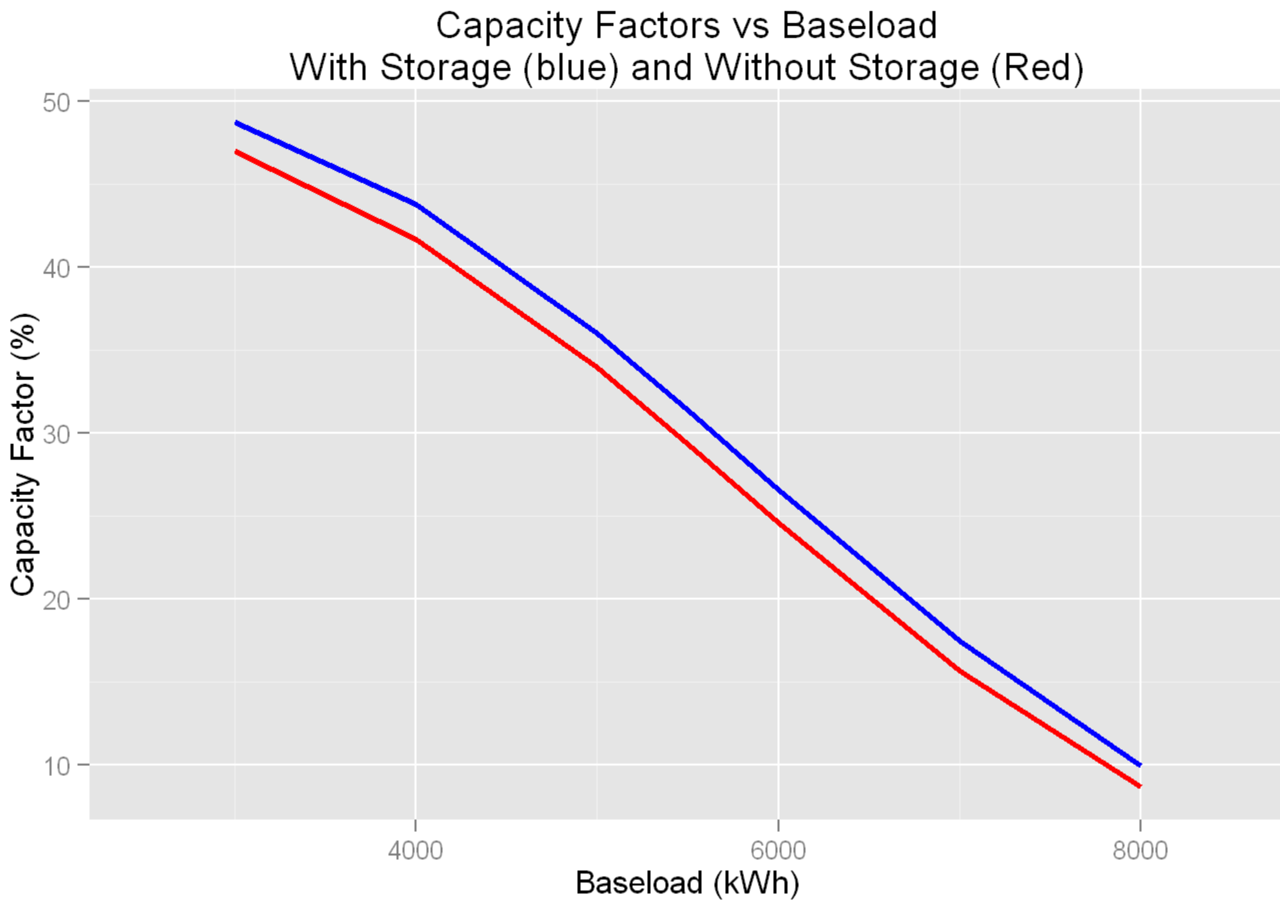


4. Perform analogous calculations for a variety of different baseload power for the 10MWh storage system. What point would be considered optimum, to deliver the highest fraction of unmet non-baseload capacity with storage discharged energy? Explain your reasoning.

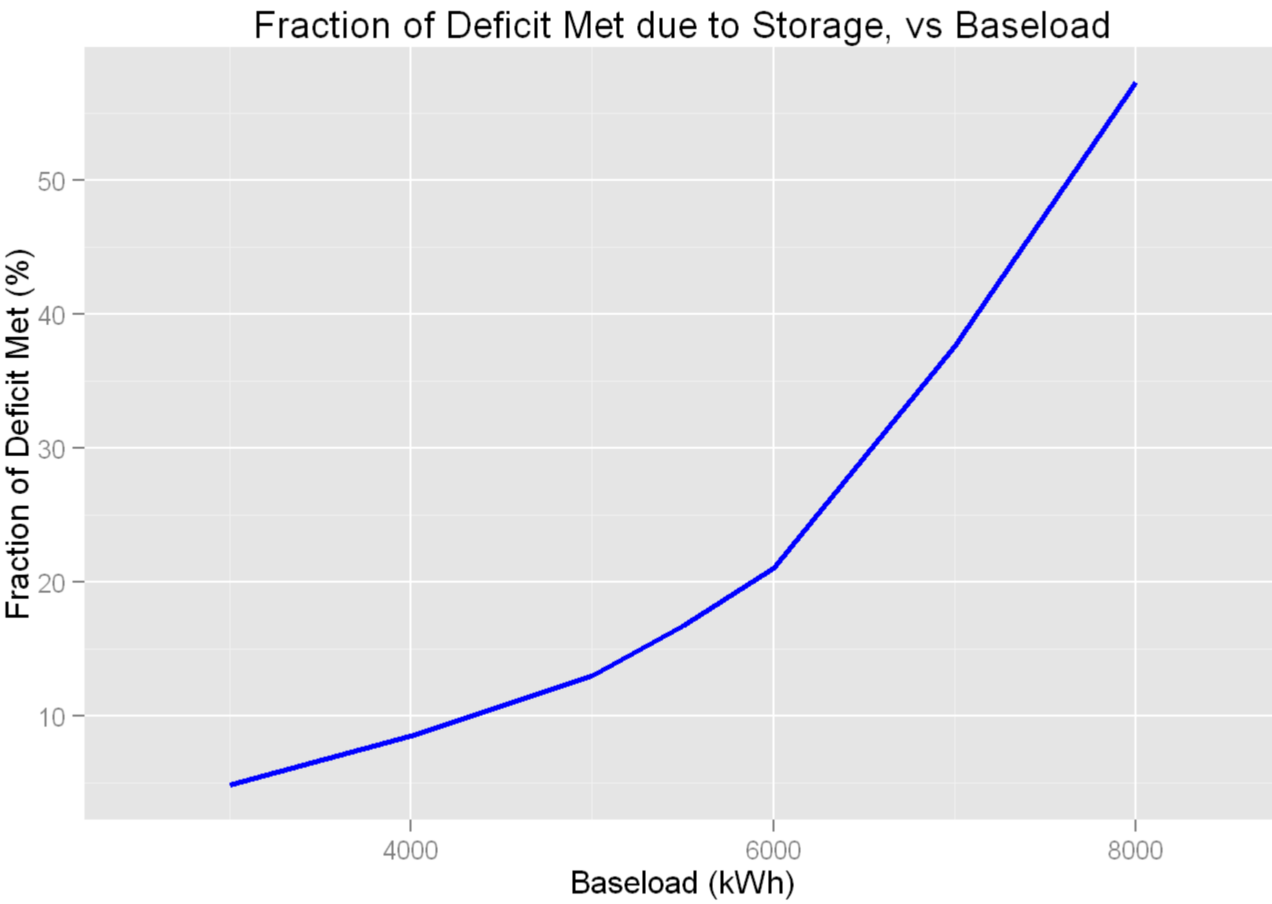
```
#Different baseload scenarios
bl<-data.frame("baseload"=c(30,40,50,55,60,70,80))

for (k in 1:nrow(bl)){
  bl$baseload[k]=bl$baseload[k]*100.0
  ad$baseload3=bl$baseload[k]

  ad$totalsupply3=ad$baseload3+ad$windgen

  for (j in 1:nrow(ad)){
      ad$ts_utilized3[j]=min(ad$demand[j],ad$totalsupply3[j])
    }
  #Calculate curtailment
  ad$ts_curtailment3=ad$totalsupply3-ad$ts_utilized3
  #Calculate deficit
  ad$ts_deficit3=ad$demand-ad$ts_utilized3

  #Print baseload
  sprintf("Baseload is %.2f kWh",summary(ad$baseload3)[4])
```

```
  #Print non-baseload energy not met by windfarm
  sprintf("For this baseload, non-baseload energy not met by wind farm over the year is %.2fkWh",sum(
ad$ts_deficit3))
  bl$deficit[k]=sum(ad$ts_deficit3)

  #Print curtailment
  sprintf("For this baseload, curtailment over the year is %.2fkWh",sum(ad$ts_curtailment3))
  bl$curtailment[k]=sum(ad$ts_curtailment3)

  #Find capacity factor
  sum3=0.0
  for (i in 1:nrow(ad)){
  sum3=sum3+max(ad$ts_utilized3[i]-ad$baseload3[i],0.0)
  }
  cf_c_bl3=sum3*100/(850*8760*7)

  #Print capacity factor
  sprintf("For this baseload, curtailed CF is %.2f percent",cf_c_bl3)
  bl$CFwst[k]=cf_c_bl3

  #Calculate state of  storage at each hour
  ad$storage3[1]=min(0.8*ad$ts_curtailment3[1],10000.0)
  for (i in 2:nrow(ad)){
    #With curtailment
    if (ad$ts_deficit3[i]==0){
      ad$storage3[i]=min((ad$storage3[i-1]+0.8*ad$ts_curtailment3[i]),10000.0)
      }
    #With deficit
    else if (ad$ts_curtailment3[i]==0){
      ad$storage3[i]=max(ad$storage3[i-1]-((ad$ts_deficit3[i])/0.8),0.0)
      }
  }

  #Calculate net WE used in each hour
  ad$we_used3[1]=max(ad$ts_utilized3[1]-ad$baseload3[1],0.0)
  #Find total wind energy supplied (including from storage) at each hour
  for (i in 2:nrow(ad)){
    if (ad$ts_deficit3[i]==0){
      ad$we_used3[i]=max(ad$ts_utilized3[i]-ad$baseload3[i],0.0)
      }
    else if (ad$ts_curtailment3[i]==0){
    ad$we_used3[i]=max(ad$ts_utilized3[i]-ad$baseload3[i],0.0)+(ad$storage3[i-1]-ad$storage3[i])*0.8
    }
  }
```

```
  #Print baseload
  sprintf("Baseload: %.2f kWh",bl$baseload[k])

  #Print previous useful WE
  sprintf("Without storage, net useful wind energy is %.2f kWh",sum3)

  #Print new useful WE
  sprintf("With storage, net useful wind energy is % .2fkWh",sum(ad$we_used3))
  bl$WE_useful[k]=sum(ad$we_used3)

  #Print additional useful WE
  sprintf("Therefore additional useful wind energy due to storage is %.2f kWh",sum(ad$we_used3)-sum3)
  bl$benefit[k]=sum(ad$we_used3)-sum3

  #Print fraction of previous curtailment saved
  sprintf("This is %.2f percent of the curtailment that would have occured without storage, %.2f kWh"
,(sum(ad$we_used3)-sum3)*100/sum(ad$ts_curtailment3),sum(ad$ts_curtailment3))
  bl$frac.c.saved[k]=(sum(ad$we_used3)-sum3)*100/sum(ad$ts_curtailment3)

  #Print fraction of previous unmet demand now met
  sprintf("Therefore, %.2f kWh (%.2f percent) of non-baseload energy not met by the wind farm earlier
, %.2f kWh, can be met by adding storage",sum(ad$we_used3)-sum3,(sum(ad$we_used3)-sum3)*100/sum(ad$ts
_deficit3),sum(ad$ts_deficit3))
  bl$frac.d.met[k]=(sum(ad$we_used3)-sum3)*100/sum(ad$ts_deficit3)

  #Calculate remaining deficit to be met by diesel generation
  bl$rem.deficit[k]=sum(ad$ts_deficit3)-(sum(ad$we_used3)-sum3)

  #Print new capacity factor
  cf_c_bl3_st=sum(ad$we_used3)*100/(850*8760*7)
  sprintf("Capacity factor with storage is %.2f percent",cf_c_bl3_st)
  bl$newCF[k]=cf_c_bl3_st
}

#Plot CFs with storage, for each baseload scenario
plot10<-ggplot(bl, aes(x=bl$baseload))
plot10+geom_line(aes(y=bl$newCF),colour="blue",size=1)+geom_line(aes(y=bl$CFwst),colour="red",size=1)
+ylab("Capacity Factor (%)")+xlab("Baseload (kWh)")+xlim(bl$baseload[1]-500,500+bl$baseload[nrow(bl)]
)+ggtitle("Capacity Factors vs Baseload\nWith Storage (blue) and Without Storage (Red)")
```




```
plot11<-ggplot(bl, aes(x=bl$baseload))
plot11+geom_line(aes(y=bl$frac.d.met),colour="blue",size=1)+ylab("Fraction of Deficit Met (%)")+xlab(
"Baseload (kWh)")+xlim(bl$baseload[1]-500,500+bl$baseload[nrow(bl)])+ggtitle("Fraction of Deficit Met
 due to Storage, vs Baseload")
```



Fraction of Deficit Met due to Storage, vs Baseload
Fraction of Deficit Met (%)
50
40
30
20
10
4000
6000
8000
Baseload (kWh)