Appendix A MATLAB CODE

Battery modeling section:

```
%% battery
%######inputs#############inputs####################inputs##
Nbat=x(3);    % no. of batteries that are selected by PSO
uinv=0.95;
dod=0.8;% battery depth of discharge. it indicates how much % the
charge can be drawn from the battery.
AD=3;
EL=convert;
Vs=48;
Bcap=AD*EL/uinv*n_bat*dod*Vs;
SOCmin=xlsread('SOCmin.xlsx',1,'A1:A180')';
SOCmax=xlsread('SOCmax.xlsx',1,'B1:B180')';
```

PV modeling section:

```
%% solar
solar=xlsread('g.xlsx',1,'E19:E8778')';
 %% solar irradiance data W/m^2
temp=xlsread('g.xlsx',1,'F19:F8778')';          %% temperature data
0C
Tam=temp;                                       %% ambient
temperature 0C
       %%%%% -------------Plotting of PV_out------------%%%%%
Gref=1000;                %% reference solar radiation (W/m^2)
NOCT=45;                  %% Nominal cell operating temperature
kt=-3.7e-3;               %% Temperature coefFicient
Tref=25;                  %% Temperature at reference condition
Tc=Tam+((NOCT-20)/800).*solar; % cell temperature
pv_eff=7.3;               %%  solar panels efficiency (rated power
under reference condition)
G=solar;
PV_out=(pv_eff.*(G/Gref)).*(1+kt.*(Tc-Tref));
%PV output power
pp=PV_out;

figure ;plot(pp);axis tight;box on;grid on
xlabel('Time (hours)');ylabel('PV output power (kW)');title(' Output
power generated from PV')
```

Wind turbine modeling section:

```
%% WIND
%% Modelling of Wind turbine
%Calculation of wind speed at HUB height
%conversion of wind speed from reference to hub height
wind=xlsread('g.xlsx',1,'G19:G8778')';    %% wind speed data m/s
load('WindTurbines.mat');                 %% LOAD WIND DATA
V1=wind;                %% wind speed
h2=70;                  %% Wind turbine at hub height
h1=43.6;                %% Wind turbine at hub height
alfa=0.25;               %% for heavily forested landscape (power law
exponential)
V2=V1*(h2/h1)^(alfa);    %% (V2)= Wind speed at hub height
%% wind turbine model
WTM=4;                                   %%Choosen wind turbine
model
bd=cell2mat(WindTurbines(WTM,2));        %%Blades diameter(m) (6.4)
```

```
as=cell2mat(WindTurbines(WTM,3));          %%Area swept by the
blade(m)  (as=pi*(rw)^2
eff=cell2mat(WindTurbines(WTM,4));         %%Efficiency 95%
vcut=cell2mat(WindTurbines(WTM,5));        %%cut out speed 40m/s
vin=cell2mat(WindTurbines(WTM,6));         %%cut out speed 2.5m/s
vr=cell2mat(WindTurbines(WTM,7));          %%cut out speed 9.5m/s
pr=cell2mat(WindTurbines(WTM,8));          %%rated power pr=5kw
pcut=cell2mat(WindTurbines(WTM,9));        %%output power at cut-out
speed pcut=4kw
pmax=cell2mat(WindTurbines(WTM,10));       %%maximum output power

for t=1:1:8760
    if V2(t)<vin
        pwt(t)=0;
    elseif vin<=V2(t)&& V2(t)<=vr
        pwt(t)=((V2(t))^3*(pr/((vr)^3-(vin)^3)))-
pr*((vin)^3/((vr)^3-(vin)^3));
    elseif vr<V2(t)&&V2(t)<vcut
        pwt(t)=0;
    end
    pwg(t)=pwt(t)*eff; %Electric power from wind turbine
end
Nwt=wind/pwg;
figure; yyaxis right;hold on;plot(pp); hold on;ylabel('PV output
power (kW)'); yyaxis left;hold on;plot(pwg);ylabel('Wind turbine
output (kW)');hold off; axis tight; box on;title('P_p_v &
P_w_t');xlabel('Time (hours)')

figure ; plot (pwg);grid on;axis tight;box on;xlabel('Time
(hours)');
ylabel('Wind Turbine output (kW)');title('Output power generated
from wind')
```

Section: plotting the population and load demand

```
Population_Number=xlsread('book1.xlsx',1,'I237:I258');
POWER_DEMAND=xlsread('book1.xlsx',1,'J237:J258');

figure; yyaxis right;hold on;plot(Population_Number); hold
on;ylabel('Population Number (Million)');

yyaxis left;hold on;plot(POWER_DEMAND);ylabel('Power demand
(MW)');grid on; hold off; axis tight; box on;xlabel('Years')
```

charge and discharge section

%%%%%%%%%%%CHARGE %%%%%%%%%%

```
function [Eb,Ech,Edch,Egrid_s,Ev] =
charge(Eb,Ebmax,Pl,t,Ech,Edch,Pw,Ps,n_bat,Egrid_s,Ev,car_av)
 %^^^^^^^^^^^^^^CHARGE^^^^^^^^^^^^^^^^^^^^^^^^^^
 uconv=0.95;  % CONVERTER efficiency
 uinv=0.95;     % inverter efficiency
 C_Rate=7.2;    %=7.4;%battery charge rate  kw/h
 Evmax=24;      %=75; capacity of EV BATTERY
 temp2=0;       % temporary variable 2 STARTING CHARGING CASE
           Edch(t)=0;
           Egrid_s(t)=0;

           Pch(t)=((Pw(t)+Ps(t))*uinv)-(Pl(t)/uinv);
        %n_bat is battery round trip efficiency.
```

```
           Ech(t)=Pch(t).*n_bat.*uconv;%The energy available to
battery after extracted converter and battery efficiency adn
        if Ech(t)<=Ebmax-Eb(t-1)
           Eb(t)=Eb(t-1)+Ech(t);
           Ev(t)=Ev(t-1);
        else
           Eb(t)=Ebmax; % max SOC constraint is implemented here, in
the else condition, the available charging is more than capacity,
instead, SOC is limited to 100%(Ebmax)
           Egrid_s(t)=(Ech(t)-(Ebmax-Eb(t-1)))/(n_bat);   % the
ammount of  energy supplied to grid.
           Ech(t)=Ebmax-Eb(t-1);

           if Egrid_s(t)>C_Rate   %deciding whether the available
Ech is greater than the charging rate of Ev
            temp1=C_Rate;
           else
            temp1=Egrid_s(t);
           end
           Ev(t)=Ev(t-1);
           if ((Ev(t-1)<=Evmax)&&(car_av(t)==1)) %deciding whether
the car is at home and available Ev is less than critical SOC of Ev
             if (temp1+Ev(t-1))>Evmax
               Ev(t)=Evmax;
               temp2=(Evmax-Ev(t-1));
               Ech(t)=Ech(t)+temp2;
               Egrid_s(t)=Egrid_s(t)-temp2;
             else
               Ev(t)=Ev(t-1)+temp1;
               temp2=temp1;
               Ech(t)=Ech(t)+temp1;
               Egrid_s(t)=Egrid_s(t)-temp1;
             end
           end
        end
end


                 %%%%%%%%%%%%DISCHARGE %%%%%%%%%%%%
function [Eb,Edch,Ech,Egrid_p,Ev] =
discharge(Pw,Ps,Eb,Ebmax,Pl,t,Ebmin,Edch,Ech,Egrid_p,Ev,car_av)
 %^^^^^^^^^^^^^^DISCHARGE^^^^^^^^^^^^^^^^^^
  uconv=0.95;
  uinv=0.95;
    Pdch(t)=(Pl(t)/uinv)-((Pw(t)+Ps(t))*uconv);
    Edch(t)=Pdch(t)*1; %one hour iteration time
    Ech(t)=0;
    Egrid_p(t)=0;
    D_Rate=7.2;%7.4; %battery discharge rate
    Evmax=24;%=75;
    temp1=0;

      if (Ev(t-1)<(Evmax*.2) && (car_av(t)==1))
            [Ev,Egrid_p]=charge_Ev(Ev,Egrid_p,t);
      end

    if(Eb(t-1)-Ebmin)>=(Edch(t)/uconv)
        Eb(t)=Eb(t-1)-(Edch(t)/uconv);
        Egrid_p(t)=0;  % no energy taken from grid
        Ev(t)=Ev(t-1);
    else
```

```
        if (((Ev(t-1)-(Edch(t)-Eb(t-
1)+Ebmin))>Evmax*.2)&&(car_av(t)==1)&&((D_Rate)+Eb(t-1)-
Ebmin>=Edch(t)))
            Eb(t)=Ebmin;
            Ev(t)=Ev(t-1)-(Edch(t)-Eb(t-1)+Ebmin);
            Edch(t)=Eb(t-1)-Ebmin;
        else
%              temp=Eb(t-1)-Ebmin;
            Eb(t)=Eb(t-1);
            Ev(t)=Ev(t-1);
            Egrid_p(t)=Edch(t);
            Edch(t)=0;
        end
    end
end
```

plotting section

```
%% Plotting section
figure; yyaxis right;hold on;plot(Ps); hold on;ylabel('PV output
power (kW)'); yyaxis left;hold on;plot(Pw);ylabel('wind turbine
output (kW)');hold off; axis tight; box on;title('P_p_v &
P_w_t');xlabel('Time (hours)')

       %% ************************************************** %%
m1=1;m2=m1+167; % m1 referes to the week whos graphs to be dispayed.

t1=1:1:168;
figure;
% area(t1,load1(m1:m2),'DisplayName','Load','FaceColor',[1 0 1])
plot(t1,convert(m1:m2),'DisplayName','Load','LineStyle','--');hold
on
plot(t1,Edch(m1:m2),'DisplayName','Bat_o_u_t');hold on
% area(t1,Edch(m1:m2),'DisplayName','Bat_o_u_t','FaceColor',[1 0 0])
temp=Pw(m1:m2);
plot(t1,temp(1:168),'DisplayName','P_W_T');hold on
% area(t1,temp,'DisplayName','P_W_T','FaceColor',[1 1 0])
plot(t1,Egrid_p(m1:m2),'DisplayName','Grid_P_u_r_c_h_a_s_e');hold
off
%
area(t1,Egrid_p(m1:m2),'DisplayName','Grid_P_u_r_c_h_a_s_e','FaceCol
or',[0 0 1])
ylabel('Energy(KW)');xlabel('Time (Hours)');grid on;grid minor;axis
tight ;legend show

figure;area(t1,convert(m1:m2),'DisplayName','Load','FaceColor',[1 0
1])
% plot(t1,load1(m1:m2),'DisplayName','Load','LineStyle','--');
hold on
plot(Ech(m1:m2),'DisplayName','Bat_i_n','Color',[1 0 0]); hold on
temp=Egrid_p(m1:m2)+Pw(m1:m2)+Ps(m1:m2)+Edch(m1:m2).*uinv;
% plot(t1,temp(m1:m2),'DisplayName','Total Power +
Bat_o_u_t+Grid_P')
area(t1,temp(m1:m2),'DisplayName','P_L+
Bat_o_u_t+Grid_P','FaceColor',[0 0 1])
 hold off;ylabel('Energy(KW)');xlabel('Time (Hours)');axis tight
;legend show; grid on;grid minor

figure;plot(t1,-Egrid_s(m1:m2),'DisplayName','Grid_s_a_l_e_s');hold
on
```

```
plot(t1,Egrid_p(m1:m2),'DisplayName','Grid_p_u_r_c_h_a_s_e');hold
off
ylabel('Energy(kW)');xlabel('Time (Hours)');axis tight;legend show;
grid on;grid minor

figure;yyaxis left;hold on
% area(t1,load1(m1:m2),'DisplayName','Load','FaceColor',[1 1
0],'LineStyle',':')
plot(convert(m1:m2),'DisplayName','Load','LineWidth',1,'LineStyle','
--','Color',[0 1 1])
plot(Pw(m1:m2),'DisplayName','P_W_T','LineWidth',1,'LineStyle','--
','Color',[0 0 1])
plot(Edch(m1:m2),'DisplayName','B_o_u_t');ylabel('Energy(kW)');xlabe
l('Time (Hours)');grid on;grid minor
yyaxis right
plot(t1,Eb(m1:m2)*100/Ebmax,'DisplayName','SOC')
% area(t1,Eb(m1:m2)*100/Ebmax,'DisplayName','SOC','FaceColor',[1 0
1])
ylabel('SOC(%)');axis tight;legend show;grid on;grid minor

figure;plot(t1,-Ech(m1:m2),'DisplayName','Bat_i_n');hold
on;plot(t1,Edch(m1:m2),'DisplayName','Bat_o_u_t');hold off
ylabel('Energy(kW)');xlabel('Time (Hours)');legend show;grid on;grid
minor

figure;plot(-Ech,'DisplayName','Bat_i_n');hold
on;plot(Edch,'DisplayName','Bat_o_u_t'); hold off
ylabel('Energy(KW)');xlabel('Time (Hours)');legend show ;grid
on;grid minor

figure;plot(Eb*100/Ebmax,'DisplayName','SOC');ylabel('SOC(%)');xlabe
l('Time (Hours)');legend show;grid on;grid minor

figure; plot(convert,'DisplayName','load');ylabel('Load Demand
(KW)');xlabel('Time (Hours)');axis tight;legend show;grid on;grid
minor

figure;plot(Pw,'DisplayName','P_W_T');ylabel('Wind Power
(KW)');xlabel('Time (Hours)');axis tight;legend show;grid on;grid
minor

figure;plot(Ps,'DisplayName','P_P_V');ylabel('Solar Power (KW)');
xlabel('Time (Hours)');axis tight;legend show;grid on;grid minor
%% -----------------------------------------------------------------
%% Four seasons SOC
%% 1th season starting from (Mar-Apr-May).
m1=1418;m2=m1+167; % m1 refers to starting hour of the season to be
displayed.
figure;plot(t1,Eb(m1:m2)*100/Ebmax,'--','DisplayName','SOC');hold on
plot(SOCmin,'c.-.','Linewidth',3);hold on
plot(SOCmax,'g.-.','Linewidth',3);hold off
axis tight;grid on;grid minor
ylabel('SOC(%)');xlabel('Time (Hours)');title ('Spring (Mar-Apr-
May)')
legend ('SOC_S_p_r_i_n_g','SOC_m_i_n','SOC_m_a_x')
%% 2nd season starting from Jun-Jul-Aug.
m1=3626;m2=m1+167; % m1 refers to starting hour of the season to be
displayed.
figure;plot(t1,Eb(m1:m2)*100/Ebmax,'--','DisplayName','SOC');hold on
plot(SOCmin,'c.-.','Linewidth',3);hold on
plot(SOCmax,'g.-.','Linewidth',3);hold off
```

```
axis tight;ylabel('SOC(%)');xlabel('Time (Hours)');
title ('Summer (Jun-Jul-Aug)');grid on;grid minor
legend ('SOC_S_u_m_m_e_r','SOC_m_i_n','SOC_m_a_x')
%% 3rd season starting from Sep-Oct-Nov.
m1=5834;m2=m1+167; % m1 refers to starting hour of the season to be
displayed.
figure;plot(t1,Eb(m1:m2)*100/Ebmax,'--','DisplayName','SOC');hold on
plot(SOCmin,'c.-.');hold on
plot(SOCmax,'g.-.');hold off;axis tight
ylabel('SOC(%)');xlabel('Time (Hours)');
title ('Autumn (Sep-Oct-Nov)');grid on;grid minor
legend ('SOC_A_u_t_u_m_n','SOC_m_i_n','SOC_m_a_x')
%% 4th season starting from Dec-Jan-Feb.
m1=8018;m2=m1+167; % m1 refers to starting hour of the season to be
displayed.
figure
plot(t1,Eb(m1:m2)*100/Ebmax,'--','DisplayName','SOC');hold on
plot(SOCmin,'c.-.');hold on
plot(SOCmax,'g.-.');hold off
axis tight;ylabel('SOC(%)');xlabel('Time (Hours)');grid on;grid
minor
title ('Winter (Dec-Jan-Feb)');legend
('SOC_W_i_n_t_e_r','SOC_m_i_n','SOC_m_a_x')
%%%%%%%%%% all in one
figure;
yyaxis left
plot(pp,'DisplayName','P_P_V');hold on
plot(pwg,'DisplayName','P_W_T');hold on
plot(convert,'DisplayName','load');hold on
plot(grids,'DisplayName','Grid_s_u_p_p_l_y');hold off
% plot(t1,-Egrid_s,'DisplayName','Grid_s_a_l_e_s');hold on
% plot(t1,Egrid_p,'DisplayName','Grid_p_u_r_c_h_a_s_e');hold off
ylabel('Power(KW)');xlabel('Time (Hours)');axis tight ;grid on;grid
minor;legend
('P_P_V','P_W_T','P_L','Grid_s_u_p_p_l_y','Bat_i_n','Bat_o_u_t')

yyaxis right
plot(-Ech,'DisplayName','Bat_i_n');hold on
plot(Edch,'DisplayName','Bat_o_u_t');hold off
ylabel('Bat_i_n&Bat_o_u_t');axis tight ;grid minor;grid on;legend
show
```

<u>objective functions</u>

```
%% objective function
figure
REAL_INTREST=3;
ir=REAL_INTREST/100;
CRF=ir.*(1+ir)^20/(1+ir)^20-1; %% capital recovery factor
NPC=ASC/CRF;
plot(NPC);axis tight;grid on;xlabel ('Renewable electricty
fraction'); ylabel ('NPC ($)')
title ('Total NPC')
display(['The value of NPC is : ', num2str(NPC)])
```

```
%% Objective function (1)
Grid_sale=0.015;
Grid_p=0.023;
grid_cost=sum(Grid_p)*.023-sum(Grid_sale)*.015
Grid_purchased=sum(Grid_p)
Grid_sale=sum(Grid_sale)
```

```
Cgrid=0.0425.*Grid_p; %%% 0.023 is the buying price Cgrid is the
cost of buying electricity
display(['The value of Cgrid is : ', num2str(Cgrid)])
         ----------------------------------------------------
REF=sum(Pw+Ps)./sum(Pw+Ps+Grid_purchased); %%% 0.980932456190068
ref=REF*100
GCF=1-REF;
display(['The value of REF is : ', num2str(REF)])
display(['The value of GCF is : ', num2str(GCF)])
ob=min (GCF);
%% objective function (2)
Egrid_s=zeros(1,8760);
R_grid=sum(0.02).*Egrid_s; %%=0.0003
display(['The value of R_grid is : ', num2str(R_grid)])
        ----------------------------------------------------
COE=((CRF.*sum(NPC))+grid_cost-R_grid./convert+Grid_sale); %% COE IN
$KWH
% display(['The value of COE is : ', num2str(COE)])

figure
ef=[0.8 .85 .9 .95 1 ];
lcoe_value=[0.2351 0.2212 0.2089 0.1980 0.1881];
plot(ef,lcoe_value,'DisplayName','SOC','Marker','*','Color',[1 0 1])
ylabel('LCOE($/KWh)');xlabel('Round trip efficiency');grid on;grid
minor;axis tight;legend show
       ------------------------------------------------------
%% LPSP OBJECTIVE (3)
R_grid=sum(0.02).*Egrid_s; %%=0.0003
% LPSP=sum(Ps+Pw)/sum(load1); %% LPSP (%)
% LPSP=sum(pp+pwg)/sum(convert); %%%%0.4975
LPS=(convert-(pp+pwg)+R_grid);
LPSP=sum(LPS)/sum(convert);
display(['The value of LPSP is : ', num2str(LPSP)]) %%=0.49854
lpsp=LPSP*100;
```