Analyze climate transition scenario data provided by the Bank of Canada

The data for this example includes these climate scenarios developed by MIT using the Economic Projection and Policy Analysis (EPPA) Mode in collaboration with the Bank of Canada .

- Baseline (2019 Policies) — Baseline scenario consistent with climate policies in place at the end of 2019
- Below 2°C Immediate — Immediate policy action scenario to limit average global warming to below 2°C by 2100
- Below 2°C Delayed — Delayed policy action scenario to limit average global warming to below 2°C by 2100
- Net-Zero 2050 (1.5°C) — More ambitious immediate policy action scenario to limit average global warming to 1.5°C by 2050 that includes current net-zero commitments by some countries

```
load BankOfCanadaClimateScenarioData.mat
head(ClimateTransitionScenarioData);
```

k	CL_GEOGRAPHY	CL_SECTOR	CL_VARIABLE	CL_UNIT	CL_S
1	Canada	National	Carbon price	US$2014/tCO2e	Baseline (
2	Canada	National	Carbon price	US$2014/tCO2e	Below 2°C
3	Canada	National	Emissions | total GHG (scope 1)	Million tonnes CO2e	Baseline (
4	Canada	National	Emissions | total GHG (scope 1)	Million tonnes CO2e	Below 2°C
5	Canada	National	Input price | Coal	Index (2014 = 1)	Baseline (
6	Canada	National	Input price | Coal	Index (2014 = 1)	Below 2°C
7	Canada	National	Input price | Crops	Index (2014 = 1)	Baseline (
8	Canada	National	Input price | Crops	Index (2014 = 1)	Below 2°C

Use the preprocessBankOfCanadaData helper function to keep only the variables that this example uses for analysis.

```
function [ClimateTransitionScenarioData,options] =
preprocessBankOfCanadaData(ClimateTransitionScenarioData)

VariableSubset = {'Direct emissions costs', ... % Emissions
    'Emission intensity','Emissions (scope 1)| CH4', ...
    'Emissions (scope 1)| CO2', ...
    'Emissions (scope 1)| HFC', ...
    'Emissions (scope 1)| N2O', ...
    'Emissions (scope 1)| PFC', ...
    'Emissions (scope 1)| SF6', ...
    'Emissions (scope 2)| total GHG', ...
    'Emissions | total GHG (scope 1)', ...
    'Emissions/removals from forestry', ...
    'Carbon price' ...  % Shadow carbon price
    'Primarsy Energy | Bioenergy', ...  % Primary energy
    'Primary Energy | Coal', ...
```

```
    'Primary Energy | Gas', ...
    'Primary Energy | Hydro', ...
    'Primary Energy | Nuclear', ...
    'Primary Energy | Oil', ...
    'Primary Energy | Renewables (wind&solar)', ...
    'Primary Energy | Total', ...
    'Secondary Energy | Electricity| Bioelectricity (CCS)', ... % Secondary
energy for electricity
    'Secondary Energy | Electricity| Bioelectricity and other', ...
    'Secondary Energy | Electricity| Coal (CCS)', ...
    'Secondary Energy | Electricity| Coal (without CCS)', ...
    'Secondary Energy | Electricity| Gas (CCS)', ...
    'Secondary Energy | Electricity| Gas (without CCS)', ...
    'Secondary Energy | Electricity| Hydro', ...
    'Secondary Energy | Electricity| Nuclear', ...
    'Secondary Energy | Electricity| Oil', ...
    'Secondary Energy | Electricity| Wind&Solar', ...
    'Capital expenditure', ...     % Components of net income
    'Direct emissions costs', ...
    'Indirect costs', ...
    'Revenue', ...
    'US GDP', ... % GDPs
    'Global GDP', ...
    'Real GDP'};

% Keep only the specific VARIABLES
ClimateTransitionScenarioData =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_VARIA
BLE, VariableSubset),:);

% Find unique values of the categories. These are useful for the controls
% that appear later.
regions = string(unique(ClimateTransitionScenarioData.CL_GEOGRAPHY));
sectors = string(unique(ClimateTransitionScenarioData.CL_SECTOR));
vars = string(unique(ClimateTransitionScenarioData.CL_VARIABLE));
SCE = unique(ClimateTransitionScenarioData.CL_SCENARIO);

% Remove table variables from data
ClimateTransitionScenarioData = removevars(ClimateTransitionScenarioData,
{'k'});
ClimateTransitionScenarioData = sortrows(ClimateTransitionScenarioData);

% Pull data by scenario
baseline =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_SCENA
RIO, 'Baseline (2019 policies)'),:);
b2delayed =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_SCENA
RIO, 'Below 2°C delayed'),:);
```

```
b2immediate =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_SCENA
RIO, 'Below 2°C immediate'),:);
netzero2050 =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_SCENA
RIO, 'Net-zero 2050 (1.5°C)'),:);

% Options for local functions
options = struct;
options.regions = regions;
options.sectors = sectors;
options.var = vars;
options.scenarios = SCE;
options.baseline = baseline;
options.b2delayed = b2delayed;
options.b2immediate = b2immediate;
options.netzero2050 = netzero2050;
end
```

```
 [ClimateTransitionScenarioData, options] =
preprocessBankOfCanadaData(ClimateTransitionScenarioData);
 regions = options.regions;
```

creat functions for plotting

```
 function options = updateOptions(options,varargin)
% varargin
% 1st: factor
% 2nd: title
% 3rd: ylabel
% 4th: energy type
if nargin<3
    options.factor = varargin{1};
elseif nargin<4
    options.factor = varargin{1};
    options.title = varargin{2};
elseif nargin<5
    options.factor = varargin{1};
    options.title = varargin{2};
    options.yLabel = varargin{3};
else
    options.factor = varargin{1};
    options.title = varargin{2};
    options.yLabel = varargin{3};
    options.energytype  = varargin{4};
end
```

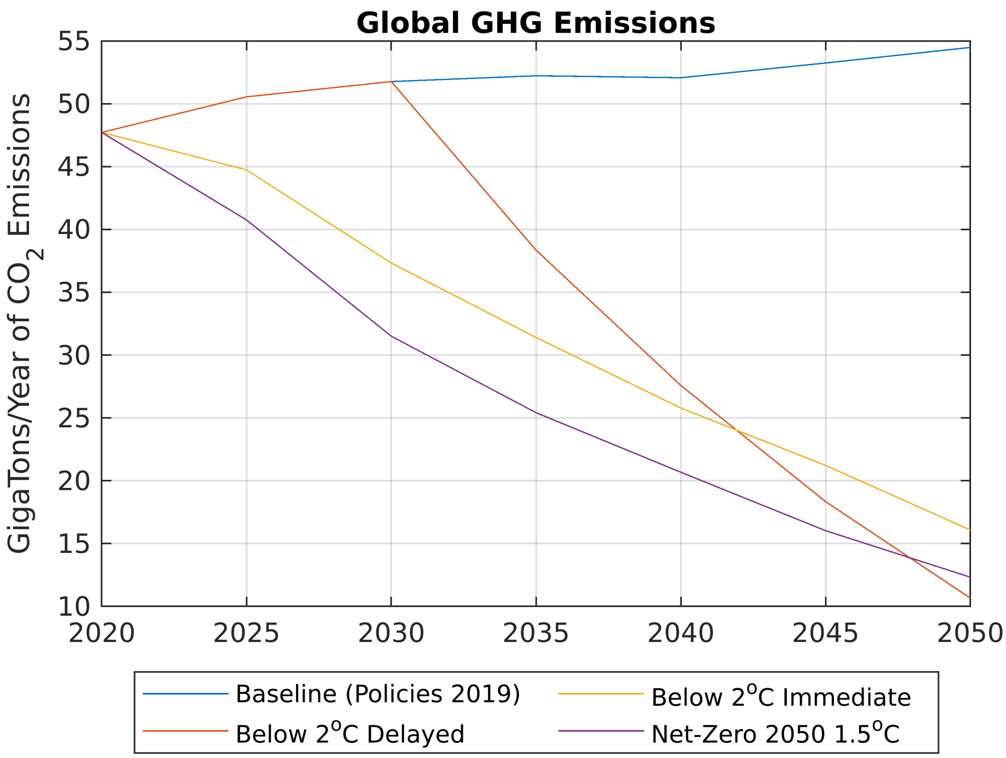
```
end
```

```
function plotVariableByCountry(country,variable,sector,options)

GDPflag = false; % Flag that the function is going to be used for GDP plots
if strcmp(variable,'GDP')
    GDPflag = true;
    if strcmp(country,'Global')
        variable = "Global GDP";
        sector = "Global";
    elseif strcmp(country,'Canada')
        variable = "Real GDP";
        sector = "National";
    else
        variable = "US GDP";
        sector = "National";
    end
end


% C02 emissions removal from forestry
baseline_sc =
options.baseline(ismember(options.baseline.CL_VARIABLE,variable),:);
b2delayed_sc =
options.b2delayed(ismember(options.b2delayed.CL_VARIABLE,variable),:);
b2immediate_sc =
options.b2immediate(ismember(options.b2immediate.CL_VARIABLE,variable),:);
netzero2050_sc =
options.netzero2050(ismember(options.netzero2050.CL_VARIABLE,variable),:);

% Global C02 emissions removal from forestry
baseline_sc_co =
sortrows(baseline_sc((ismember(baseline_sc.CL_GEOGRAPHY,country) &
ismember(baseline_sc.CL_SECTOR,sector)),:),"CL_YEAR","ascend");
b2delayed_sc_co =
sortrows(b2delayed_sc((ismember(b2delayed_sc.CL_GEOGRAPHY,country) &
ismember(b2delayed_sc.CL_SECTOR,sector)),:),"CL_YEAR","ascend");
b2immediate_sc_co =
sortrows(b2immediate_sc((ismember(b2immediate_sc.CL_GEOGRAPHY,country)
&ismember(b2immediate_sc.CL_SECTOR,sector)),:),"CL_YEAR","ascend");
netzero2050_sc_co =
sortrows(netzero2050_sc((ismember(netzero2050_sc.CL_GEOGRAPHY,country) &
ismember(netzero2050_sc.CL_SECTOR,sector)),:),"CL_YEAR","ascend");

figure
```

```
if ~GDPflag,
plot(baseline_sc_co.CL_YEAR,baseline_sc_co.CL_VALUE.*options.factor), end
hold on
plot(b2delayed_sc_co.CL_YEAR,b2delayed_sc_co.CL_VALUE.*options.factor)
plot(b2immediate_sc_co.CL_YEAR, b2immediate_sc_co.CL_VALUE.*options.factor)
plot(netzero2050_sc_co.CL_YEAR,netzero2050_sc_co.CL_VALUE.*options.factor)
hold off
if ~GDPflag
    legend('Baseline (Policies 2019)','Below 2^oC Delayed','Below 2^oC
Immediate','Net-Zero 2050 1.5^oC','Location','southoutside','NumColumns',2)
else
    legend('Below 2^oC Delayed','Below 2^oC Immediate','Net-Zero 2050
1.5^oC','Location','southoutside','NumColumns',3)
end
ylabel(options.yLabel)
title(options.title)
grid on

end
```

creaete global GHG emissions by years

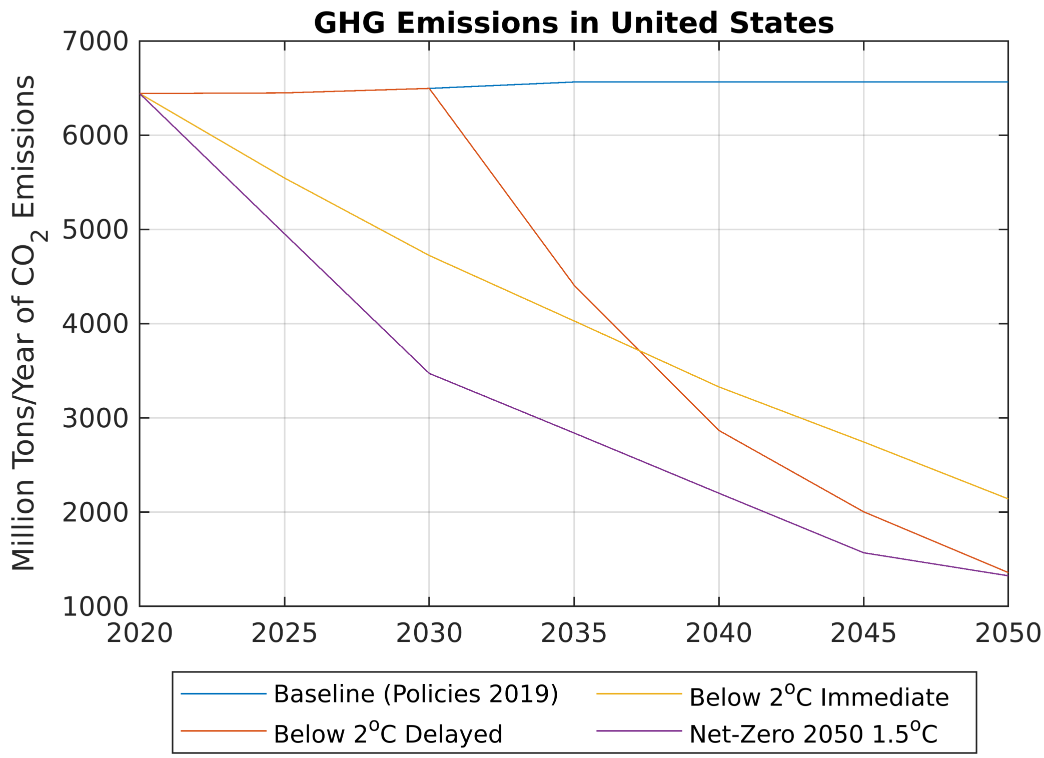
```
options = updateOptions(options,1e-3,"Global GHG Emissions","GigaTons/Year
of CO_2 Emissions");
plotVariableByCountry('Global',{'Emissions | total GHG (scope 1)'},'Global',
options);
```



As expected, the global GHG emissions for the Baseline (2019 Policies) are increasing. The GHG emissions for the Below 2°C Delayed scenario are increasing in the same manner until 2030, when a reduction in carbon dioxde emissions begins, and then shows a sharp reduction in emissions until 2050. The two other scenarios, Below 2°C Immediate and Net-Zero 2050 (1.5°C) show sharper decreases as the actions for emission mitigation start on 2020. The Net-Zero 2050 (1.5°C) scenario shows a faster decrease in carbon dioxide emissions because the target is an average decrease in global temperature of about 1.5 degrees by 2050. This target is a more aggressive assumption than the Below 2°C Delayed scenario, which aims to achieve an average decrease in global temperature of about 2 degrees by 2100.

Regional CO2 emissions

```
region = regions(9);
options = updateOptions(options,1,strcat("GHG Emissions in ",
region),"Million Tons/Year of CO_2 Emissions");
plotVariableByCountry(region,'Emissions | total GHG (scope 1)',
{'National','Global'},options);
```



Regional Sectorial Carbon Dioxide Emissions

Create a plotVariableBySector function to show bar graphs for the predicted GHG emissions, by sector, for the four climate scenarios.

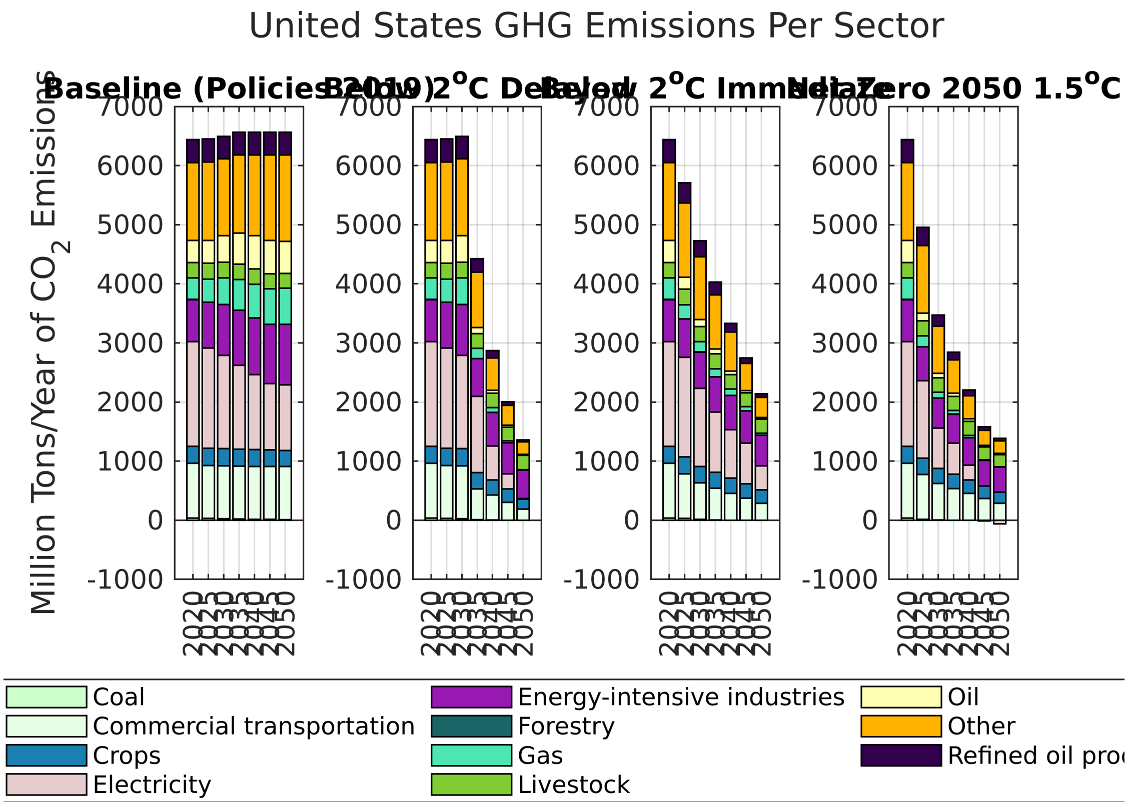
```
function plotVariableBySector(country,variable,options)

baseline_sc =
options.baseline(ismember(options.baseline.CL_VARIABLE,variable),:);
b2delayed_sc =
options.b2delayed(ismember(options.b2delayed.CL_VARIABLE,variable),:);
b2immediate_sc =
options.b2immediate(ismember(options.b2immediate.CL_VARIABLE,variable),:);
netzero2050_sc =
options.netzero2050(ismember(options.netzero2050.CL_VARIABLE,variable),:);

baseline_sc_co =
sortrows(baseline_sc(ismember(baseline_sc.CL_GEOGRAPHY,country),:),"CL_YEAR",
"ascend");
b2delayed_sc_co =
sortrows(b2delayed_sc(ismember(b2delayed_sc.CL_GEOGRAPHY,country),:),"CL_YEAR
","ascend");
b2immediate_sc_co =
sortrows(b2immediate_sc(ismember(b2immediate_sc.CL_GEOGRAPHY,country),:),"CL_
YEAR","ascend");
```

```
netzero2050_sc_co =
sortrows(netzero2050_sc(ismember(netzero2050_sc.CL_GEOGRAPHY,country),:),"CL_
YEAR","ascend");

YRS = unique(baseline_sc_co.CL_YEAR);
SEC = unique(baseline_sc_co.CL_SECTOR); SEC(SEC=="Oil & Gas") = [];
SEC(SEC=="Global") = []; SEC(SEC=="National") = [];

scenariosTitles = {'Baseline (Policies 2019)','Below 2^oC Delayed','Below
2^oC Immediate','Net-Zero 2050 1.5^oC'};

% Perform initiatilization
for ii = 1:length(YRS)
    for jj = 1:length(SEC)
        idx = jj+((ii-1)*length(SEC));
        fun = @max;
        max_baseline_sc_co(idx,:) =
varfun(fun,baseline_sc_co((ismember(baseline_sc_co.CL_YEAR,YRS(ii))
& ismember(baseline_sc_co.CL_SECTOR,SEC(jj))),
["CL_VALUE","CL_YEAR","CL_SECTOR","CL_VARIABLE"]),'GroupingVariables',
{'CL_SECTOR','CL_VARIABLE'});
        max_b2delayed_sc_co(idx,:) =
varfun(fun,b2delayed_sc_co((ismember(b2delayed_sc_co.CL_YEAR,YRS(ii))&
ismember(b2delayed_sc_co.CL_SECTOR,SEC(jj))),
["CL_VALUE","CL_YEAR","CL_SECTOR","CL_VARIABLE"]),'GroupingVariables',
{'CL_SECTOR','CL_VARIABLE'});
        max_b2immediate_sc_co(idx,:) =
varfun(fun,b2immediate_sc_co((ismember(b2immediate_sc_co.CL_YEAR,YRS(ii))&
ismember(b2immediate_sc_co.CL_SECTOR,SEC(jj))),
["CL_VALUE","CL_YEAR","CL_SECTOR","CL_VARIABLE"]),'GroupingVariables',
{'CL_SECTOR','CL_VARIABLE'});
        max_netzero2050_sc_co(idx,:) =
varfun(fun,netzero2050_sc_co((ismember(netzero2050_sc_co.CL_YEAR,YRS(ii))&
ismember(netzero2050_sc_co.CL_SECTOR,SEC(jj))),
["CL_VALUE","CL_YEAR","CL_SECTOR","CL_VARIABLE"]),'GroupingVariables',
{'CL_SECTOR','CL_VARIABLE'});
    end
end

T1 = [];
T2 = [];
T3 = [];
T4 = [];

% Prepare data to stack
for ii = 1:length(YRS)
    T1 = [T1;
table2array(max_baseline_sc_co(ismember(max_baseline_sc_co.max_CL_YEAR,YRS(ii
)),"max_CL_VALUE"))'.*options.factor];
```

```
    T2 = [T2;
table2array(max_b2delayed_sc_co(ismember(max_b2delayed_sc_co.max_CL_YEAR,YRS(
ii)),"max_CL_VALUE"))'.*options.factor];
    T3 = [T3;
table2array(max_b2immediate_sc_co(ismember(max_b2immediate_sc_co.max_CL_YEAR,
YRS(ii)),"max_CL_VALUE"))'.*options.factor];
    T4 = [T4;
table2array(max_netzero2050_sc_co(ismember(max_netzero2050_sc_co.max_CL_YEAR,
YRS(ii)),"max_CL_VALUE"))'.*options.factor];

end

% Create colorSet
rng(0)
colorSet = round(rand(length(SEC),3),1);

figure
t = tiledlayout(1,4);
t.Title.String = options.title;
t.YLabel.String = options.yLabel;
colororder(colorSet)

ax1 = nexttile;
bar(ax1,YRS,T1,'stacked');
xtickangle(90)
grid on
title(scenariosTitles(1))


ax2 = nexttile;
bar(ax2,YRS,T2,'stacked');
xtickangle(90)
grid on
title(scenariosTitles(2))

ax3 = nexttile;
bar(ax3,YRS,T3,'stacked');
xtickangle(90)
grid on
title(scenariosTitles(3))

ax4 = nexttile;
bar(ax4,YRS,T4,'stacked')
xtickangle(90)
grid on
title(scenariosTitles(4))

linkaxes([ax1 ax2 ax3 ax4],'xy')

lg = legend(SEC,'Location','southoutside','NumColumns',3);
```

```
lg.Layout.Tile = 'South'; % Legend placement with tiled layout

end
```

```
region = regions(9);
if (strcmp(region, "Global"))
    options = updateOptions(options,1e-3,strcat(region, " GHG Emissions Per
Sector"),"Gigatons/year of CO_2 Emissions");
else
    options = updateOptions(options,1,strcat(region, " GHG Emissions Per
Sector"),"Million Tons/Year of CO_2 Emissions");
end
plotVariableBySector(region,{'Emissions | total GHG (scope 1)','Emissions
and removals from forestry'},options)
```



The largest impact in the reduction of gas emissions is achieved by the electricity sector. The electricity sector uses low to zero emission technologies like wind and solar. Also many sectors leverage electricity as a substitute to fossil-fuel products. For example, in the commercial transportation sector, you can see the transition to electric vehicles.

Regional Electricity Generation

create a plotEnergyBySector function to show bar graphs for electricity generation by region.

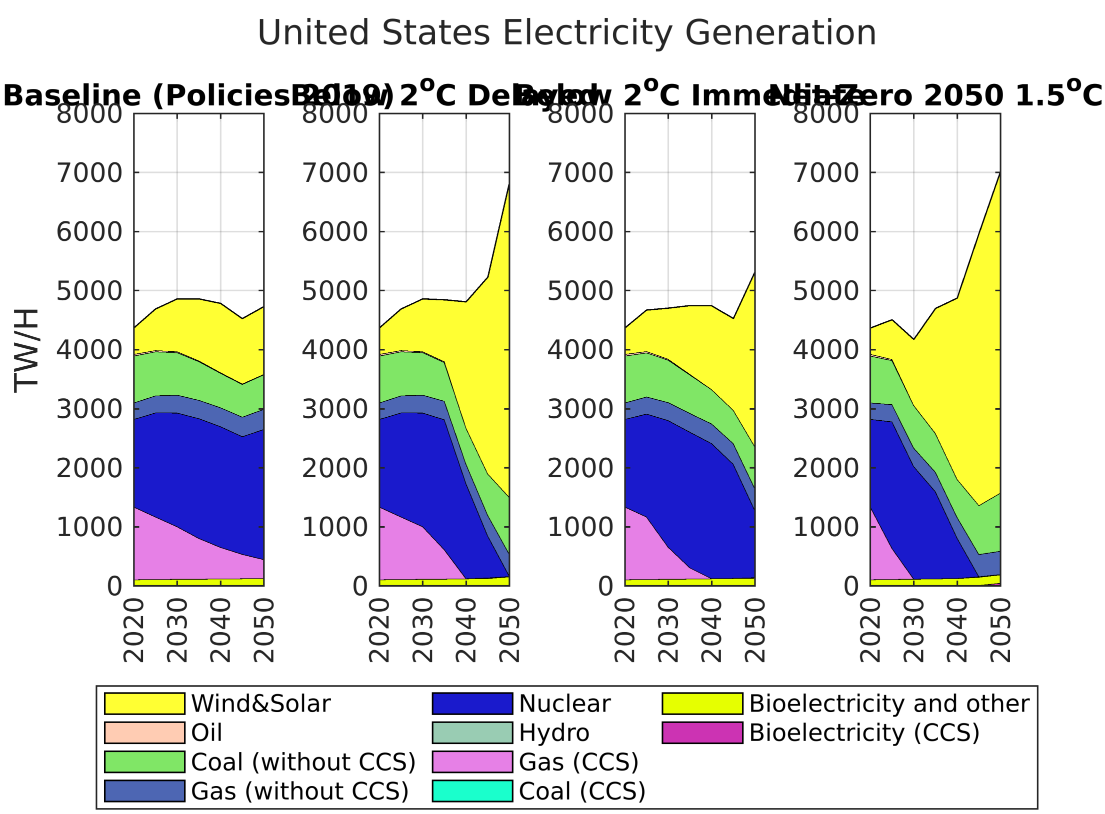
```
function plotEnergyBySector(country,sector,options)
```

```
Prim =  {'Primary Energy | Bioenergy','Primary Energy | Coal','Primary
Energy | Gas', 'Primary Energy | Hydro', ...
    'Primary Energy | Nuclear','Primary Energy | Oil','Primary Energy |
Renewables (wind&solar)'};
Sec =  {'Secondary Energy | Electricity| Bioelectricity (CCS)', ...
    'Secondary Energy | Electricity| Bioelectricity and other', ...
    'Secondary Energy | Electricity| Coal (CCS)', ...
    'Secondary Energy | Electricity| Gas (CCS)', ...
    'Secondary Energy | Electricity| Hydro', ...
    'Secondary Energy | Electricity| Nuclear', ...
    'Secondary Energy | Electricity| Gas (without CCS)', ...
    'Secondary Energy | Electricity| Coal (without CCS)', ...
    'Secondary Energy | Electricity| Oil', ...
    'Secondary Energy | Electricity| Wind&Solar'};
if strcmp(options.energytype,'primary')
    EnergyVars = Prim;
else
    EnergyVars = Sec;
end


baseline_co =
sortrows(options.baseline((ismember(options.baseline.CL_GEOGRAPHY,country)
& ismember(options.baseline.CL_VARIABLE,EnergyVars) &
ismember(options.baseline.CL_SECTOR,sector)),:),"CL_YEAR","ascend");
b2delayed_co =
sortrows(options.b2delayed((ismember(options.b2delayed.CL_GEOGRAPHY,country)
& ismember(options.b2delayed.CL_SECTOR,sector) &
ismember(options.b2delayed.CL_VARIABLE,EnergyVars)),:),"CL_YEAR","ascend");
b2immediate_co =
sortrows(options.b2immediate((ismember(options.b2immediate.CL_GEOGRAPHY,count
ry) & ismember(options.b2immediate.CL_SECTOR,sector) &
ismember(options.b2immediate.CL_VARIABLE,EnergyVars)),:),"CL_YEAR","ascend");
netzero2050_co =
sortrows(options.netzero2050((ismember(options.netzero2050.CL_GEOGRAPHY,count
ry) & ismember(options.netzero2050.CL_SECTOR,sector) &
ismember(options.netzero2050.CL_VARIABLE,EnergyVars)),:),"CL_YEAR","ascend");

scenariosTitles = {'Baseline (Policies 2019)','Below 2^oC Delayed','Below
2^oC Immediate','Net-Zero 2050 1.5^oC'};


YRS = unique(baseline_co.CL_YEAR);
VARS = unique(baseline_co.CL_VARIABLE);

T1 = [];
T2 = [];
T3 = [];
T4 = [];
```

```
% Prepare data to stack
for ii = 1:length(YRS)
    T1 = [T1;
table2array(baseline_co(ismember(baseline_co.CL_YEAR,YRS(ii)),"CL_VALUE"))'.*
options.factor];
    T2 = [T2;
table2array(b2delayed_co(ismember(b2delayed_co.CL_YEAR,YRS(ii)),"CL_VALUE"))'
.*options.factor];
    T3 = [T3;
table2array(b2immediate_co(ismember(b2immediate_co.CL_YEAR,YRS(ii)),"CL_VALUE
"))'.*options.factor];
    T4 = [T4;
table2array(netzero2050_co(ismember(netzero2050_co.CL_YEAR,YRS(ii)),"CL_VALUE
"))'.*options.factor];

end

rng(0)
colorSet = round(rand(length(VARS),3),1);

figure
t = tiledlayout(1,4);
t.Title.String = options.title;
t.YLabel.String = options.yLabel;
colororder(colorSet)

ax1 = nexttile;
area(YRS,T1);
grid on
xtickangle(90)
title(scenariosTitles(1))


ax2 = nexttile;
area(YRS,T2);
grid on
xtickangle(90)
title(scenariosTitles(2))

ax3 = nexttile;
area(YRS,T3);
xtickangle(90)
grid on
title(scenariosTitles(3))


ax4 = nexttile;
area(YRS,T4)
```

```
xtickangle(90)
grid on
title(scenariosTitles(4))

if strcmp(options.energytype,'primary')
    newVars = strrep(EnergyVars,'Primary Energy | ','');
else
    newVars = strrep(EnergyVars,'Secondary Energy | Electricity| ','');
end
lg  = legend(newVars,'Location','southoutside','NumColumns',3) ;
lg.Layout.Tile = 'South'; % Legend placement with tiled layout

linkaxes([ax1 ax2 ax3 ax4],'xy')
xtickangle(90)

end
```

```
region = regions(9);
options = updateOptions(options, 1,strcat(region," Electricity Generation"),
"TW/H",'secondary');
plotEnergyBySector(region,'Electricity',options)
```



Measure Transition Risk for Loan Portfolios with Respect to Climate Scenarios

load the data again and trim it to get what we want

```
load BankOfCanadaClimateScenarioData.mat
head(ClimateTransitionScenarioData)
```

k	CL_GEOGRAPHY	CL_SECTOR	CL_VARIABLE	CL_UNIT	CL_S
_	____________	_________	_______________________________	___________________	__________
1	Canada	National	Carbon price	US$2014/tCO2e	Baseline (
2	Canada	National	Carbon price	US$2014/tCO2e	Below 2°C
3	Canada	National	Emissions | total GHG (scope 1)	Million tonnes CO2e	Baseline (
4	Canada	National	Emissions | total GHG (scope 1)	Million tonnes CO2e	Below 2°C
5	Canada	National	Input price | Coal	Index (2014 = 1)	Baseline (
6	Canada	National	Input price | Coal	Index (2014 = 1)	Below 2°C
7	Canada	National	Input price | Crops	Index (2014 = 1)	Baseline (
8	Canada	National	Input price | Crops	Index (2014 = 1)	Below 2°C

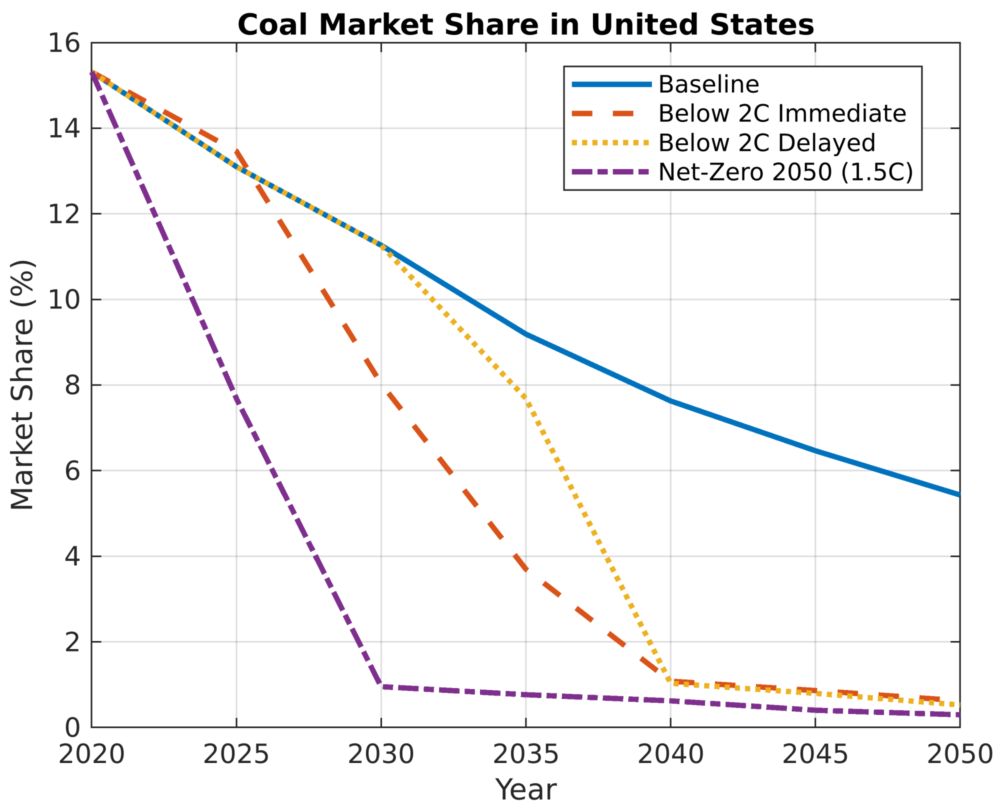
```
% This example uses only the Primary Energy variables to compute market
shares for different geographies.
VariableSubset = {'Primary Energy | Bioenergy', 'Primary Energy | Coal',
'Primary Energy | Gas', ...
'Primary Energy | Hydro', 'Primary Energy | Nuclear', 'Primary Energy |
Oil', ...
'Primary Energy | Renewables (wind&solar)', 'Primary Energy | Total'};
ClimateTransitionScenarioData =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_VARIA
BLE, VariableSubset),:);

% Remove columns 'k','CL_SECTOR' and 'CL_UNIT' and then sort the rows.
ClimateTransitionScenarioData = removevars(ClimateTransitionScenarioData,
{'k','CL_SECTOR','CL_UNIT'});
ClimateTransitionScenarioData = sortrows(ClimateTransitionScenarioData);

% Pull market share data out according to climate scenario.
baseline =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_SCENA
RIO, 'Baseline (2019 policies)'),:);
b2delayed =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_SCENA
RIO, 'Below 2°C delayed'),:);
b2immediate =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_SCENA
RIO, 'Below 2°C immediate'),:);
netzero2050 =
ClimateTransitionScenarioData(ismember(ClimateTransitionScenarioData.CL_SCENA
RIO, 'Net-zero 2050 (1.5°C)'),:);

% Compile all the scenarios into one data set.
MarketShareData = baseline;
MarketShareData = removevars(MarketShareData, "CL_SCENARIO");
MarketShareData.Properties.VariableNames(4) = "BASELINE";
```

```
MarketShareData.BELOW_2C_IMMEDIATE = b2immediate.CL_VALUE;
MarketShareData.BELOW_2C_DELAYED = b2delayed.CL_VALUE;
MarketShareData.NETZERO_2050 = netzero2050.CL_VALUE;
head(MarketShareData)
```

CL_GEOGRAPHY	CL_VARIABLE	CL_YEAR	BASELINE	BELOW_2C_IMMEDIATE	BELOW_2C_DE
Africa	Primary Energy | Bioenergy	2020	15.502	15.502	15.502
Africa	Primary Energy | Bioenergy	2025	15.302	15.302	15.302
Africa	Primary Energy | Bioenergy	2030	15.221	15.203	15.221
Africa	Primary Energy | Bioenergy	2035	15.072	15.042	15.084
Africa	Primary Energy | Bioenergy	2040	15.016	15.055	15.23
Africa	Primary Energy | Bioenergy	2045	14.249	14.273	14.652
Africa	Primary Energy | Bioenergy	2050	13.591	14	14.645
Africa	Primary Energy | Coal	2020	4.5909	4.5909	4.5909

Select the geography and subsector, and then compute the market share.

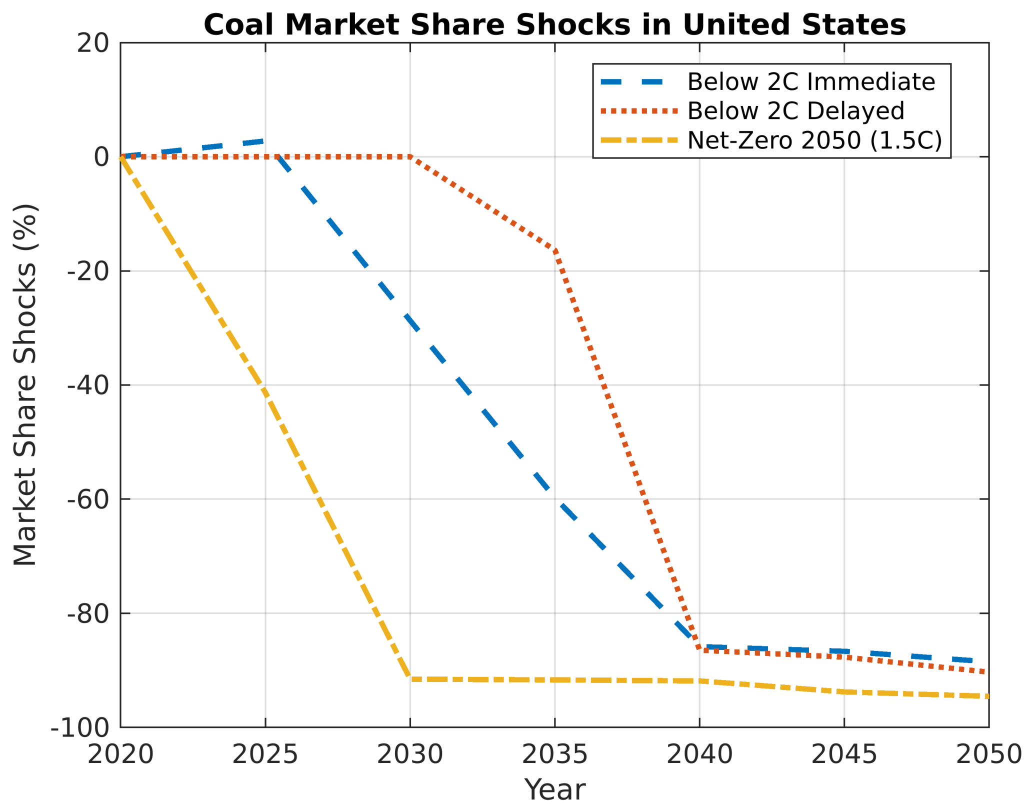
```
Geography = "United States";
Sector = "Coal";
SectorFullName = "Primary Energy | " + Sector;
BaseSector = "Primary Energy | Total";

Years = (2020:5:2050)';
GeographyData = MarketShareData(MarketShareData.CL_GEOGRAPHY ==
Geography, :);
MarketShare = GeographyData{GeographyData.CL_VARIABLE == SectorFullName,
4:7} ./ GeographyData{GeographyData.CL_VARIABLE == BaseSector, 4:7} * 100;
figure;
msPlot = plot(Years, MarketShare, 'LineWidth',2);
grid on
set(msPlot, {'LineStyle'}, {'-';'--';':';'-.'})
legend("Baseline", "Below 2C Immediate", "Below 2C Delayed", "Net-Zero 2050
(1.5C)", 'Location','best');
xlim([2020 2050])
ylabel('Market Share (%)')
xlabel('Year')
title(Sector + " Market Share in " + Geography)
```



For the coal sector in the US, the baseline scenario shows a drop in market share. However, this drop is accelerates in each of the three climate scenarios. The Below 2C Delayed scenario coincides with the baseline up until 2030, after which there is a sudden fall in market share, whereas the other two scenarios (Below 2C Immediate and Net-Zero 2050) lose market share have a much earlier drop.

Compute shocks for all climate scenarios.

```
Shocks = (MarketShare(:,2:4) - MarketShare(:,1))./MarketShare(:,1)*100;
% plot
figure;
shp = plot(Years, Shocks, 'LineWidth',2);
grid on
set(shp, {'LineStyle'}, {'--';':';'-.'})
xlabel('Year')
ylabel('Market Share Shocks (%)')
xlim([2020 2050])
legend("Below 2C Immediate", "Below 2C Delayed", "Net-Zero 2050 (1.5C)",
'Location','best');
title(Sector + " Market Share Shocks in " + Geography);
```



For the default coal sector in the US, the Below 2C Immediate and the Net-Zero 2050 scenarios have a linear negative market share shock over time. However, the Below 2C Delayed scenario shows no market share shock until 2030, and then there is a sudden drop until 2050.

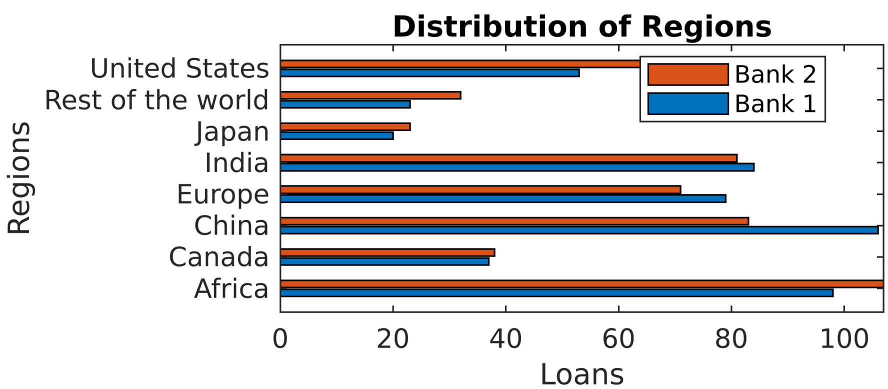
Obtain Loan Portfolio Data

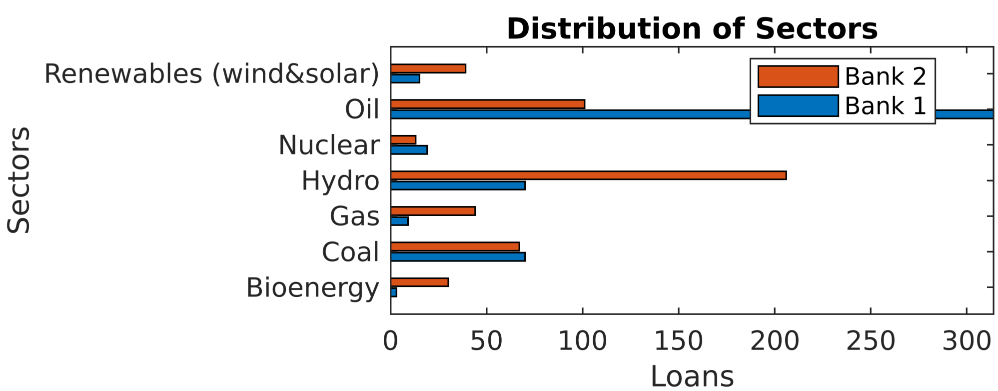
This example uses a second data set (ClimateLoanPortfolioData.mat) for a loan portfolio. This data set contains simulated loan data of two fictitious banks: Bank 1 and Bank 2. The portfolio of loans are from different geographies and sectors. The example uses the face value of the loans to compute the change in reserves that a bank has to allocate when a climate shock occurs.

Generate histograms to show the distribution of loans, by region and sector, for the two simulated banks.

```
load ClimateLoanPortfolioData
LoanPortfolioDataBank1 =
ClimateLoanPortfolioData(ClimateLoanPortfolioData.Bank=='Bank1',:);
LoanPortfolioDataBank2 =
ClimateLoanPortfolioData(ClimateLoanPortfolioData.Bank=='Bank2',:);

[CountsRegion1, BinsRegion1] =
histcounts(LoanPortfolioDataBank1.BorrowerRegion);
[CountsSector1, BinsSector1] =
histcounts(LoanPortfolioDataBank1.BorrowerSector);
[CountsRegion2, BinsRegion2] =
histcounts(LoanPortfolioDataBank2.BorrowerRegion);
```

```
[CountsSector2, BinsSector2] =
histcounts(LoanPortfolioDataBank2.BorrowerSector);

figure
tiledlayout(2,1)
nexttile
barh(categorical(BinsRegion1), [CountsRegion1; CountsRegion2]);
xlabel('Loans')
ylabel('Regions')
title('Distribution of Regions')
legend({'Bank 1', 'Bank 2'},'Location','best')
nexttile
barh(categorical(BinsSector1), [CountsSector1; CountsSector2]);
xlabel('Loans')
ylabel('Sectors')
title('Distribution of Sectors')
legend({'Bank 1', 'Bank 2'},'Location','best')
```





Bank 1 is heavily invested in fossil fuel projects (primarily oil) and Bank 2 is invested in green energy projects (primarily hydro). Regarding the distribution of projects across geographies, both banks are similar, with a larger number of projects in developing regions like China, India, and Africa.

Create Valuation Framework for Loan Contracts Subject to Climate Policy Shocks

Computes the change in value for one loan. By default, the 12th row of the data set is selected, which is an oil project in the United States for Bank 1. You can also select a different ClimateScenario from the three available scenarios. By default, the Below 2°C Delayed scenario is selected.

```
Loan = 12;
ClimateScenario = 2;
Geography = string(ClimateLoanPortfolioData{Loan,'BorrowerRegion'});
Sector = string(ClimateLoanPortfolioData{Loan,'BorrowerSector'});
LoanID = ClimateLoanPortfolioData{Loan,'LoanID'};
FaceValueOfLoan = ClimateLoanPortfolioData{Loan,"FaceValue"};
SectorFullName = "Primary Energy | " + Sector;
disp(ClimateLoanPortfolioData(Loan,:));
```

LoanID	BorrowerCreditRating	LoanType	Bank	InterestRate	InterestType	Borrower
"786801JSP"	A2	Term	Bank1	0.028	Fixed	"SI1447619

You can modify the recovery rate , as well as, . By default, and . A normal range of is from 0.2 to 0.6.

Following the Monasterolo et al., (2018) discussion in appendix I, set to correspond to the assumption that the magnitude of the initial net worth and width of the distribution of the idiosyncratic shocks are comparable. You can adjust the EjDeltaRatio value using the slider.

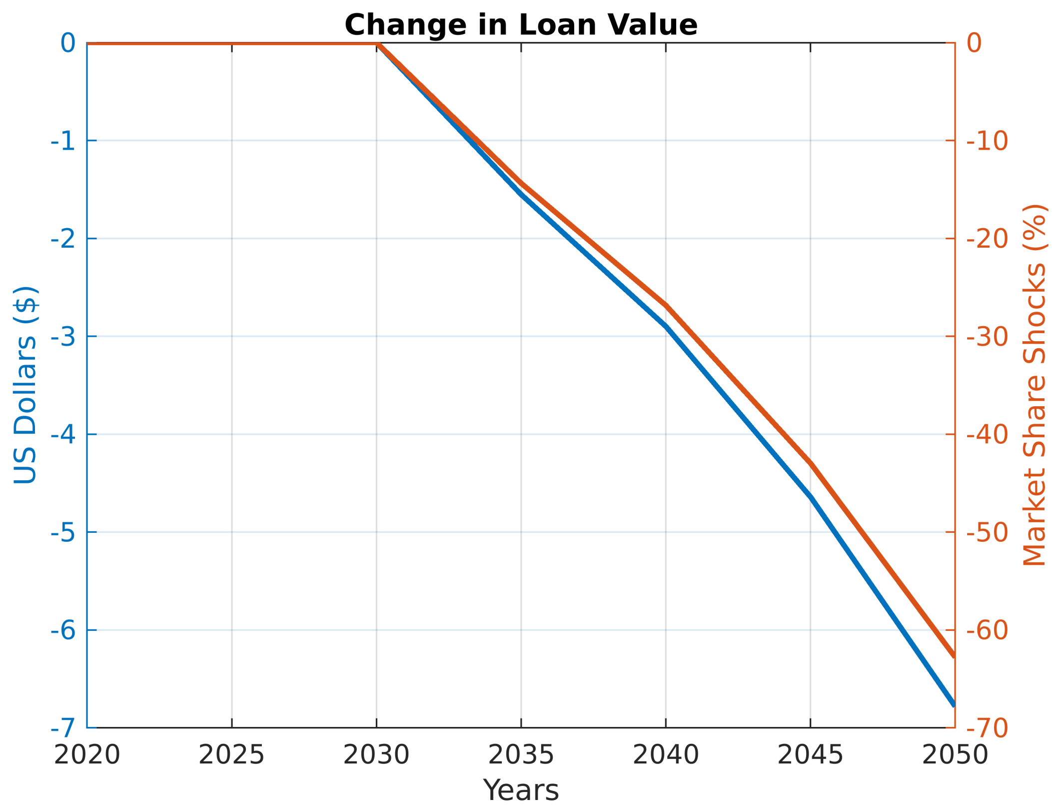
```
RecoveryRate =0.4;
Chi =0.3;
EjDeltaRatio = 1;
TargetYear = 4;

GeographyData = MarketShareData(MarketShareData.CL_GEOGRAPHY ==
Geography, :);
MarketShare = GeographyData{GeographyData.CL_VARIABLE == SectorFullName,
4:7} ./ GeographyData{GeographyData.CL_VARIABLE == BaseSector, 4:7} * 100;
Shocks = (MarketShare(:,2:4) - MarketShare(:,1))./MarketShare(:,1)*100;

ChangeInDefaultProbability = -EjDeltaRatio.*Chi.*(Shocks(:,ClimateScenario)/
100);
ChangeInValue = -FaceValueOfLoan.*(1-
RecoveryRate).*ChangeInDefaultProbability;
disp("The change in value of the loan in the selected climate scenario and
target year = $" + num2str(ChangeInValue(TargetYear)));
```

```
The change in value of the loan in the selected climate scenario and target year = $-155161.6488
```

The change in value of a loan is directly translated into a change in the reserves that need to be allocated by the bank for that particular loan.

```
% Plot change in value of loan over time superimposed over corresponding
shock.
f = figure;
```

```
ax = axes(f);
yyaxis(ax, 'left')
plot(Years, ChangeInValue, 'LineWidth', 2)
xlabel('Years');
ylabel('US Dollars ($)')
yyaxis(ax, 'right')
plot(Years, Shocks(:, ClimateScenario), 'LineWidth', 2);
ylabel('Market Share Shocks (%)');
title('Change in Loan Value');
grid on
```



Compute Change in Value of Entire Portfolio of Loans

For each of the two banks, Bank 1 and Bank 2, compute the total change in loan value of the entire portfolio of loans for each climate scenario.

```
% For each of the region and sector pairs, compute the market shocks for all
scenarios and store these values.
MarketShocks = struct();

Bank1Combos = unique(table(LoanPortfolioDataBank1.BorrowerRegion,
LoanPortfolioDataBank1.BorrowerSector,'VariableNames',
{'Region','Sector'}),'rows');
Bank2Combos = unique(table(LoanPortfolioDataBank2.BorrowerRegion,
LoanPortfolioDataBank2.BorrowerSector,'VariableNames',
{'Region','Sector'}),'rows');
TotalCombos = union(Bank1Combos, Bank2Combos);
```

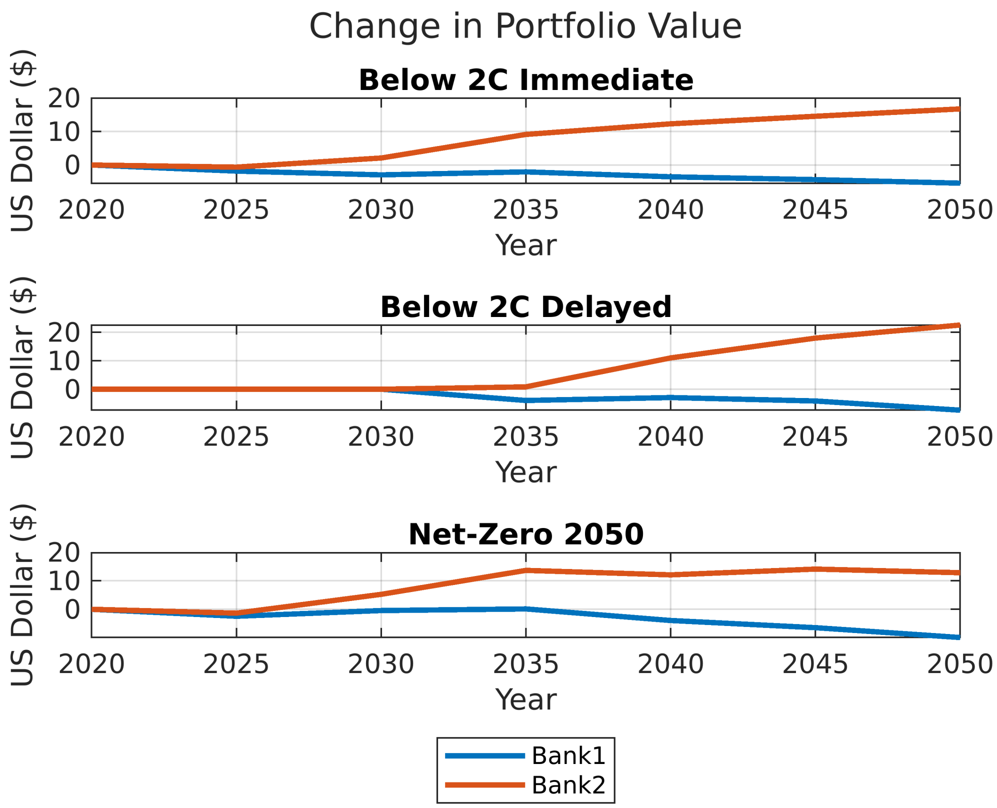
```
for i = 1:height(TotalCombos)
    Region = string(TotalCombos.Region(i));
    Sector = string(TotalCombos.Sector(i));
    SectorFullName = "Primary Energy | " + Sector;
    GeographyData = MarketShareData(MarketShareData.CL_GEOGRAPHY ==
Region, :);
    MarketShare = GeographyData{GeographyData.CL_VARIABLE == SectorFullName,
4:7} ./ GeographyData{GeographyData.CL_VARIABLE == BaseSector, 4:7} * 100;
    Shocks = (MarketShare(:,2:4) - MarketShare(:,1))./MarketShare(:,1)*100;
    if Sector == "Renewables (wind&solar)"
        SectorSplit = strsplit(Sector);
        Sector = SectorSplit(1);
    end
    MarketShocks.(strrep(Region,' ','')).(strrep(Sector,' ','')) = Shocks;
end
```

Create a table containing the values of each loan, for each bank, for each climate scenario, and for each target year. Use the same model parameter values for simplicity. However, you can change these parameters for different issuers.

```
RecoveryRate =0.46;
Chi =0.3;
EjDeltaRatio = 1;

LoanValues = ClimateLoanPortfolioData;
LoanValues = removevars(LoanValues,
{'LoanType','BorrowerCreditRating','InterestRate','InterestType','BorrowerID'
,'OriginationDate','MaturityDate','FairValue'});
LoanValues = repelem(LoanValues, 7, 1);
LoanValues.Year = repmat([2020; 2025; 2030; 2035; 2040; 2045; 2050], 1000,
1);
LoanValues.Below2CImmediate = zeros(7000, 1);
LoanValues.Below2CDelayed = zeros(7000, 1);
LoanValues.NetZero2050 = zeros(7000, 1);

for i = 1:7:height(LoanValues)
    Region = string(LoanValues.BorrowerRegion(i));
    Sector = string(LoanValues.BorrowerSector(i));
    if Sector == "Renewables (wind&solar)"
        SectorSplit = strsplit(Sector);
        Sector = SectorSplit(1);
    end
    Value = LoanValues.FaceValue(i);
    ChangeInValue = Value.*(1-
RecoveryRate).*EjDeltaRatio.*Chi.*(MarketShocks.(strrep(Region,' ','')).
(strrep(Sector,' ',''))/100);
    LoanValues{i:i+6, {'Below2CImmediate','Below2CDelayed','NetZero2050'}} =
ChangeInValue;
end
```

Compare the change in portfolio values of the two banks, for each climate scenario, and for all target years.

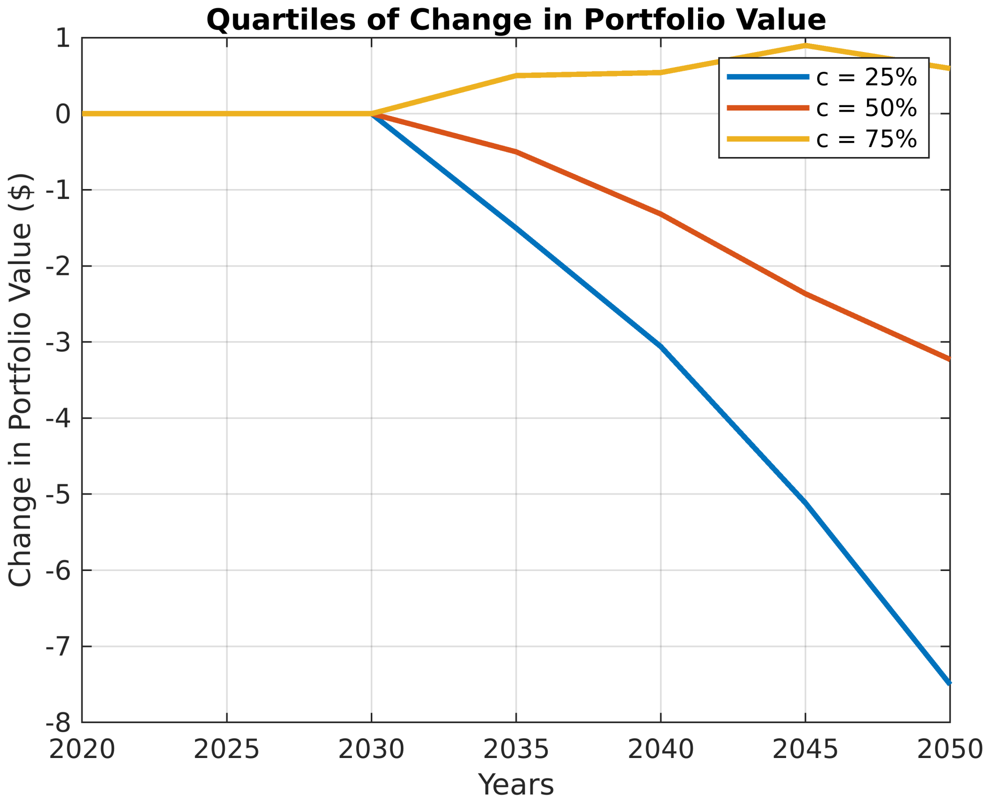
```
TPVBank1 = zeros(length(Years),3);
TPVBank2 = zeros(length(Years),3);
for i = 1:length(Years)
    TBank1 = LoanValues((LoanValues.Bank == "Bank1") & (LoanValues.Year ==
Years(i)), :);
    TBank2 = LoanValues((LoanValues.Bank == "Bank2") & (LoanValues.Year ==
Years(i)), :);
    TPVBank1(i,:) = sum(TBank1{:,7:9});
    TPVBank2(i,:) = sum(TBank2{:,7:9});
end

figure;
t = tiledlayout(3,1);
nexttile
plot(Years, [TPVBank1(:,1),TPVBank2(:,1)], 'LineWidth', 2)
xlabel('Year');
ylabel('US Dollar ($)')
title('Below 2C Immediate')
grid on
nexttile
plot(Years, [TPVBank1(:,2),TPVBank2(:,2)], 'LineWidth', 2)
xlabel('Year');
ylabel('US Dollar ($)')
title('Below 2C Delayed')
grid on
nexttile
plot(Years, [TPVBank1(:,3),TPVBank2(:,3)], 'LineWidth', 2)
xlabel('Year');
ylabel('US Dollar ($)')
title('Net-Zero 2050')
leg = legend({'Bank1','Bank2'});
leg.Layout.Tile = 'south';
grid on
title(t,'Change in Portfolio Value');
```



Considering that Bank 1 is weighted towards fossil fuels and Bank 2 is weighted toward green energy, the portfolio value of Bank 1 decreases over time, while the portfolio value of Bank 2 increases over time for each climate scenario.

Compute and plot the quartiles of the changes in portfolio values over time for the selected bank.

```
Bank = 'Bank1';
PLV = zeros(length(Years),3);
for i = 1:length(Years)
    t = LoanValues((LoanValues.Bank == Bank) & (LoanValues.Year ==
Years(i)), :);
    PLV(i,1) = prctile(t{:,6+ClimateScenario}, 25);
    PLV(i,2) = prctile(t{:,6+ClimateScenario}, 50);
    PLV(i,3) = prctile(t{:,6+ClimateScenario}, 75);
end

figure;
plot(Years, PLV, 'LineWidth', 2)
xlabel('Years');
ylabel('Change in Portfolio Value ($)')
title('Quartiles of Change in Portfolio Value')
legend({'c = 25%','c = 50%','c = 75%'})
grid on
```



To compute some standard metrics of risk such as the Value-at-Risk (VaR) of the portfolio, you need to know the joint probability distribution of the idiosyncratic shocks and the probability of occurrence of climate policy shocks. In the absence of these estimations, Monasterolo (et al., 2018) defines a project-level climate VaR as the value such that, conditional to the same climate policy shock for all n loans, the fraction of loans leading to losses higher than the VaR equals the confidence level c

This project-level climate VaR metric is a percentile of the distribution of value changes for the portfolio.

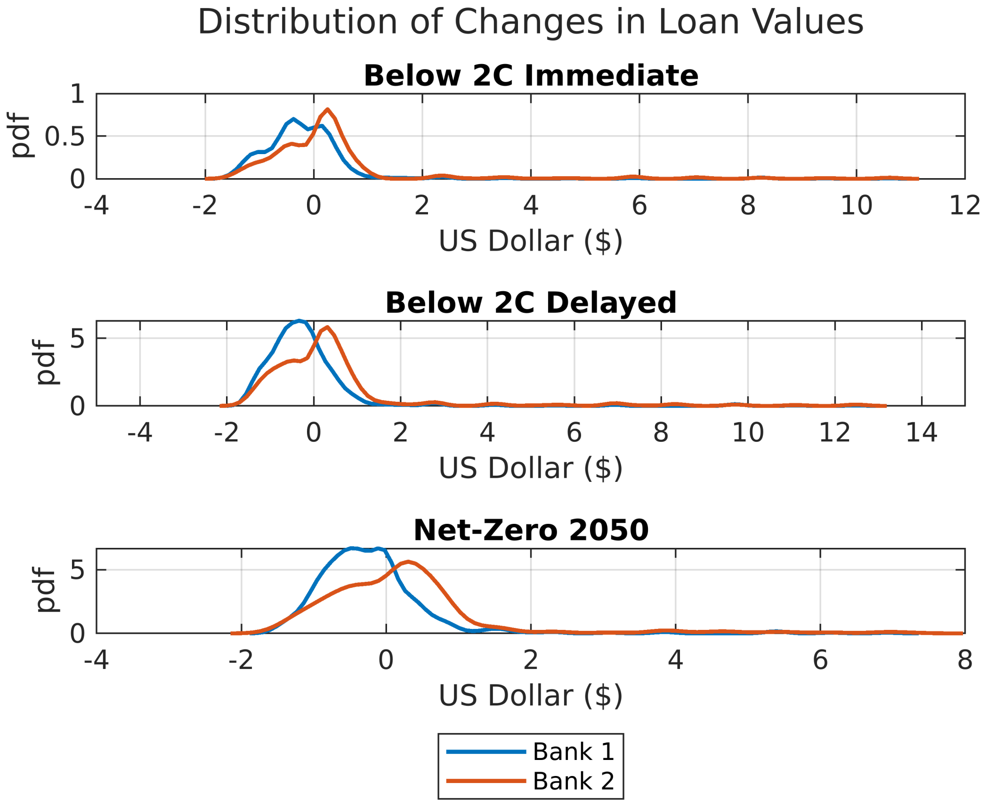
```
Bank = "Bank1";
ClimateScenario = 2;
TargetYear = "2050";
NewTable = LoanValues((LoanValues.Bank == Bank) & (LoanValues.Year ==
str2double(TargetYear)), :);
ConfidenceLevel = 1;
ProjVaR = -prctile(NewTable{:,6+ClimateScenario}, ConfidenceLevel);
disp("The project-level climate VaR at the " + ConfidenceLevel + "%
confidence level = $" + num2str(ProjVaR));
```

```
The project-level climate VaR at the 1% confidence level = $1453621.915
```

Plot a graph of distributions of changes in loan values for each target year and for a given scenario and bank. Use the kernel smoothing function estimate for univariate data. The estimate is based on a normal kernel function and is evaluated at equally spaced points that cover the range of the data.

```
[F1Bank1, Xi1Bank1] = ksdensity(TBank1.Below2CImmediate);
[F1Bank2, Xi1Bank2] = ksdensity(TBank2.Below2CImmediate);
```

```
[F2Bank1, Xi2Bank1] = ksdensity(TBank1.Below2CDelayed);
[F2Bank2, Xi2Bank2] = ksdensity(TBank2.Below2CDelayed);

[F3Bank1, Xi3Bank1] = ksdensity(TBank1.NetZero2050);
[F3Bank2, Xi3Bank2] = ksdensity(TBank2.NetZero2050);

figure;
t = tiledlayout(3,1);
ax1 = nexttile;
plot(Xi1Bank1, F1Bank1, 'LineWidth', 1.5)
hold on
plot(Xi1Bank2, F1Bank2, 'LineWidth', 1.5)
ax1.Title.String = "Below 2C Immediate";
xlabel('US Dollar ($)')
ylabel('pdf')
grid on
ax2 = nexttile;
plot(Xi2Bank1, F2Bank1, 'LineWidth', 1.5)
hold on
plot(Xi2Bank2, F2Bank2, 'LineWidth', 1.5)
ax2.Title.String = "Below 2C Delayed";
xlabel('US Dollar ($)')
ylabel('pdf')
grid on
ax3 = nexttile;
plot(Xi3Bank1, F3Bank1, 'LineWidth', 1.5)
hold on
plot(Xi3Bank2, F3Bank2, 'LineWidth', 1.5)
leg = legend("Bank 1","Bank 2");
leg.Layout.Tile = 'south';
ax3.Title.String = "Net-Zero 2050";
xlabel('US Dollar ($)')
ylabel('pdf')
grid on
title(t,'Distribution of Changes in Loan Values');
```


Distribution of Changes in Loan Values
Below 2C Immediate
pdf
US Dollar ($)
Below 2C Delayed
pdf
US Dollar ($)
Net-Zero 2050
pdf
US Dollar ($)
Bank 1
Bank 2