DEFINE-CLIMATE

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1. Brief description

DEFINE-CLIMATE is a simplified module of DEFINE, which shows how climate change is affected by economic activity. Higher economic growth leads to a generation of higher carbon emissions (for a given level of energy intensity, carbon intensity, sequestration rate and share of renewables). These carbon emissions cumulative carbon emissions which in turn increase atmospheric temperature.

2. Module equations

Output: $Y_t = Y_{t-1}(1+g_Y)$ (1)

Total energy: $E_t = \varepsilon Y_t$ (2)

Fossil energy: $E_{Ft} = (1-\theta)E_t$ (3)

Industrial CO_2 emissions: $EMIS_{INt} = \omega(1-seq)E_{Ft}$ (4)

Land-use CO_2 emissions: $EMIS_{Lt} = EMIS_{Lt-1}(1-g_{EMISLt})$ (5)

Growth rate of land-use CO_2 emissions: $g_{EMISLt} = g_{EMISLt-1}(1-\zeta_9)$ (6)

Total emissions: $EMIS_t = EMIS_{INt} + EMIS_{Lt}$ (7)

Cumulative CO_2 emissions: $CO2_{CUMt} = CO2_{CUMt-1} + EMIS_t$ (8)

Atmospheric temperature: $T_{ATt} = T_{ATt-1} + t_1(t_2\varphi CO2_{CUM-1} - T_{ATt-1})$ (9)

3. Symbols and values

Symbol	Description	Value/calculation
	Parameters	
g_Y	Growth rate of GDP	0.029
ε	Energy intensity, i.e. energy use per unit of GDP (EJ/trillion US$)	Calculated from equation (2)
ϑ	Share of non-fossil energy in total energy	0.15
ω	CO_2 intensity, i.e. CO2 emissions per unit of non-renewable energy use (Gt/EJ)	Calculated from equation (4)
seq	Proportion of carbon that is sequestrated	0.002186
ζ_9	Rate of decline of the growth rate of $EMIS_L$	0.0140
t_1	Coefficient capturing the timescale of the initial adjustment of the climate system to an increase in cumulative emissions	0.5
t_2	Coefficient that captures the global warming that stems from non-CO2 greenhouse gas	1.1
φ	Transient Climate Response to cumulative carbon Emissions (TCRE) ($^oC/GtCO_2$)	0.0005
	Endogenous variables	
Y	Output (trillion US$)	85.9
E	Energy used for the production of output (EJ)	590.0
E_F	Energy produced from fossil sources (EJ)	Calculated from equation (3)
$EMIS_{IN}$	Industrial CO_2 emissions ($GtCO_2$)	36.6
$EMIS_L$	Land-use CO_2 emissions ($GtCO_2$)	5.5
g_{EMISL}	Growth rate of land emissions	0.016
$EMIS$	Total CO_2 emissions ($GtCO_2$)	Calculated from equation (7)
$CO2_{CUM}$	Cumulative CO_2 emissions ($GtCO_2$)	2210
T_{AT}	Atmospheric temperature over pre-industrial levels (^oC)	1.14

4. Steps for simulating the model in R

#Open R and create a new R script (File->New file->R script). Save this file as 'Climate' (File->Save as).

#Clear the workspace and identify how many time periods (T) you wish your model to run (once you write the commands, press 'Source')

```
rm(list=ls(all=TRUE))
T<-83
```

#STEP 1: For each endogenous variable, create a vector that has a length equal to the time periods. (Once you have written the commands, press 'Source'.)

```
#Endogenous variables
Y<- vector(length=T)
E<- vector(length=T)
E_F<- vector(length=T)
EMIS_IN<- vector(length=T)
EMIS_L<- vector(length=T)
EMIS<- vector(length=T)
g_EMIS_L<- vector(length=T)
CO2_CUM<- vector(length=T)
T_AT<- vector(length=T)
```

#STEP 2: Give values to the parameters (use the values reported in the table in Section 3).

```
#Parameters
for (i in 1:T) {
if (i == 1) {
   for (iterations in 1:10){
g_Y<-0.029
epsilon <- E[i]/Y[i] #EJ/trillion US$
theta<-0.15
omega<-EMIS_IN[i]/E_F[i] #Gt/EJ
seq<- 0.002186
zeta_9<-0.014
t_1<- 0.5
t_2<- 1.1
phi<-1.72/(3.667*1000)
```

#STEP 3: Give values to your initial variables (use the values reported in the table in Section 3).

```
#Initial values
Y[i] <- 85.9 #trillion US$
E[i]<-590 #EJ
E_F[i]<-(1-theta)*E[i] #EJ
EMIS_IN[i]<-36.6 #Gt
EMIS_L[i] <-5.5 #Gt
g_EMIS_L[i]<-0.016
EMIS[i]<- EMIS_IN[i]+EMIS_L[i] #Gt
CO2_CUM[i]<-2210 # GtCO2
T_AT[i] <-1.14 #°C
   }
  }
```

#STEP 4: Write down the equations and run the model. (Once you have written the commands, press 'Source'.)

```
#Equations
else {

for (iterations in 1:10){

Y[i] <- Y[i-1]*(1+g_Y) #Eq. (1)
E[i] <- epsilon*Y[i] #Eq. (2)
E_F[i] <- (1-theta)*E[i] #Eq. (3)
EMIS_IN[i] <- omega*(1-seq)*E_F[i] #Eq. (4)
EMIS_L[i]<- EMIS_L[i-1]*(1-g_EMIS_L[i]) #Eq. (5)
g_EMIS_L[i]<-g_EMIS_L[i-1]*(1-zeta_9) #Eq. (6)
EMIS[i] <- EMIS_IN[i]+EMIS_L[i] #Eq. (7)
CO2_CUM[i]<-CO2_CUM[i-1]+EMIS[i] #Eq. (8)
T_AT[i]<-T_AT[i-1]+t_1*(t_2*phi*CO2_CUM[i-1]-T_AT[i-1]) #Eq. (9)
```

```
    }
  }
}
```

#STEP 5: Create a table to report the following variables: Y, E_F, EMIS_IN, EMIS, CO2_CUM, T_AT. Create also 3 graphs for the variables Y, EMIS and T_AT. (Once you have written the commands, press 'Source'.)

```
#Table
matrixname<-paste("Table")
assign (matrixname, (round(cbind(Y, E_F, EMIS_IN, EMIS, CO2_CUM, T_AT), digits=4)))

plot(Table[1:83,c("Y")], type="l", xlab= "Year", ylab="Output (trillion US$)", xaxt="n")
axis(side=1, at=c(1, 13, 23, 33, 43, 53, 63, 73, 83) , labels=c("2018", "2030","2040","2050","2060",
"2070", "2080", "2090", "2100"))

plot(Table[1:83,c("EMIS")], type="l", xlab= "Year", ylab=expression("CO" [2]*" emissions
(Gt)"),xaxt="n")
axis(side=1, at=c(1, 13, 23, 33, 43, 53, 63, 73, 83) , labels=c("2018", "2030","2040","2050","2060",
"2070", "2080", "2090", "2100"))

plot(Table[1:83,c("T_AT")], type="l", xlab= "Year", ylab=expression("Temperature ("^{o}*"C above
pre-industrial)"), xaxt="n")
axis(side=1, at=c(1, 13, 23, 33, 43, 53, 63, 73, 83) , labels=c("2018", "2030","2040","2050","2060",
"2070", "2080", "2090", "2100"))
```