DEFINE-MATTER

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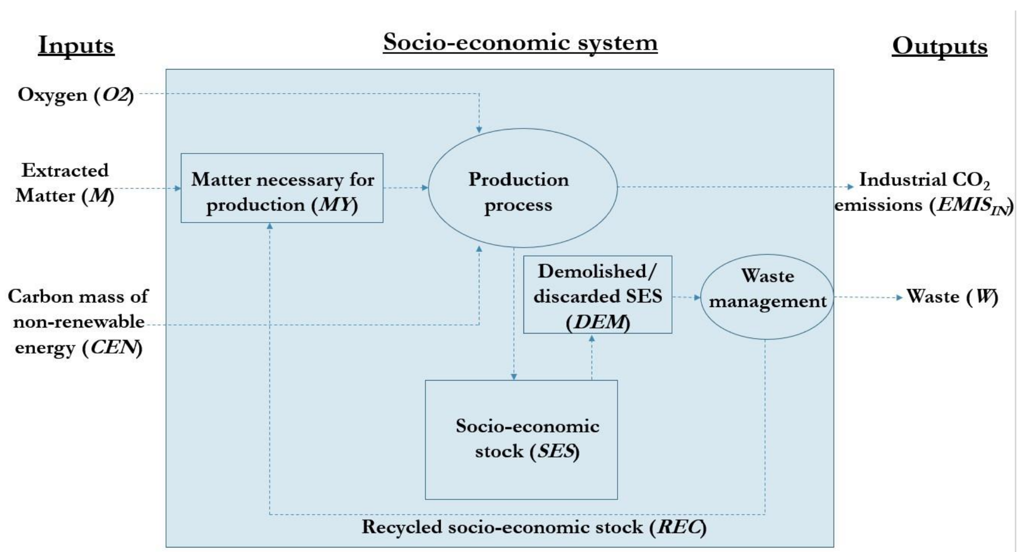
www.define-model.org

1. Brief description

DEFINE-MATTER is a simplified module of DEFINE, which shows how economic growth leads to the extraction of matter and the generation of waste. The figure below outlines how the module works. When production takes place, a specific amount of matter is necessary (this is the 'output in material terms'). This matter can be either extracted from the environment or come from recycling. When matter is extracted, the material reserves (i.e. those volumes of matter expected to be produced economically using the existing technology) tend to decline.

Figure 1: Material inputs and outputs and the socio-economic system



Non-fossil energy (that relies on carbon) is also necessary for the production process. Once the production has taken place, the material content of this energy is extracted to the environment in the form of CO_2 emissions.

The production process generates consumption and investment goods that are accumulated in the socio-economic system. The material content of these goods is called 'socio-economic stock'. A part of this socio-economic stock is demolished/discarded every year. Through waste management, a proportion of demolished/discarded socio-economic stock is recycled. The rest of it becomes waste that is discarded to the environment. Part of this waste is hazardous and can have negative effects both on the environment and the health of the population.

2. Module equations

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

Output in material terms: $MY_t = \mu Y_t$ (2)

Extracted matter: $M_t = MY_t - REC_t$ (3)

Recycled socio-economic stock: $REC_t = \rho DEM_t$ (4)

Demolished/discarded socio-economic stock: $DEM_t = propSES_{t-1}$ (5)

Socio-economic stock: $SES_t = SES_{t-1} + MY_t - DEM_t$ (6)

Waste: $W_t = DEM_t - REC_t$ (7)

Cumulative hazardous waste: $HW_{CUMt} = HW_{CUMt-1} + hazW_t$ (8)

Material reserves: $REV_{Mt} = REV_{Mt-1} + CON_{Mt} - M_t$ (9)

Amount of material resources converted into material reserves: $CON_{Mt} = con_M RES_{Mt-1}$ (10)

Material resources: $RES_{Mt} = RES_{Mt-1} - CON_{Mt}$ (11)

Material depletion ratio: $dep_{Mt} = \frac{M_t}{REV_{Mt-1}}$ (12)

3. Symbols and values

Symbol	Description	Value/calculation
	Parameters	
g_Y	Growth rate of GDP	0.029
μ	Material intensity (kg/$)	Calculated from equation (2)
ρ	Recycling rate	Calculated from equation (4)
prop	Proportion of socio-economic stock that is demolished/discarded	0.013
haz	Proportion of hazardous waste in total waste	0.04
con_M	Conversion rate of material resources into reserves	0.0015
	Endogenous variables	
Y	Output (US$ trillion)	85.9
MY	Output in material terms (Gt)	52.22
M	Extracted matter (Gt)	Calculated from equation (3)
REC	Recycled socio-economic stock (Gt)	4.8
DEM	Demolished/discarded socio-economic stock (Gt)	17.67
SES	Socio-economic stock (Gt)	1230.5
W	Waste (Gt)	Calculated from equation (7)
HW_{CUM}	Cumulative hazardous waste (Gt)	14.6
REV_M	Material reserves (Gt)	Calculated from equation (12)
CON_M	Amount of material resources converted into material reserves (Gt)	Calculated from equation (10)
RES_M	Material resources (Gt)	63.81*REV_M
dep_M	Material depletion ratio	0.02

4. Steps for simulating the module in R

#Open R and create a new R script (File->New file->R script). Save this file as 'Matter' (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)
MY<- vector(length=T)
M<- vector(length=T)
REC<- vector(length=T)
DEM<- vector(length=T)
SES<- vector(length=T)
W<- vector(length=T)
HW_CUM<- vector(length=T)
REV_M<- vector(length=T)
CON_M<- vector(length=T)
RES_M<- vector(length=T)
dep_M<- 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
mu<- MY[i]/Y[i] #Gt/$ trillion  or kg/$
rho<- REC[i]/DEM[i]
prop<-0.013
haz<-0.04
con_M<-0.0015
```

#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$
MY[i]<- 52.22#Gt
M[i]<- MY[i]-REC[i]#Gt
```

```
REC[i]<-4.8 #Gt
DEM[i]<-17.67 #Gt
SES[i]<- 1230.5 #Gt
W[i]<-DEM[i]-REC[i]#Gt
HW_CUM[i]<-14.09 #Gt
REV_M[i]<-M[i]/dep_M[i] #Gt
CON_M[i]<-con_M*RES_M[i] #Gt
RES_M[i]<-63.81*REV_M[i] #Gt
dep_M[i]<-0.02

  }
 }
```

#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){
#Economy
Y[i] <- Y[i-1]*(1+g_Y)

#Matter, recycling and waste
MY[i]<- mu*Y[i]
M[i]<-MY[i]-REC[i]
REC[i]<-rho*DEM[i]
DEM[i]<- prop*SES[i-1]
SES[i]<-SES[i-1]+MY[i]-DEM[i]
W[i]<-DEM[i]-REC[i]
HW_CUM[i]<-HW_CUM[i-1]+haz*W[i]
REV_M[i]<-REV_M[i-1]+CON_M[i]-M[i]
CON_M[i]<-con_M*RES_M[i-1]
RES_M[i]<-RES_M[i-1]-CON_M[i]
dep_M[i]<-M[i]/REV_M[i-1]

  }
 }
}
```

#STEP 5: Create a table to report the following variables: Y, W and dep_M. Create also 3 graphs for these variables. (Once you have written the commands, press 'Source'.)

```
#Table
matrixname<-paste("Table")
assign (matrixname, (round(cbind(Y, W, dep_M), digits=4)))
```

```
plot(Table[1:T,c("Y")], type="l", xlab= "Year", ylab="GDP (US$ trillion)", 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:T,c("W")], type="l", xlab= "Year", ylab=expression("Waste"),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:T,c("dep_M")], type="l", xlab= "Year", ylab="Matter depletion ratio", 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"))
```