CRESCIMENTO VERDE

ANALYSIS

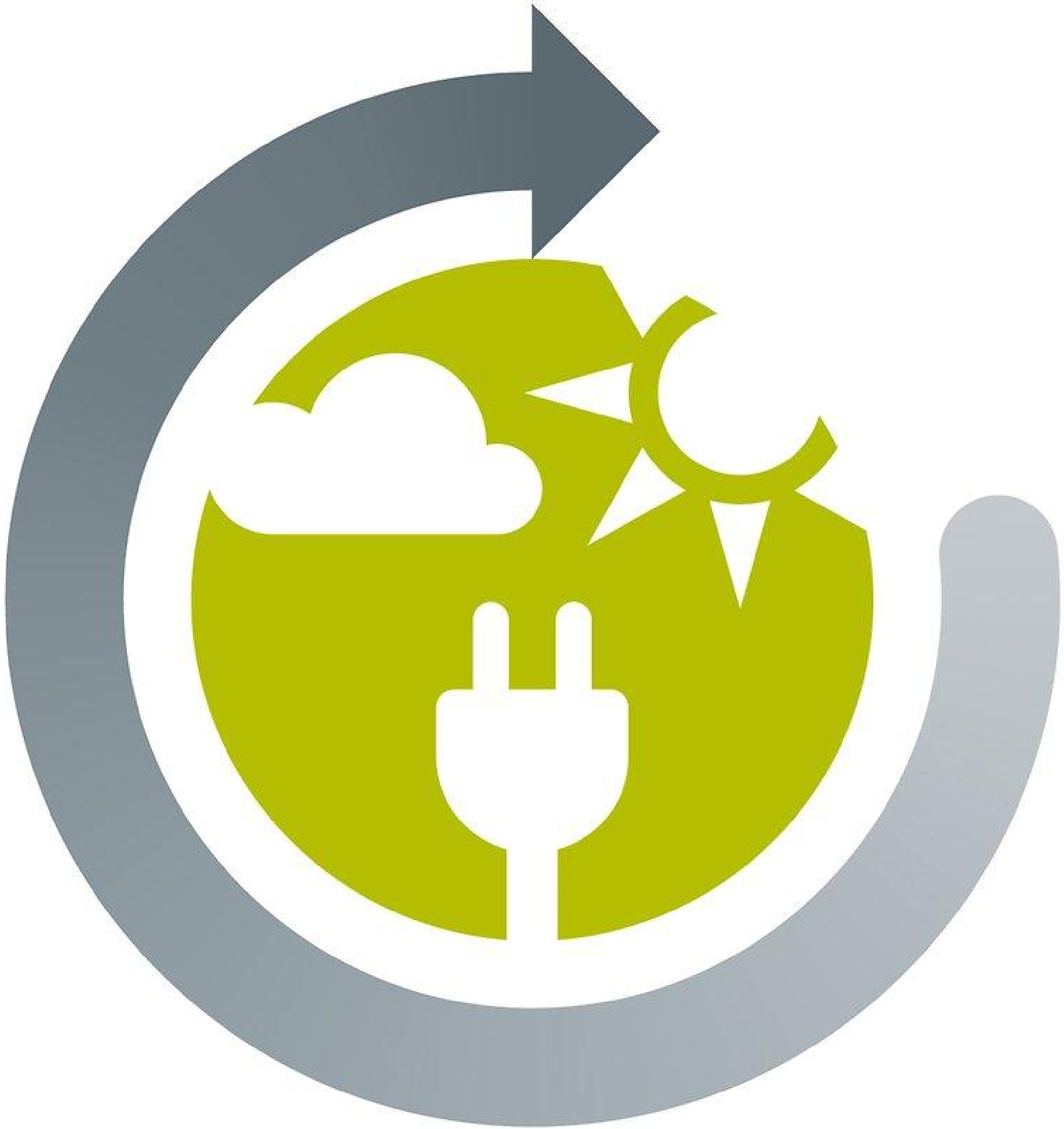
EMSD 2017

Energy and Climate

ALEC ECKERT

AMANDA KARAPICI

2017



Introduction

Goal

Boost the share of renewable energy from 25.7% of final energy consumption in 2013 to 31% in 2020 and 40% in 2030.

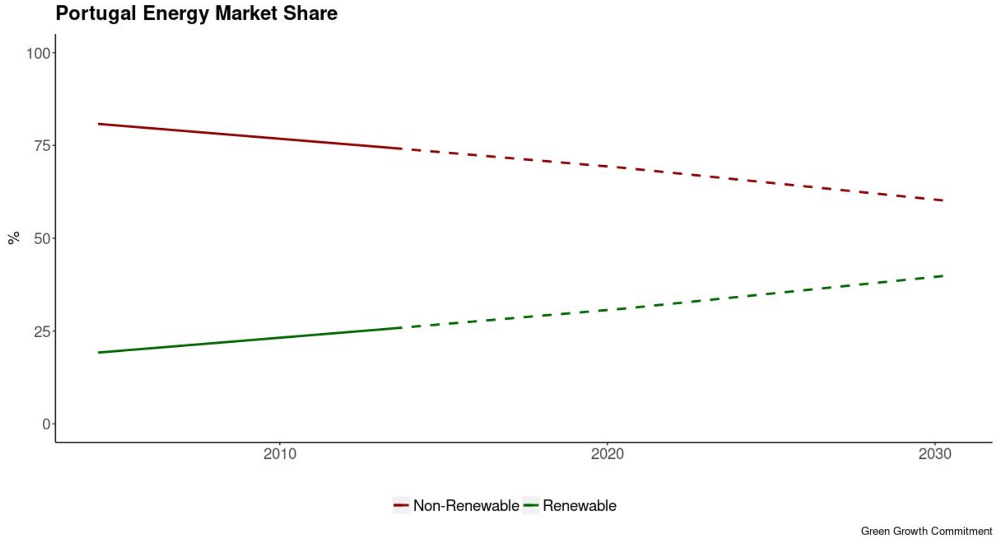


Figure 2.5 TFC by sector, 1973-2013

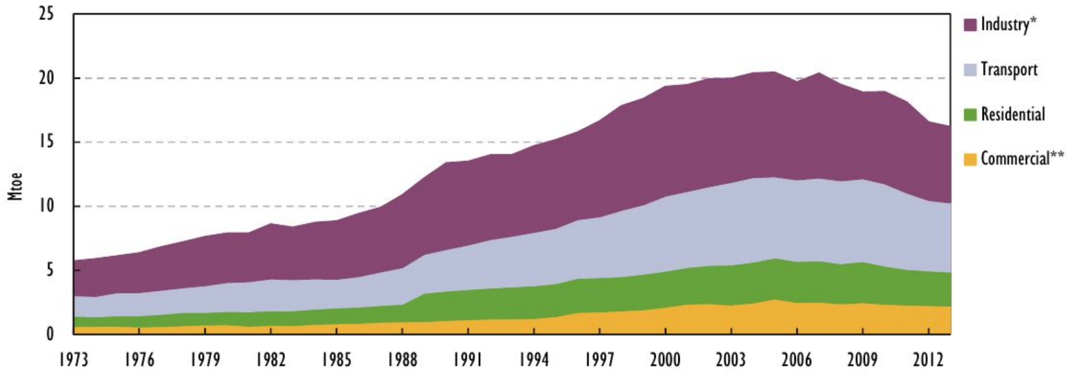
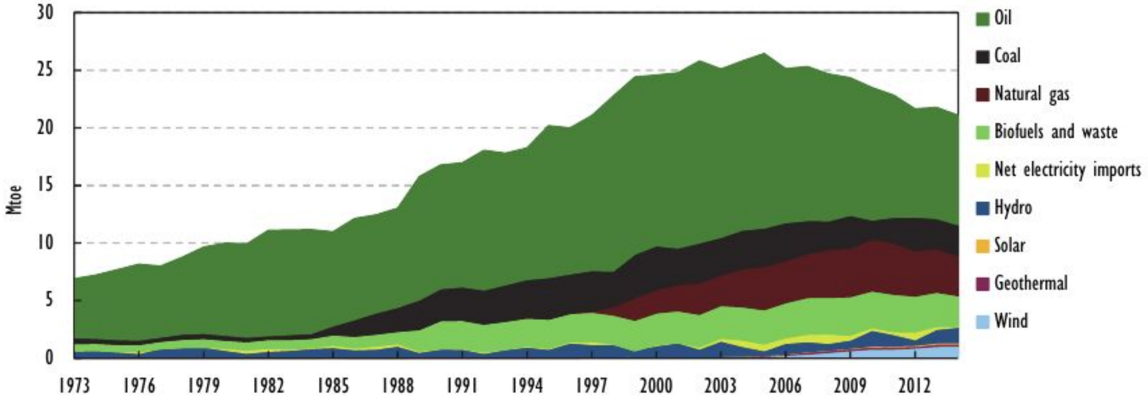
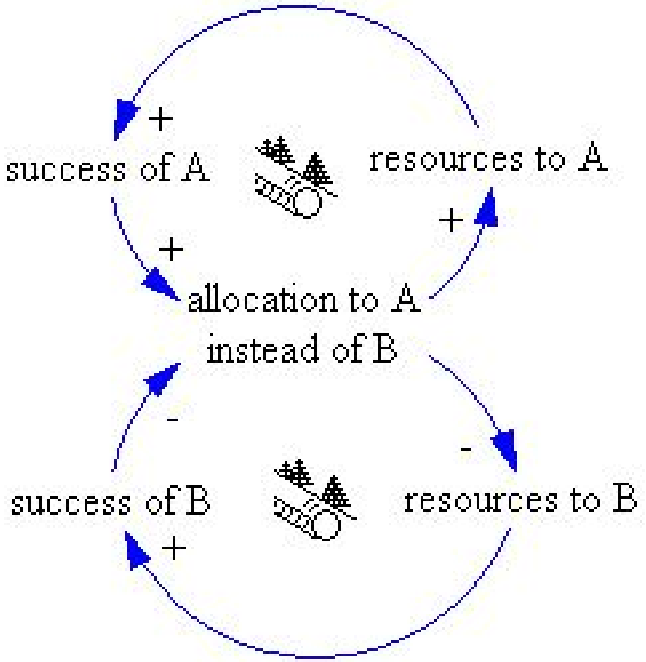


Figure 2.3 TPES, 1973-2014



Approach:

Success to the Successful



Data:

Energy Sector data aggregated.

Demand for energy is an exogenous parameter

Main Unit:

MTOE (Million Tonnes of Oil Equivalent) - unit of energy defined as the amount of energy released by burning one tonne of crude oil

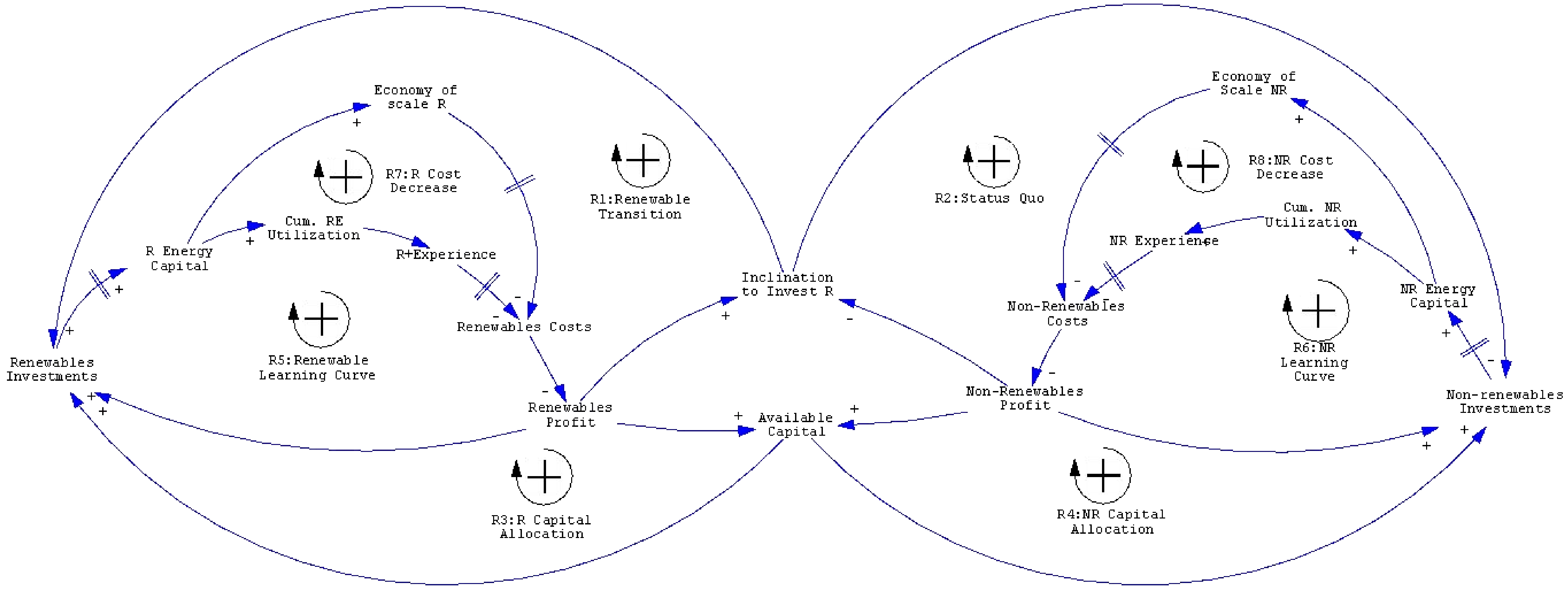
Main Variables:

TPES (Total Primary Energy Supply) - total supply of energy that is consumed domestically, either in transformation or in final use

TFC (Total Final Energy Consumption) - final consumption by end-users, i.e. in the form of electricity, heat, gas, oil products, etc.

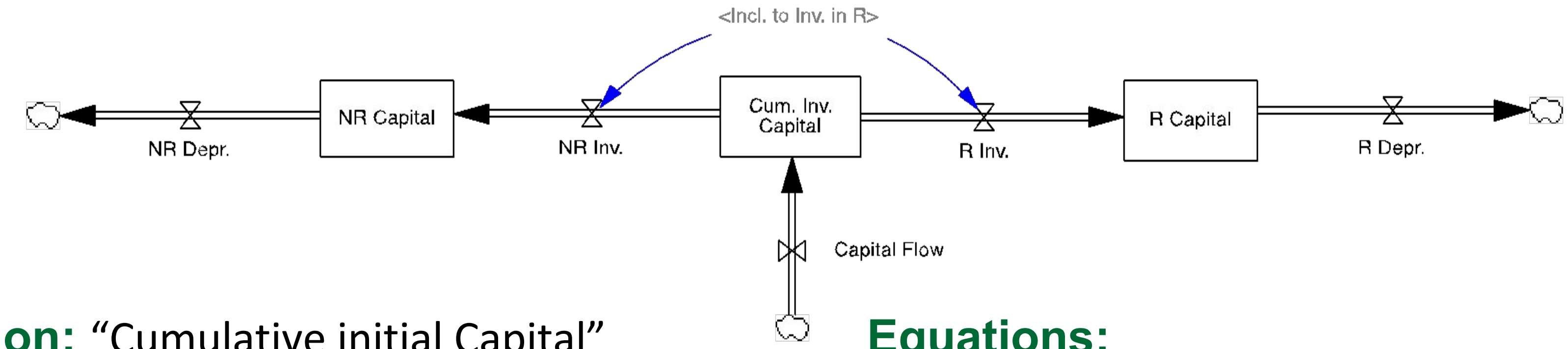
Inclination to Invest – an information delay as a function of energy cost and/or profit

CLD



Economy of scale R
R7:R Cost Decrease
R1:Renewable Transition
R2:Status Quo
Economy of Scale NR
R8:NR Cost Decrease
Cum. RE Utilization
R Energy Capital
R+Experience
Cum. NR Utilization
NR Experience
Inclination to Invest R
Non-Renewables Costs
NR Energy Capital
Renewables Costs
R5:Renewable Learning Curve
R6:NR Learning Curve
Renewables Investments
Renewables Profit
Available Capital
Non-Renewables Profit
Non-renewables Investments
R3:R Capital Allocation
R4:NR Capital Allocation

Model Development: Capital Investment



Explanation: "Cumulative initial Capital" represents the available capital which flows into in the two subsystems, conventional and alternative energy-technology.

Assumptions: These flows are controlled by information feedback loops that symbolize the decision-making process in allocating the (financial) capital.

Equations:

Cum. Inv. Capital= INTEG (Capital Flow +"NR Inv."+"R Inv.", Init Cap)

R Capital= INTEG ("R Inv."-"R Depr.",Init R)

NR Capital= INTEG ("NR Inv."-"NR Depr.",Init NR)

Model Development: Utilization Rate

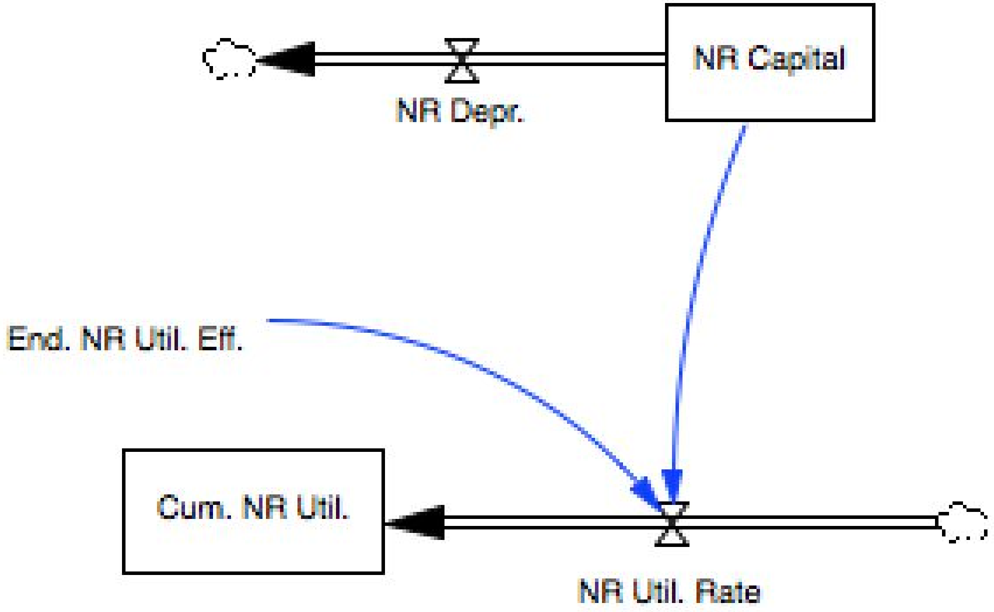
Explanation: "Cumulative Non-Renewable Utilization" represents the amount of energy expressed in mtoe produced based on the Capital.

Equations:

Cum. NR Util.= INTEG ("NR Util. Rate","Init NR Cum. Util.")

NR Util. Rate= NR Capital * "End. NR Util. Eff." * "NR Time Adj. Util."

Assumptions: An endogenous variable expressing the amount of mtoe units produced per each unit of euro used, determines the Utilization Rate.



Model Development: Cost & Profit

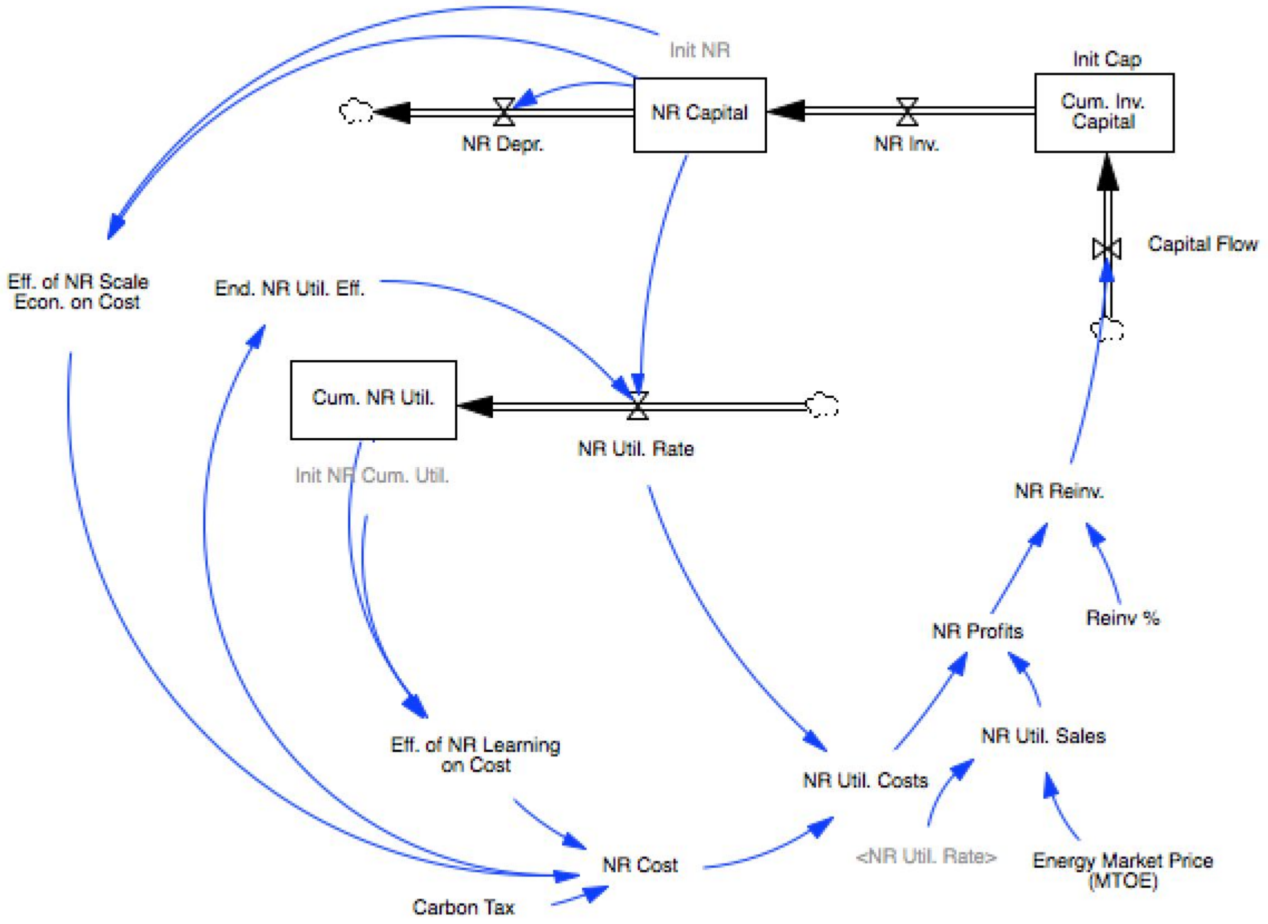
Explanation: Cost are calculated based on the historical cost, the tax or subsidy applied based on the technology and the effect that technology, economy of scale and the learning curve has on cost.

Equations:

NR Cost= ("Init. NR Cost" * "Eff. of NR Learning on Cost" * "Eff. of NR Util. Eff. on Cost" * "Eff. of NR Scale Econ. on Cost") + Carbon Tax + Import Tariff

R Cost= ("Init. R Cost" * "Eff. of R Learning on Cost" * "Eff. of R Scale Econ. on Cost" * "Eff. of R Util. Eff. on Cost")

Assumptions: Cost structure is influenced by improvements in technology, economy of scale and the learning curve.



Model Development: Investment Inclination

Explanation: Inclination to invest in renewables is a ratio of the Renewables Profit per mtoe over the total profit generated by the two subsystems.

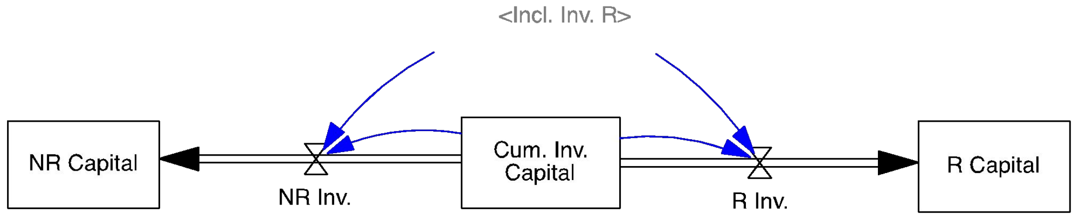
Equations:

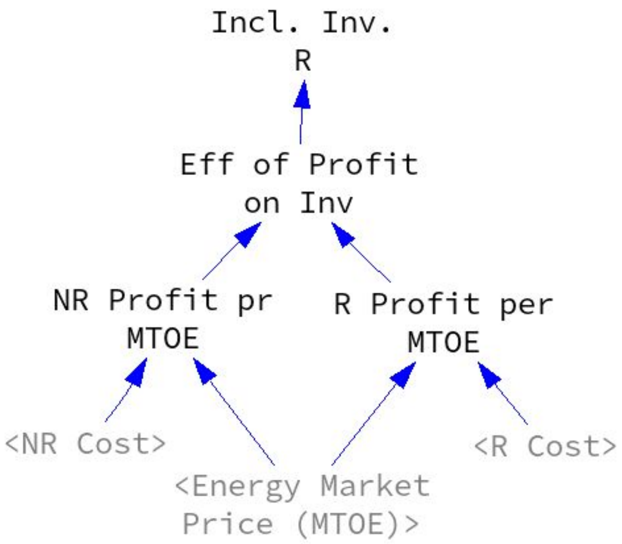
Incl. Inv. R=Eff of Profit on Investment

Eff of Pro on Inv=R Profit per MTOE / (R Profit per MTOE + NR Profit pr MTOE)

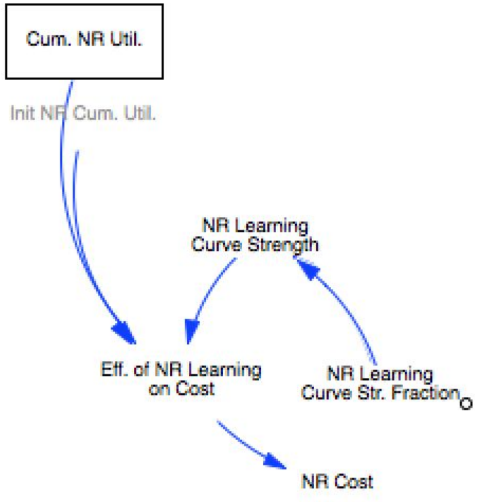
NR Profit pr MTOE="Energy Market Price (MTOE)"-NR Cost

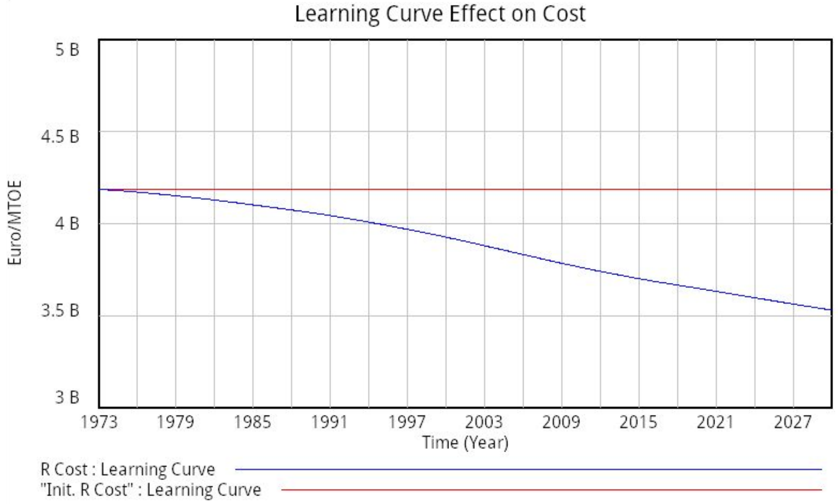
Assumptions: The model assumes that the allocation towards one of the energy-technology subsystems depends on an inclination to or a preference for a particular subsystem.





Model Development: Learning Curve





Explanation: The learning curve arises as workers and firms learn from experience. Accumulation of experience increases utility. Learning leads to reinforcing feedback.

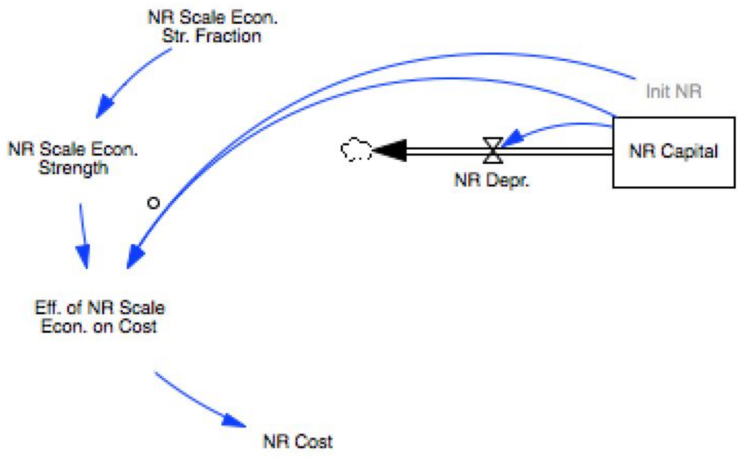
Assumptions: The unit costs of production fall by a fixed percentage every time cumulative production experience doubles. NR has is reaching it's peak learning, while R is just beginning

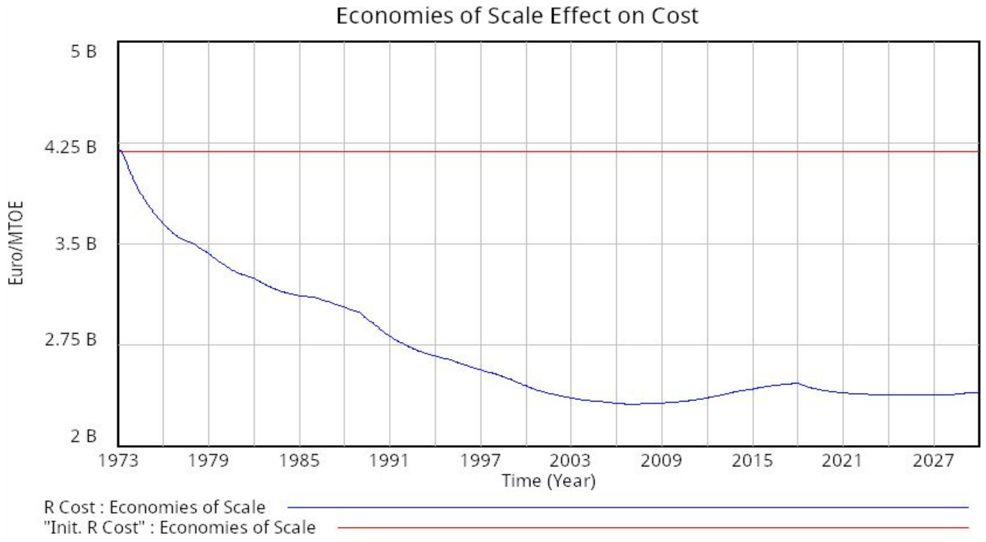
Equations:

Eff. of NR Learning on Cost= ("Cum. NR Util."/"Init NR Cum. Util.")^NR Learning Curve Strength

NR Learning Curve Strength= LOG("NR Learning Curve Str. Fraction"+ ((1 - "NR Learning Curve Str. Fraction")*NR L Switch), 2)

Model Development: Economies of Scale





Explanation: Spreading up-front development costs over a larger volume lower unit costs.

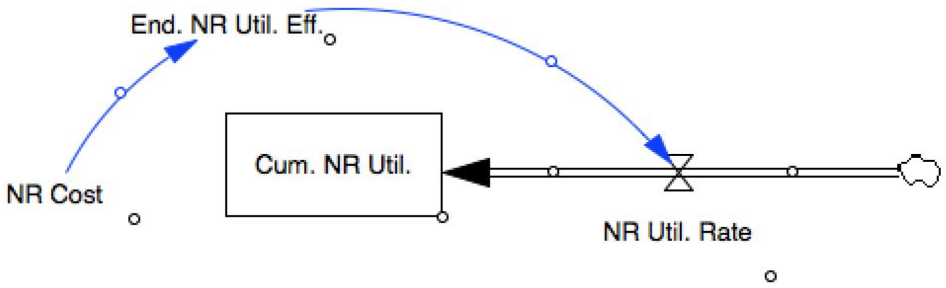
Assumptions: Unit costs fall as the scale of production rises. NR has largely already reached scale, and thus the effect is weaker on that side of the system.

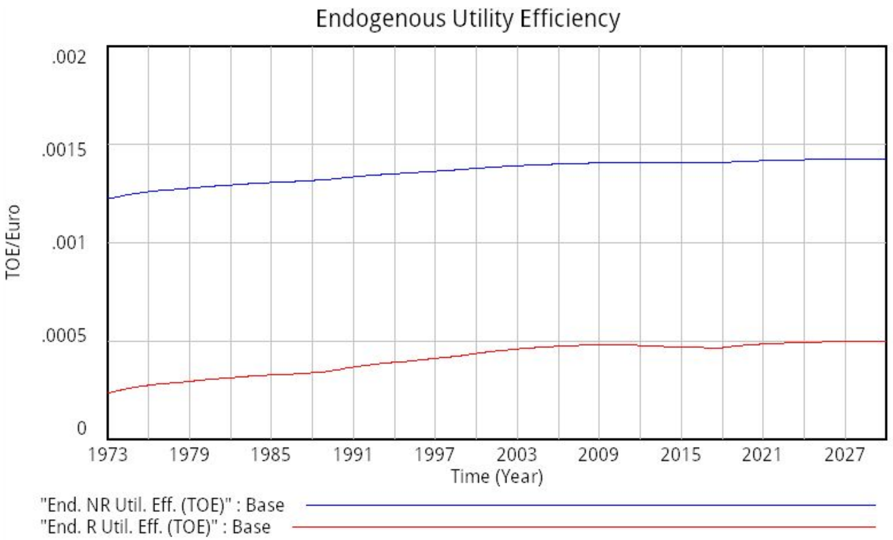
Equations:

Eff. of NR Scale Econ. on Cost= (NR Capital/Init NR)^"NR Scale Econ. Strength"

NR Scale Econ. Strength"= LOG("NR Scale Econ. Str. Fraction" + ((1 - "NR Scale Econ. Str. Fraction") * "NR Ec. Switch"), 2)

Model Development: Utilization Efficiency





Explanation: The amount of mtoe per each unit of Euro increases as cost decreases

Assumptions: Utilization Efficiency expressed as an endogenous variable changes over time due to the decrease of costs from the learning effect and economy of scale

Equations:

"End. NR Util. Eff."= 1 / NR Cost

Policies: Carbon Tax

Explanation: Carbon Taxes of 5 Euro per Gtonne of Carbon began in 2008

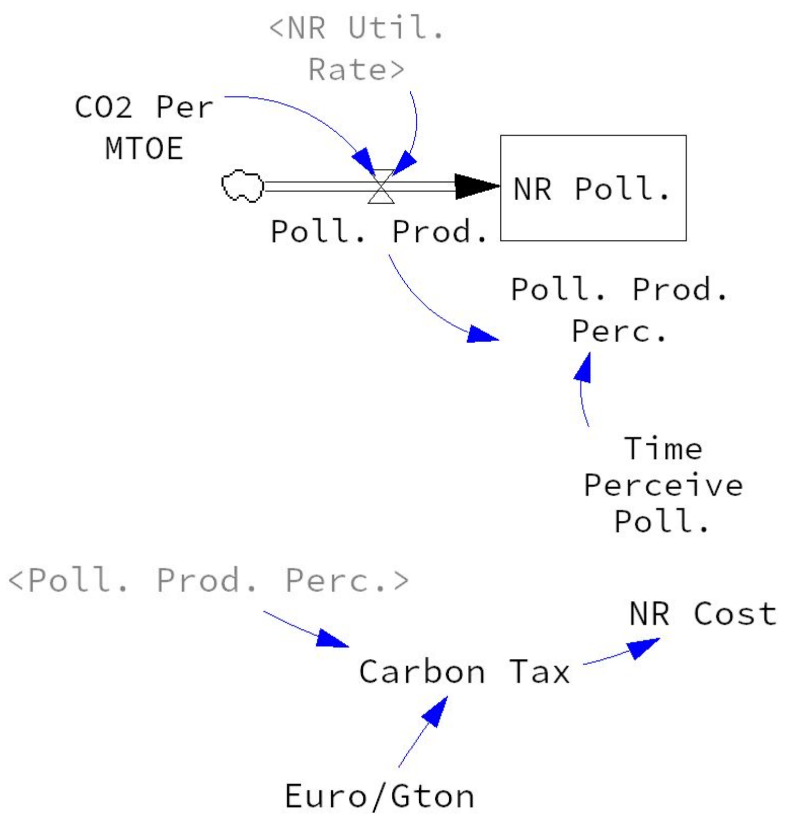
Equations:

IF THEN ELSE(Time >= CT Start,

("Euro/Gton"*"Poll. Prod. Perc.")*CT Switch ,

0)

Assumptions: The effects of Carbon Taxes are aggregated, Kyoto Protocol taxation schemes are not accounted for,



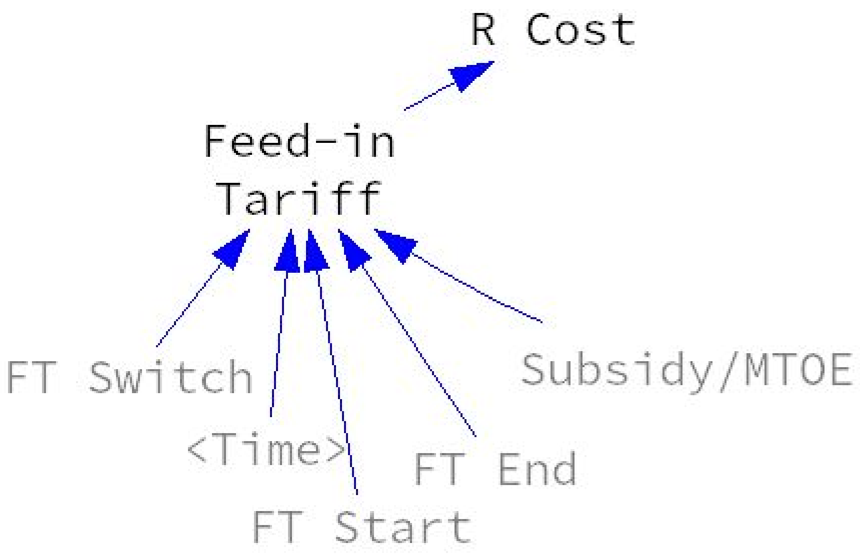
Policies: Feed-in Tariff

Explanation: Feed-in Tariffs are subsidies for emerging technologies, values range between 50 Euro/MWh to 700 Euro/MWh per technology; Tariffs began in 1988 and are planned to end in 2017 due to swelling tariff deficit; expectations are grim for the impact that will have on Renewables

Equations:

IF THEN ELSE(Time <= FT End,

IF THEN ELSE(Time >=FT Start , (Subsidy*FT Switch), 0), 0)



Assumptions: Effects of Feed-in Tariffs are aggregated at one value over time

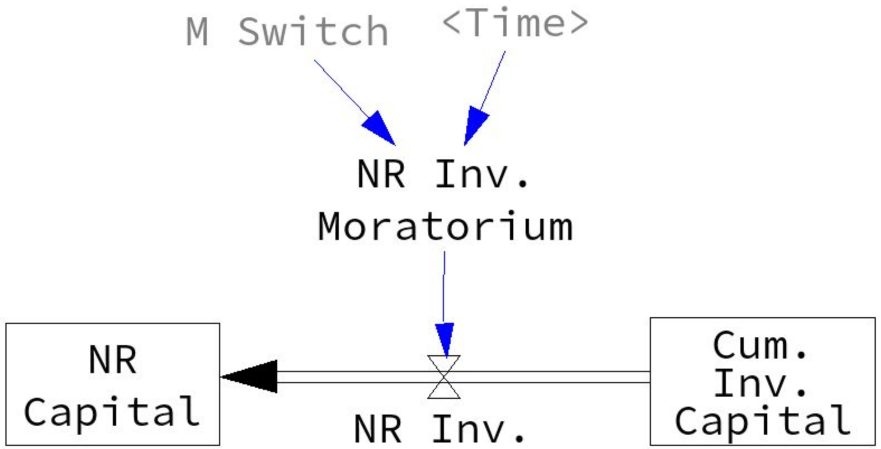
Policies: Investment Moratorium

Explanation: A moratorium halts investment in Conventional Energy capital, however allows for the utilization of existing capital until depreciated

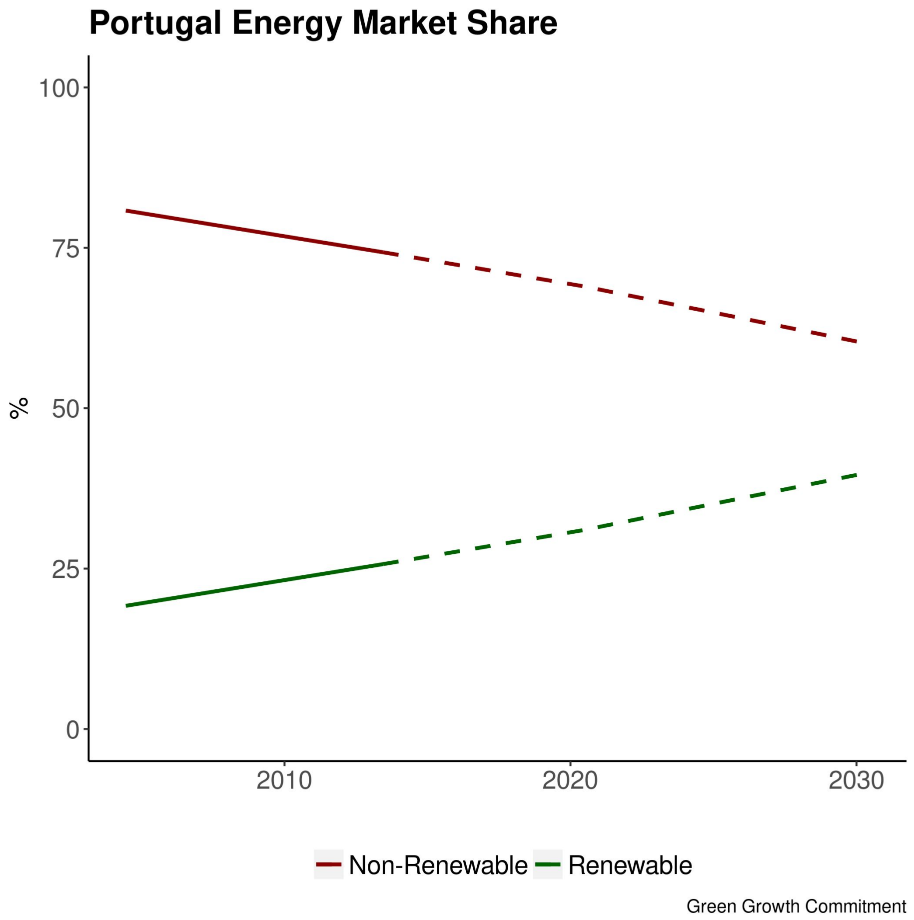
Equations:

IF THEN ELSE(Time >= 2020, 1*M Switch, 1)

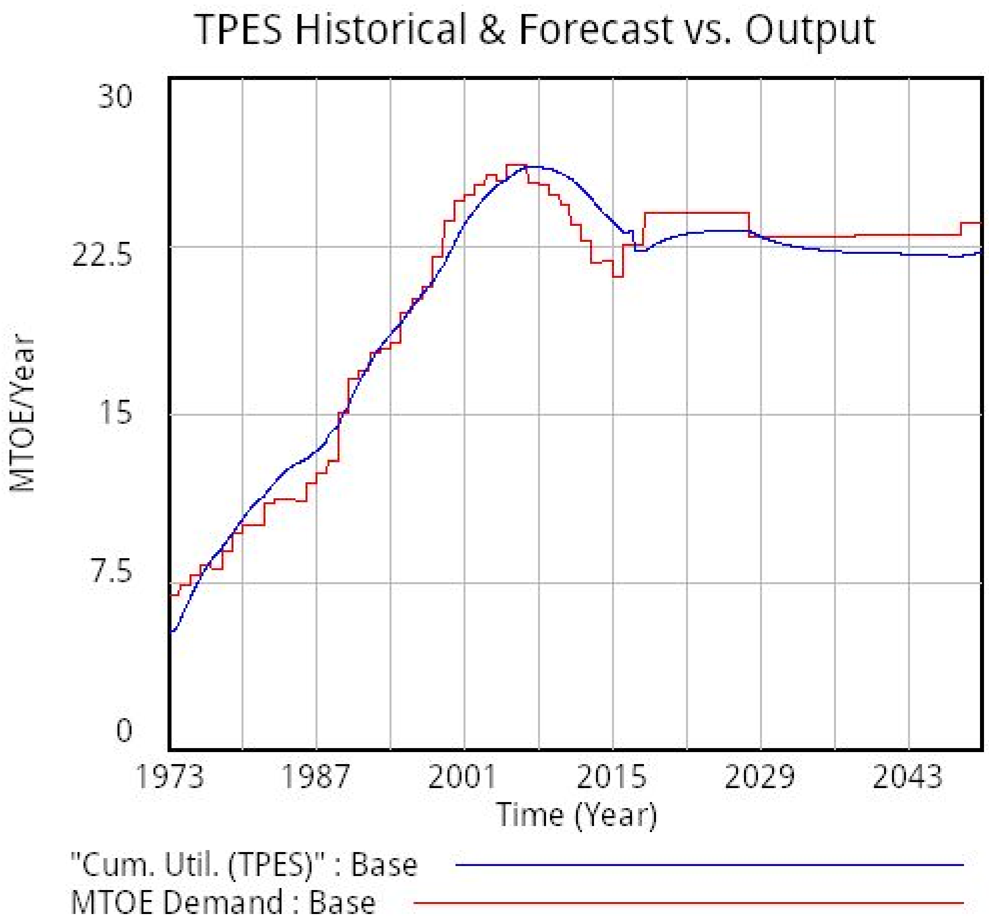
Assumptions: Unlikely policy option, investment is halted, but could also be decreased slowly for a more realistic option

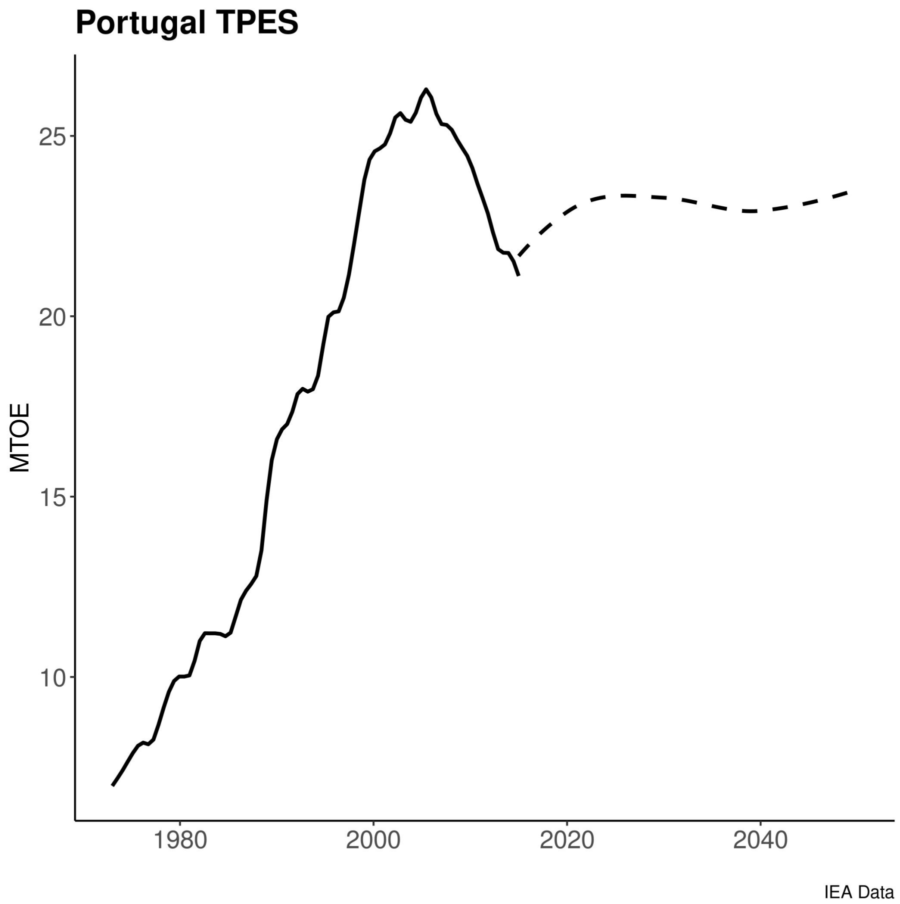


Simulation: Reference & Forecast

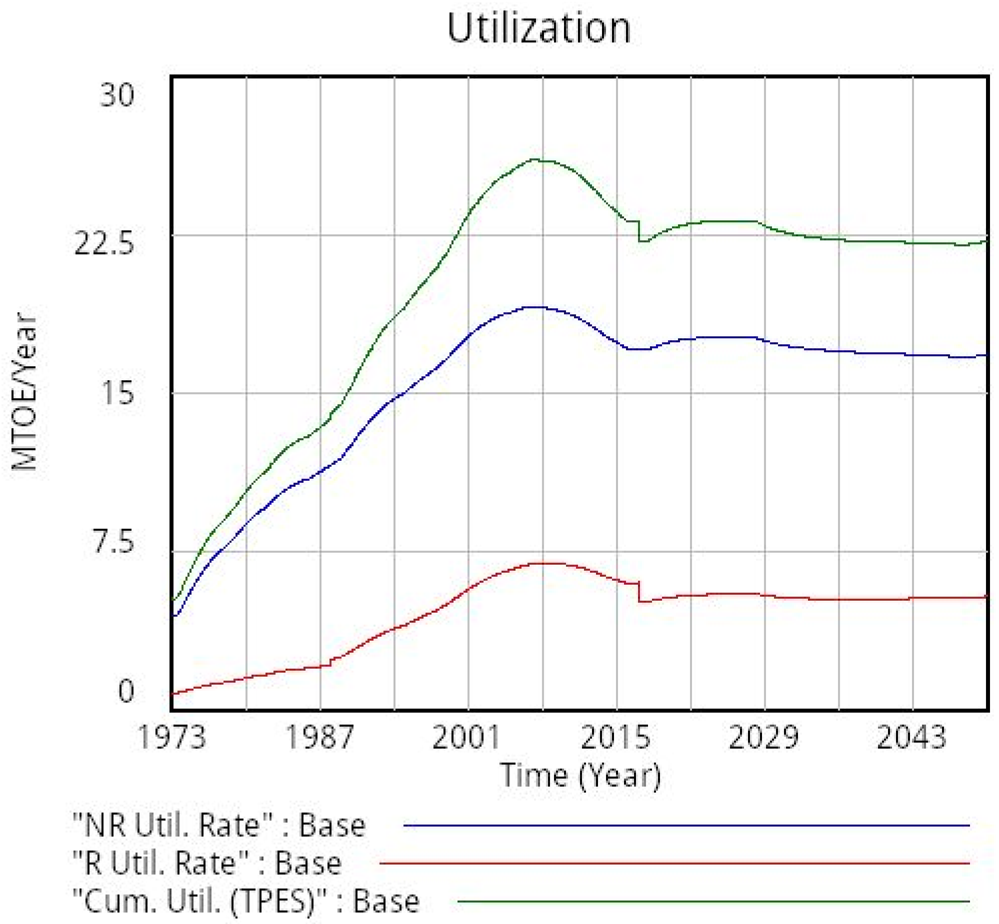


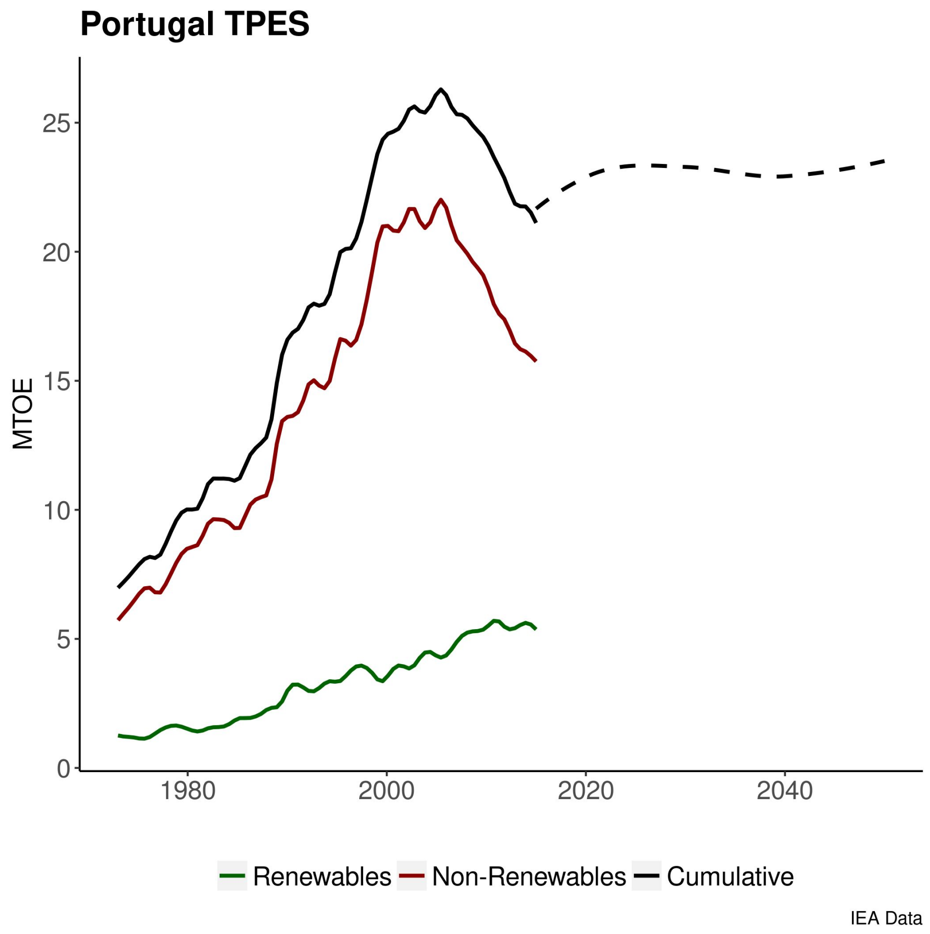
Simulation: Reference & Forecast



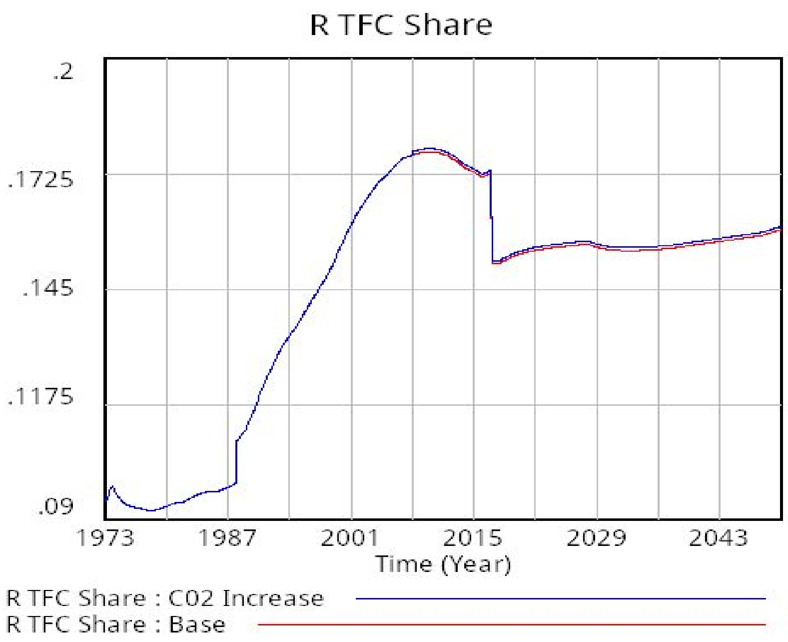


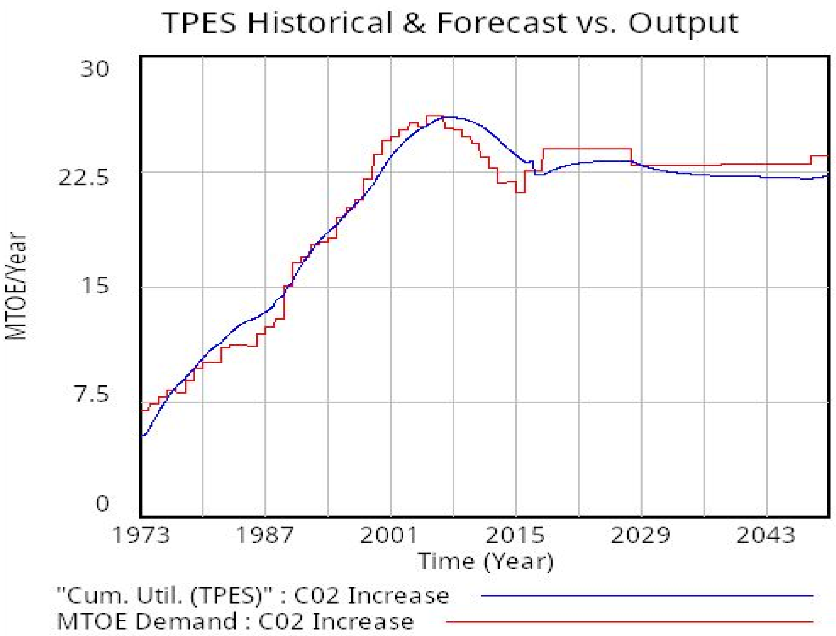
Simulation: Reference & Forecast

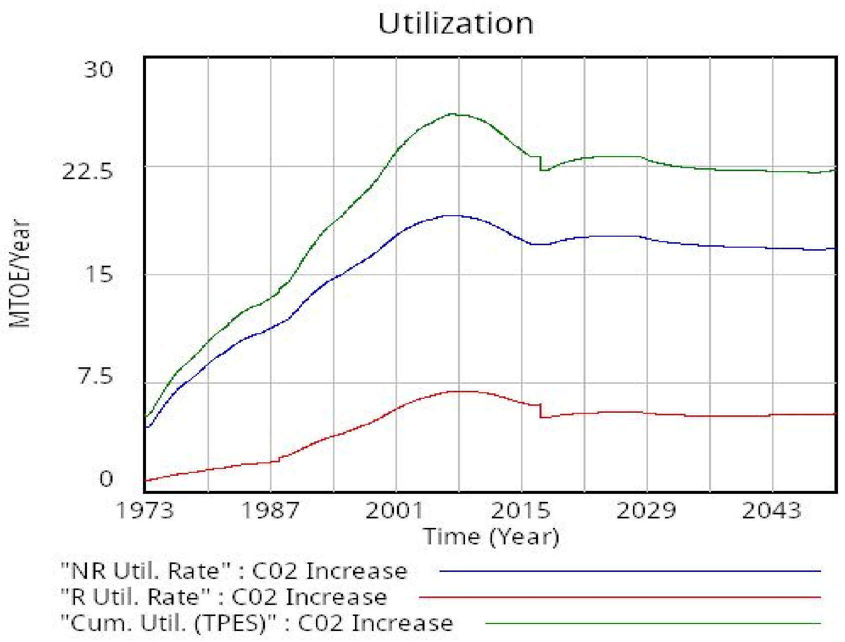




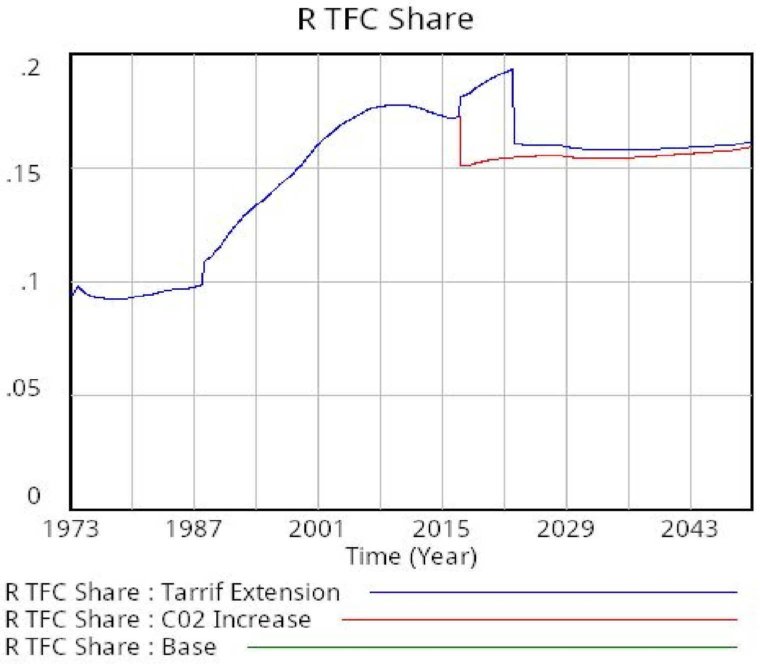
Simulation: Stepping Up CO2 Tax

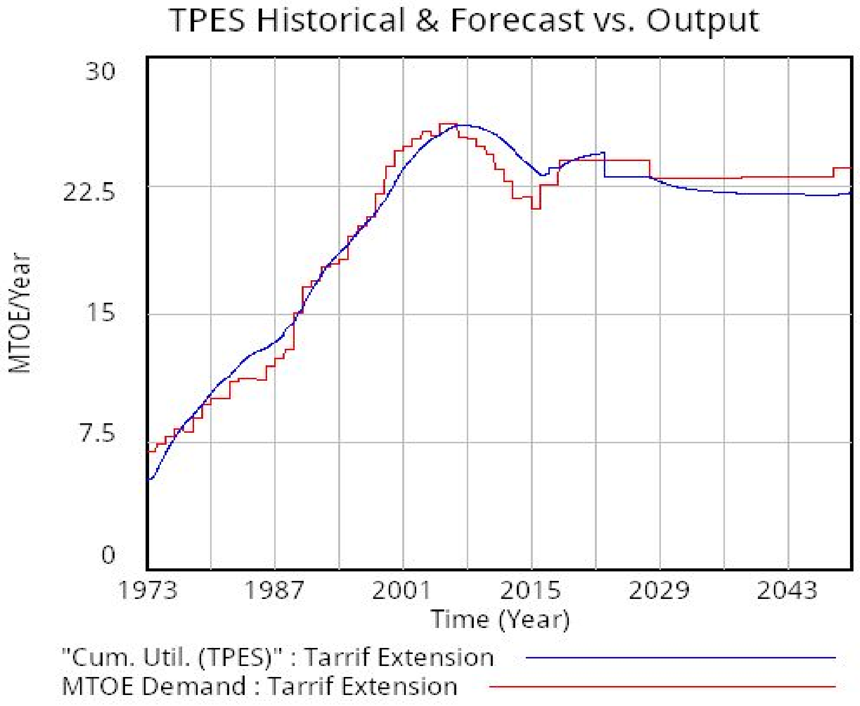


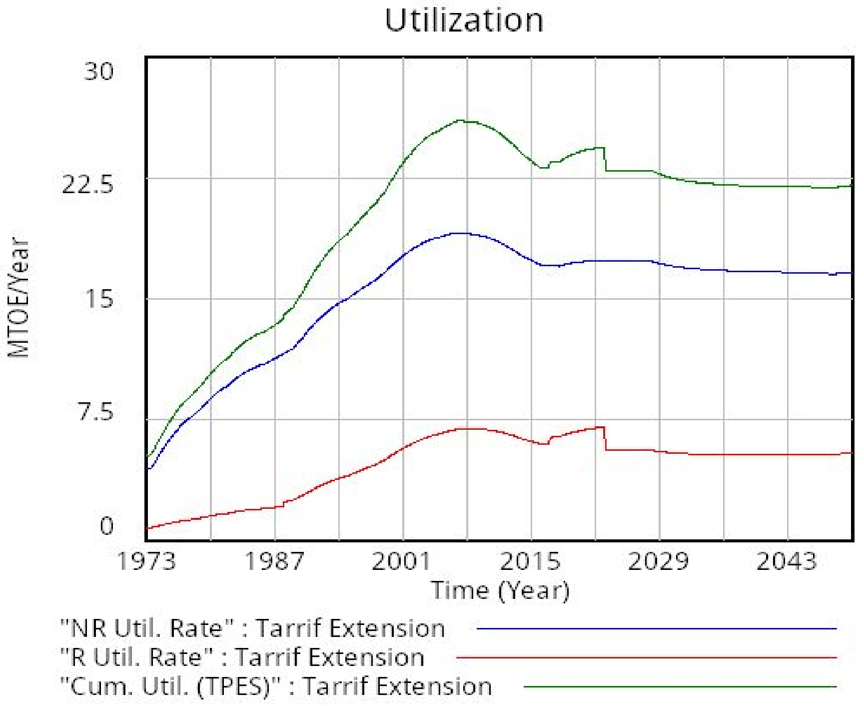




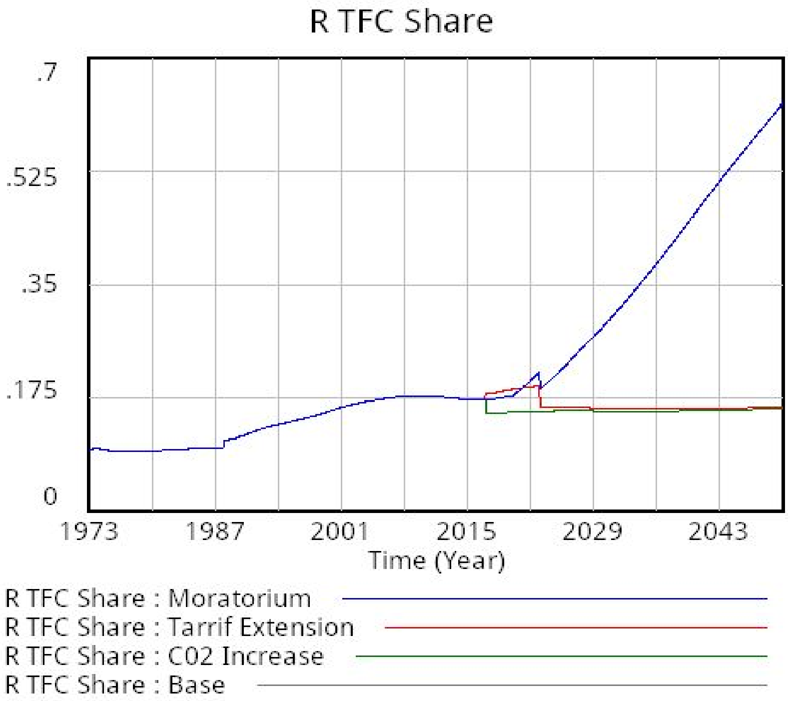
Simulation: Prolonging Feed-in Tariff

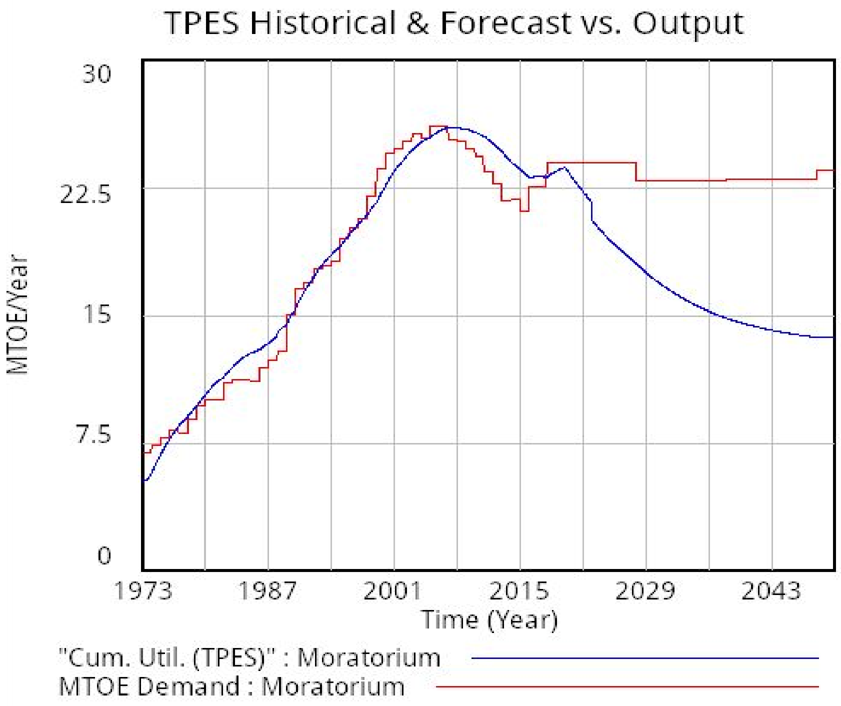


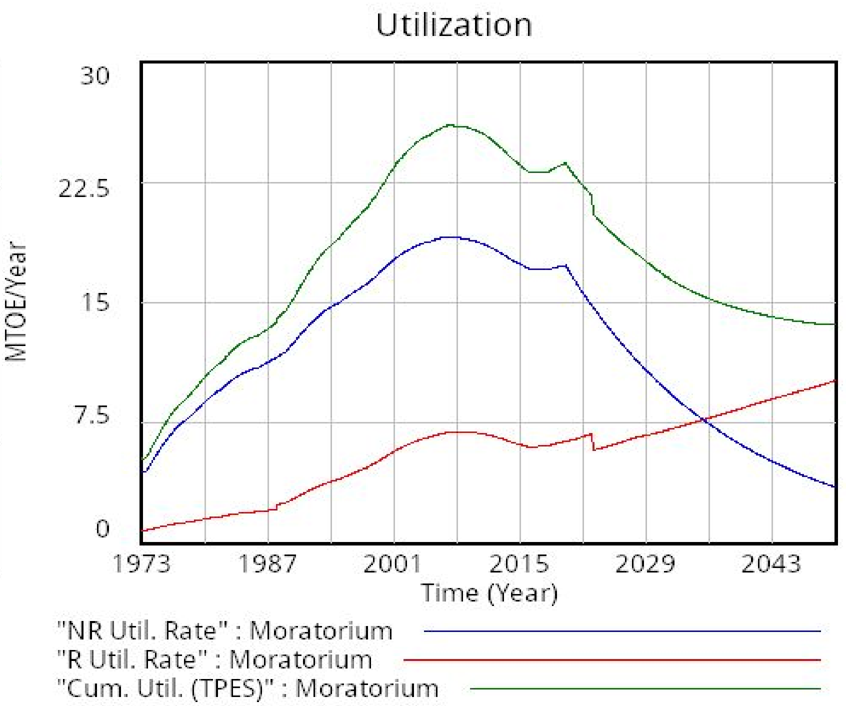




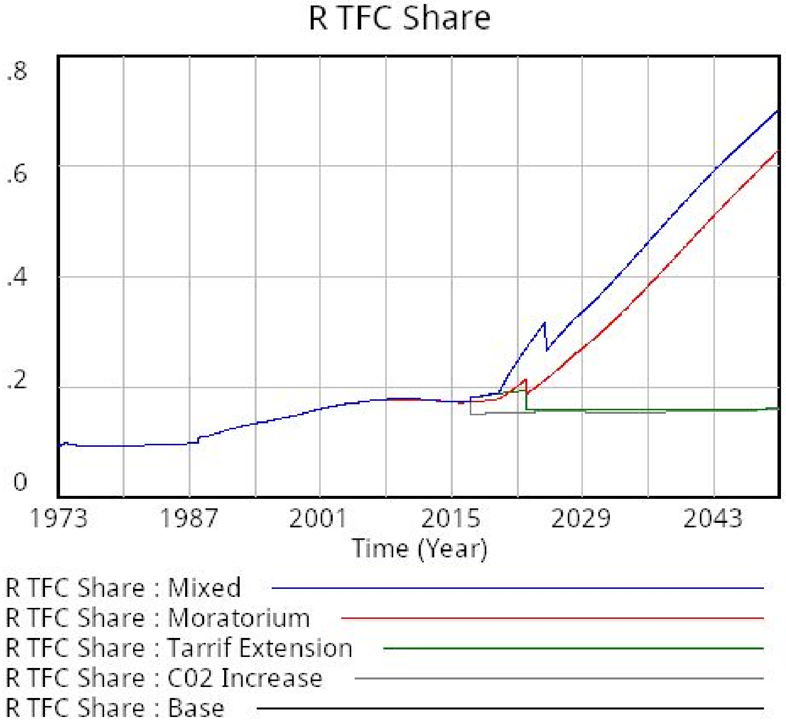
Simulation: Investment Moratorium

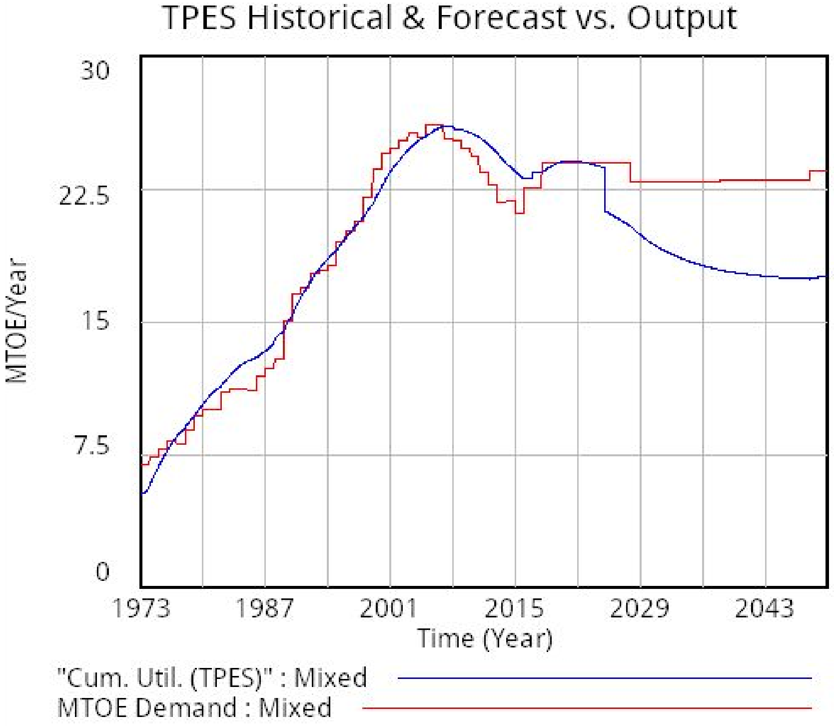


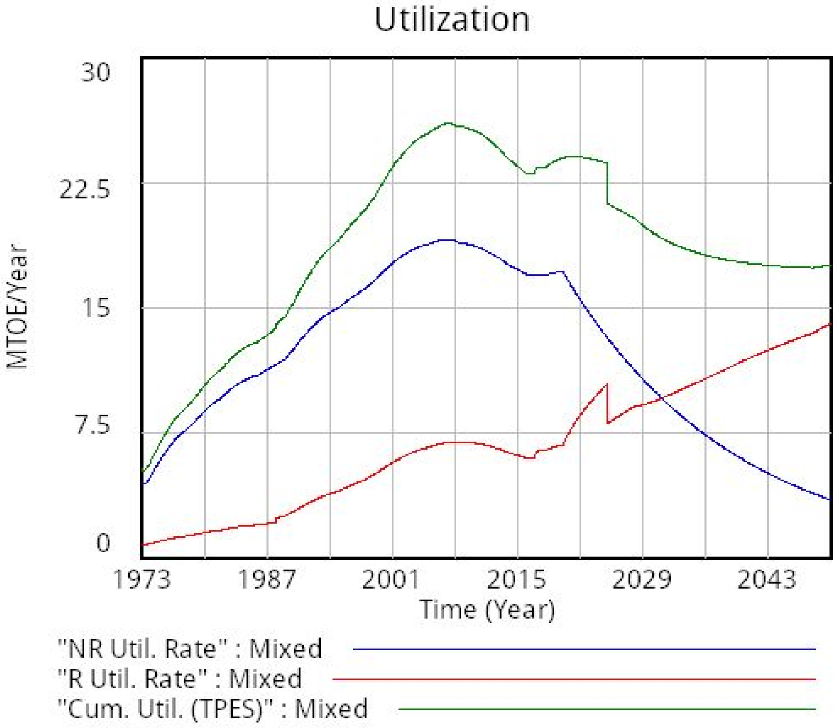




Simulation: Mixed Policies





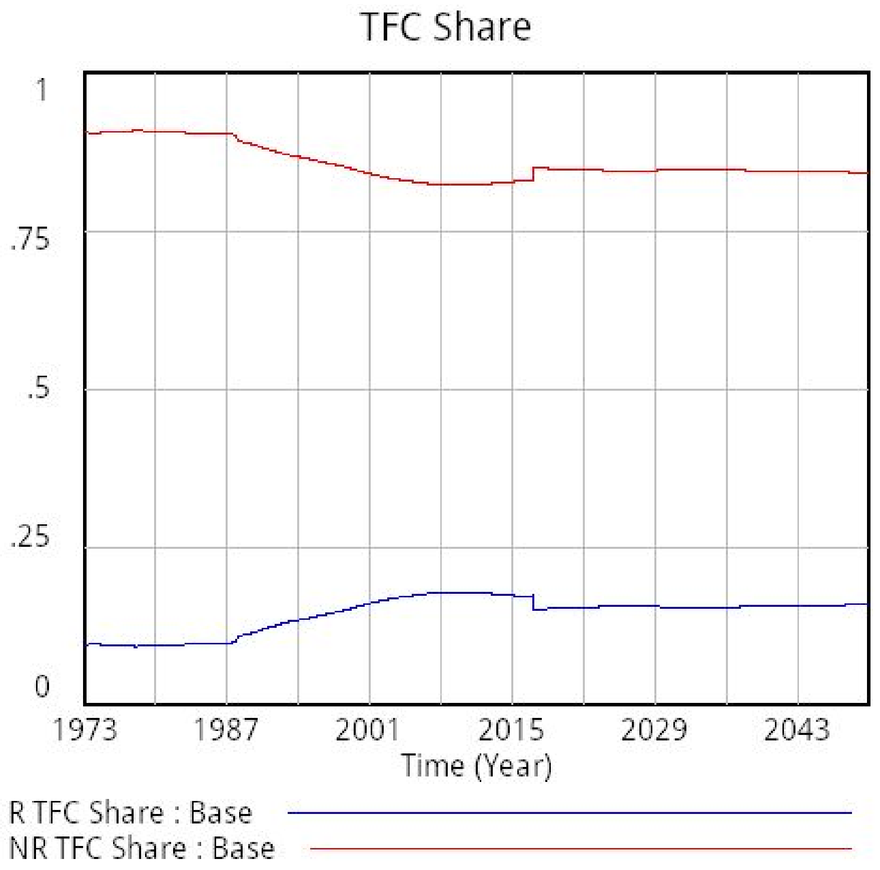


Policies: Conclusion

Goal: Boost the share of renewable energy from 25.7% of final energy consumption in 2013 to 31% in 2020 and 40% in 2030.

Base Case: Current policies will not lead to hitting the goals set by the GGC based on this model's assumptions. However, missing considerations may tip conditions towards achieving the goals.

Lock-in: Overcoming lock-in likely takes a quick and powerful action to reverse the effects of success to the successful as seen in the moratorium and mixed cases, however much more support will need to be provided in order to ensure a successful, and safe transition.



Limitations & Further Work

Resource Depletion's Impact on Prices:

As Non-renewable sources of energy are depleted, prices will increase; this is not taken into consideration in the model

Saturation:

If resource endowment remains fixed, there are diminishing returns for energy production. For renewables & non-renewables, sites with the highest potential or the most convenient location are exploited first.

Energy Intensity:

Energy intensity improvements from infrastructure & technology progress can decrease TPES supply from conv. energy; energy utilization is Renewables > Conventional, thus decreasing market share as efficiency increases

Disaggregating Capital Stocks:

Each energy type, or for conventional, mature renewables and emerging renewables

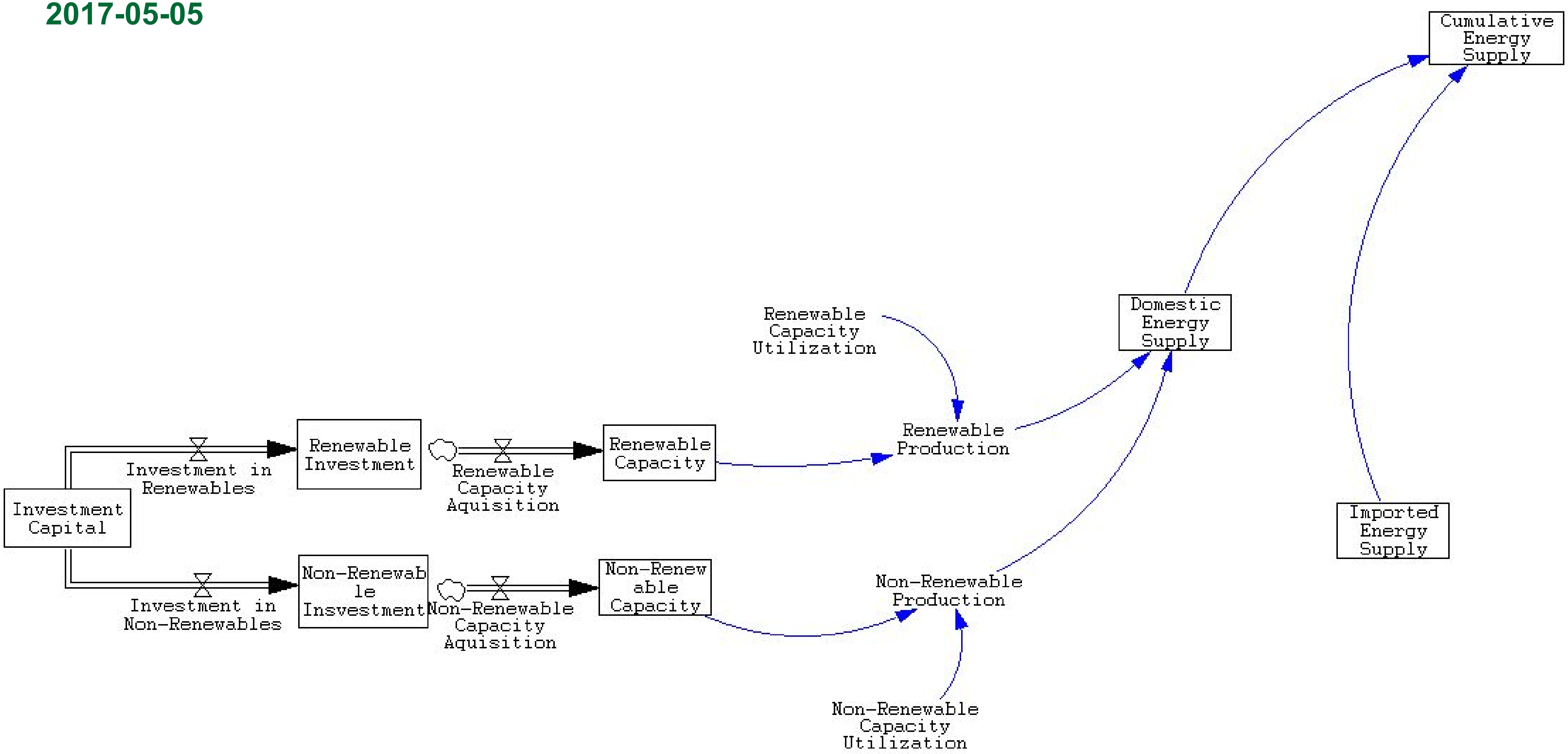
Disaggregating Investment Dynamics:

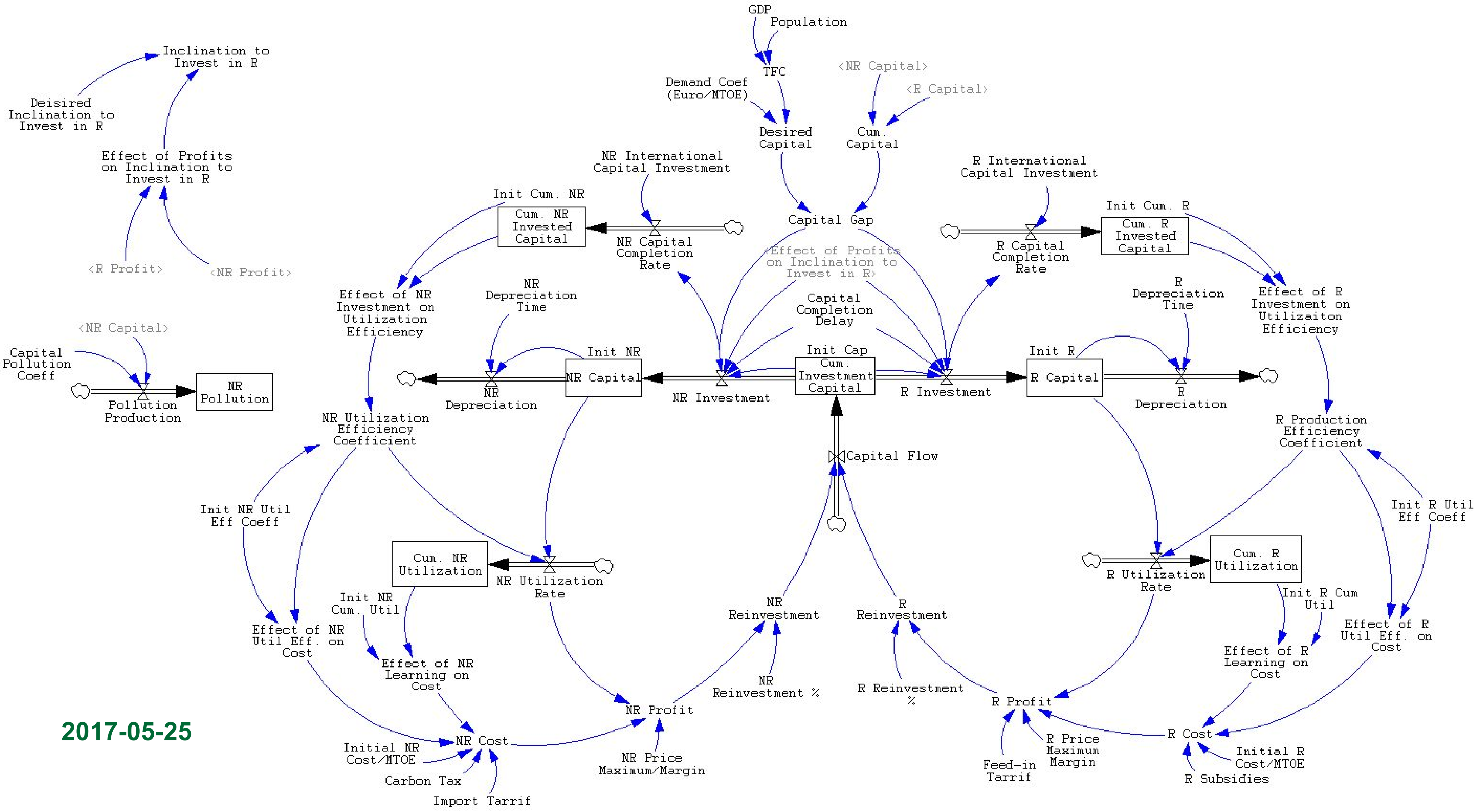
There is competition between each type of energy within renewables & the conventional system, as well as for Organizations large and small, and families

Technology R&D:

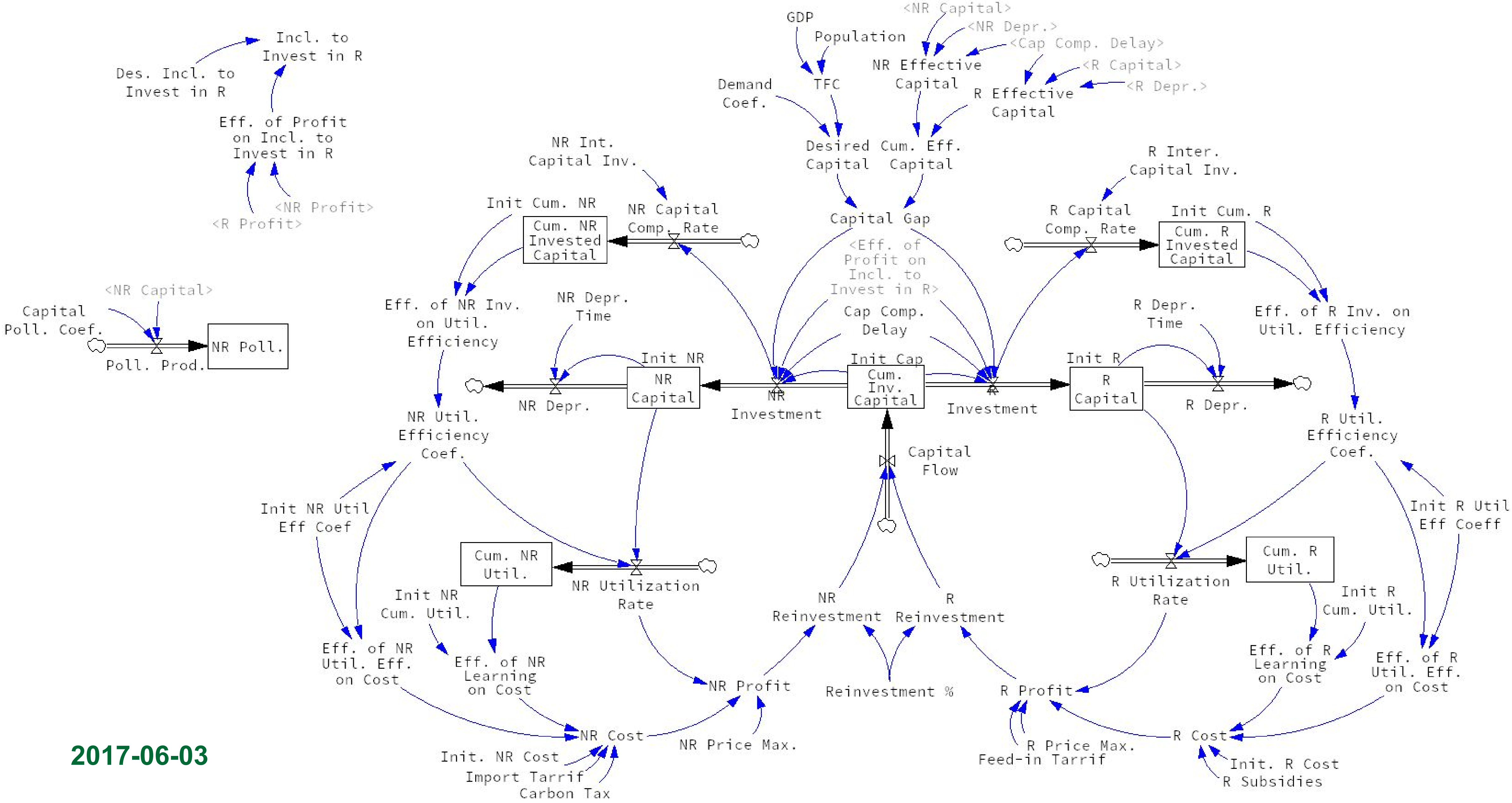
R&D is internationally operated, and thus is not endogenous, however plays a very important part in decreasing the costs for renewable technologies in transport and energy

2017-05-05


Cumulative Energy Supply
Renewable Capacity Utilization
Domestic Energy Supply
Renewable Investment
Renewable Capacity
Renewable Production
Investment in Renewables
Renewable Capacity Aquisition
Investment Capital
Imported Energy Supply
Non-Renewable Insvestment
Non-Renewable Capacity
Non-Renewable Production
Investment in Non-Renewables
Non-Renewable Capacity Aquisition
Non-Renewable Capacity Utilization

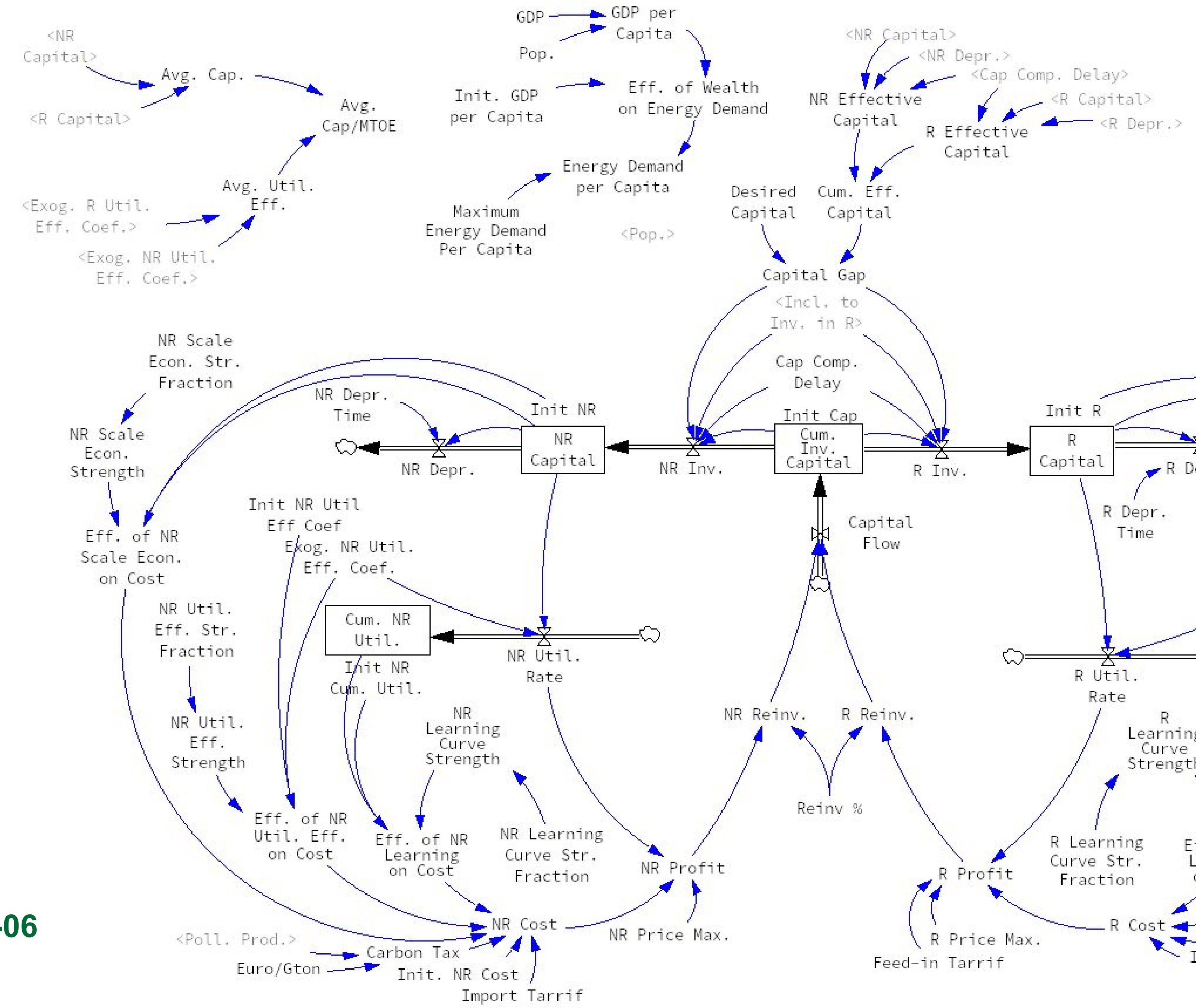

GDP
Population
TFC
Demand Coef (Euro/MTOE)
Desired Capital
<NR Capital>
<R Capital>
Cum. Capital
Inclination to Invest in R
Deisired Inclination to Invest in R
Effect of Profits on Inclination to Invest in R
<R Profit>
<NR Profit>
NR International Capital Investment
R International Capital Investment
Init Cum. NR
Cum. NR Invested Capital
NR Capital Completion Rate
Capital Gap
<Effect of Profits on Inclination to Invest in R>
R Capital Completion Rate
Init Cum. R
Cum. R Invested Capital
Effect of NR Investment on Utilization Efficiency
NR Depreciation Time
Capital Completion Delay
R Depreciation Time
Effect of R Investment on Utilizaiton Efficiency
<NR Capital>
Capital Pollution Coeff
NR Pollution
Pollution Production
Init NR
NR Capital
NR Depreciation
NR Investment
Init Cap
Cum. Investment Capital
R Investment
Init R
R Capital
R Depreciation
NR Utilization Efficiency Coefficient
R Production Efficiency Coefficient
Capital Flow
Init NR Util Eff Coeff
Init R Util Eff Coeff
Cum. NR Utilization
NR Utilization Rate
R Utilization Rate
Cum. R Utilization
Init NR Cum. Util
Init R Cum Util
Effect of NR Util Eff. on Cost
Effect of NR Learning on Cost
NR Reinvestment
R Reinvestment
Effect of R Learning on Cost
Effect of R Util Eff. on Cost
NR Reinvestment %
R Reinvestment %
NR Profit
R Profit
NR Cost
R Cost
Initial NR Cost/MTOE
Carbon Tax
Import Tarrif
NR Price Maximum/Margin
Feed-in Tarrif
R Price Maximum Margin
Initial R Cost/MTOE
R Subsidies

2017-05-25



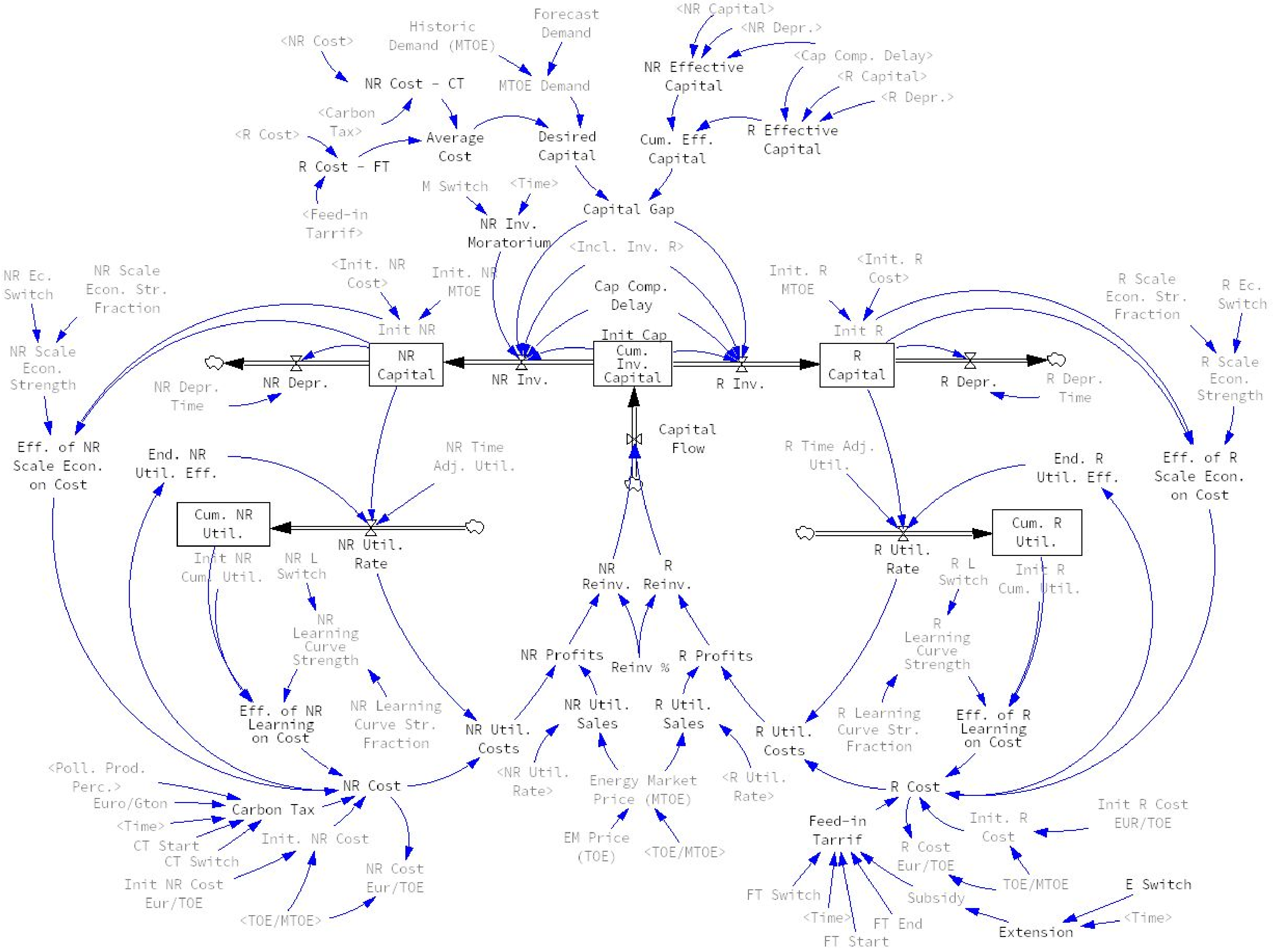
Incl. to Invest in R
Des. Incl. to Invest in R
Eff. of Profit on Incl. to Invest in R
<NR Profit>
<R Profit>
Capital Poll. Coef.
<NR Capital>
NR Poll.
Poll. Prod.
GDP
Population
Demand Coef.
TFC
<NR Capital>
<NR Depr.>
<Cap Comp. Delay>
NR Effective Capital
<R Capital>
<R Depr.>
R Effective Capital
Desired Capital
Cum. Eff. Capital
Capital Gap
NR Int. Capital Inv.
Init Cum. NR
Cum. NR Invested Capital
NR Capital Comp. Rate
R Inter. Capital Inv.
R Capital Comp. Rate
Init Cum. R
Cum. R Invested Capital
<Eff. of Profit on Incl. to Invest in R>
Cap Comp. Delay
Eff. of NR Inv. on Util. Efficiency
NR Depr. Time
Init NR
NR Capital
NR Depr.
NR Investment
Init Cap
Cum. Inv. Capital
Investment
Init R
R Capital
R Depr. Time
R Depr.
Eff. of R Inv. on Util. Efficiency
NR Util. Efficiency Coef.
Capital Flow
R Util. Efficiency Coef.
Init NR Util Eff Coef
Init R Util Eff Coeff
Cum. NR Util.
NR Utilization Rate
Cum. R Util.
R Utilization Rate
Init NR Cum. Util.
NR Reinvestment
R Reinvestment
Init R Cum. Util.
Eff. of NR Util. Eff. on Cost
Eff. of NR Learning on Cost
NR Profit
Reinvestment %
R Profit
Eff. of R Learning on Cost
Eff. of R Util. Eff. on Cost
NR Cost
NR Price Max.
R Price Max.
Feed-in Tarrif
R Cost
Init. NR Cost
Import Tarrif
Carbon Tax
Init. R Cost
R Subsidies

2017-06-03



<NR Capital>
Avg. Cap.
<R Capital>
Avg. Cap/MTOE
Avg. Util. Eff.
<Exog. R Util. Eff. Coef.>
<Exog. NR Util. Eff. Coef.>
GDP
GDP per Capita
Pop.
Init. GDP per Capita
Eff. of Wealth on Energy Demand
Energy Demand per Capita
Maximum Energy Demand Per Capita
<Pop.>
<NR Capital>
<NR Depr.>
<Cap Comp. Delay>
<R Capital>
<R Depr.>
NR Effective Capital
R Effective Capital
Desired Capital
Cum. Eff. Capital
Capital Gap
<Incl. to Inv. in R>
Cap Comp. Delay
Init Cap
Cum. Inv. Capital
NR Scale Econ. Str. Fraction
NR Scale Econ. Strength
NR Depr. Time
Init NR
NR Capital
NR Depr.
NR Inv.
R Inv.
Init R
R Capital
R Depr.
R Depr. Time
R Scale Econ. Str. Fraction
R Scale Econ. Strength
Eff. of R Scale Econ. on Cost
Capital Flow
Eff. of NR Scale Econ. on Cost
Init NR Util Eff Coef
Exog. NR Util. Eff. Coef.
Cum. NR Util.
NR Util. Rate
Init NR Cum. Util.
NR Util. Eff. Str. Fraction
NR Util. Eff. Strength
NR Learning Curve Strength
NR Learning Curve Str. Fraction
Eff. of NR Util. Eff. on Cost
Eff. of NR Learning on Cost
NR Profit
NR Reinv.
R Reinv.
Reinv %
NR Cost
NR Price Max.
<Poll. Prod.>
Carbon Tax
Euro/Gton
Init. NR Cost
Import Tarrif
Init R Util Eff Coeff
Exog. R Util. Eff. Coef.
R Util. Rate
Cum. R Util.
Init R Cum. Util.
R Util. Eff. Str. Fraction
R Util. Eff. Strength
R Learning Curve Strength
R Learning Curve Str. Fraction
Eff. of R Learning on Cost
Eff. of R Util. Eff. on Cost
R Profit
R Price Max.
Feed-in Tarrif
R Cost
Init. R Cost

2017-06-06


<NR Cost>
Historic Demand (MTOE)
Forecast Demand
<NR Capital>
<NR Depr.>
NR Effective Capital
<Cap Comp. Delay>
<R Capital>
<R Depr.>
NR Cost - CT
MTOE Demand
<Carbon Tax>
Average Cost
Desired Capital
Cum. Eff. Capital
R Effective Capital
<R Cost>
R Cost - FT
M Switch
<Time>
Capital Gap
<Feed-in Tarrif>
NR Inv. Moratorium
<Incl. Inv. R>
NR Ec. Switch
NR Scale Econ. Str. Fraction
<Init. NR Cost>
Init. NR MTOE
Cap Comp. Delay
Init. R MTOE
<Init. R Cost>
R Scale Econ. Str. Fraction
R Ec. Switch
Init NR
Init Cap
Init R
NR Scale Econ. Strength
NR Capital
Cum. Inv. Capital
R Capital
NR Depr.
NR Inv.
R Inv.
R Depr.
NR Depr. Time
R Depr. Time
R Scale Econ. Strength
Capital Flow
Eff. of NR Scale Econ. on Cost
End. NR Util. Eff.
NR Time Adj. Util.
R Time Adj. Util.
End. R Util. Eff.
Eff. of R Scale Econ. on Cost
Cum. NR Util.
NR Util. Rate
Cum. R Util.
R Util. Rate
Init NR Cum. Util.
NR L Switch
NR Reinv.
R Reinv.
R L Switch
Init R Cum. Util.
NR Learning Curve Strength
R Learning Curve Strength
NR Profits
Reinv %
R Profits
Eff. of NR Learning on Cost
NR Learning Curve Str. Fraction
NR Util. Sales
R Util. Sales
NR Util. Costs
R Util. Costs
R Learning Curve Str. Fraction
Eff. of R Learning on Cost
<Poll. Prod. Perc.>
<NR Util. Rate>
Energy Market Price (MTOE)
<R Util. Rate>
Euro/Gton
NR Cost
R Cost
Carbon Tax
Feed-in Tarrif
Init. R Cost
Init R Cost EUR/TOE
<Time>
CT Start
Init. NR Cost
EM Price (TOE)
<TOE/MTOE>
R Cost Eur/TOE
CT Switch
NR Cost Eur/TOE
TOE/MTOE
E Switch
Init NR Cost Eur/TOE
FT Switch
Subsidy
<Time>
FT End
<Time>
<TOE/MTOE>
FT Start
Extension

2017-06-15