*Note to Reviewers –*

*In this assignment, students are required to construct a causal and a stock-flow model that simulates change in some domain in the world with two variations – changing some structural part(s) of the model and changing some parameters in the model and noting how those changes change the behavior of the variables.*

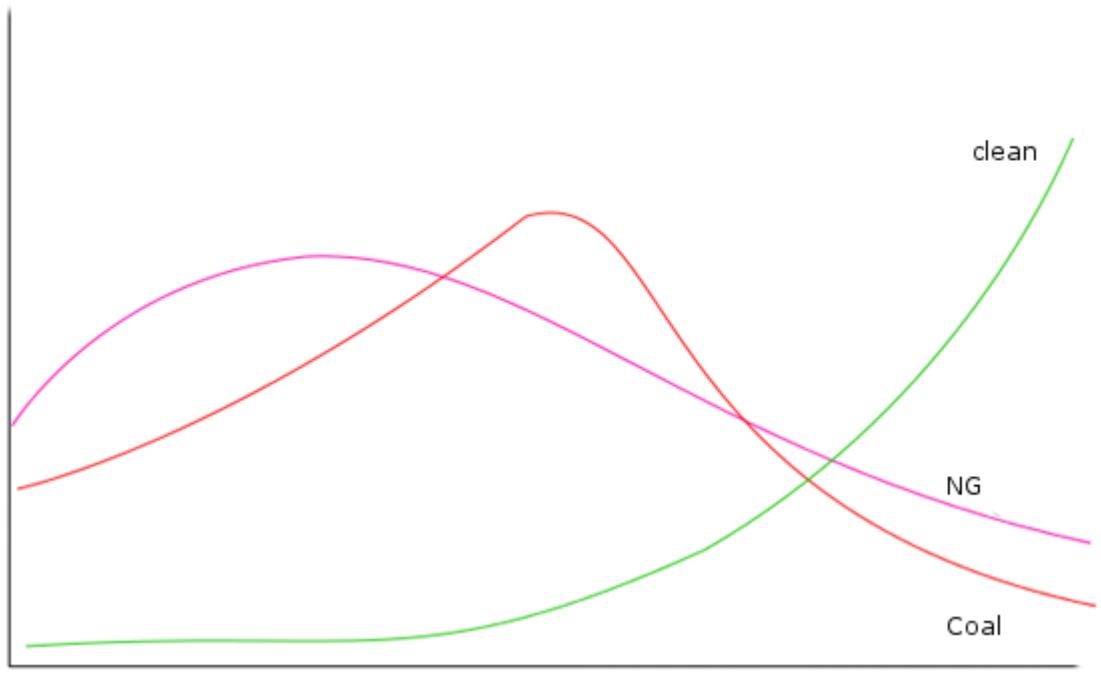
**Systems Thinking**
**Model form II – Original model**
Ricardo Vera

**Citation:** Why World Coal Consumption Keeps Rising; What Economists Missed

## ***Verbal description***

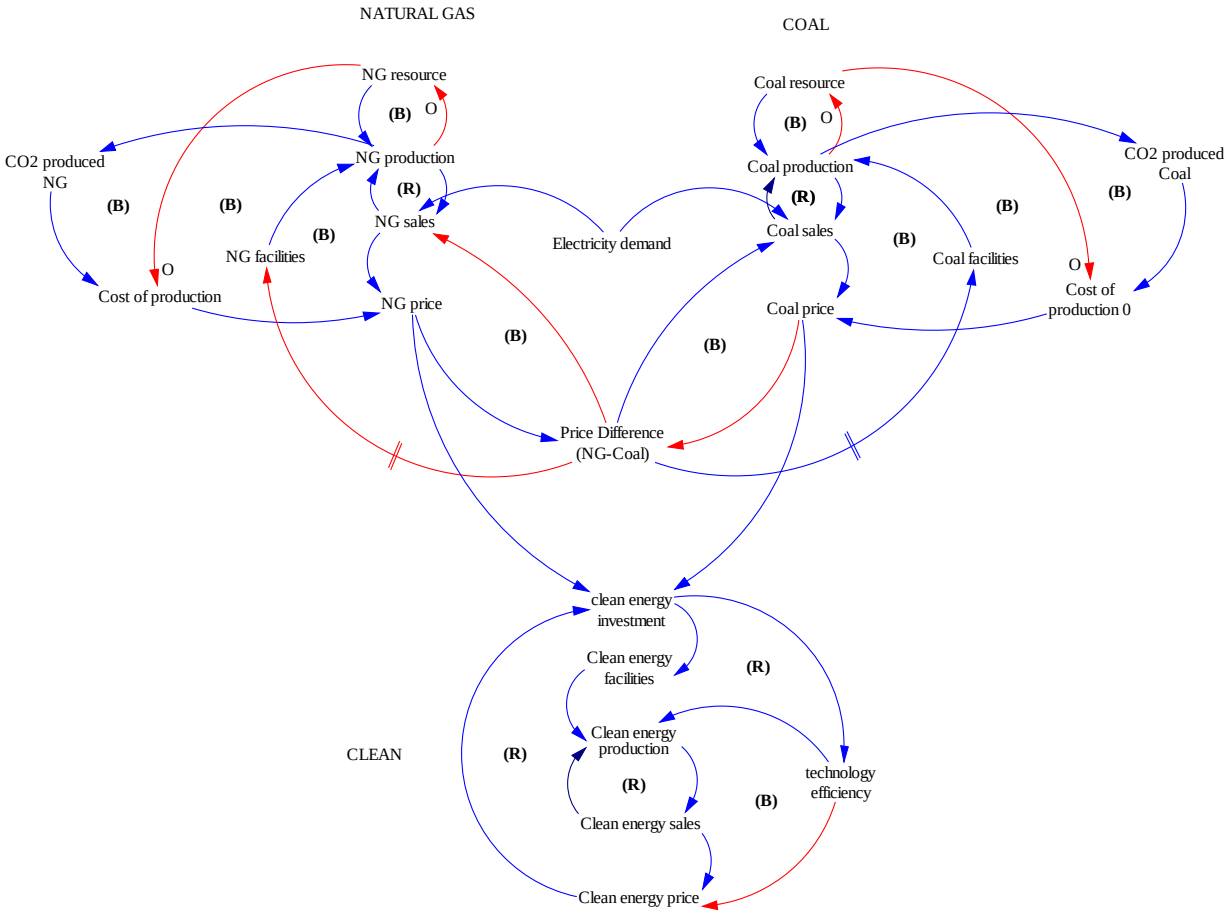
In the electricity production market, coal and natural gas are the most important fuels. The price of them depends on the total amount of the known natural deposits and the consumption rate. At the beginning, the price for NG is lower than Coal. Therefore, its exploitation rate grows even faster in relation with the difference with the price for Coal. But with more exploitation, the price increase. On the other hand, with less proportional exploitation, the price of coal will decrease. The total natural reserves also have a direct impact on the prices for NG and Coal: both reserves keep declining and the prices will rise in the same proportion. The highest-priced fuel will foster the growth of the lower-priced fuel production, because it's a better solution for the growth in demand. But Natural gas extraction rises and NG deposits start to deplete faster than coal. This makes NG prices increase even faster, and in time it becomes the highest-priced fuel.

***Initial Behavior over time (BOT)***

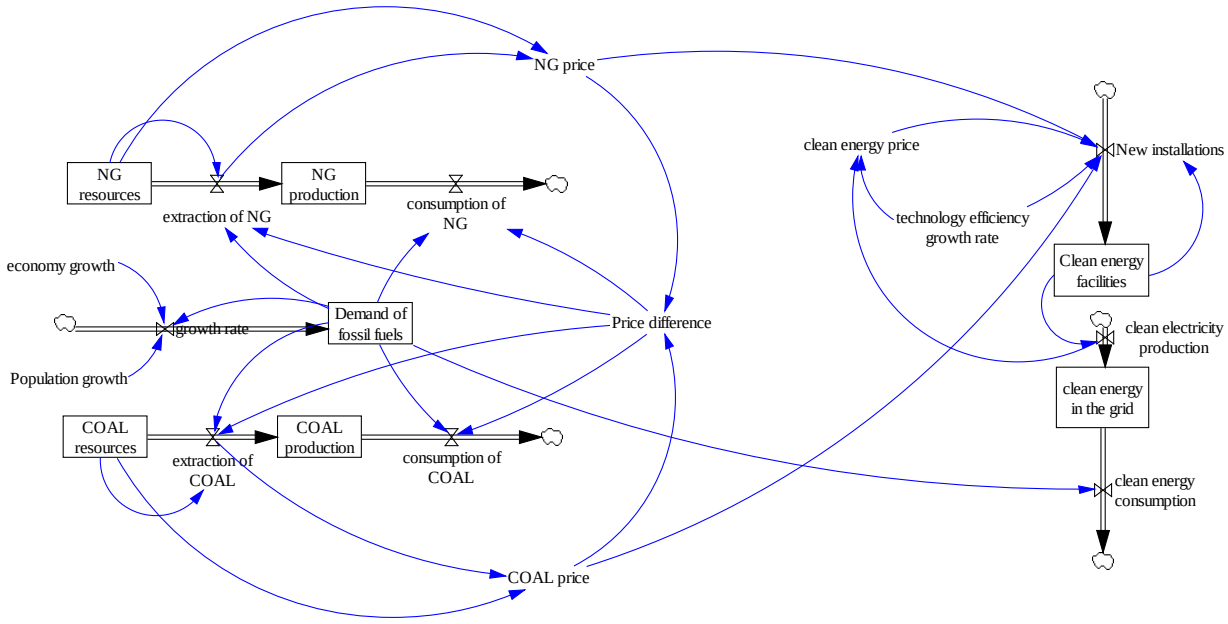



Production of electricity from coal, natural gas and clean sources

## ***Causal model***

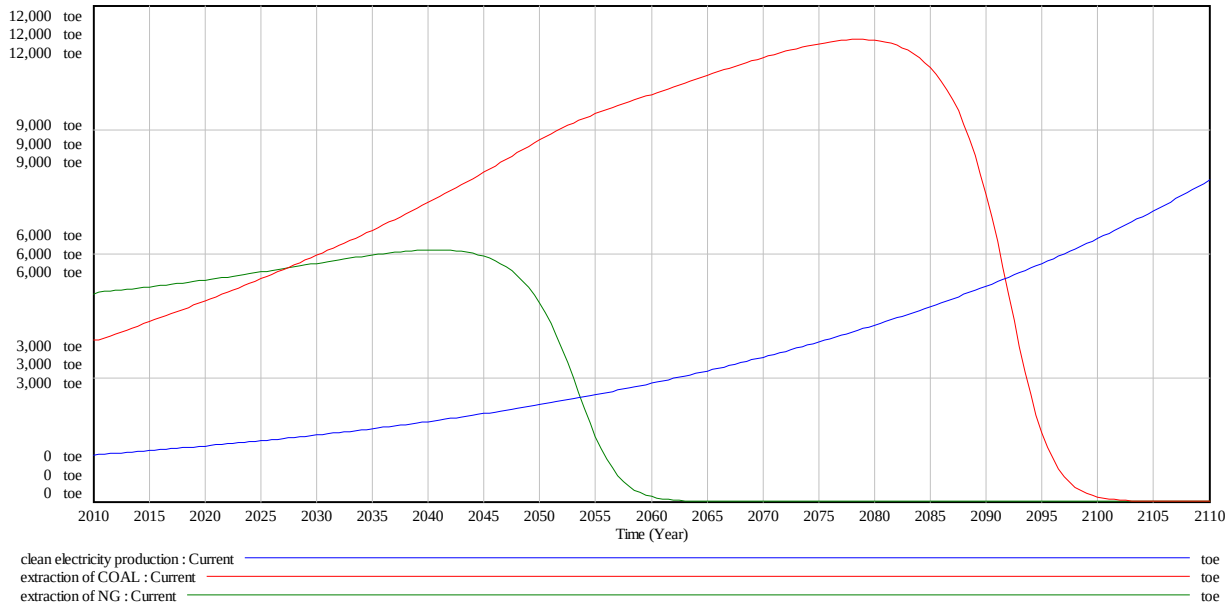


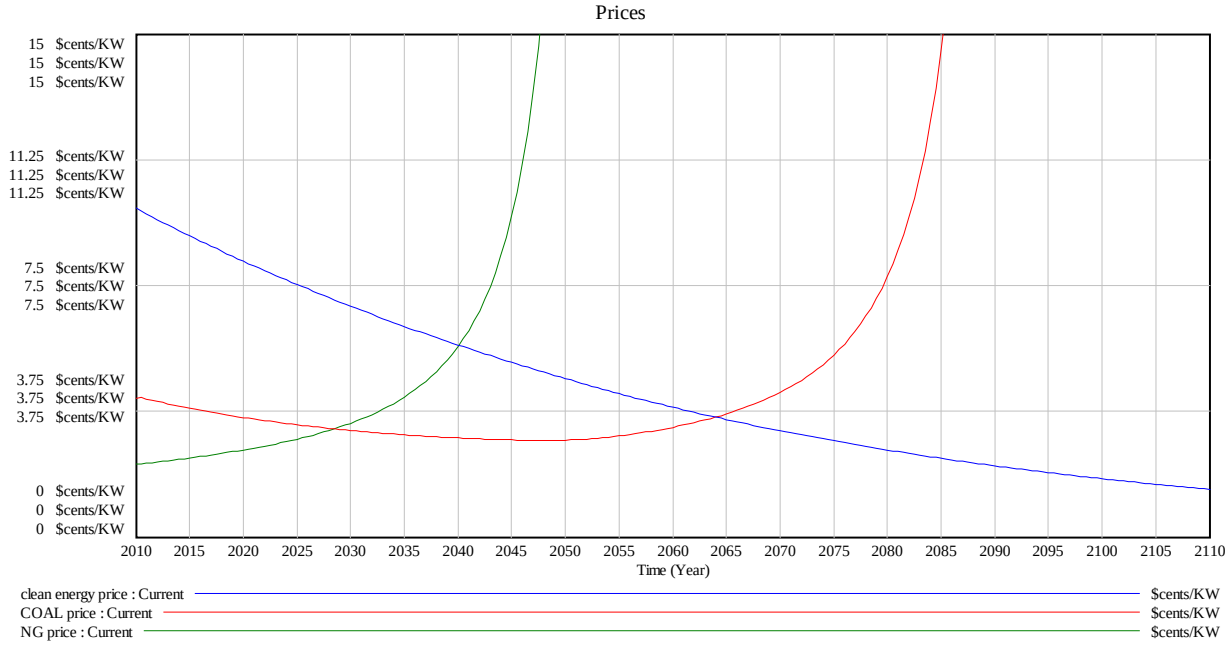

## ***Stock-Flow Model***



## ***Final Behavior over time (BOTs)***

NG behavior is similar to the coal behavior, but with a more “flat” envelope, until it goes away and all the new Demand is met by Coal. I think that happened because of the way the system is programed: there are mathematical values that almost compensate each other. For example, the lower price of NG at the beginning makes the system increase its exploitation, but that also increases the price and decreases the resources faster, therefore we can extract less NG.



## ***Equations***

(01) clean electricity production=
113*Clean energy facilities/28000
Units: toe

(02) clean energy consumption=
Demand of fossil fuels/100
Units: **undefined**

(03) Clean energy facilities= INTEG (
New installations,
280000)
Units: **undefined**

(04) clean energy in the grid= INTEG (
clean electricity production-clean energy consumption,
113*Clean energy facilities/280000)
Units: **undefined**

(05) clean energy price=
((113/clean electricity production)*(1-technology efficiency growth rate)
)*100
Units: $cents/KW

(06) COAL price=
SIMULTANEOUS((4*(676350/COAL resources)*(4050/extraction of COAL)),4)
Units: $cents/KW

(07) COAL production= INTEG (
extraction of COAL-consumption of COAL,
4050)
Units: **undefined**

(08) COAL resources= INTEG (
-extraction of COAL,
676350)
Units: toe

(09) consumption of COAL=
SIMULTANEOUS(Demand of fossil fuels * (1-Price difference),4050)
Units: **undefined**

(10) consumption of NG=
SIMULTANEOUS(Demand of fossil fuels*Price difference,3650)
Units: **undefined**

(11) Demand of fossil fuels= INTEG (
growth rate,
7700)
Units: toe

(12) economy growth=
0.01
Units: **undefined**

(13) extraction of COAL=
SIMULTANEOUS((COAL resources*(4050/7000)*Demand of fossil fuels/(Demand of fossil fuels
+COAL resources))+ ((Price difference-0.5)*(COAL resources*0.005)),4050)
Units: toe

(14) extraction of NG=
SIMULTANEOUS((NG resources*0.6*Demand of fossil fuels/(Demand of fossil fuels
+NG resources)) + ((0.5-Price difference)*(NG resources*0.015)),3650)
Units: toe

(15) FINAL TIME = 2110
Units: Year
The final time for the simulation.

(16) growth rate=

Demand of fossil fuels*((economy growth+Population growth)/2)
Units: **undefined**

(17) INITIAL TIME = 2010
Units: Year
The initial time for the simulation.

(18) New installations=
((COAL price+NG price)/((clean energy price/10)+COAL price+NG price))*(technology efficiency growth rate )*(Clean energy facilities)
Units: **undefined**

(19) NG price=
SIMULTANEOUS((3*(244550/NG resources)*(3650/extraction of NG)),3)
Units: $cents/KW

(20) NG production= INTEG (
extraction of NG-consumption of NG,
3650)
Units: **undefined**

(21) NG resources= INTEG (
-extraction of NG,
244550)
Units: toe

(22) Population growth=
0.02
Units: **undefined**

(23) Price difference=
SIMULTANEOUS((NG price)/(COAL price+NG price),(0.42))
Units: **undefined**

(24) SAVEPER =
TIME STEP
Units: Year [0,?]
The frequency with which output is stored.

(25) technology efficiency growth rate=
0.02
Units: **undefined**

(26) TIME STEP = 0.5
Units: Year [0,?]
The time step for the simulation.

***Include the Vensim model as a separate attached file*** *(or in Zip file with this file if Blackboard only allows one attachment to Discussion Board postings, I think!)*

## ***Original article***

Why World Coal Consumption Keeps Rising; What Economists Missed

http://ourfiniteworld.com/2012/12/19/why-world-coal-consumption-keeps-rising-what-economists-missed/

**Systems Thinking**
**Model form II – Structural variation**
Ricardo Vera

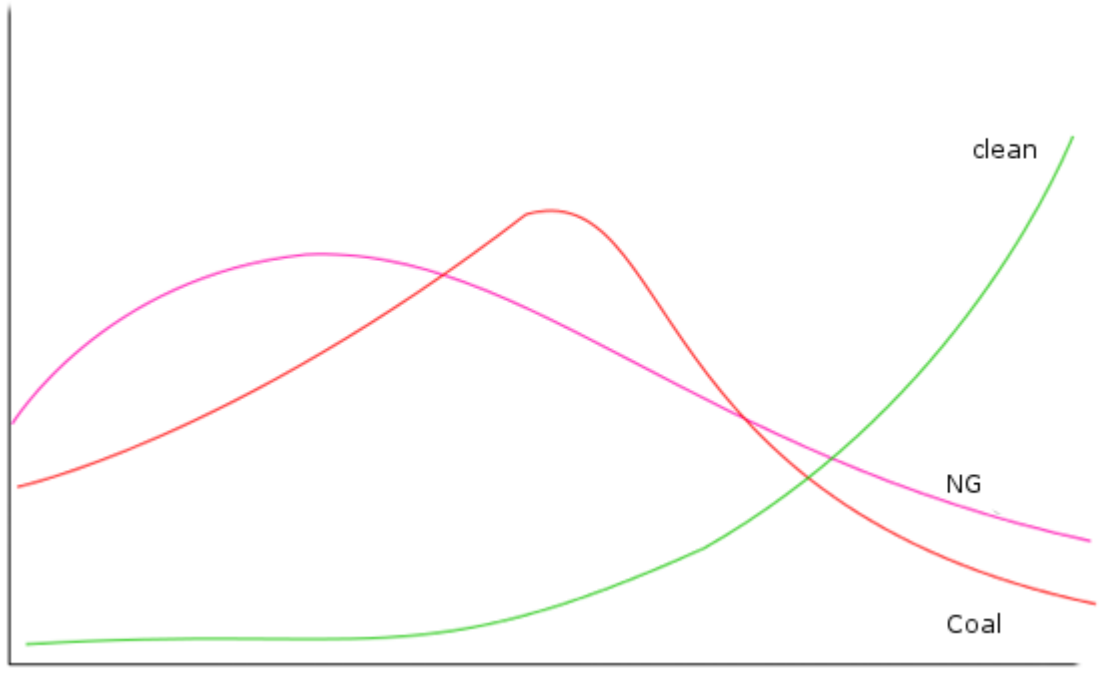
**Citation:** "Why World Coal Consumption Keeps Rising; What Economists Missed", and "How would a carbon tax work? Ask British Columbia"

**Verbal description**

In the electricity production market, coal and natural gas are the most important fuels. The price of them depends on the total amount of the known natural deposits and the consumption rate. At the beginning, the price for NG is lower than Coal. Therefore, its exploitation rate grows even faster in relation with the difference with the price for Coal. But with more exploitation, the price increase. On the other hand, with less proportional exploitation, the price of coal will decrease. The total natural reserves also have a direct impact on the prices for NG and Coal: both reserves keep declining and the prices will rise in the same proportion. The highest-priced fuel will foster the growth of the lower-priced fuel production, because it's a better solution for the growth in demand. But Natural gas extraction rises and NG deposits start to deplete faster than coal. This makes NG prices increase even faster, and in time it becomes the highest-priced fuel.

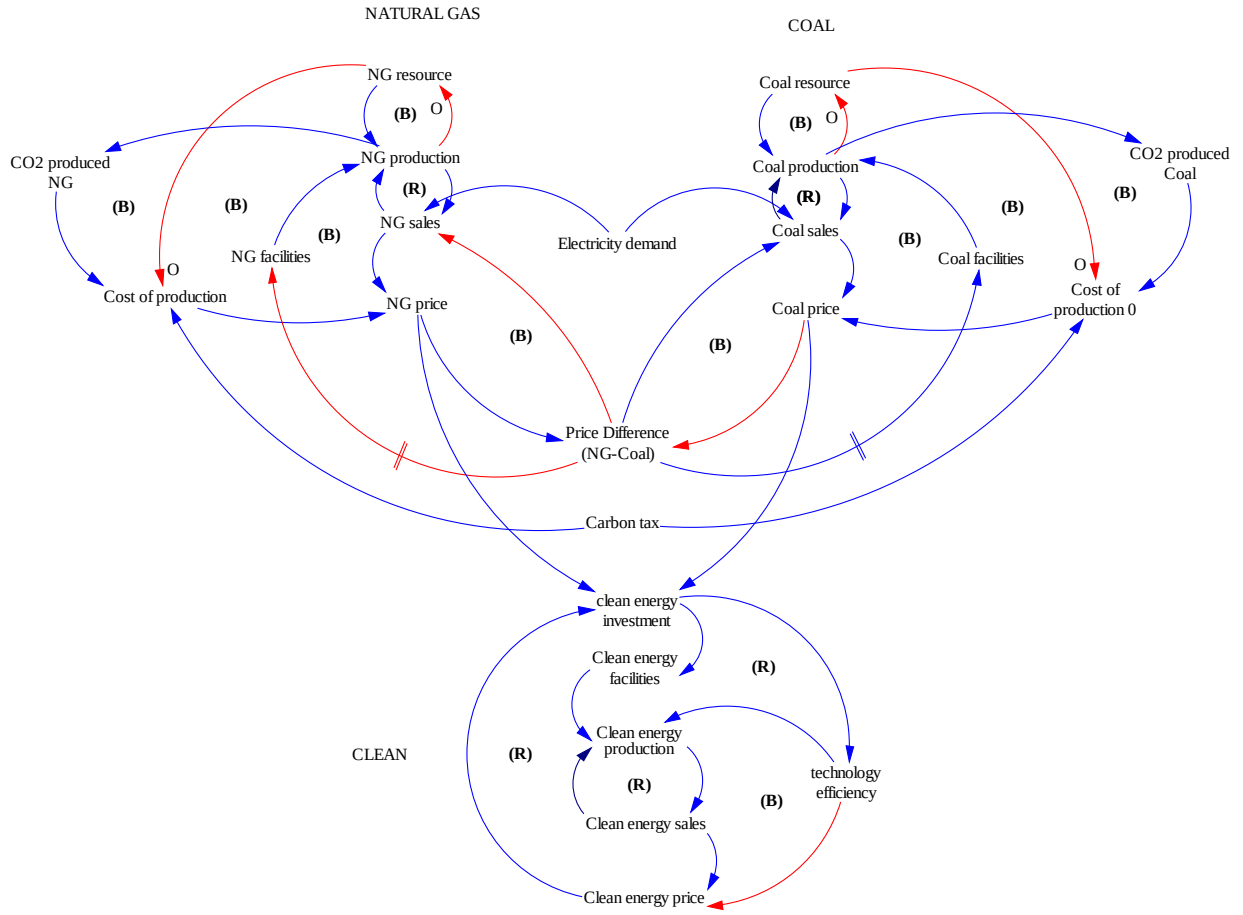
The addition of a CO2-TAX should promote the transition to natural gas, and in time, to clean energy production, because it affects the increment in Coal price even further.

**Initial Behavior over time (BOT)**

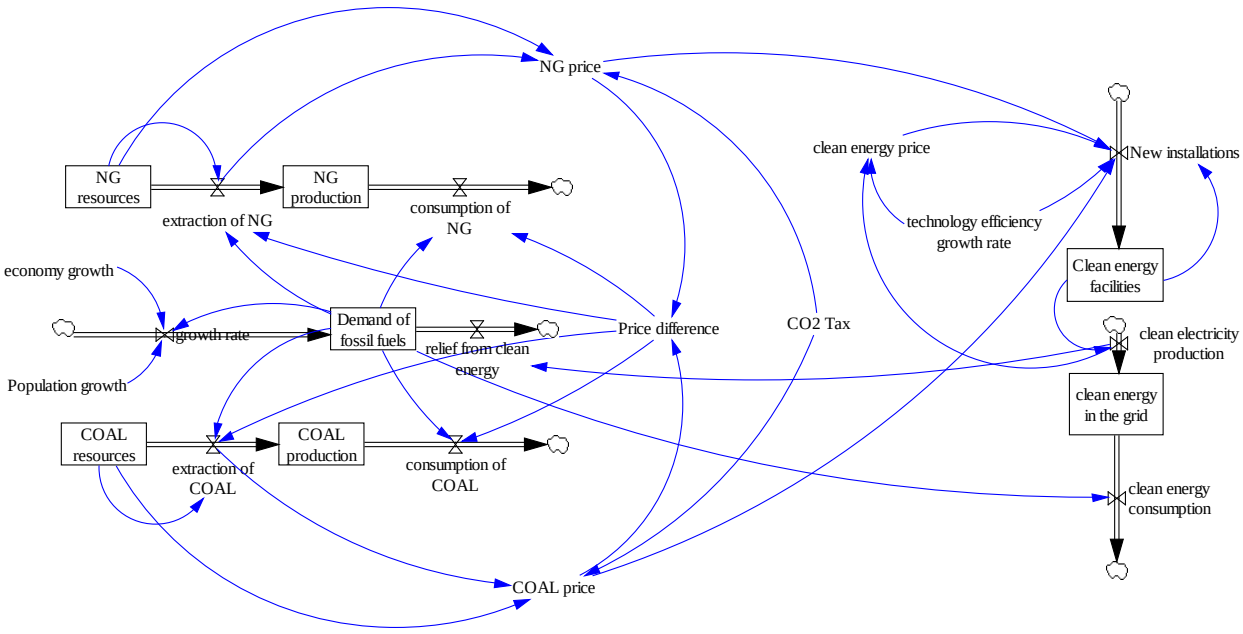



Production of electricity from coal, natural gas and clean sources

## Causal model

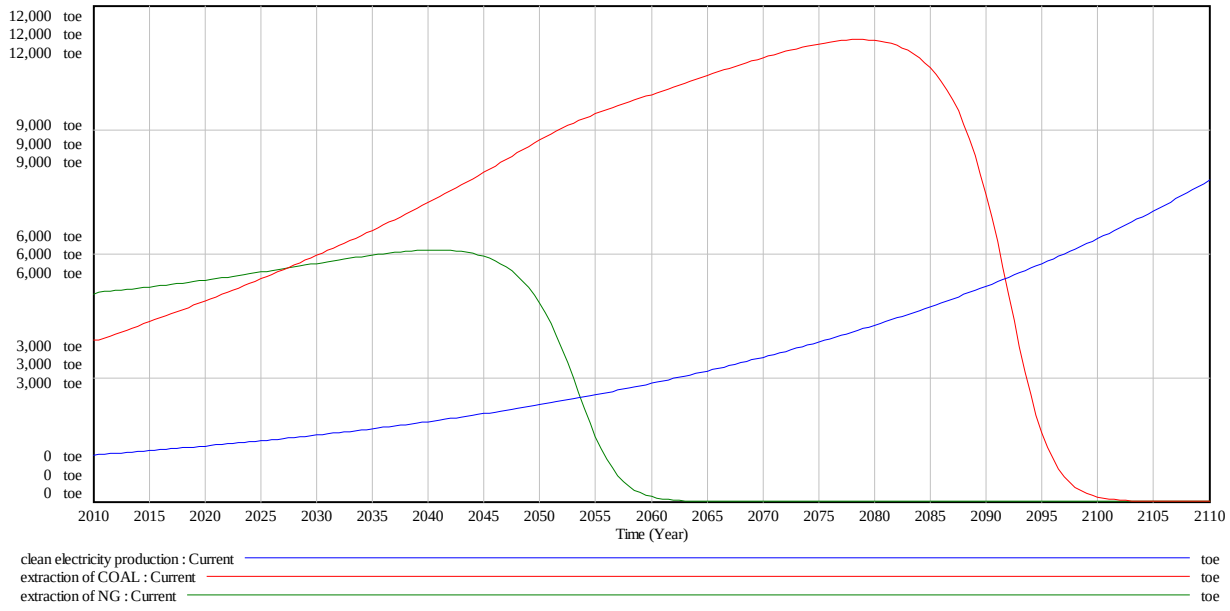


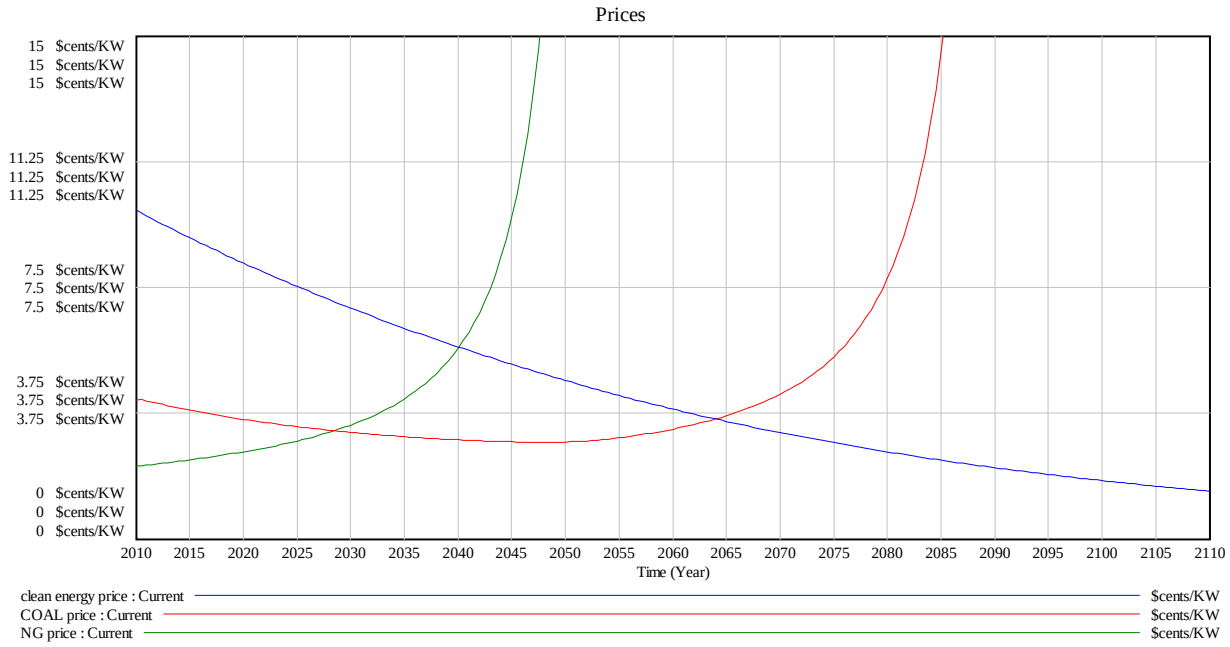

## Model



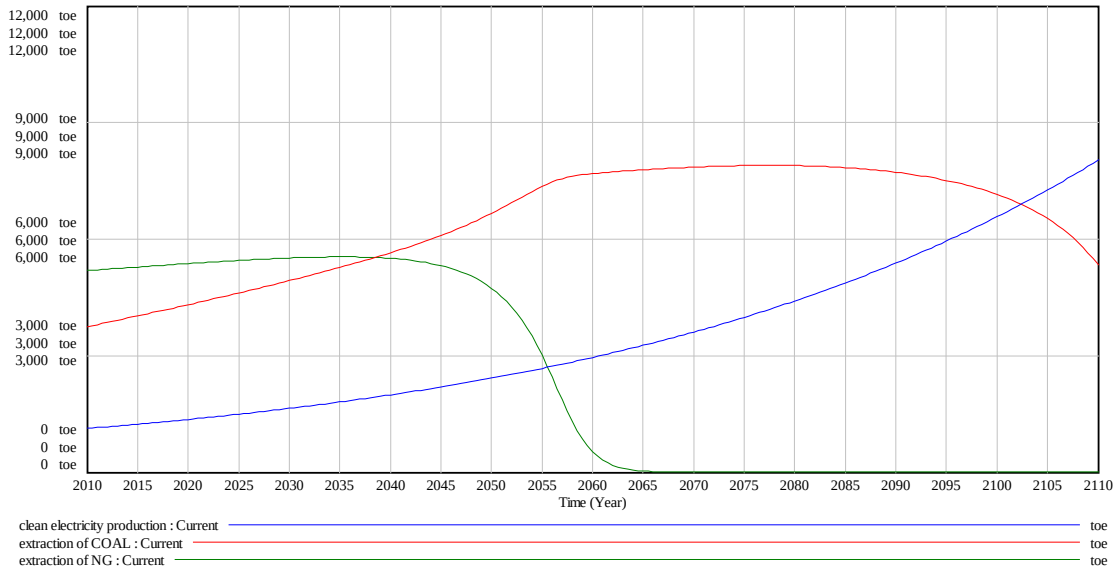
## Final Behavior over time (BOTs)

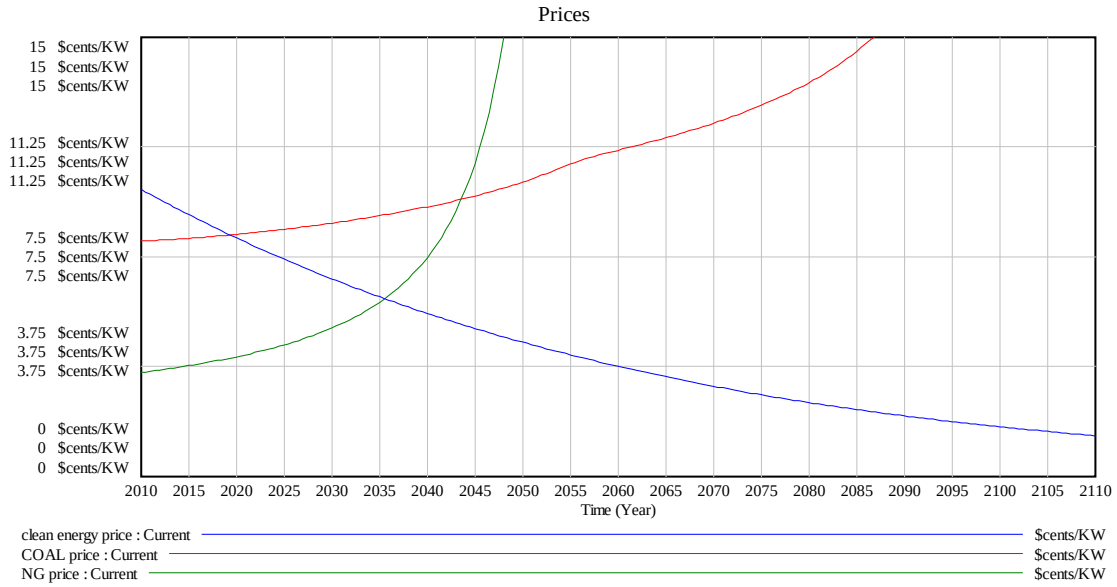
### Original BOT



## Alternate BOT




I added 2 structure interventions to this model: a link from CO2 Tax to NG price and Coal price, which will affect them in direct proportion to their resources extraction. In the case of Coal, its tax is 4 times the tax on NG. I also added an outflow to the demand of fossil fuel. My idea was to show a decrease on the demand of fossil fuels because of an increase of the clean-energy production. I called that outflow “relief from clean energy sources”.

The NG production behavior is very close to the original. The addition of the CO2 Tax put more pressure on the coal price. Ng runs out a little bit faster and has a flatter envelope now. I think that is because of how the increasing-demand of fossil fuels in partially met by the clean-energy production, therefore decreasing the pressure on NG extraction a little bit. I think that explains the extreme change in the coal behavior too. After the depletion of the NG reserves, there is no big increment in the coal extraction, because at that time, clean-energy production is large enough to compensate the increasing demand of energy. The coal production will flatten until depletion of the resources.

## Equations

(01) clean electricity production=
113*Clean energy facilities/28000
Units: toe

(02) clean energy consumption=
Demand of fossil fuels/100
Units: **undefined**

(03) Clean energy facilities= INTEG (
New installations,
280000)
Units: **undefined**

(04) clean energy in the grid= INTEG (
clean electricity production-clean energy consumption,
113*Clean energy facilities/280000)
Units: **undefined**

(05) clean energy price=
((113/clean electricity production)*(1-technology efficiency growth rate)
)*100
Units: $cents/KW

(06) CO2 Tax=
2
Units: cents$/KW

(07) COAL price=
SIMULTANEOUS((4*(676350/COAL resources)*(4050/extraction of COAL))+((CO2 Tax
*2)*(extraction of COAL/4050)),4)
Units: $cents/KW

(08) COAL production= INTEG (
extraction of COAL-consumption of COAL,
4050)
Units: **undefined**

(09) COAL resources= INTEG (
-extraction of COAL,
676350)
Units: toe

(10) consumption of COAL=
SIMULTANEOUS(Demand of fossil fuels * (1-Price difference),4050)
Units: **undefined**

(11) consumption of NG=
SIMULTANEOUS(Demand of fossil fuels*Price difference,3650)
Units: **undefined**

(12) Demand of fossil fuels= INTEG (
growth rate-relief from clean energy,
7700)
Units: toe

(13) economy growth=
0.01
Units: **undefined**

(14) extraction of COAL=
SIMULTANEOUS((COAL resources*(4050/7000)*Demand of fossil fuels/(Demand of fossil fuels
+COAL resources))+ ((Price difference-0.5)*(COAL resources*0.005)),4050)
Units: toe

(15) extraction of NG=
SIMULTANEOUS((NG resources*0.6*Demand of fossil fuels/(Demand of fossil fuels
+NG resources)) + ((0.5-Price difference)*(NG resources*0.015)),3650)
Units: toe

(16) FINAL TIME = 2110
Units: Year
The final time for the simulation.

(17) growth rate=
Demand of fossil fuels*((economy growth+Population growth)/2)
Units: **undefined**

(18) INITIAL TIME = 2010
Units: Year
The initial time for the simulation.

(19) New installations=
((COAL price+NG price)/((clean energy price/10)+COAL price+NG price))*(technology efficiency growth rate )*(Clean energy facilities)
Units: **undefined**

(20) NG price=
SIMULTANEOUS((3*(244550/NG resources)*(3650/extraction of NG))+((CO2 Tax/ 2)*(extraction of NG/3650)),3)
Units: $cents/KW

(21) NG production= INTEG (
extraction of NG-consumption of NG,
3650)
Units: **undefined**

(22) NG resources= INTEG (
-extraction of NG,
244550)
Units: toe

(23) Population growth=
0.02
Units: **undefined**

(24) Price difference=
SIMULTANEOUS((NG price)/(COAL price+NG price),(0.42))
Units: **undefined**

(25) relief from clean energy=
clean electricity production/30
Units: **undefined**

(26) SAVEPER =
TIME STEP
Units: Year [0,?]
The frequency with which output is stored.

(27) technology efficiency growth rate=
0.02
Units: **undefined**

(28) TIME STEP = 0.5
Units: Year [0,?]
The time step for the simulation.

## Original article

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http://ourfiniteworld.com/2012/12/19/why-world-coal-consumption-keeps-rising-what-economists-missed/

How would a carbon tax work? Ask British Columbia
http://washingtonpost.com/blogs/wp/2012/09/how-would-a-carbon-tax-work-lets-ask-british-columbia/

**Systems Thinking**
**Model form II – Parametric variation**
Ricardo Vera

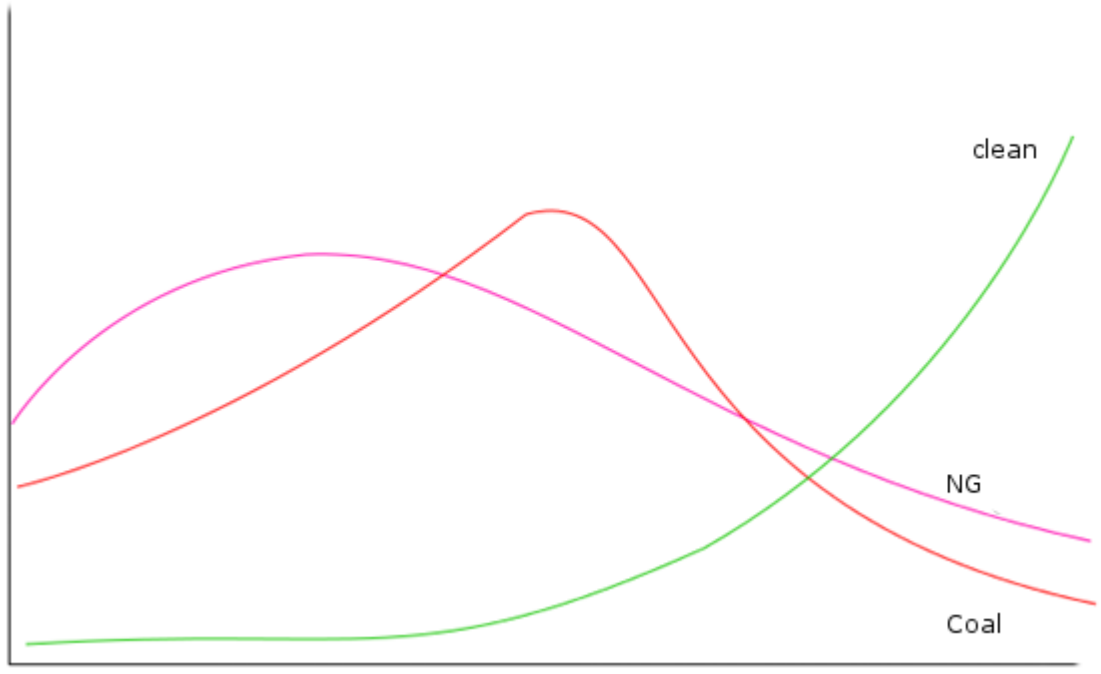
**Citation:** "Why World Coal Consumption Keeps Rising; What Economists Missed", and "How would a carbon tax work? Ask British Columbia"

**Verbal description**

In the electricity production market, coal and natural gas are the most important fuels. The price of them depends on the total amount of the known natural deposits and the consumption rate. At the beginning, the price for NG is lower than Coal. Therefore, its exploitation rate grows even faster in relation with the difference with the price for Coal. But with more exploitation, the price increase. On the other hand, with less proportional exploitation, the price of coal will decrease. The total natural reserves also have a direct impact on the prices for NG and Coal: both reserves keep declining and the prices will rise in the same proportion. The highest-priced fuel will foster the growth of the lower-priced fuel production, because it's a better solution for the growth in demand. But Natural gas extraction rises and NG deposits start to deplete faster than coal. This makes NG prices increase even faster, and in time it becomes the highest-priced fuel.

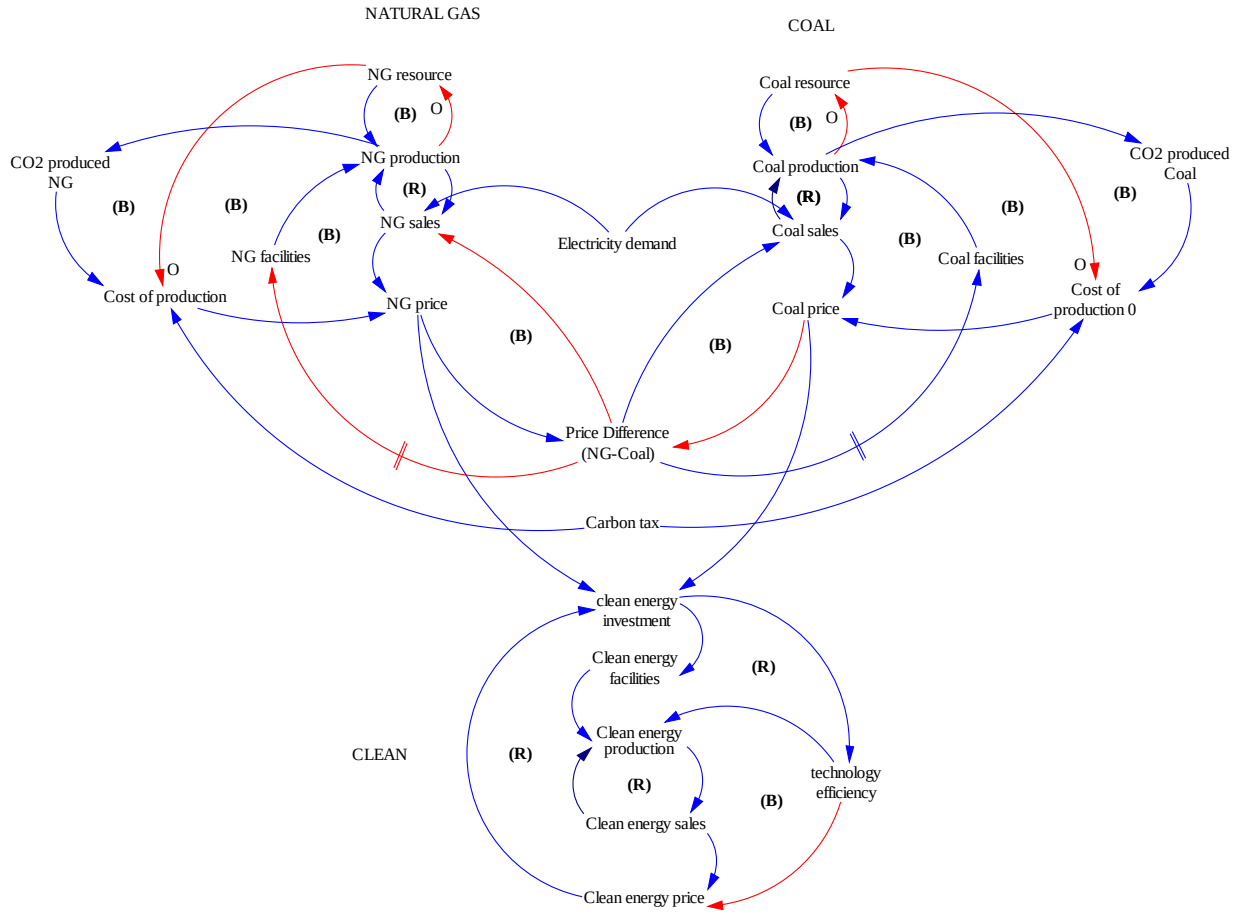
For this model, I'm keeping the addition of a CO2-TAX, but I'm assuming that new discoveries Natural Gas reserves will increase the known reserves to its double.

**Initial Behavior over time (BOT)**

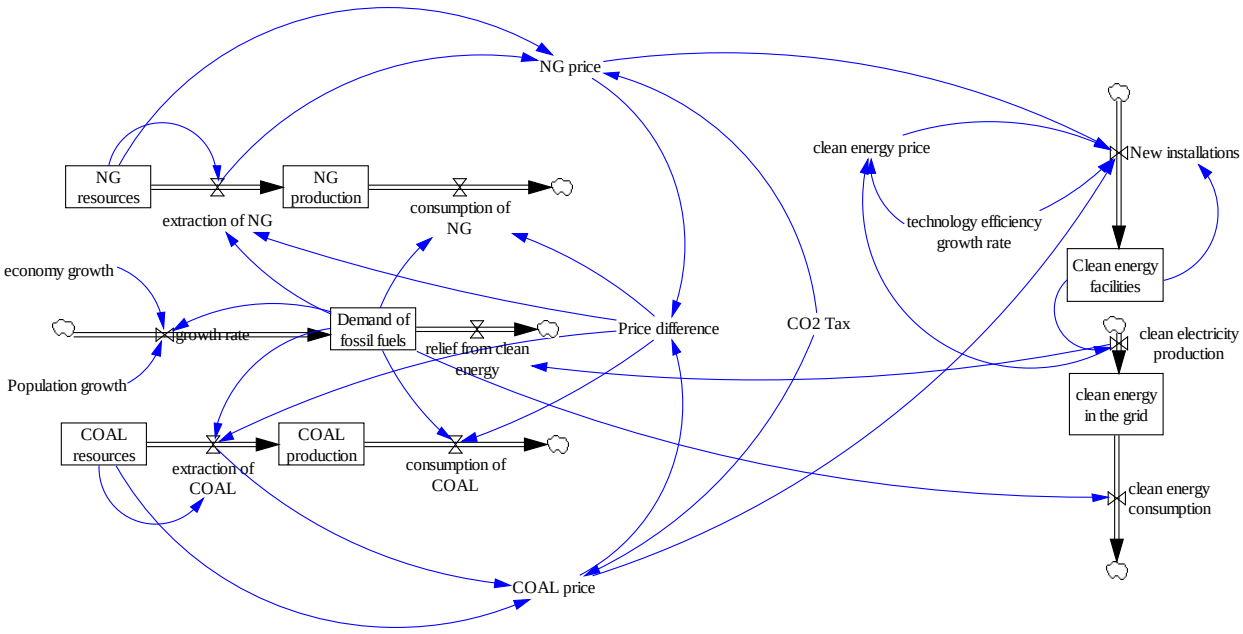



Production of electricity from coal, natural gas and clean sources

## Causal model

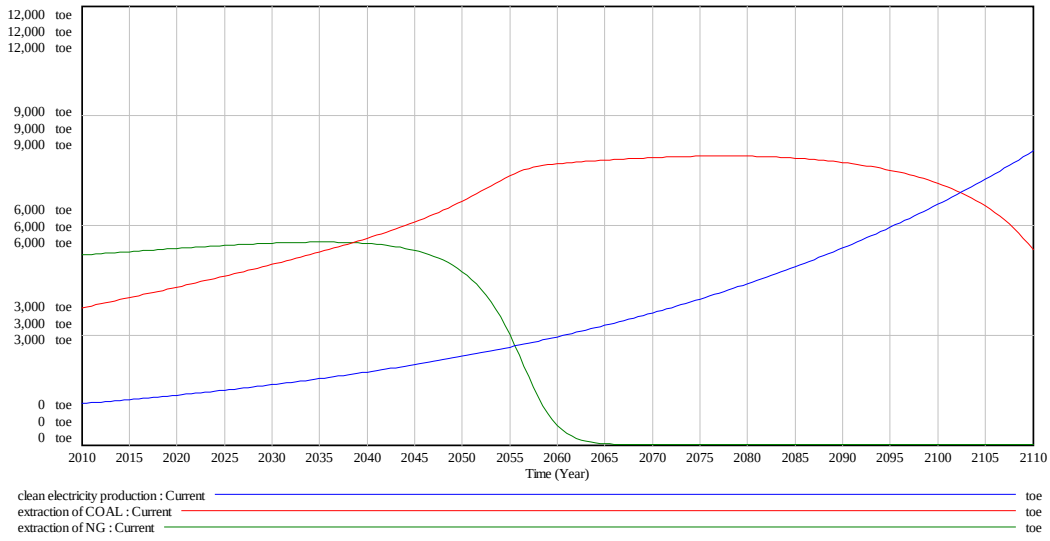



## Model

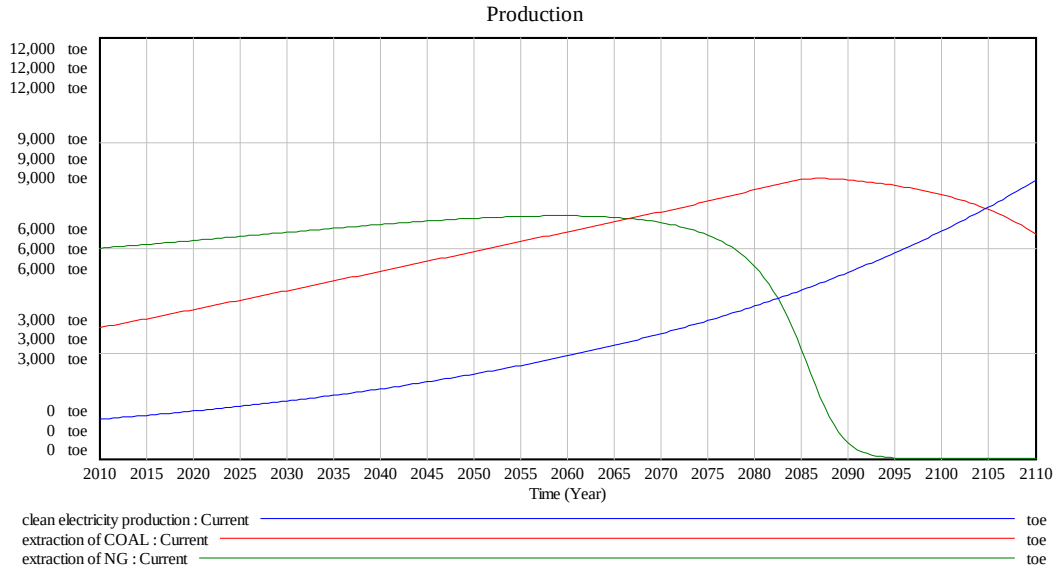


## Final Behavior over time (BOTs)

### Original BOT (with streucture intervention)




### Alternate BOT




I kept the 2 structure interventions to the previous model: a link from CO2 Tax to NG price and Coal price, and the "relief from clean energy sources" outflow. The parametric change is that I increased the NG resources to its double (from 244550 TOE to 489100 TOE). The NG production behavior is very close to the original though. The increased availability of a cheap fuel (The addition of the CO2 Tax put more pressure on the coal price) makes the NG extraction rise fast and stay in approximately 6000 TOE. I think the flatter envelope is still a result of the increasing availability of clean energy, therefore decreasing the pressure on NG extraction a little bit. Naturally, NG resources take more time to deplete now. After the depletion of the NG reserves, there is no big increment in the coal extraction again. In fact, after a small peak coal production will flatten until depletion of the resources. I was thinking that, if we compare the total area under the graphs for coal and NG, and considering that coal produces almost 4 times more CO2 that NG, this new scenario is a much "cleaner" one than the previous.

## Equations

(01) clean electricity production=
113*Clean energy facilities/28000
Units: toe

(02) clean energy consumption=
Demand of fossil fuels/100
Units: **undefined**

(03) Clean energy facilities= INTEG (
New installations,
280000)
Units: **undefined**

(04) clean energy in the grid= INTEG (
clean electricity production-clean energy consumption,
113*Clean energy facilities/280000)
Units: **undefined**

(05) clean energy price=
((113/clean electricity production)*(1-technology efficiency growth rate)
)*100
Units: $cents/KW

(06) CO2 Tax=
2
Units: cents$/KW

(07) COAL price=
SIMULTANEOUS((4*(676350/COAL resources)*(4050/extraction of COAL))+((CO2 Tax
*2)*(extraction of COAL/4050)),4)
Units: $cents/KW

(08) COAL production= INTEG (
extraction of COAL-consumption of COAL,
4050)
Units: **undefined**

(09) COAL resources= INTEG (
-extraction of COAL,
676350)
Units: toe

(10) consumption of COAL=
SIMULTANEOUS(Demand of fossil fuels * (1-Price difference),4050)
Units: **undefined**

(11) consumption of NG=
SIMULTANEOUS(Demand of fossil fuels*Price difference,3650)
Units: **undefined**

(12) Demand of fossil fuels= INTEG (
growth rate-relief from clean energy,
7700)
Units: toe

(13) economy growth=
0.01
Units: **undefined**

(14) extraction of COAL=
SIMULTANEOUS((COAL resources*(4050/7000)*Demand of fossil fuels/(Demand of fossil fuels
+COAL resources))+ ((Price difference-0.5)*(COAL resources*0.005)),4050)
Units: toe

(15) extraction of NG=
SIMULTANEOUS((NG resources*0.6*Demand of fossil fuels/(Demand of fossil fuels
+NG resources)) + ((0.5-Price difference)*(NG resources*0.015)),3650)
Units: toe

(16) FINAL TIME = 2110
Units: Year
The final time for the simulation.

(17) growth rate=
Demand of fossil fuels*((economy growth+Population growth)/2)
Units: **undefined**

(18) INITIAL TIME = 2010
Units: Year
The initial time for the simulation.

(19) New installations=
((COAL price+NG price)/((clean energy price/10)+COAL price+NG price))*(technology efficiency growth rate )*(Clean energy facilities)
Units: **undefined**

(20) NG price=
SIMULTANEOUS((3*(400000/NG resources)*(3650/extraction of NG))+((CO2 Tax/ 2)*(extraction of NG/3650)),3)
Units: $cents/KW

(21) NG production= INTEG (
extraction of NG-consumption of NG,
3650)
Units: **undefined**

(22) NG resources= INTEG (
-extraction of NG,
400000)
Units: toe

(23) Population growth=
0.02
Units: **undefined**

(24) Price difference=
SIMULTANEOUS((NG price)/(COAL price+NG price),(0.42))
Units: **undefined**

(25) relief from clean energy=
clean electricity production/30
Units: **undefined**

(26) SAVEPER =
TIME STEP
Units: Year [0,?]
The frequency with which output is stored.

(27) technology efficiency growth rate=
0.02
Units: **undefined**

(28) TIME STEP = 0.5
Units: Year [0,?]
The time step for the simulation.

## Original article

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How would a carbon tax work? Ask British Columbia
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