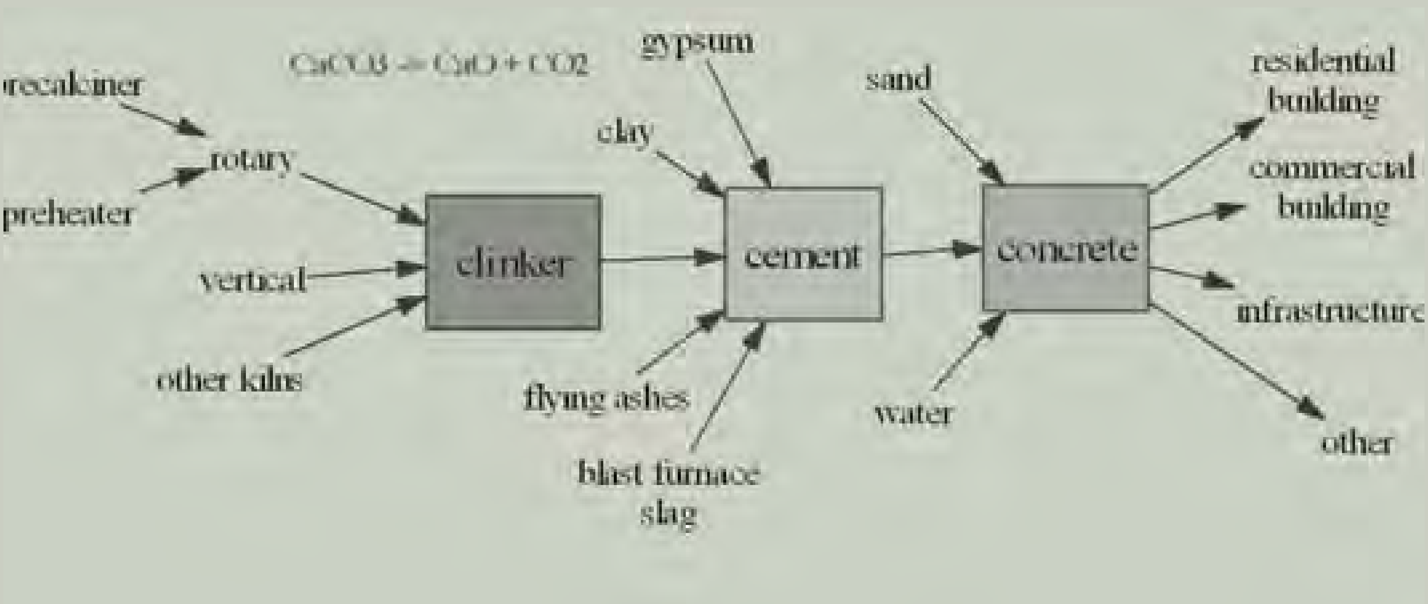
Using the T-21 Computing Model to Assess Alternative Scenarios of GHG Emissions in China's Cement and Steel Sectors in Developing Countries



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Discussion Paper
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Disclamer

This paper was produced as a reference paper to inform the discussion paper "New Mechanisms for Financing Mitigation: Transforming economies sector by sector." The views expressed in this paper do not represent the views of WWF nor the agencies that committed financial support to carry out this project.

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An Introduction to the Global Financial Mechanism Supporting Studies Series

Beginning in mid-2008, at the request of several European governments, WWF led an analysis and dialogue on international financing arrangements to address climate change in developing countries. That meant, on the one hand, advancing a technically strong proposal capable of mobilizing the considerable public and private funds that may be needed to attain the below 2 degrees centigrade goal for climate change stabilization and, on the other hand, advancing an equitable proposal that could garner the support of the parties at COP15.

The work approach is designed (a) to bring a bottom-up perspective to the to the current top-down discussion, based on a suit of developing countries' sectoral studies that focus on what it would actually take to move whole economic sectors towards a low emission trajectory; (b) to focus on the operational requirements of an international financing scheme; (c) to engage leading experts on a critical review of relevant experiences and government proposals; (d) to convene experts and negotiators from South and North to discuss these issues; and (e) to present the project findings to key stakeholders and forums in the run-up to COP15.

The program's main conclusions and proposals are in the document: "Global Financial Mechanism. The Institutional Architecture for Financing a Global Climate Deal" that can be downloaded from http://www.panda.org/what_we_do/how_we_work/policy/macro_economics/our_solutions/gfm/

In this Supporting Studies Series we are presenting a dozen reports that were used as inputs to the project. All these studies were commissioned to independent experts or institutions. Some are case studies of mitigation opportunities in different sectors of developing countries (e.g. cement and iron & steel in China and Mexico, coal based power generation in India, renewable energy opportunities in Morocco). Others are stock-taking reports focusing on critical issues for the global climate change financing (e.g. mapping new financing options for climate change, a review of sectoral mitigation proposals, a review of proposals to fund technology cooperation, etc.).

Some of the ideas and proposals in these support series have been carried over to the project recommendations and have been summarized in the main document (either as short summaries, theme boxes, or pull quotes). Still, these documents have much more to offer, and for that reason we present them here in full. As usual, opinions in each document are the sole responsibility of its author(s), and should in no way be considered representative of WWF positions.

Authors and titles in this GFM Supporting Studies Series include:

1. Michael Rock; (Bryn Mawr College) Using External Finance to Foster a Technology Transfer-Based CO_2 Reduction Strategy in the Cement and Iron and Steel Industries in China
2. Christine Woerlen (Arepo consult, Berlin) ; "Opportunities for renewable energy in Tunisia: A country Study
3. The Energy and Resources Institute (TERI, Delhi) "Strategies to reduce GHG emissions from India's coal-based power generation"
4. Britt Childs with Casey Freeman (WRI, Washington DC) "Tick Tech Tick Tech: Coming to Agreement on Technology in the Countdown to Copenhagen"
5. Energia, Tecnologia y Educacion, SC (ETE, Mexico DF) "Strategies to reduce Mexico's cement and iron & steel industry GHG emissions"
6. Charlotte Streck (Climate Focus, Brussels) "Sectoral Transformation Plans as Strategic Planning Tools"

7. Charlotte Streck (Climate Focus, Brussels) “Financing REDD a Review of Selected Policy Proposals
8. Charlotte Streck (Climate Focus, Brussels) “Financing Climate Change: Institutional Aspects of a Post-2012 Framework”
9. Silvia Magnoni “Review of the CDM and Other Existing and Proposed Financial Mechanisms to Transfer Funds from North to South for Mitigation and Adaptation Actions in Developing Countries”
10. Silvia Magnoni “Sectoral approaches to GHG mitigation and the post-2012 climate framework”
11. Weishuang Qu (Millennium Institute, Washington DC) “Using the T21 computing model to forecast production and emissions in China’s cement and steel sectors”
12. Neil Bird et al (ODI, London) “New financing for climate change. And the environment in the developing world”

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Executive Summary

Historical review

Since economic reform and an open-door policy in China started about 30 years ago, the country has experienced explosive economic growth, and with this came production growth in the cement and steel industries (which are over 99 percent for domestic uses).

Cement production grew from 210 million tons in 1990 to 1.35 billion tons in 2007, a 643 percent growth, about 11.5 percent annually on average. Cement is basically produced in two types of kilns: rotary kilns (more energy efficient) and vertical shaft kilns (less efficient). In the seven years from 2000 to 2007, production from rotary kilns grew about 10 times, and their share in cement production rose from 12 percent in 2000 to 55 percent in 2007. During 2004–-2007, where data is available, added annual rotary capacity was over 100 million tons. This fast growth of rotary capacity is the result of a few factors: (1) Unit cement production from rotary kilns needs about 75 percent as much energy as from vertical kilns, and its emissions are much lower too. (2) Since 2001 China has learned to produce rotary kilns domestically, and the price of rotary kilns has fallen sharply. (3) Government policy supports the more energy-efficient and less polluting rotary kilns.

Although China has made great efforts to reduce energy use per unit output of production, reducing the energy consumption per ton of cement from 0.195 tce (tons of coal equivalent) in 1990 to 0.137 tce in 2007, total energy use has been climbing, from 40 Mtce (million tons of coal equivalent) in 1990 to 185 Mtce in 2007. The energy used in cement production is primarily coal and electricity generated from coal, both generating CO_2 emissions. The chemical process of turning limestone into calcium oxide also releases CO_2. Total emissions from cement production grew from 204 million tons in 1990 to 1.05 billion tons in 2007.

The iron and steel industry has seen similar development in the past. Steel production grew from 66 million tons in 1990 to 489 million tons in 2007, a 732 percent growth, about 12.4 percent annually on average. Most crude steel is still produced from basic oxygen furnaces (BOFs), which use pig iron produced from blast furnaces (BFs). This process from BF to BOF is not as energy efficient as the electric arc furnace (EAF), which uses scrap steel to produce crude steel. But because of the lack of usable scrap steel, use of the EAF has not expanded very fast.

As a result of technology progress and the government's policy implementation of replacing smaller furnaces with larger, more efficient ones, energy use per ton of steel dropped from 1.44 tce in 1990 to 0.69 tce in 2007, a reduction of over 50 percent. But because of a huge production increase, total energy use still increased significantly, from 93 Mtce in 1990 to 327 Mtce in 2007. The energy used in steel production is primarily coal and electricity generated from coal, both generating CO_2 emissions. Total CO_2 emissions from steel production grew from 259 million tons in 1990 to 914 million tons in 2007.

The model presented here generates results for the historical period of 1990 to 2008, matching the available data very well in demand, production, energy use, and CO_2 emissions, which generates confidence in future scenarios.

Future Scenarios

The model can be used to explore different scenarios for the future from 2009 to 2030. To slow down the growth of, or even reduce, emissions from these two sectors, efforts should be made in multiple fields. These fields can be characterized as either on the demand side or on the technology side.

From the demand side, urban per capita living space and infrastructure construction are probably the two strongest forces that determine the future demand for and production of cement and steel. Urban per capita living space has more than doubled from1990 to 2008 (from 13.7 to 29.5 square meters). For the future, China can follow either the Japanese living style or the American one. In the baseline scenario, the Japanese style is assumed, with a slowing of urban per capita living space, which is projected to be 45 square meters in 2030.

Infrastructure construction could be an important measure to deal with the tough economic and employment situations in China. In the baseline of the model, it is assumed that infrastructure consumption of cement and steel will continue to be strong in 2009-2012 when national systems of highways, railways, and roads are being developed. After 2012, it is assumed that this consumption will start to decline as the infrastructure systems mature.

From the technology side of cement, many factors are included in the model: using alternative fuels to reduce emissions, lowering the share of clinker in cement to save energy, building larger and more efficient rotary kilns with precalciners and preheaters, establishing management centers, and increasing heat recovery. In iron and steel technologies, the model includes advanced iron-making technologies, such as COREX; availability of scrap steel to reduce the demand on pig iron (which requires lots of energy to make); building larger and more efficient furnaces/ovens; using dry coke quenching, powder coal injection in BFs, continuous casting, and direct rolling; establishing management centers; and increasing heat recovery.

Four scenarios have been developed to explore possible futures. They are categorized as Baseline, Optimistic, Pessimistic, and External Aid. Different values from the demand-side and technology-side variables were chosen for the scenarios, and final results are presented in two tables in the last section, one for the year 2015 and the other for 2030. These tables show that the futures can be very different depending on the paths (or policies) one chooses. For instance, in 2015, cement demand could be 1.92 billion tons for Pessimistic or 1.27 billion tons for Optimistic, and their CO_2 emissions could be 1.38 billion tons or 791 million tons respectively. Because of technology differences and the changing mix of technologies, per ton CO_2 emission could be 0.719 tons for Pessimistic or 0.622 tons for Optimistic. In 2030, the differences between these scenarios become even more significant. Cement demand could be 1.93 billion tons for Pessimistic or 659 million tons for Optimistic, a difference of almost three times. The difference in their CO_2 emissions is even bigger, 1.26 billion tons for Pessimistic or 292 million tons for Optimistic. Again because of technology differences, per ton CO_2 emission could be 0.649 tons for Pessimistic or 0.44 tons for Optimistic. The scenarios for steel demand and emissions show similar trends in 2015 and 2030.

This work was supported by World Wildlife Fund (WWF) USA. Several recommendations are made to WWF and similar international organizations, and some further work is proposed, all presented in the last section.

I. Background, Data Collection, and Historical Review

Since economic reform and an open-door policy in China started about 30 years ago, the country has experienced explosive economic growth, and with this came production growth in the cement and steel industries. Over 99 percent of cement produced has been for domestic use. China has been importing scrap steel and some steel products (such as sheet steel for automobile body manufacturing) and exporting crude steel. Combining the import and export quantities, China has been a net steel importer. WWF USA requested the Millennium Institute (MI) to build a cement and iron and steel model, based on the T21 China model jointly developed by MI and the Institute of Scientific and Technical Information of China (ISTIC), to project future growths of these industries and explore ways to reduce greenhouse gas (GHG) emissions from these two industries.

From November 2008 to January 2009, MI and ISTIC jointly collected data, reviewed literature, visited Chinese experts in these industries, and developed the model.

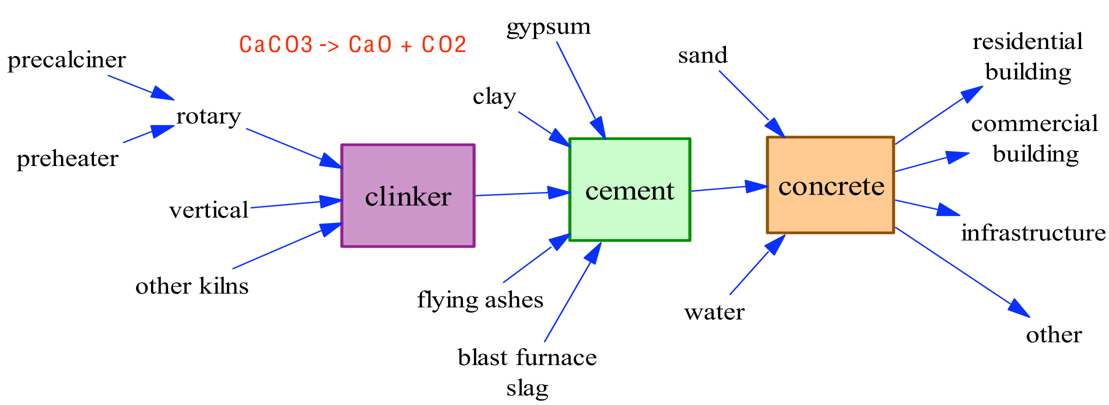
Data collection and verification were big efforts, as all data required by the model were not available, and available data from different sources did not always agree with each other. Detailed data work is included in the two attached files "CementComputation WQ.xls" and "SteelComputation WQ.xls."

We present the historical review first.

I.1 Cement historical review

Overview

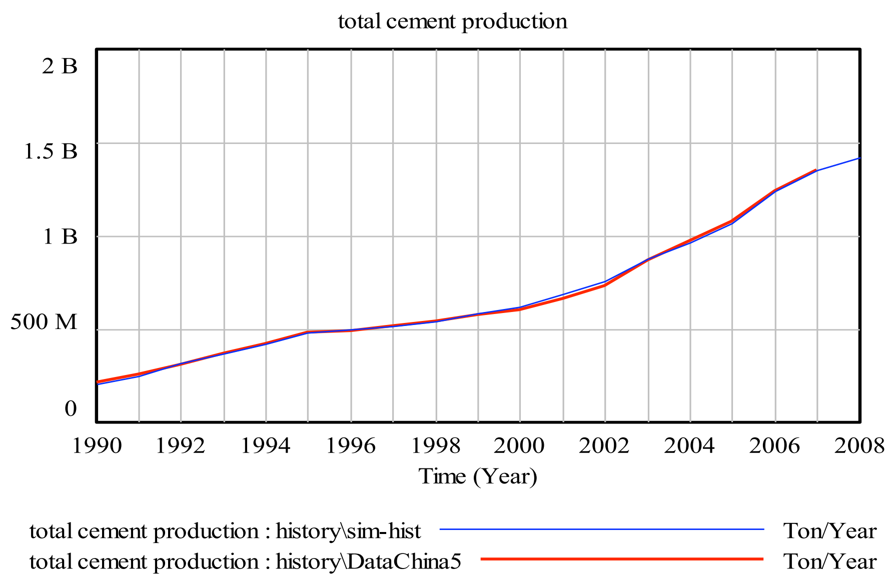
The production and use (or demand) of cement are shown in the following graph:



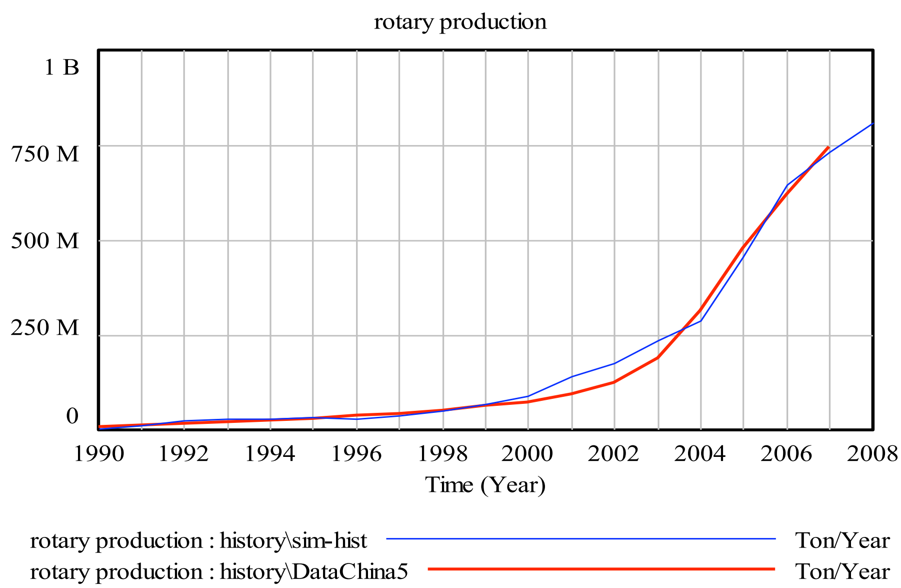
From the left to the box "concrete" is the flow of production process, while the right section shows the major sources of demand for cement products.

Production

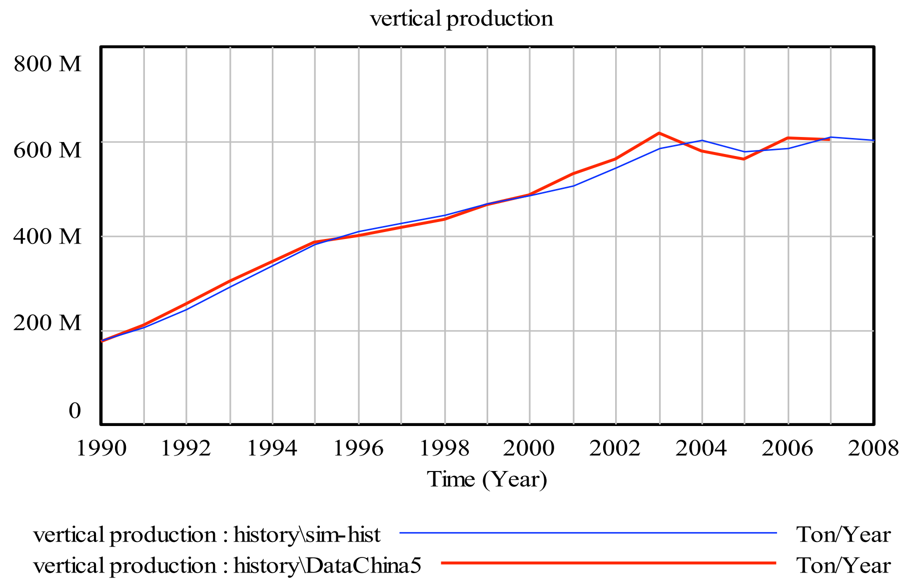
Cement production grew from 210 million tons in 1990 to 1.35 billion tons in 2007, a 643 percent growth, about 11.5 percent annually on average, as shown in the following graph. The blue line is what the model generated (named sim-hist), while the red line is the actual data from 1990 to 2007 (2008 data were not available when the model was built). This color scheme is consistent within this section of historical review: Blue represents the model result, and red represents the data we have.



Cement in China is basically produced in two types of kilns: rotary kilns (more energy efficient) and vertical shaft kilns (less efficient). In the seven years from 2000 to 2007, production from rotary kilns grew about 10 times, and its share in cement production rose from 12 percent in 2000 to 55 percent in 2007. This trend will continue into the future. The following is the model result together with data.

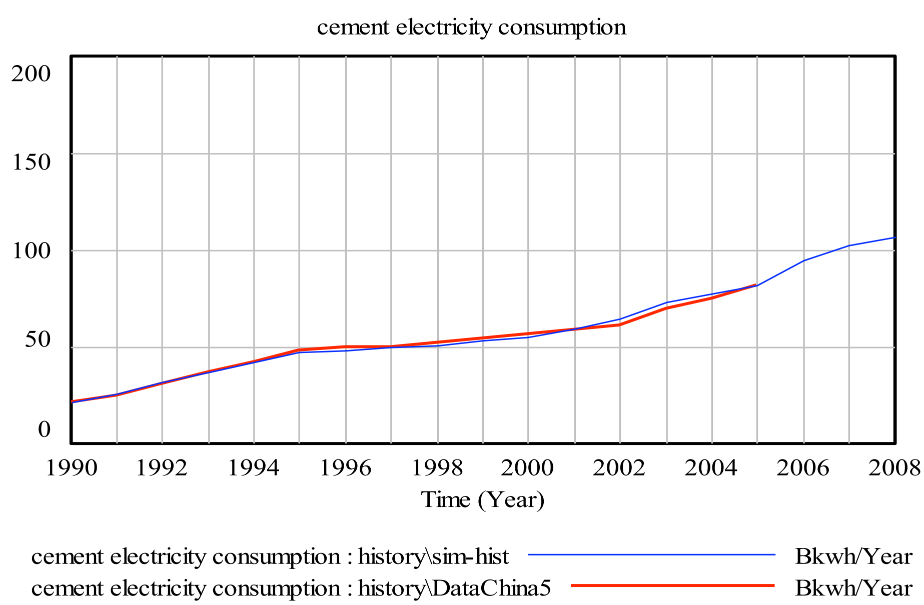


As a result of the fast growth in cement demand, vertical production has also grown, but not as fast since 2000; it shows a declining trend since 2003, as the following graph shows. Investments in new vertical kilns started to decline fast from 2003 and reached zero in 2007–2008.

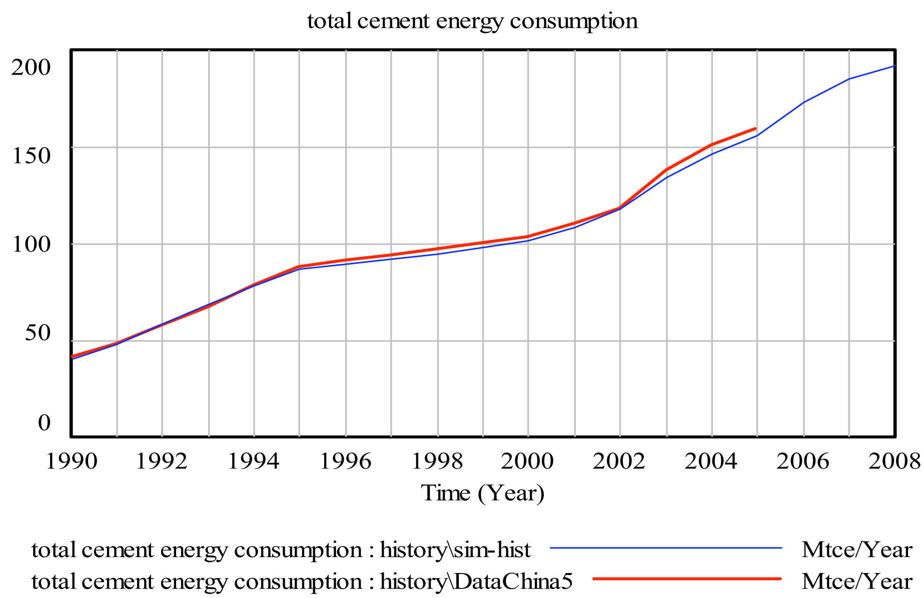


Energy use

Both rotary kilns and vertical kilns use coal and electricity. Total electricity used by them, measured in billions of kilowatt-hours (kWh), is shown below:



Total energy consumption, including electricity, coal, and some other fuels in small amounts, like gasoline, is shown below. The unit is million tons of coal equivalent, or Mtce.



Total energy consumption has gone up faster than electricity. This is probably a result of the higher cost of electricity relative to other energy sources in China.

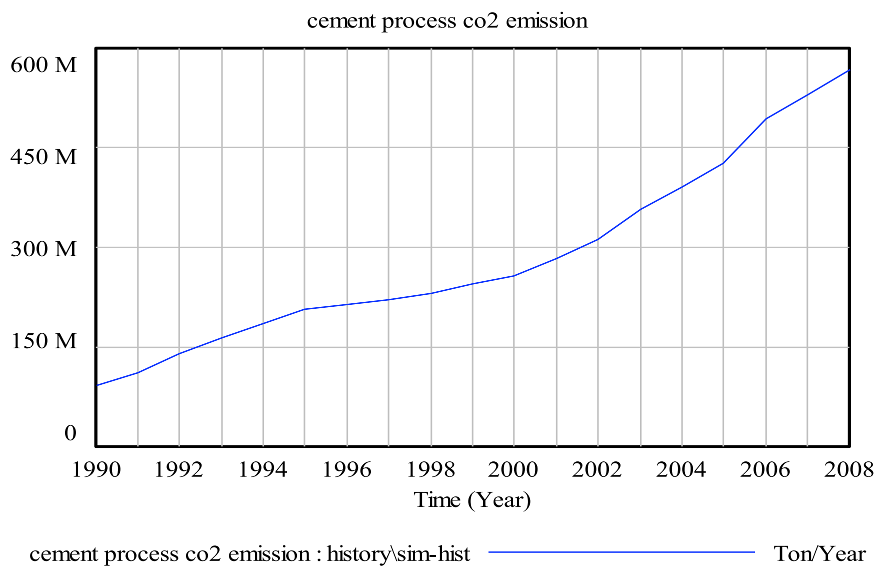
Dividing total energy use by total production, per ton energy use can be obtained, which has been improving since 1990. From 1990 to 2007, rotary and vertical energy efficiencies have each improved about 12 percent; however, the overall higher rate of energy use and emissions from vertical kilns supports the shift in the industry to rotary kilns.

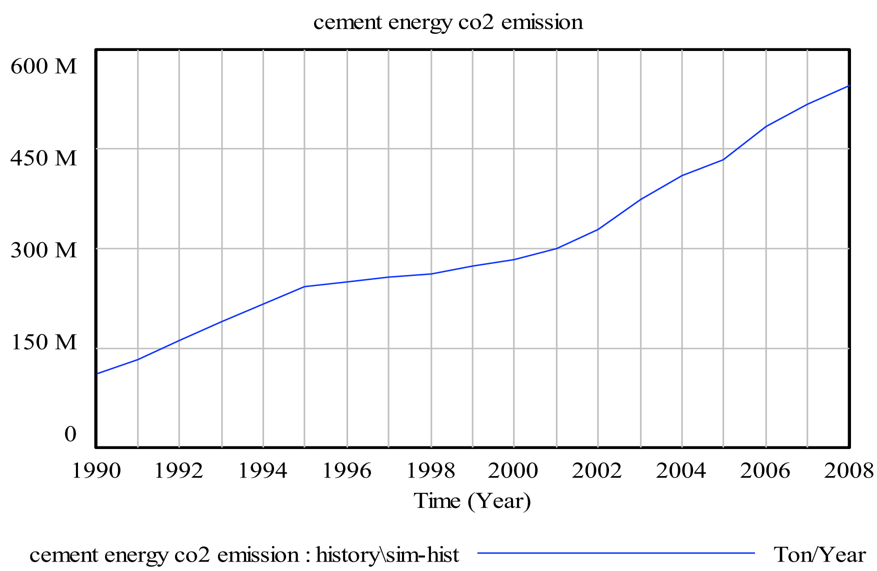
Emissions

Cement emissions can be classified as deriving from two sources:

1. from the chemical process when limestone calcium carbonate ($CaCO_3$) is converted to calcium oxide (CaO) and CO_2 and that CO_2 is released into the air, and
2. from energy use – when coal is burned, CO_2 is released; when electricity is used, it needs coal to generate the electricity, so CO_2 is also released.

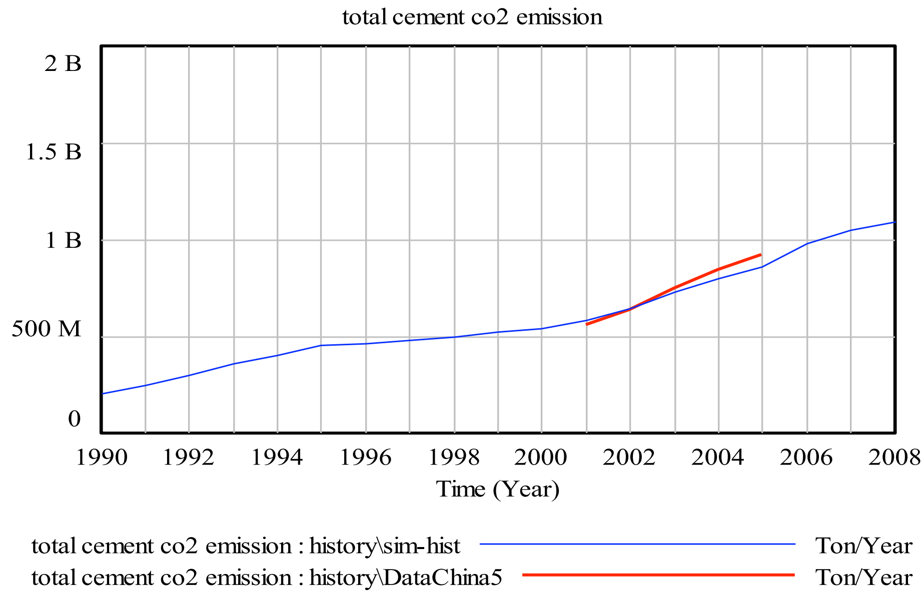
We did not find data for these two emissions, so the following two graphs show only model results:





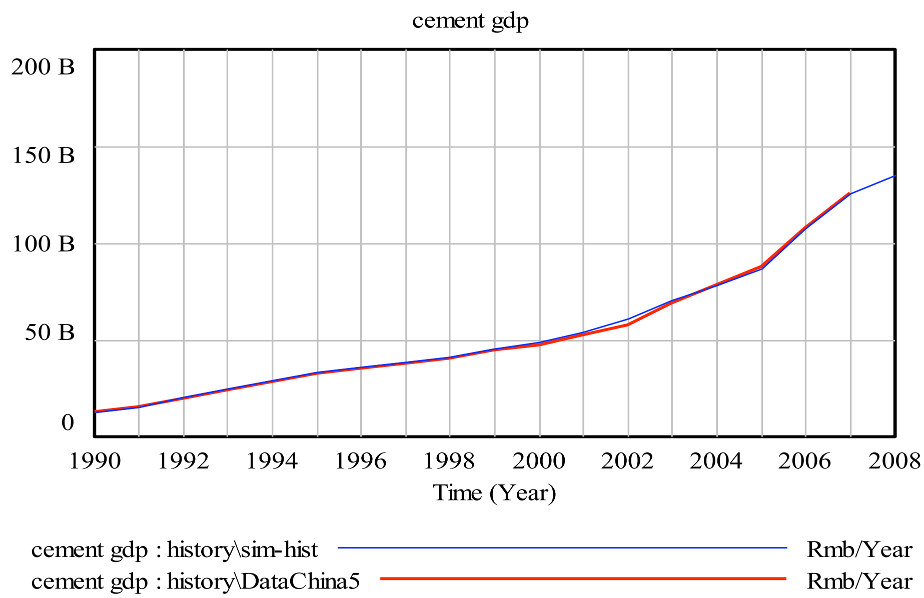
As shown in the above two graphs, cement process emission and energy emission of CO_2 both reached about 500 million tons in 2008.

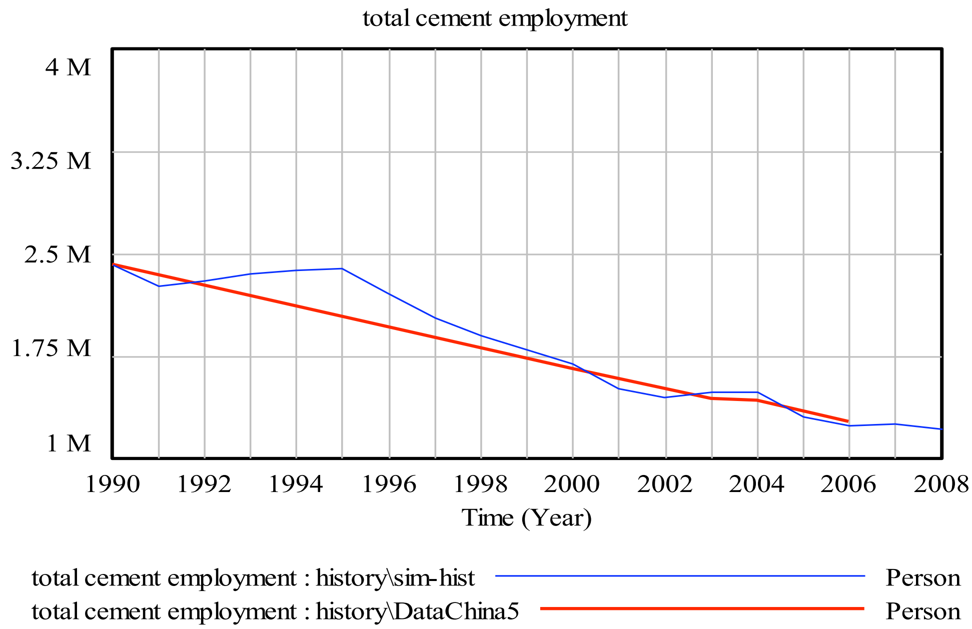
Total emissions from these two sources are shown below (for which we found some data but only from 2001 to 2005).



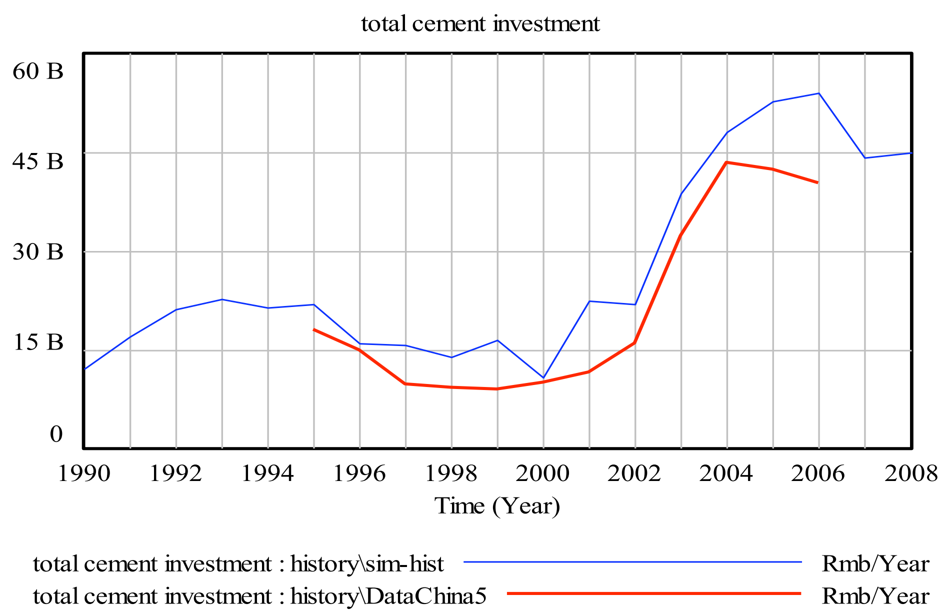
Gross domestic product, employment, and investment

Value added (gross domestic product, or GDP), employment, and total investment of the cement industry are shown in the next three graphs. The units for GDP and investments are in nominal renminbi (RMB) per year.





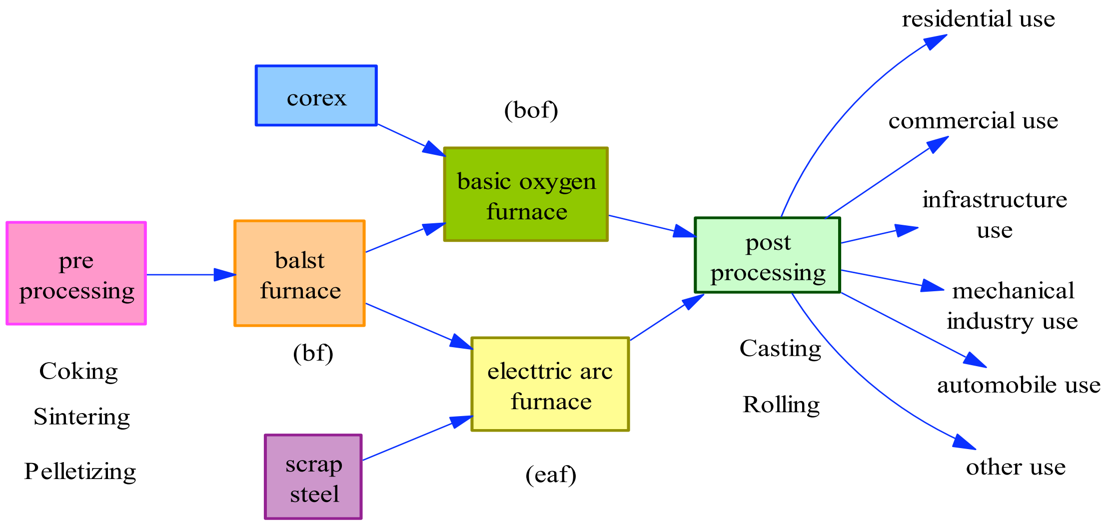
Cement employment has gone down significantly when production was going up. This is due to changes in both technology (the shift to rotary kilns) and the economic system (from iron-bowl to market competition).



I.2 Steel historical review

Overview

The production and use (or demand) of steel are shown in the following graph:



The seven boxes represent the seven major processes in steelmaking. Some processes, like preprocessing and post-processing, include subprocesses, listed under the boxes. From the left to the box "post processing" is the flow of production process, while the right side shows the major sources of demand for steel products.

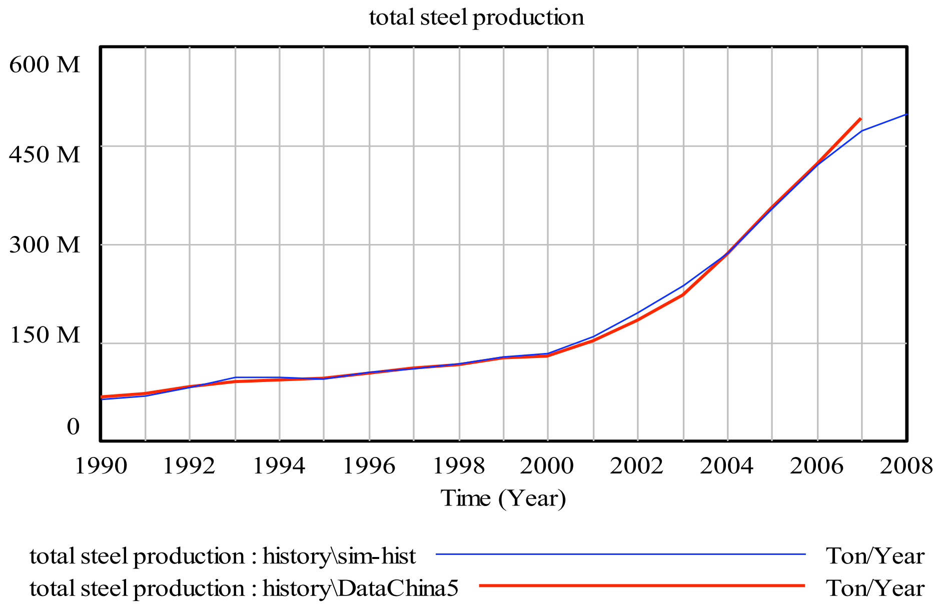
To make steel, either pig iron or scrap steel has to be used. In China today, a large amount of pig iron is produced in blast furnaces (BFs), which requires preprocessing; and the whole process (including preprocessing and BFs) consumes lots of energy (primarily coal and electricity). The new technology for iron-making, such as COREX (the blue box above), uses less energy, but it is still being improved and is quite expensive now. Domestic scrap steel is not enough to fully supply the need of electric arc furnaces (EAFs), so China has been importing scrap steel.

Steelmaking is primarily done in two types of furnaces: EAFs and basic oxygen furnaces (BOFs). Although BOFs use less energy than EAFs, the total energy used along the middle line of the graph from preprocessing to BF to BOF is much bigger that the bottom line from scrap steel to EAF. However, EAF production is limited by the availability of scrap steel. The assumption for future availability of scrap steel is presented in Section III.3 below.

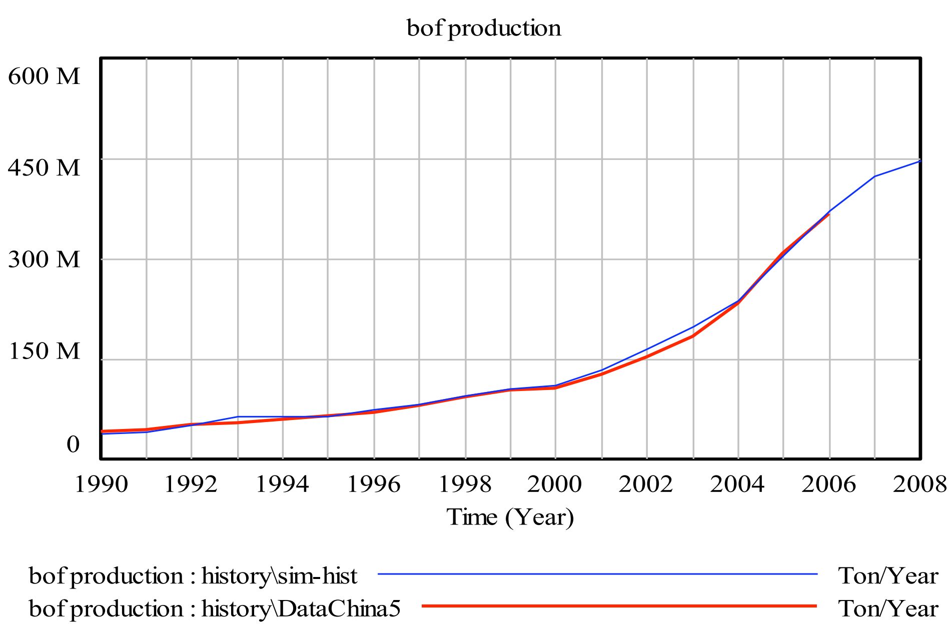
After post-processing of casting and rolling, steel is used in six categories: residential, commercial, infrastructure, mechanical industry, auto industry, and other.

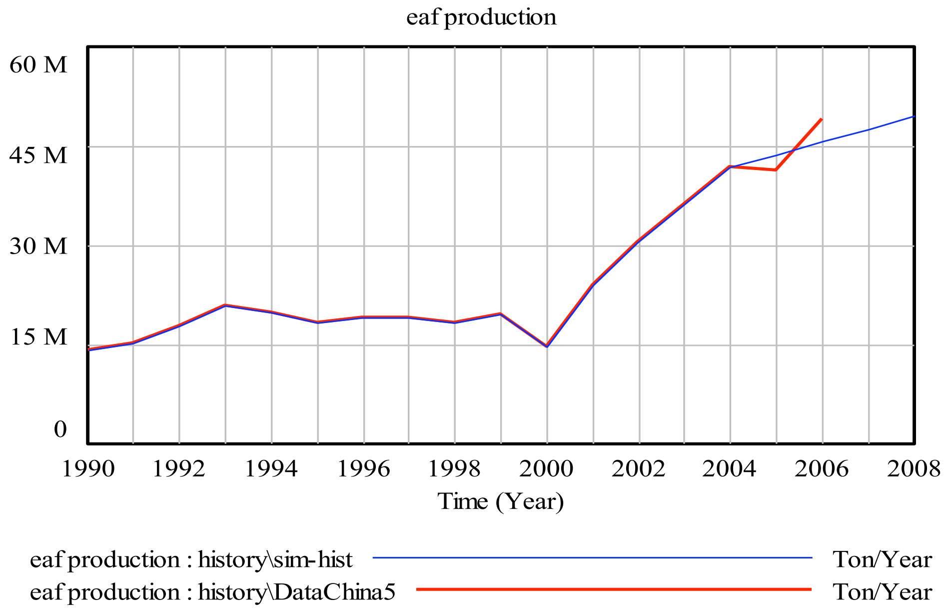
Production

Steel production grew from 66 million tons in 1990 to 489 million tons in 2007, a 732 percent growth, about 12.4 percent annually on average, as shown in the following graph.



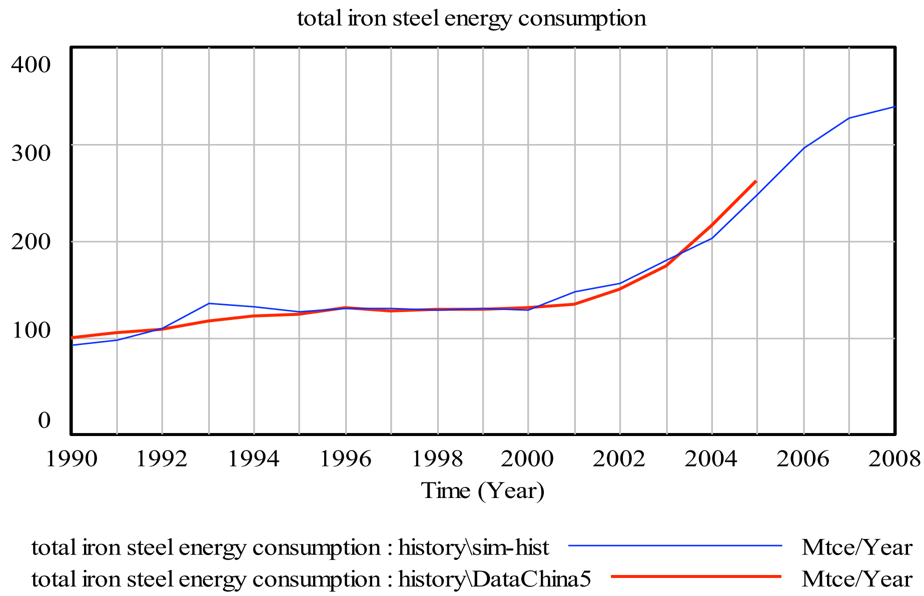
Steel in China is basically produced in two types of furnaces: BOFs and EAFs. EAF production is limited by the availability of scrap steel, although it requires less energy and less cost. The historical productions are shown in the next two graphs.



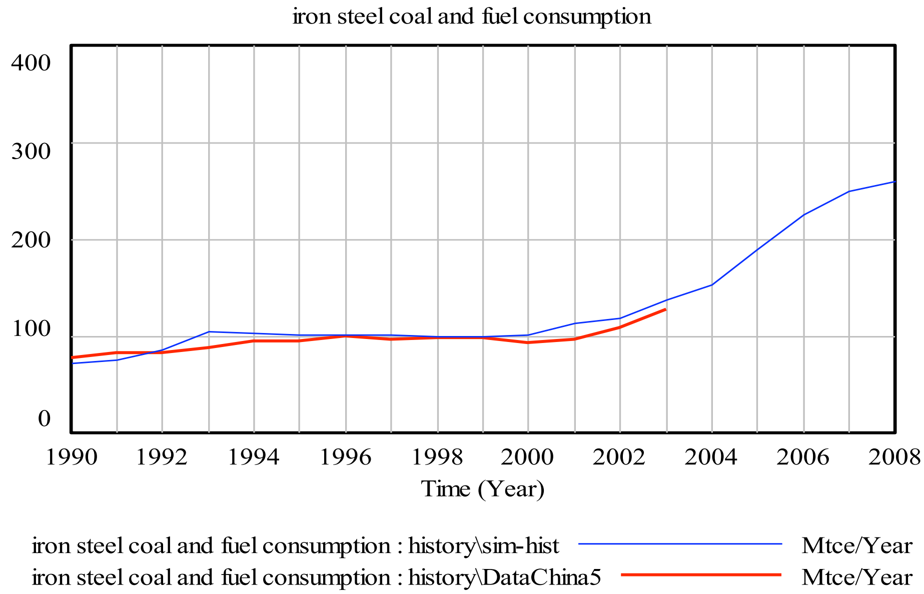


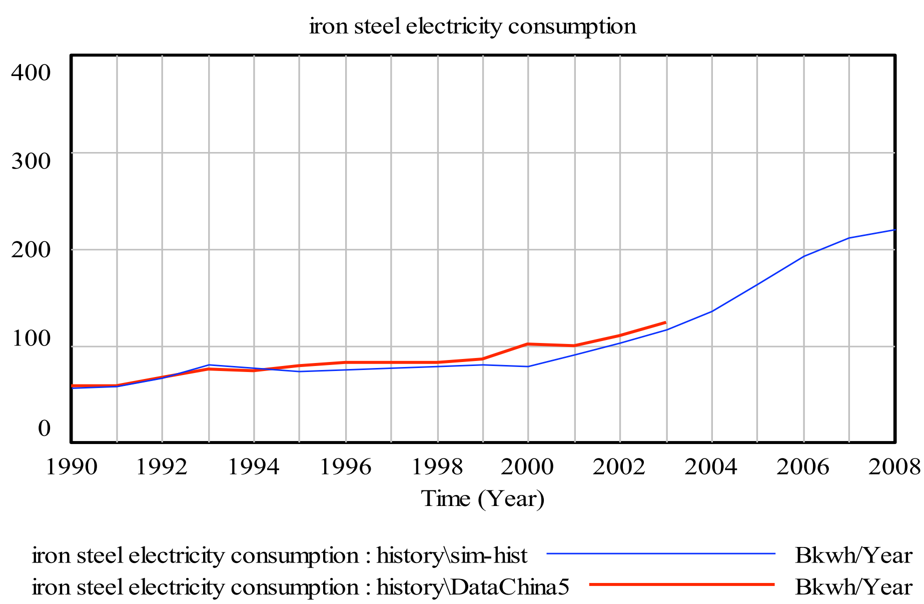
Energy use

All the seven processes in steelmaking consume energy, including coal, electricity, and fuel oil. Their total energy consumption, measured in Mtce, is shown below.



Total national coal and fuel oil consumption, and electricity consumption for steelmaking, are presented in the two following graphs. Notice that data were available only for 1990 to 2003.

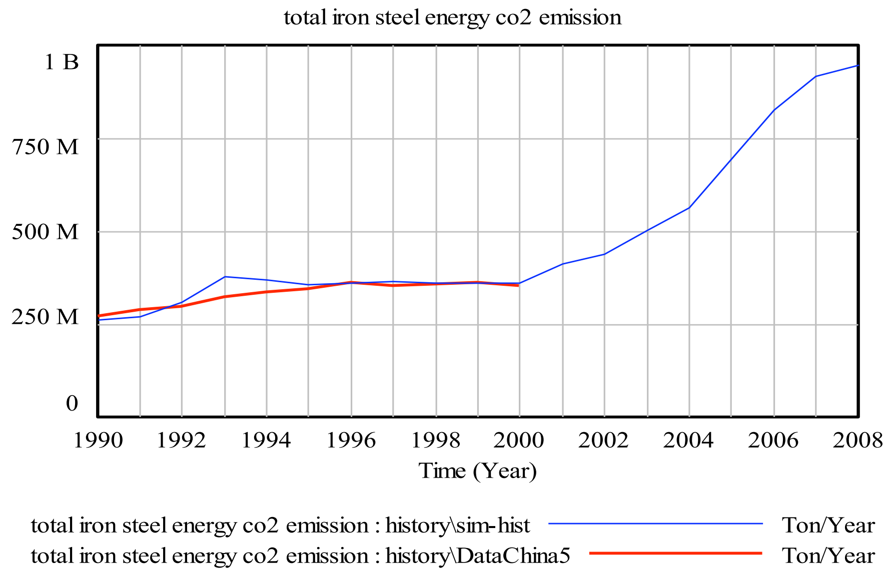




Dividing total energy use by total production, per ton energy use can be obtained, which has been improving fast since 1990. From 1990 to 2007, per ton steel energy consumption has been reduced over 50 percent, from 1.4395 tce in 1990 to 0.6927 tce in 2007.

Emissions

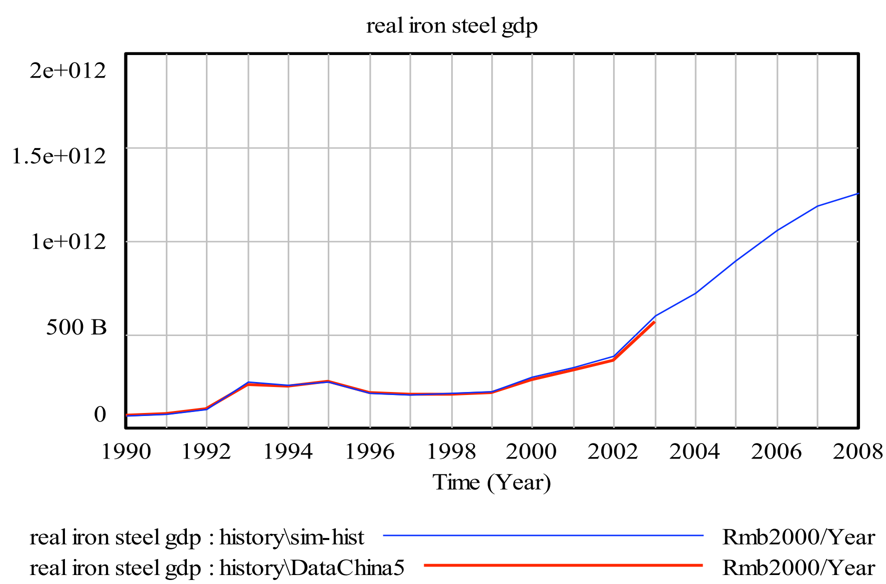
Steel CO_2 emissions result from coal, fuel oil, and electricity uses. But again data were available only for 1990-2000, as the following graph shows. In 2008, according to the model, CO_2 emissions from the iron and steel industry were close to 1 billion tons!

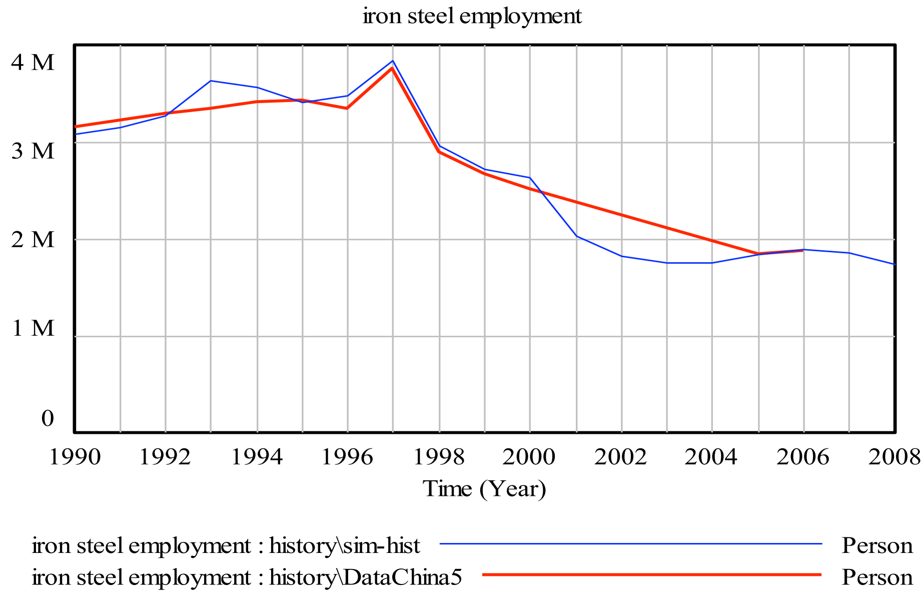


Per ton steel CO_2 emission can be obtained from either per ton energy use or by dividing total emission by total steel production. It decreased from about 4 tons CO_2 in 1990 to about 1.9 tons in 2007.

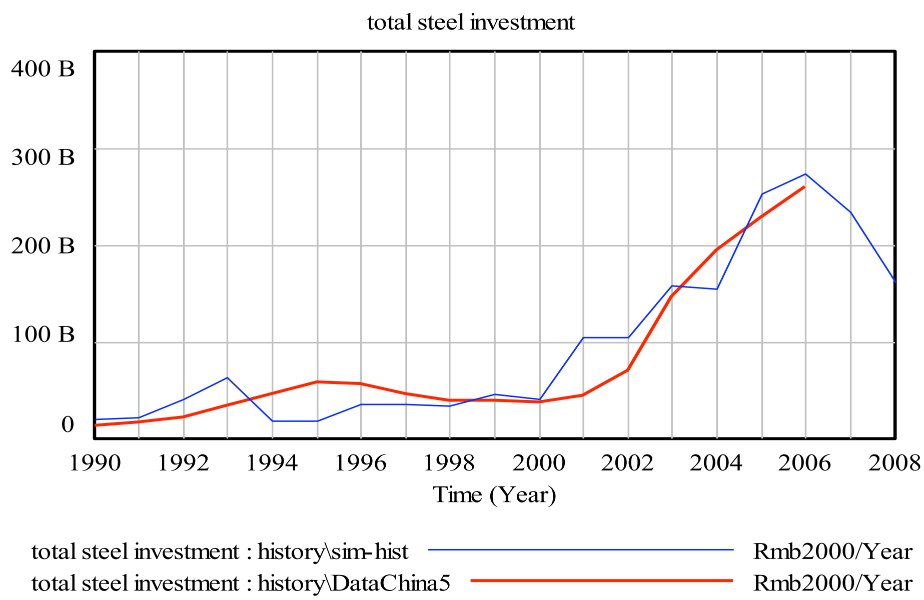
Gross domestic product, employment, and investment

Value added (gross domestic product), employment, and total investment of the iron and steel industry are shown in the next three graphs. Notice that the units for gross domestic product (GDP) and investments are in real renminbi (RMB) (base year 2000) per year.





Data show that since 1997 labor productivity has increased significantly. This is due to similar reasons as in cement: technology improvements and economic system change.



The investment drop after 2006 is due to the slower growth rate of production capacity after 2006, from about 20 percent in 2001–2006 to about 10 percent in 2007 and 2008.

I.3 Questions that could be raised

After considering the above historical review and comparisons between model results and data, one might ask:

1. How did the model reproduce the historical performances that fit the data reasonably well?

2. How will the future Chinese cement and steel industries grow, and how will their CO_2 emissions grow?

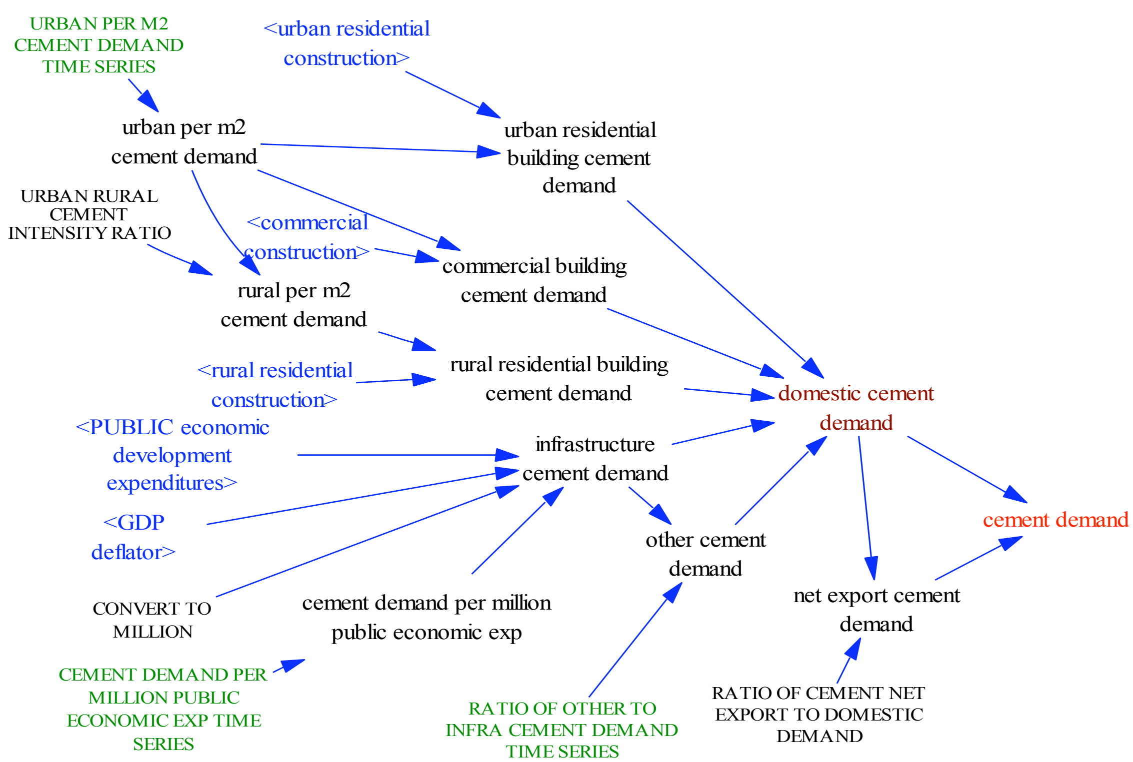
3. What can be done to improve the situation in terms of energy use and emissions?

To respond to these questions, we explain how the model was constructed, describe its major assumptions (things that the Chinese people and government can do now and in the future), and extend the simulation to 2030.

II. Cement Model Structure

II.1 Cement Demand

Cement demand is shown below.



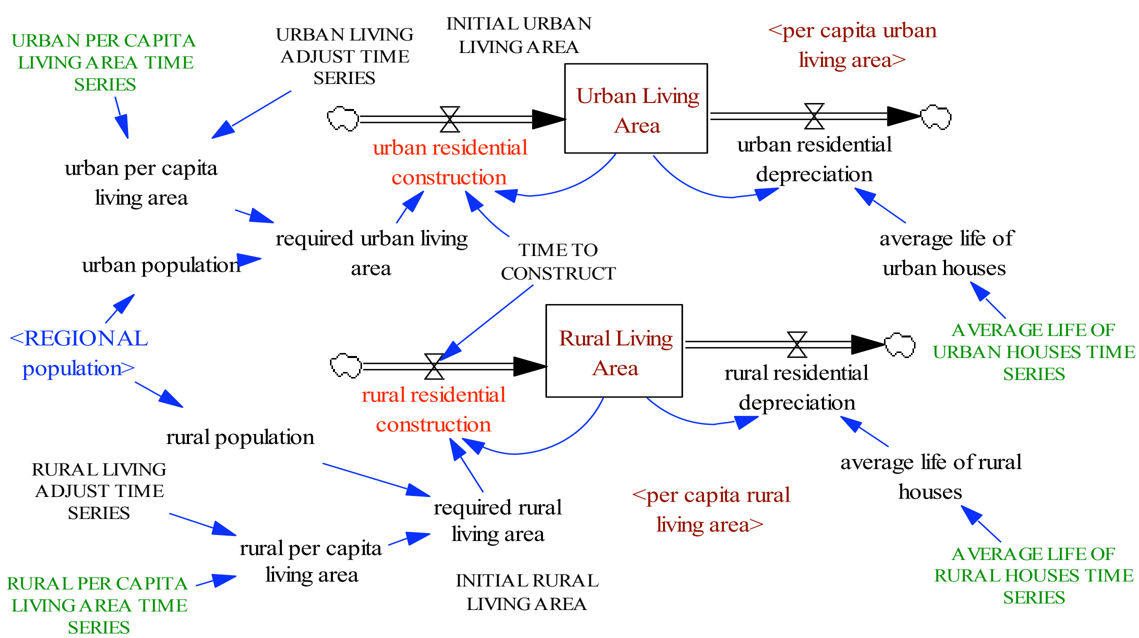
The arrows connecting the variables represent causality. The head of the arrow points to the consequences, which is the left-hand side of the equation. The tail of the arrow points to a cause, which is the right-hand side of the equation. For instance, *cement demand* is pointed to from two variables, *domestic cement demand* and *net export cement demand,* and the actual equation is

cement demand = domestic cement demand + net export cement demand

The color of a variable shows whether it is a common variable (black), an input variable from another sector (blue), an output variable that will be used by other sectors (red), a policy variable whose value can be changed to represent various policy options (green), or a variable for which we have historical data (brown). Exogenous variable inputs for the future are in uppercase. For example, from the sketch you can see that *urban residential construction* is an input variable, while *cement demand* is an output variable.

From right to left in the above graph, you can see how *cement demand* is modeled one level at a time. First cement demand is *domestic cement demand* plus *net export cement demand*. *Domestic cement demand* has five components (or is being pointed to by five variables): (1) *urban residential building cement demand,* (2) *rural residential building cement demand,* (3) *commercial building cement demand,* (4) *infrastructure cement demand,* and (5) *other cement demand.*

Each of the five is further modeled. *Urban residential building cement demand* is *urban residential construction* (measured in square meters, or m^2, per year) times *urban per* m^2 *cement demand. Rural residential building cement demand* is computed similarly. *Commercial building cement demand* is assumed to be 0.374 of *urban residential construction* (Reference 11 of cement). *Infrastructure cement demand* is assumed to be related closely to ***public*** *economic development expenditures*, which is an input variable from T21 China. *Urban residential construction* and *rural residential construction* are blue variables and are modeled in another sector called *living areas*, which is shown below:



Urban residential construction (the top variable in red) depends on basically two factors: (1) average urban per capita living area and (2) urban population. *Urban per capita living area* depends on the green time series variable on top left, *urban per capita living area time series,* while *urban population* is from ***regional*** *population,* an input variable from T21 China. We could also define *urban per capita living area* to be related to per capita income, with a declining elasticity, to make it an endogenous variable, if we were more confident of how it would change with income in the future.

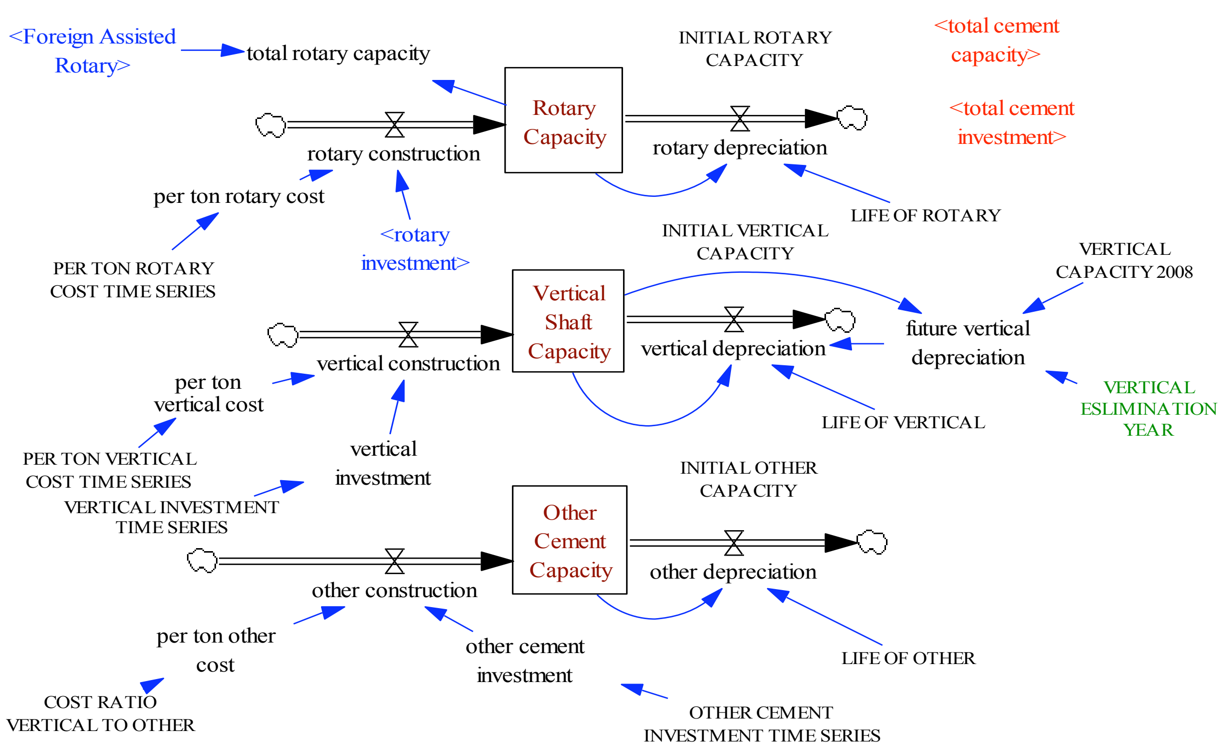
The box variables at the center, *urban living area* and *rural living area,* are stock variables that increase with constructions (the two red variables) and decrease with depreciations (the two outflowing variables to the right of the box variables). Depreciation is happening as residential houses become in bad shape and no longer fit for living or as livable houses are taken down to make room for new residential buildings. It is estimated that during the last two decades or so, each year about 2 percent of existing urban houses are taken down for these two reasons. Rural living area, construction, and depreciation are similarly modeled.

Because of time and space constraints, we do not present each equation. But interested users can use the model and its accompanying script to examine the equation of any variable.

It seems that the growth of future *per capita living area* has a big impact on cement and steel demand and hence on CO_2 emissions as well. We discuss it in the following sections.

II.2 Cement Capacity and Investment

Cement capacity is divided into three parts: rotary capacity, vertical capacity, and other cement capacity. Each capacity increases with construction of new plants and decreases with depreciation. Construction depends on investment and per ton capacity cost, and depreciation depends on the life of the equipment. The sum of the three capacity levels and the three investment levels are the two red variables at the top right of the following graph.

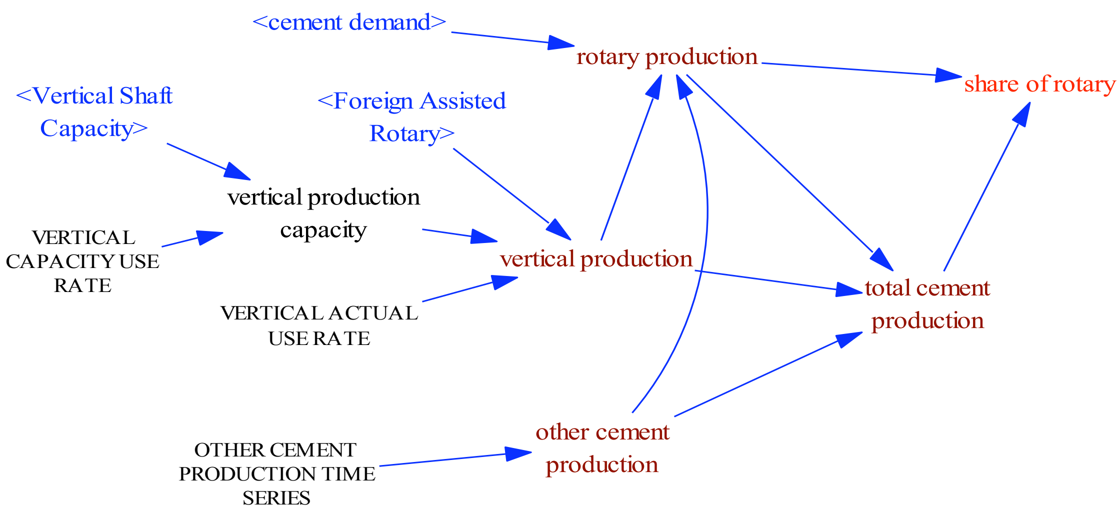


II.3 Cement Production

This sector is modeled as the following graph shows.

Other cement production, at the bottom of the graph, is the least efficient and most polluting. In 2007, it was less than 1 percent of cement production and will soon die out. The Chinese government's policy toward *vertical shaft production,* in the middle, is to replace vertical shaft kilns with the more efficient rotary kilns wherever economically and administratively possible. But if closing some of them is too difficult, it lets them run out their lives, making all the new ones rotary, as new rotary kilns are cheaper (including all costs of equipment, energy input, and labor). This policy is modeled here by stopping all new vertical capacity investment and letting vertical capacity shrink each year. As using existing vertical capacity to produce cement is still cheaper than building new rotary capacity in the near term, the remaining vertical capacity will still be in use.

Rotary production is taken as the residual, and it is equal to cement demand minus production from two other methods. This algorithm works well in the China situation, as demand keeps rising. If there are declines in demand, it is likely the vertical kilns will run at lower capacity.



II.4 Cement Energy Use

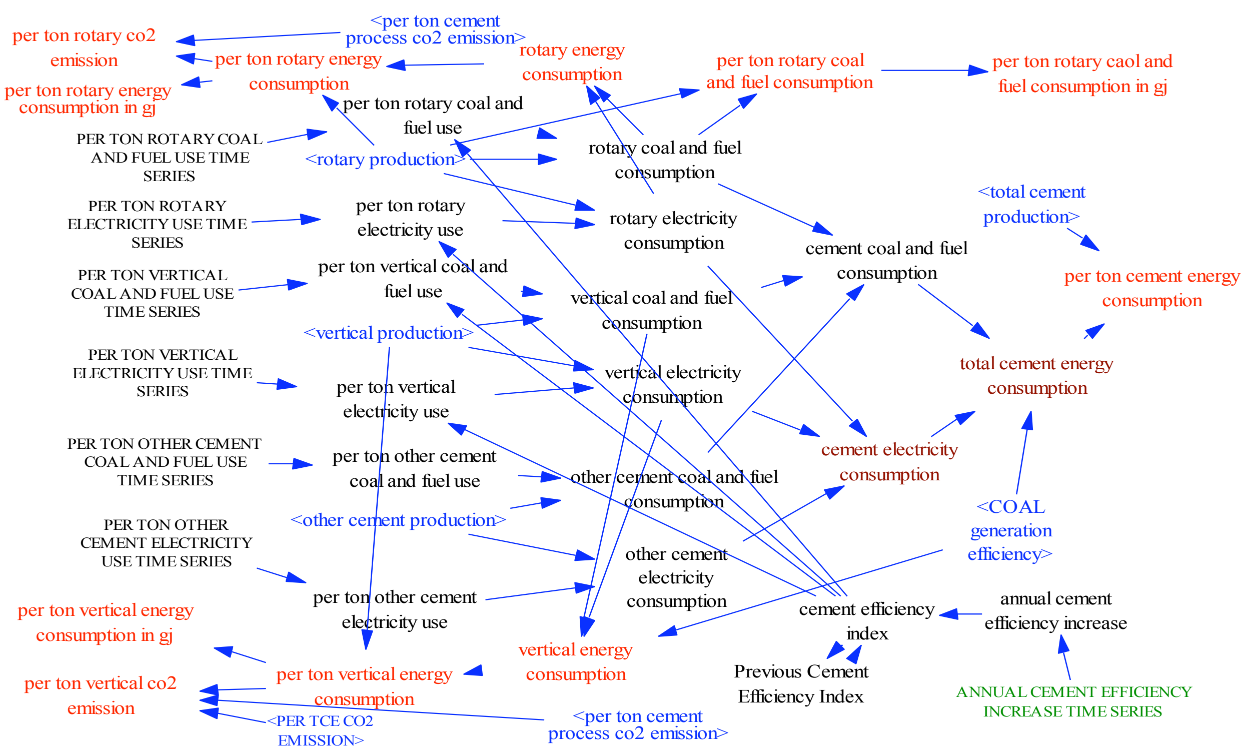
The following graph looks a little complicated. But if you ignore all the red variables, which are indicators as model outputs, you basically see five columns. The first column from the left has six time series variables, representing per ton coal and fuel use or electricity use, for each of the three production methods: rotary, vertical, and other.

The second column from the left has per ton coal and fuel use and electricity use for the three production methods (in blue).

The third column from the left computes total coal and fuel consumption and electricity consumption from each of the three production methods.

The fourth column from the left has only two variables, which compute the total coal and fuel consumption and electricity consumption for all the cement produced.

The fifth column from the left has only one variable: *total cement energy consumption*. Electricity is converted to a coal equivalent with ***coal** generation efficiency,* which is an input variable from T21 China.



II.5 Cement Emissions

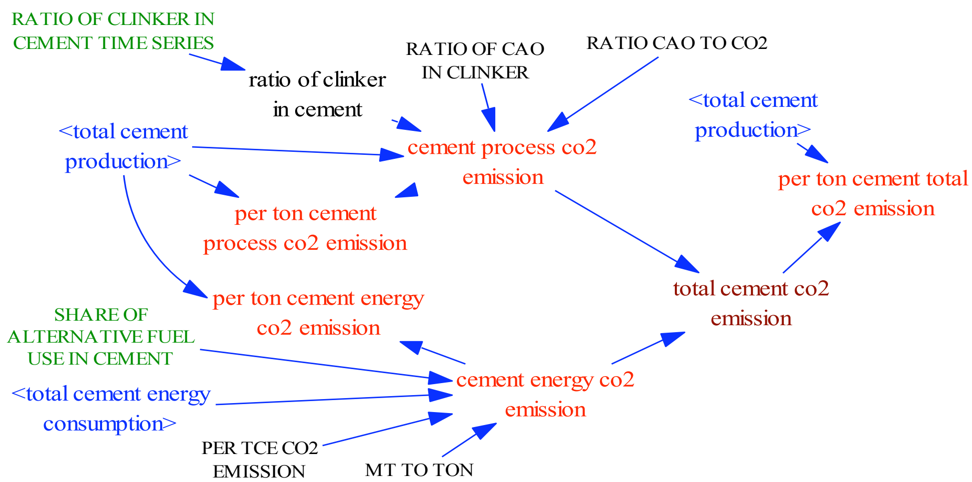
CO_2 emissions from cement production come from two sources: the chemical process and fuel and electricity use.

The chemical process can be represented by the following equation:

$CaCO_3 = CaO + CO_2$

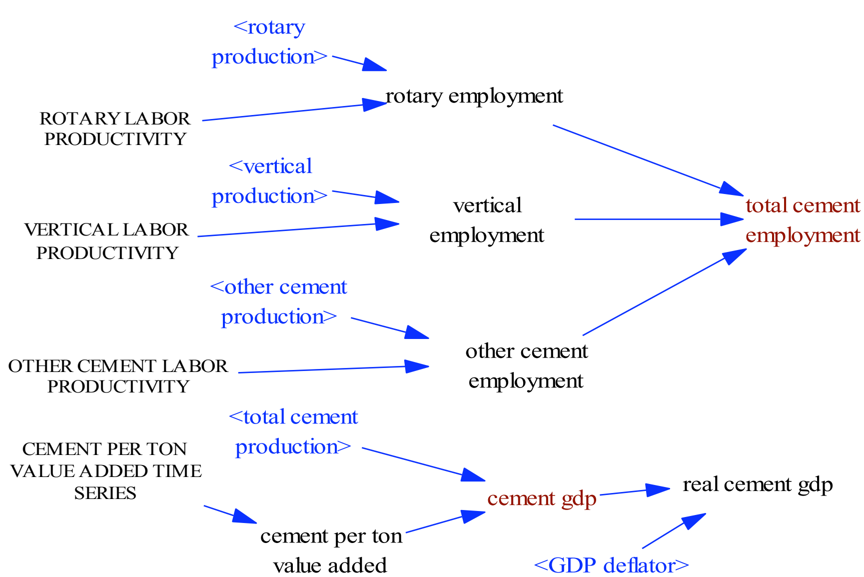
Thus when limestone is converted to CaO, CO_2 is released. The amount of CO_2 released is captured by the red variable, *cement process CO_2 emission*, in the upper half of the graph.

The amount of CO_2 generated by energy use is computed in the red variable, *cement energy CO_2 emission*, in the lower half of the graph.



II.6 Cement GDP and Employment

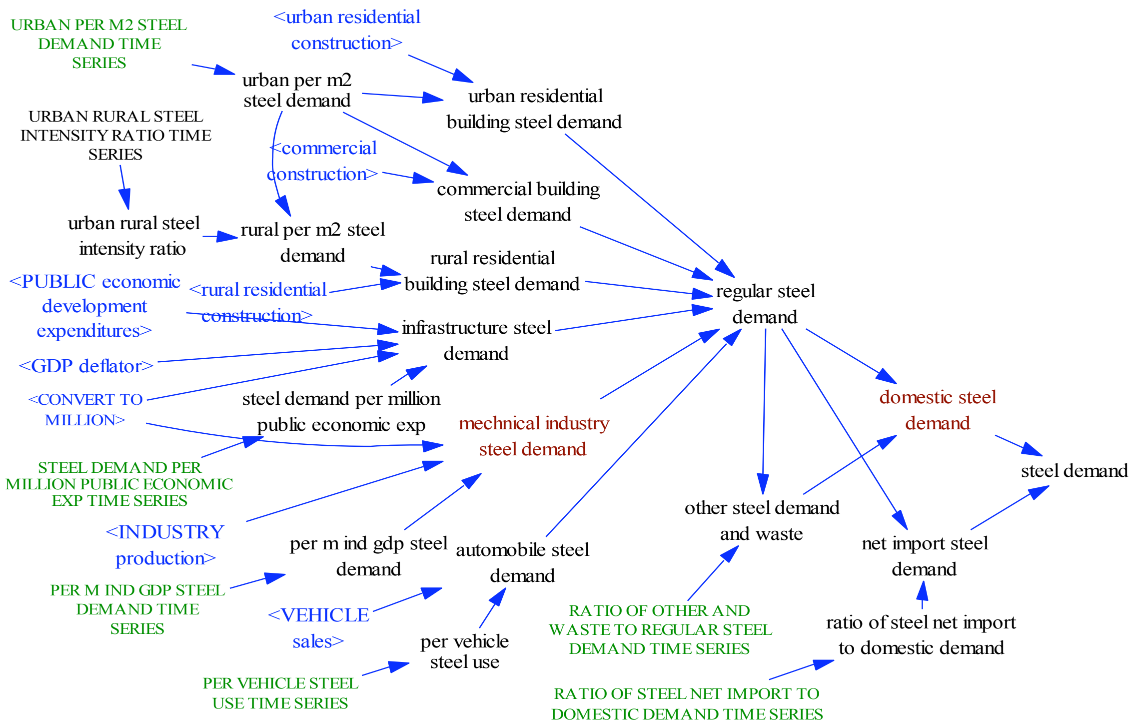
The modeling for this sector is shown in the following graph, and it is relatively straightforward.



III. Steel Model Structure

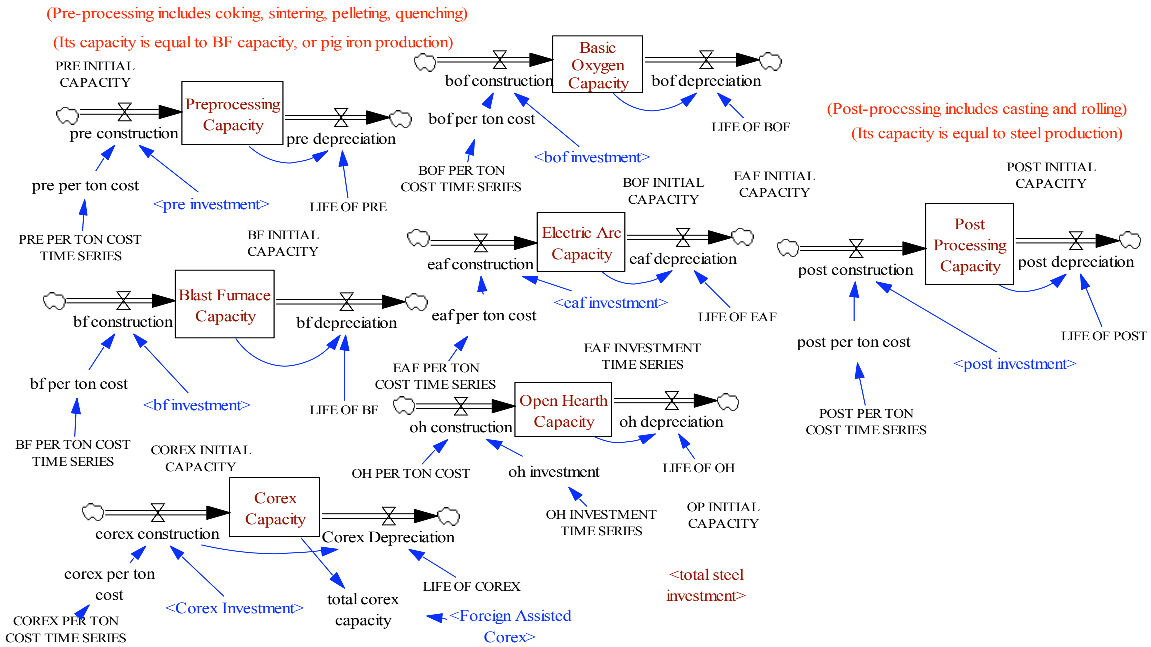
III.1 Steel Demand

Steel demand is modeled similarly to cement demand, except that it has two more categories: *mechanical industry steel demand* and *automobile steel demand*. *Mechanical industry steel demand* is related to ***industry** production*, which is an input variable from T21 China, while *automobile steel demand* is related to ***vehicle** sales*, another input variable from T21 China.



III.2 Steel Capacity and Investment

This sector includes the capacities and investments of the seven processes in iron- and steelmaking. The left column has three processes for iron-making. The central column includes three processes for steelmaking, and the right column represents post-processing (casting and rolling). Each process has a similar structure: capacity, construction, and depreciation.

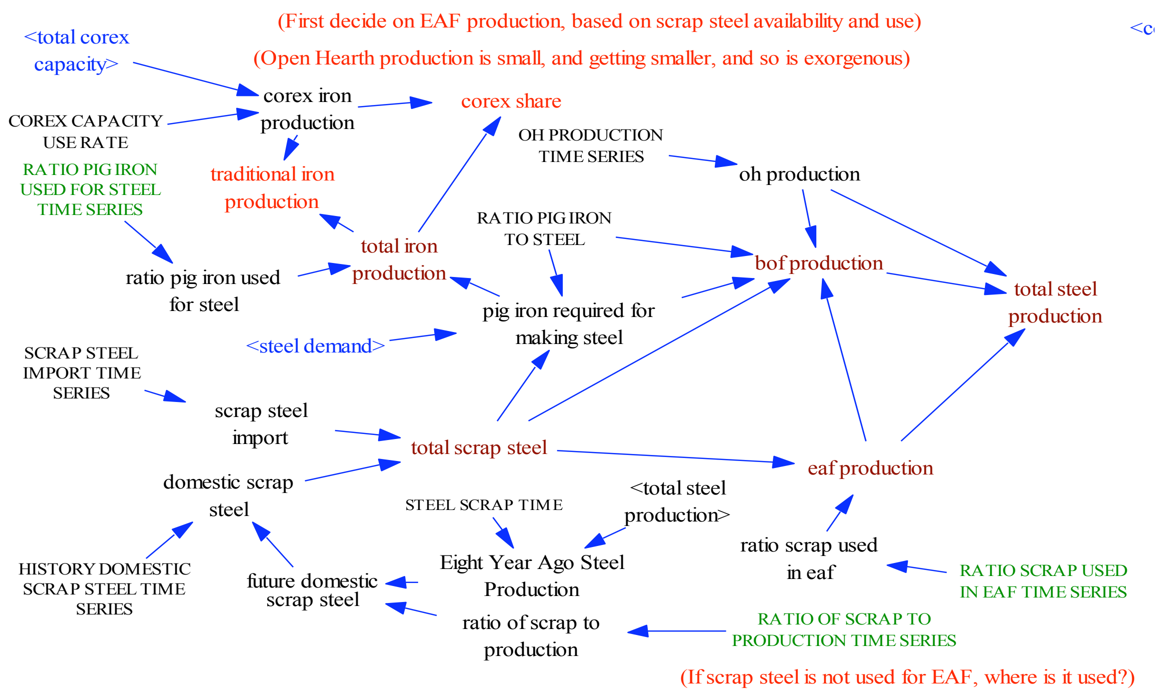


III.3 Steel Production

This sector includes iron production (from both COREX and BF) in the top left and steel production from BOFs, EAFs, and open hearths (OHs).

OH production was about 1 percent in 2007 and is getting smaller, so it is set as exogenous. EAF production is computed first, as it is cheaper to build, uses less energy, and generates less pollutant. Its production is however constrained by scrap steel availability and use. Based on data analysis, it is assumed that scrap steel is a certain percentage (40 percent for China) of steel production of eight years ago. BOF production is then computed as total steel demand less production from EAFs and OHs.

Iron production is primarily for BOF production and for its own use. (A certain percentage of iron is used for making iron products; this percentage has been shrinking since 1990.)



III.4 Steel Energy Use

This sector is similar to the cement energy use presented before, if one ignores the three red variables in the far right of the graph.

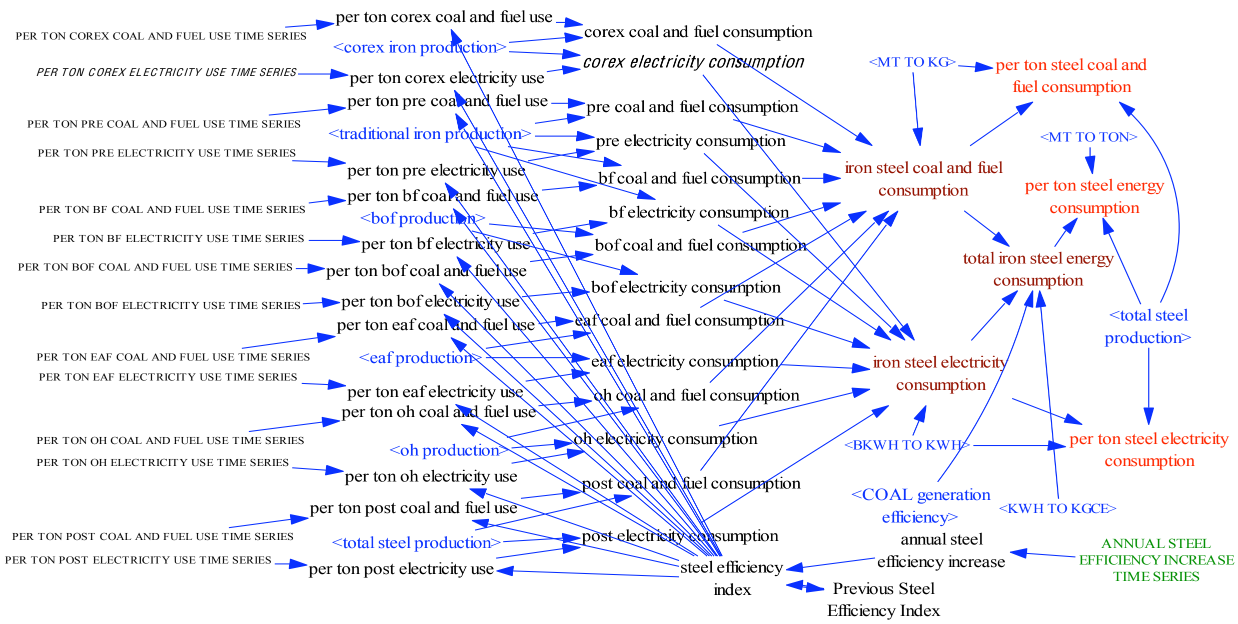
There are five columns. The first column from the left has 14 time series variables, representing per ton coal and fuel use or electricity use, for each of the seven production processes.

The second column from the left has per ton coal and fuel use and electricity use for the seven processes (which basically repeats the above line for modeling purposes) and seven productions (in blue).

The third column from the left computes total coal and fuel consumption and electricity consumption from each of the seven production processes.

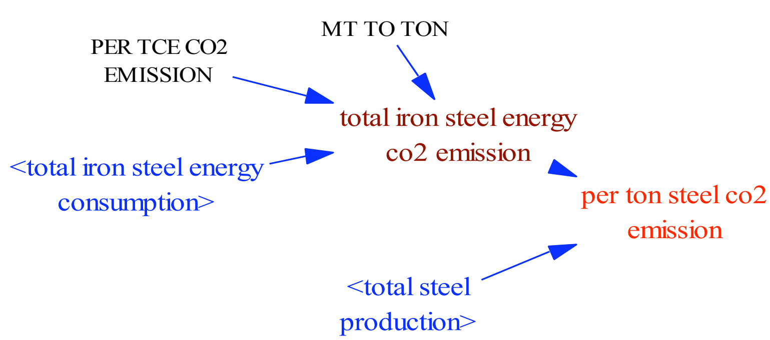
The fourth column from the left has only two variables, which compute the total coal and fuel consumption and electricity consumption for all the iron and steel produced.

The fifth column from the left has only one variable: *total iron steel energy consumption*. Electricity is converted to the coal equivalent with ***coal** generation efficiency*, which is an input variable from T21 China.



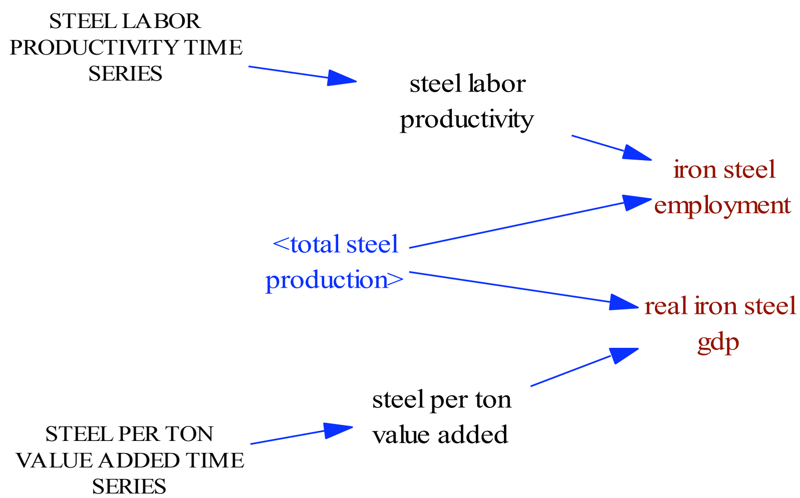
III.5 Steel Emissions

Total iron steel energy CO_2 emission and *per ton steel CO_2 emission* are computed in the following graph. Basically, steel's energy consumption, measured in coal equivalent, determines its CO_2 emissions.



III.6 Steel GDP and Employment

Value added from the iron and steel industry, and its total employment, are modeled in the following graph.



IV. Baseline and Alternative Scenarios

In this section we explore what the future of the cement and iron and steel industries might look like, from 2008 to 2030. We introduce the major assumptions (or policy variables) of the baseline scenario, and at the same time we change these assumptions to generate three more scenarios: Optimistic (meaning less energy consumption and emissions), Pessimistic (meaning more energy consumption and emissions), and External Aid (meaning a large amount of investment from foreign sources flows into these industries to build new, more efficient plants). We then present the results of selected indicators for the four scenarios.

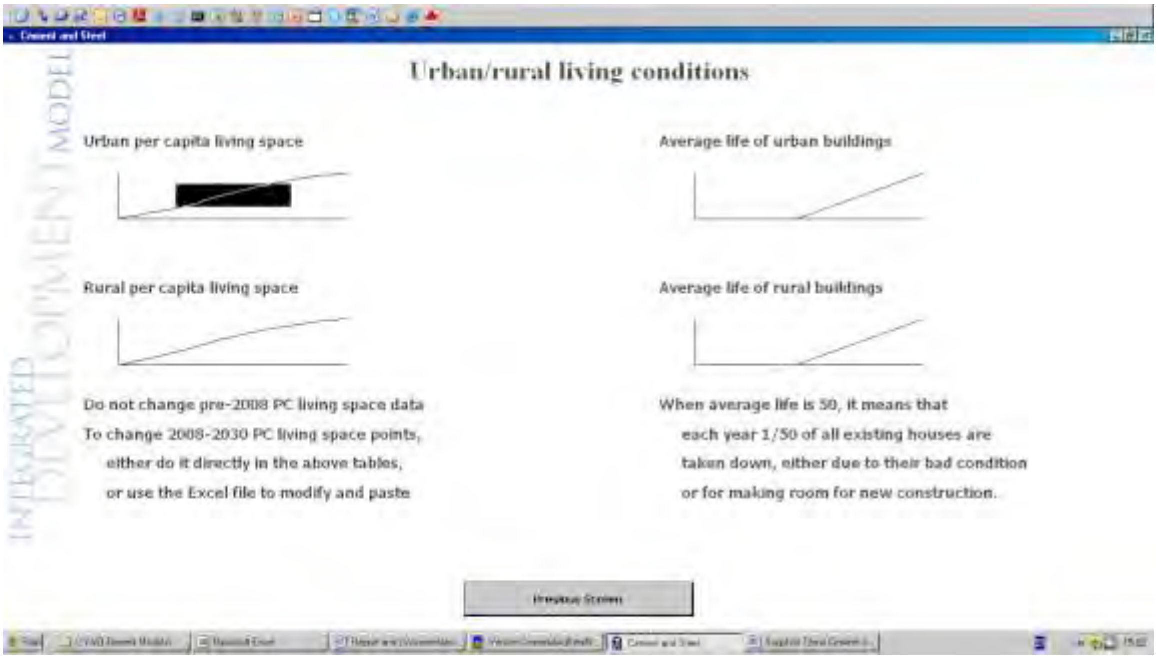
In the following presentation, the attached model package is assumed to have been installed on your personal computer, and the graphs you see are exactly the same as you would see when running the model.

IV.1 Per Capita Living Area Assumptions

As residential construction consumes about 50 percent of total cement produced and over 30 percent of total steel produced, it is an important factor for future-demand forecasts.

Residential construction demand is closely related to per capita living area growth. From 1990 to 2006 (the latest year data was available), urban per capita living area doubled from 13.7 to 27.1 square meters, while rural per capita living area increased from 17.8 to 30.7 square meters, almost double. Because of the low quality of existing residential houses and the lack of land for new construction, many houses were taken down, and sometimes whole communities were demolished to make room for new residential buildings. Increasingly these buildings are high-rise apartments. According to our estimate, from 1990 to 2007, each year about one-fiftieth (or 2 percent) of existing houses in urban areas were taken down, indicating an average life of 50 years. In the future, however, this fraction could become smaller, as there are fewer low-quality houses still standing, meaning that average life could become longer. The combined effects of fast per capita living area growth and destruction of existing houses resulted in significant construction each year, consuming huge amounts of cement and steel.

The policy screen for living area is shown below:



If you click the center of the *Urban per capita living space* box, a graph input box will appear in the top left of the screen. You can modify the numbers in the Output column (second column from left), or use the Excel file “PC living area computation.xls” to make changes quickly, as explained in the attached file “Script for China Cement and Steel Version 3.doc.” You can do the same to all the other three variables in a similar way. You can also use the clicker to move the line to make approximate changes over time.

For each assumption in the above graph, we have chosen different values for the four scenarios.

For *urban per capita living space:*

Baseline: as is, i.e., gradually rise to 45 m^2 in 2030

Optimistic: gradually rise to 40 m^2

Pessimistic: gradually rise to 50 m^2

External Aid: same as baselin

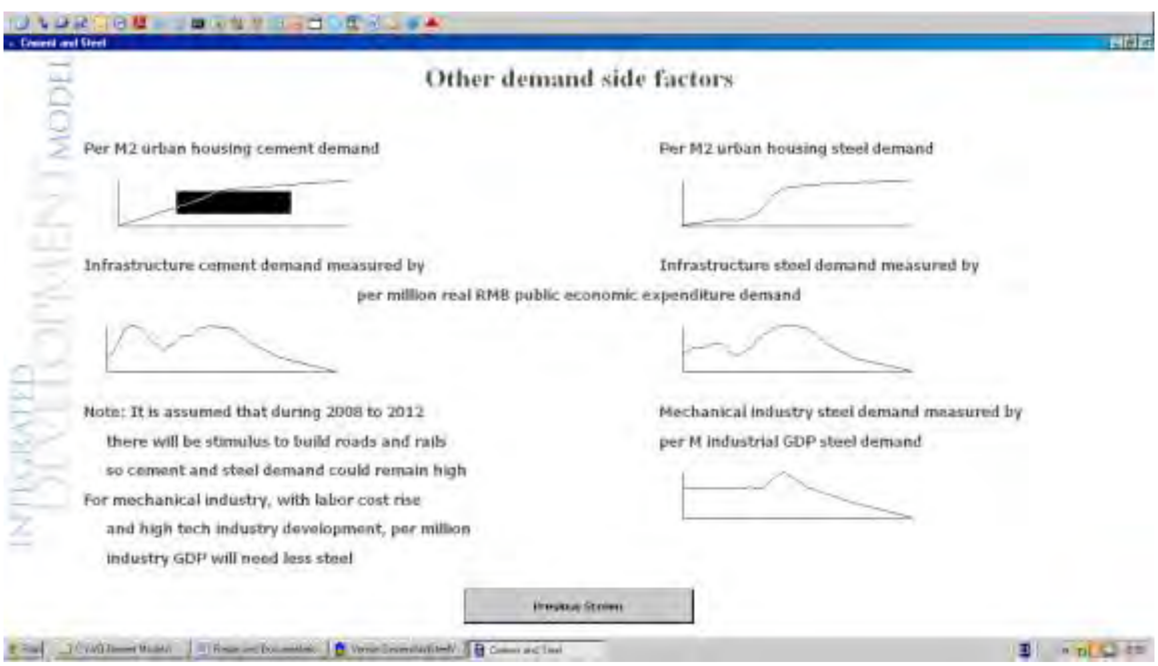
For *rural per capita living space:*
Baseline: as is, i.e., gradually rise to 45 m^2 in 2030
Optimistic: gradually rise to 40 m^2
Pessimistic: gradually rise to 50 m^2
External Aid: same as baseline

For *average life of urban buildings:*
Baseline: as is, i.e., gradually rise to 70 years in 2030
Optimistic: gradually rise to 80 years
Pessimistic: gradually rise to 60 years
External Aid: same as baseline

For *average life of rural buildings:*
Baseline: as is, i.e., gradually rise to 60 years in 2030
Optimistic: gradually rise to 70 years
Pessimistic: gradually rise to 50 years
External Aid: same as baseline

IV.2. Other Demand Assumptions

The policy screen for other demand factors in the model is shown below:



The two variables in the first row are per square meter urban housing cement and steel demand.

The variable on the left, *per m^2 urban housing cement demand,* seems to have risen steadily from 1990 to 2008 as more urban houses are high-rise apartments, which require more cement to build per square meter. According to the data we have (Reference 12 of cement), for brick structure housing, per square meter needs about 200 kg of cement, while for high-rise buildings it needs 300 to 400 kg of cement, or 0.3 to 0.4 tons.

In rural areas, per m^2 cement demand is lower than in urban areas (Reference 11 of cement), and in the model it is assumed that *per m2 rural housing cement demand* is half of *per m^2 urban housing cement demand.*

The variable on the right, *per m^2 urban housing steel demand,* has also risen steadily from 1990 to 2008, as more urban houses are high-rise apartments, which require more steel to build per square meter. According to the data we have (Reference 12 of cement and 21 of steel), for brick structure housing, per square meter needs 40 to 50 kg of steel, while high-rise buildings could require 100 kg of steel, or 0.1 tons.

In rural areas, per m^2 steel demand is much lower than in urban areas (References 12 and 21 of steel), and in the model it is assumed that rural per m2 steel demand is about 11 percent of urban per m^2 steel demand in 1990 and increases to 17 percent in 2030.

The variables in the second row are cement and steel demands for infrastructure construction, including roads, railways, and bridges. It is assumed that these demands are related to government expenditures for economic development (Reference 13 of cement and 12 of steel), measured in tons per million real RMB (base year 2000). It should be noted that in the 22 years from 2008 to 2030, China's GDP may continue to grow at a fast rate and may more than triple. Government expenditures are assumed to grow with GDP.

The variable at the lower right, *mechanical industry steel demand*, should be related to mechanical industry GDP. As we do not have a separate sector for mechanical industry in T21 China, we have to use total industry GDP as a proxy. Based on data for three years of 2002–2004 (Reference 14 of steel), each million real RMB industry GDP consumes about 5 tons of steel. During 2004 to 2008, this rate seems to have risen a bit, to about 6 tons, probably as a result of mechanical industry expansion. In the long term, it is assumed that this rate should fall, as substitute material for steel will become more widespread, and higher-tech products will need less steel per unit of output in value added.

For each assumption in the above graph, we have chosen different values for the four scenarios, as below.

For *per m^2 urban housing cement demand in tons:*
Baseline: as is, i.e., gradually rise to 0.4 tons in 2030
Optimistic: stay flat at 2010 level of 0.35 tons
Pessimistic: gradually rise to 0.45 tons
External Aid: same as baseline

For *per m^2 urban housing steel demand in tons:*
Baseline: as is, i.e., gradually rise to 0.11 tons in 2030
Optimistic: stay flat at 2015 level of 0.105 tons
Pessimistic: gradually rise to 0.115 tons
External Aid: same as baseline

For *infrastructure cement demand in tons:*
Baseline: as is, i.e., gradually fall to 100 tons in 2030
Optimistic: gradually fall to 50 tons (50 tons lower for last four points)
Pessimistic: gradually fall to 200 tons (350, 300, 200 tons for last three points)
External Aid: same as baseline

For *infrastructure steel demand in tons:*
Baseline: as is, i.e., gradually fall to 18 tons in 2030
Optimistic: gradually fall to 10 tons (8 tons lower for last four points)
Pessimistic: gradually fall to 30 tons (55, 45, 30 tons for last three points)
External Aid: same as baseline

For *mechanical industry steel demand:*
Baseline: as is, i.e., gradually fall to 2 tons in 2030
Optimistic: gradually fall to 1 ton (1 ton lower for last three points)
Pessimistic: gradually fall to 4 tons (5.5, 4.5, 4 tons for last three points)
External Aid: same as baseline

IV.3 Cement Production Technology Assumptions

The policy screen for cement technology factors in the model is shown below:

On the cement production and technology side for energy saving and emission reduction, there are many things one can do, such as using alternative fuels to reduce emissions, reducing the share of clinker in cement to save energy, building larger and more efficient rotary kilns with precalciner and preheater technologies, establishing management centers, and increasing heat recovery. The two shares of alternative fuels and clinker in cement are provided in the first row for users to modify, and all the other factors are combined into an annual energy efficiency improvement during 2008–2030. To change that efficiency improvement, you can either drag the slider or type a number into the number box.

For each assumption in the above screen, we have chosen different values for the four scenarios, as below.

For *share of alternative fuels used:*

Baseline: as is, i.e., gradually rise to 0.15 (15 percent) in 2030

Optimistic: gradually rise to 0.25

Pessimistic: gradually rise to 0.05

External Aid: same as baseline

For *share of clinker in cement:*

Baseline: as is, i.e., gradually fall to 0.6 (60 percent) in 2030

Optimistic: gradually fall to 0.5

Pessimistic: gradually fall to 0.7

External Aid: same as baseline

For *annual cement energy efficiency improvement:*

Baseline: as is, i.e., 1 (1 percent per year)

Optimistic: 1.5 (change both 2008 and 2030 values to 1.5)

Pessimistic: 0.5 (change both 2008 and 2030 values to 0.5)

External Aid: same as baseline

For *vertical elimination year:*

Baseline: as is, i.e., 2023

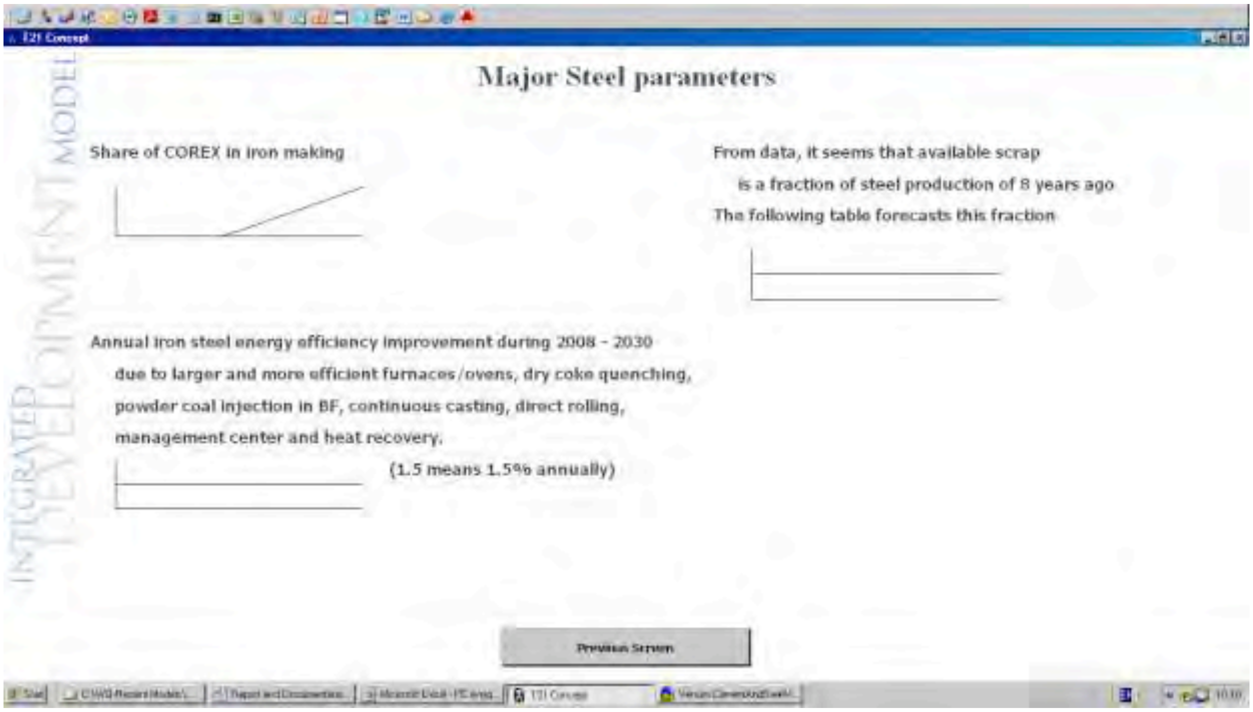
Optimistic: 2015

Pessimistic: 2030

External Aid: same as baseline

IV.4 Steel Production Technology Assumptions

The policy screen for steel technology factors in the model is shown below:



On the steel production and technology side for energy saving and emission reduction, there are lots of things one can do, such as adopting advanced direct reduction iron-making technology like COREX (which is still quite expensive); making more scrap steel available to increase the steelmaking from an EAF to reduce energy use; building larger and more efficient furnaces/ovens; using dry coke quenching, powder coal injection in BFs, continuous casting, and direct rolling; establishing management centers; and increasing heat recovery. The share of COREX in iron-making and the availability of scrap steel as a fraction of eight-years-ago production are provided in the first row for users to modify, and all the other factors are combined into an annual energy efficiency improvement during 2008–2030, which can be changed similarly as in the previous screen.

For each assumption in the above screen, we have chosen different values for the four scenarios, as below.

For *share of COREX in iron-making:*

Baseline: as is, i.e., gradually rise to 0.15 (15 percent) in 2030

Optimistic: gradually rise to 0.25 (change 2030 value to 0.25)

Pessimistic: gradually rise to 0.05 (change 2030 value to 0.05)

External Aid: same as baseline

For *available scrap steel as a fraction of eight-years-ago production:*

Baseline: as is, i.e., 0.4 (40 percent) all the way for 2008–2030

Optimistic: gradually rise to 0.5 in 2030 (change 2030 value to 0.5)

Pessimistic: gradually fall to 0.3 in 2030 (change 2030 value to 0.3)

External Aid: same as baseline

For *annual iron and steel energy efficiency improvement:*

Baseline: as is, i.e., 1.5 (1.5 percent per year)

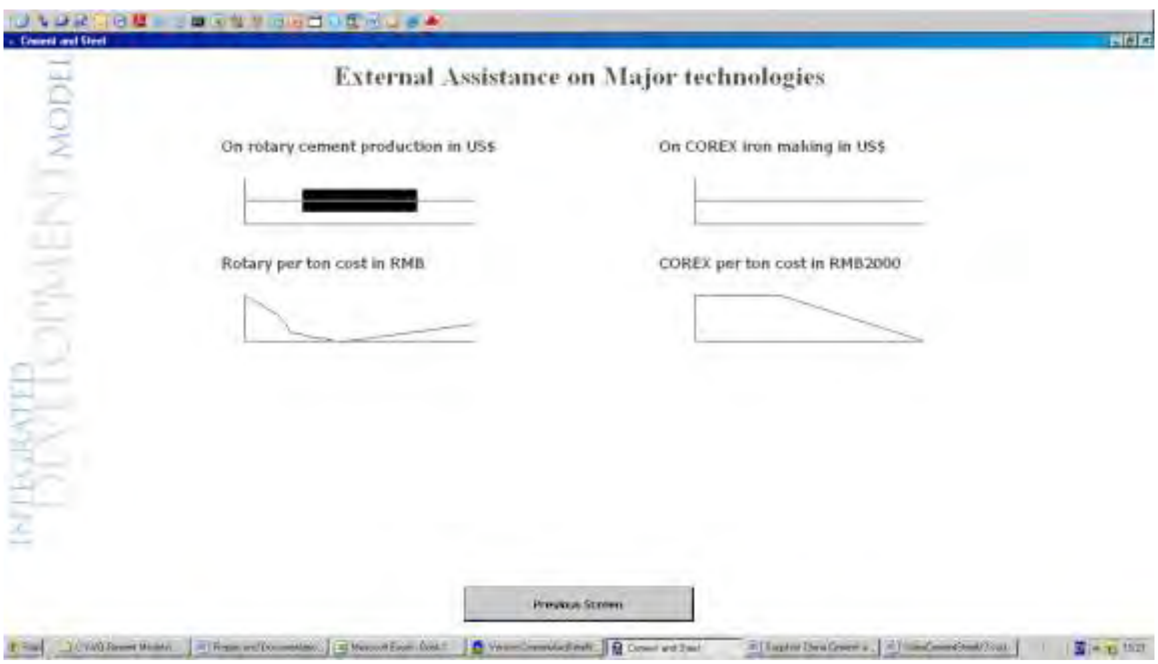
Optimistic: 2.5 (change 2008 and 2030 values to 2.5)

Pessimistic: 0.5 (change 2008 and 2030 values to 0.5)

External Aid: same as baseline

IV.5 External Aid Assumptions

The policy screen for external assistance in the model is shown below:



Two technologies have known prices, so one can test how external financial assistance in them can help save energy and reduce emissions. In cement, the rotary system with precalciner and preheater cost about 250 RMB per ton in 2008 (i.e., for a rotary system with 1-million-ton annual capacity, the cost is 250 million RMB in 2008). In the baseline, it is assumed that this price will stay constant in real value, while in nominal value it will rise about 5 percent per year. In the steel sector, COREX had a price of 3,100 RMB per ton a few years ago. With technology advances, this price is assumed to decrease in the future.

Since 2003, China's own annual investments have been at the level of about 40 billion RMB in the cement industry and about 200 billion RMB in the steel industry, equivalent to about US$6 billion and US$30 billion respectively.

For each assumption in the above screen, we have chosen different values for the four scenarios, as below.

For *on rotary cement production in US$:*

Baseline: as is, i.e., zero during 2008 to 2030

Optimistic: same as baseline

Pessimistic: same as baseline

External Aid: $1 billion each year for three years from 2009 to 2011 and then zero from 2012 to 2030

For *on COREX iron-making in US$:*

Baseline: as is, i.e., zero during 2008 to 2030

Optimistic: same as baseline

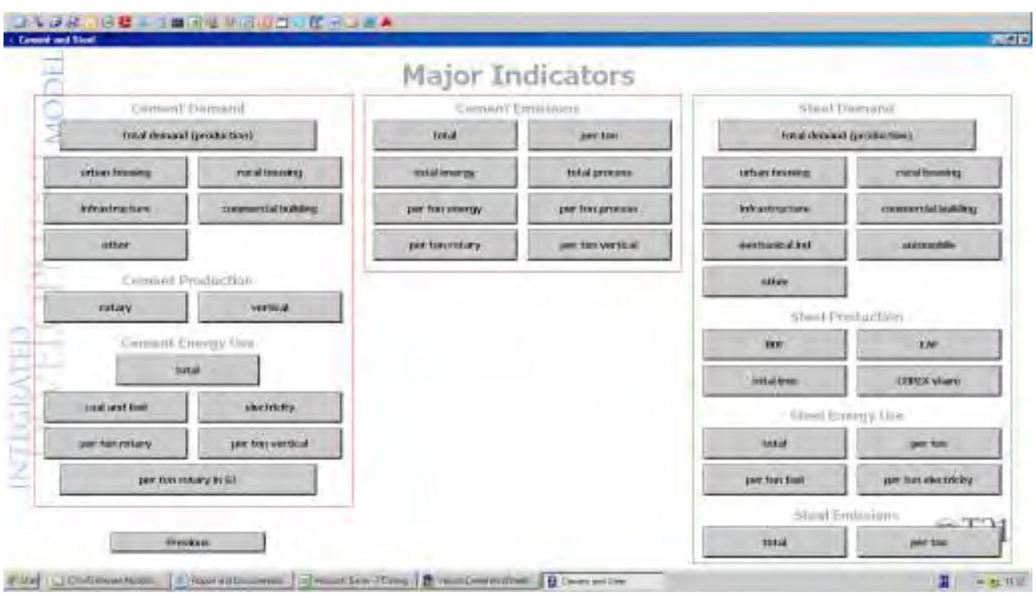
Pessimistic: same as baseline

External Aid: $1 billion each year for three years from 2009 to 2011 and then zero from 2012 to 2030

For *rotary per ton cost in RMB* and *COREX per ton cost in RMB 2000:* All scenarios use the values as they are in the screen.

IV.6 Major Results of Baseline and Alternative Scenarios

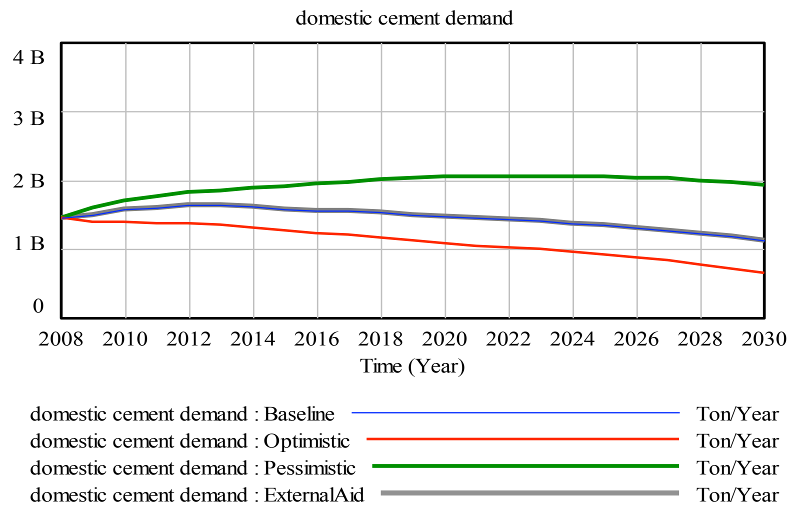
When you are running the model, the Major Indicators screen presents results in four categories for cement and steel: Demand, Production, Energy Use, and Emissions, as shown below:



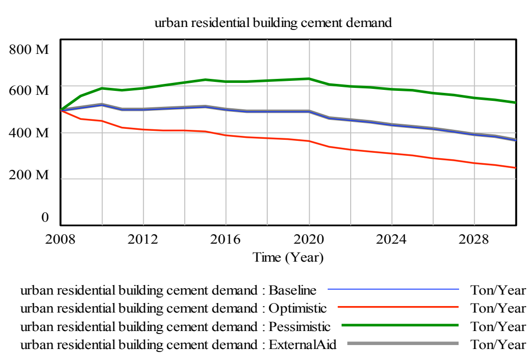
We select some indicators from the above screen to compare these scenarios.

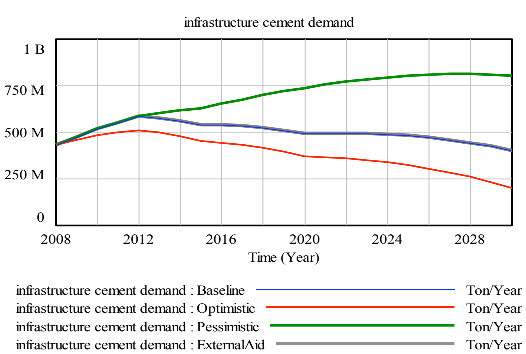
Cement Scenario Comparison

Total cement demand is quite different for the selected scenarios shown below. Notice that the Baseline and External Aid scenarios have the same results, which is reasonable, as the External Aid scenario invests in better technology but does not do other things to influence demand. When running the model, you can also use the button "View as Table" to look at the numeric values of all the scenarios.

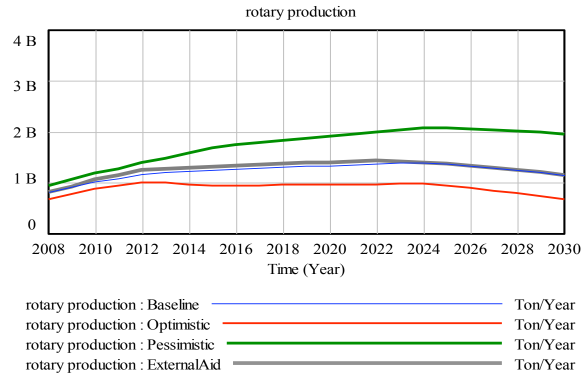


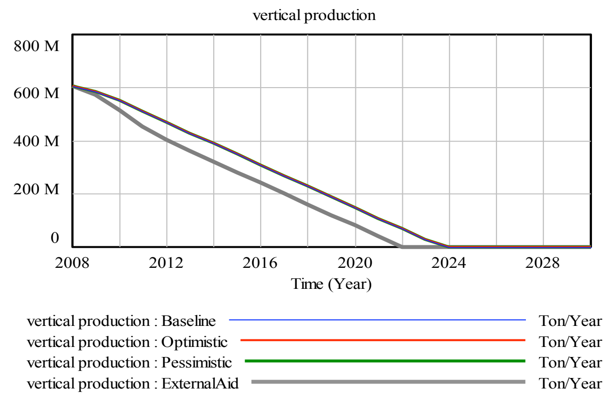
The biggest demand components are urban housing and infrastructure, which are shown below:



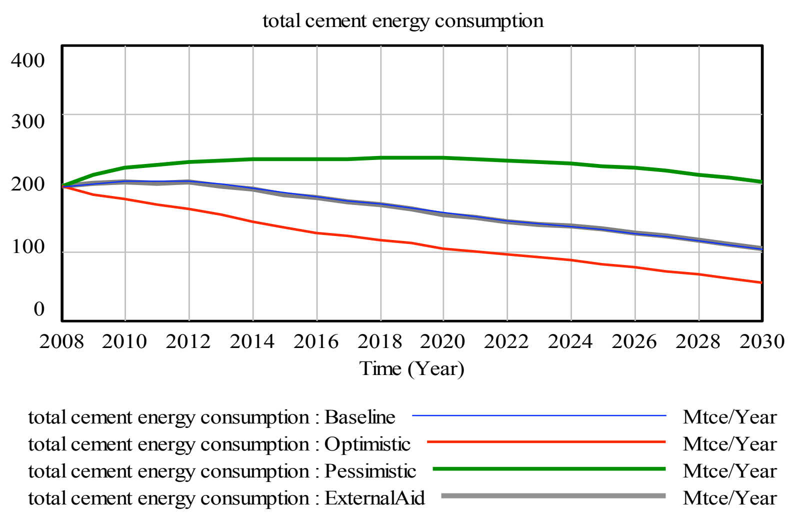


Rotary kiln and vertical shaft kiln production is shown below. The External Aid scenario has higher (just a bit, from the left graph) values than the Baseline, as US$1 billion for three years can add a total of about 70 million tons of production capacity, while rotary production capacity in place is about 1 billion tons per year. However, its effect on reducing vertical production is more obvious because of the scale factor.

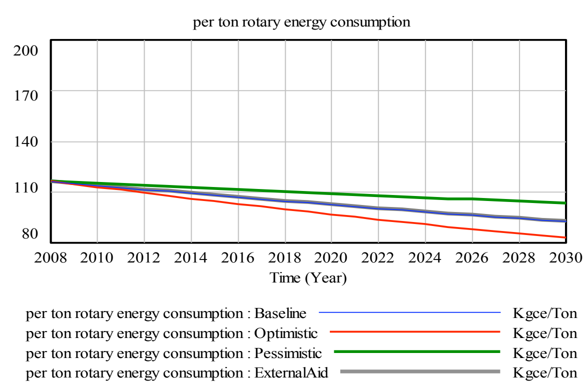


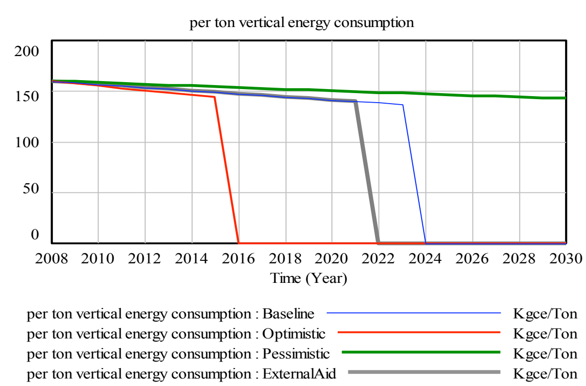


Total energy use, measured in Mtce (million tons of coal equivalent) per year, is shown below:



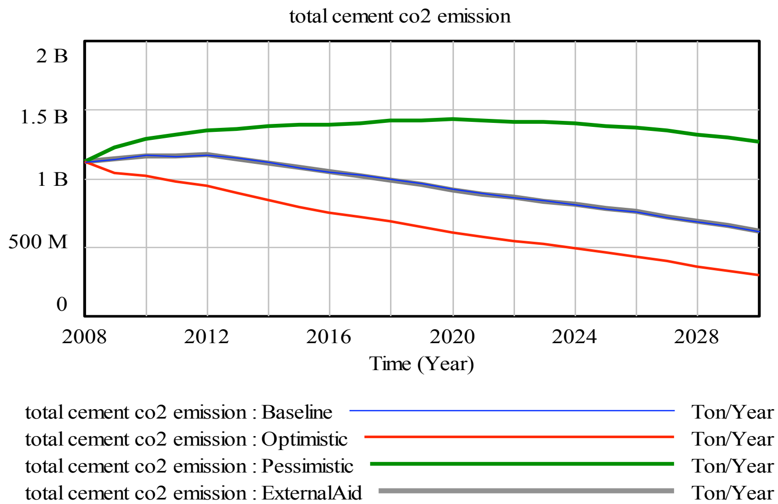
Per ton energy use for rotary and vertical production, measured in kgce (kilograms of coal equivalent), is shown below:



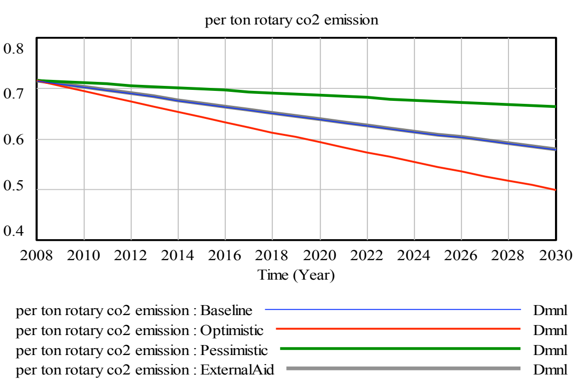


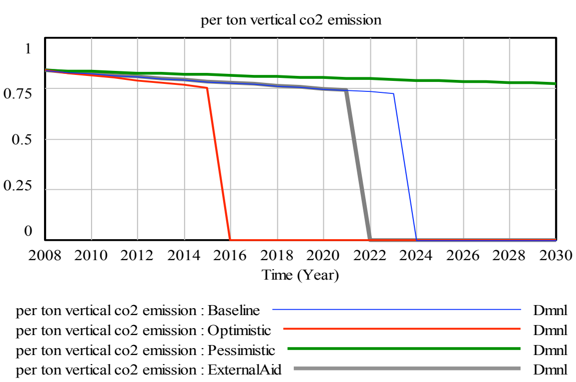
In the right graph, the values go to zero after a certain year because vertical production becomes zero then.

Total cement CO_2 emissions, measured in tons, are shown below:

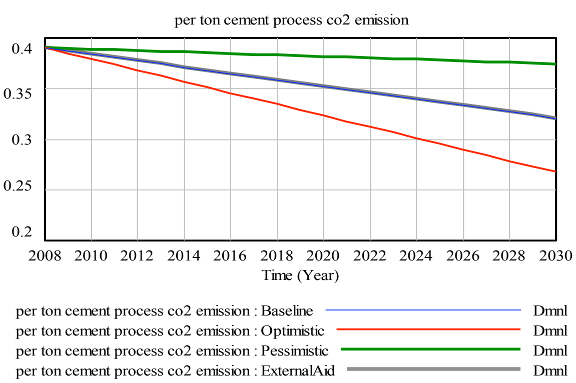


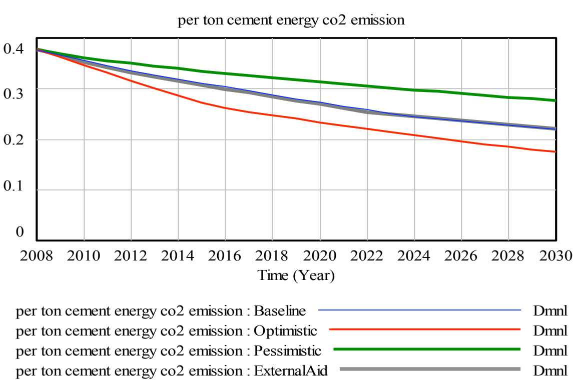
Per ton cement emissions for rotary and vertical production are shown below:





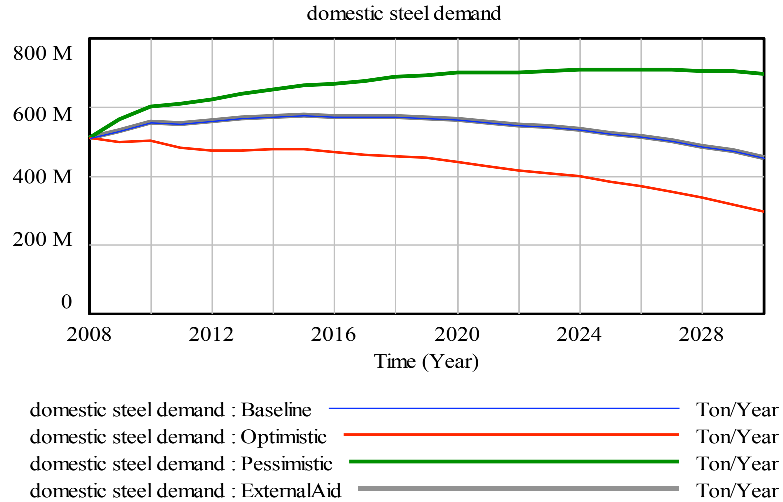
As explained earlier, cement CO_2 emissions come from two sources: chemical process and energy use. Per ton emissions from these two sources are shown below:



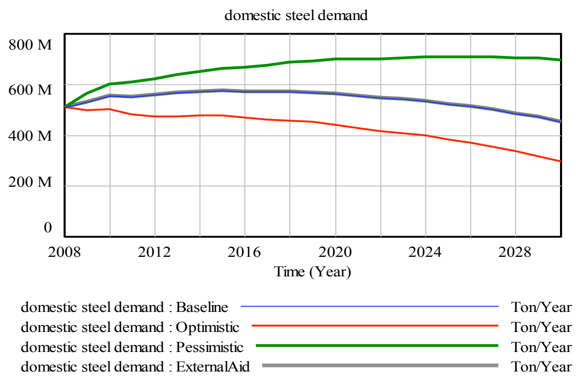


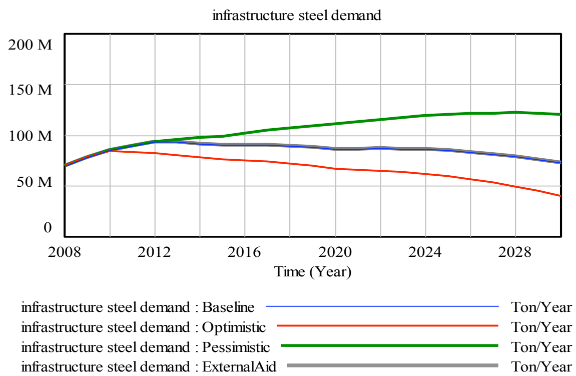
Steel Scenario Comparison

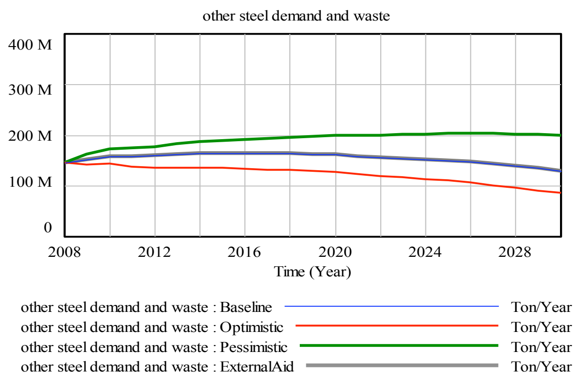
Total steel demand is quite different for the scenarios, as shown below. Again, the Baseline and External Aid scenarios have the same results, which is reasonable, as the External Aid scenario invests in better technology but does not do other things to influence demand.



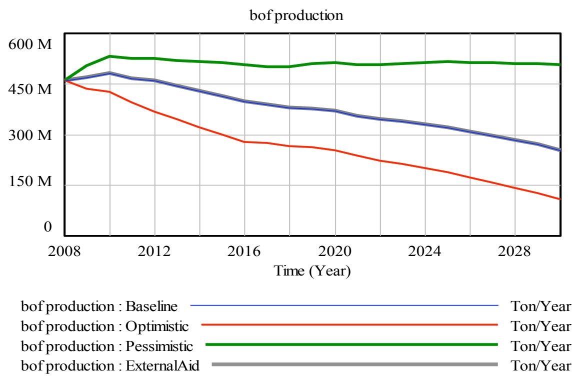
The biggest demand components are urban housing, infrastructure, and other (including all other uses, such as petrochemicals, pipelines, and home appliances), which are shown below:

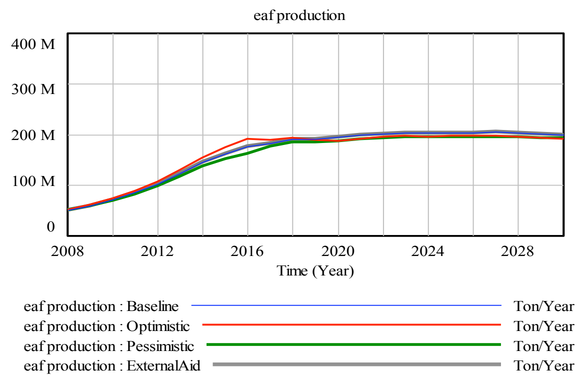




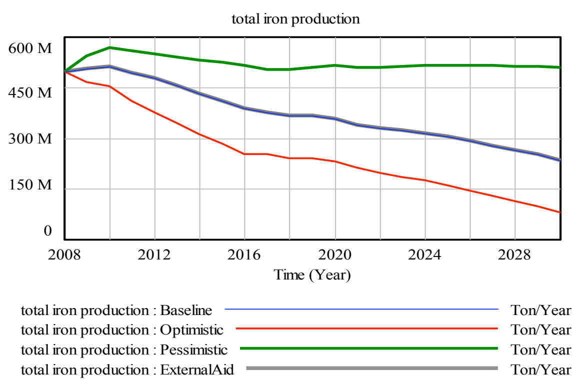


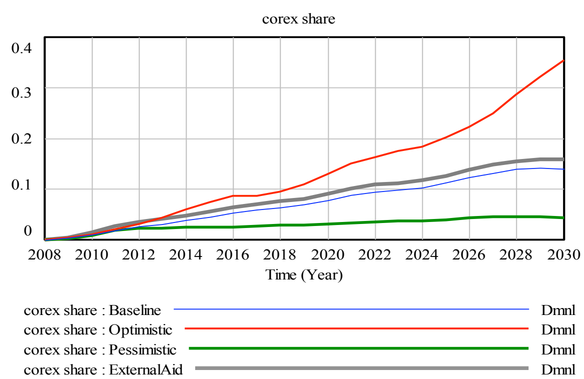
Steel production from BOFs and EAFs is shown below. Although it looks like the more efficient EAF production is quite the same for all the scenarios (right graph), its share in total steel production is quite different. For the Optimistic scenario, the EAF share rises to 37 percent in 2015 and 64 percent in 2030, as scrap steel availability rises and total demand falls. The BOF share falls from 67 percent in 2015 to 36 percent in 2030.





Total iron production and COREX share are presented below.

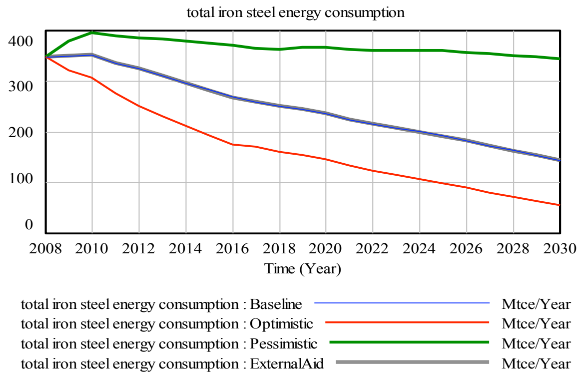


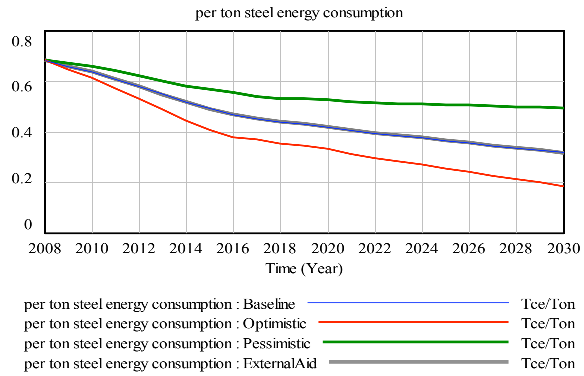


In the right graph above, the External Aid scenario has higher values than the Baseline one, as External Aid invests in COREX. The Optimistic scenario has fast-rising COREX share values toward 2030 because its total iron production is decreasing while the existing COREX capacity is already built.

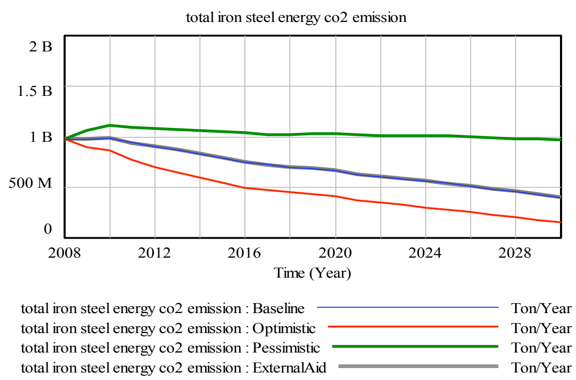
Total energy use, measured in Mtce per year, and per ton steel energy use, measured in tce (tons of coal equivalent), are below. The External Aid and Baseline scenarios overlap on the same line. You can click the button “View as Table” to see their very small differences in numeric values. The reason for this small difference is explained below:

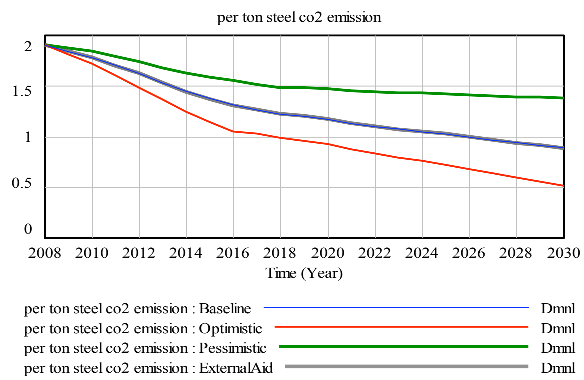
1. With External Aid, COREX capacity in 2012 is about 5 million tons higher than the Baseline, while total iron production for 2012 is about 474 million tons. In other words, External Aid has improved iron-making for about 1 percent of total iron production.
2. With COREX, it took 381 kgce to produce one ton of iron in 2008, while the traditional method of preprocessing (coking, sintering, and pelletizing) and blast furnaces used about 558 kgce in 2008, a saving of about 32 percent.
3. Iron-making is only a part of steelmaking. In other processes of steelmaking and steel post-processing, lots of energy is consumed.





Total steel CO_2 emissions, measured in tons per year, and per ton steel emissions, measured in tons of CO_2 per tons of steel, are shown below. The lines for External Aid and Baseline overlap, as explained above.





V. Summaries, Recommendations, and Further Work

V.1 Summaries

The T21 model is an initial effort to try to quantify and model the future CO_2 emissions from China's cement and iron and steel industries. The model allows users to test a wide range of what-if policy options and generates results in a matter of seconds.

To slow down the growth of, or even reduce, emissions from these two sectors, efforts should be made in multiple fields. These fields can be summarized as either on the demand side or on the technology side.

On the demand side, urban per capita living space and infrastructure construction are probably the two strongest forces that determine the future demands of cement and steel. Urban per capita living space doubled from 1990 to 2006. For the future, China could follow either the Japanese living style or the American one. Following the American style of continuing increase in unit size not only will demand huge amounts of cement and steel for construction (as China lacks timber resources), thus resulting in huge energy demand and CO_2 emissions, but will also consume lots of energy to heat and cool the houses during their lifetime, sending more CO_2 into the air. In the Baseline scenario, the Japanese style of more limited housing size is assumed.

Infrastructure construction could be an important measure to deal with the tough economic and employment situations in China. The Baseline scenario assumes that infrastructure consumptions of cement and steel will continue to be strong in the coming four years, when the national systems of highways, railways, and roads are being developed. After 2012, the assumption is that these programs will slow and their consumption of cement and steel will start to decline.

Rural house building consumes a lot less cement and steel per square meter. Commercial construction is assumed to be closely related to urban residential house construction.

From the technology side of cement, there are many things we can do: Alternative fuels can be used to reduce emissions, and the share of clinker in cement can be lowered to save energy. These two variables are provided on the screen for users to make what-if inputs. All other things, such as building larger and more efficient rotary kilns with precalciners and preheaters, establishing management centers, and increasing heat recovery, are combined into a single variable, *annual cement energy efficiency improvement*.

From the technology side of steel, there are also many things we can do: Advanced iron-making technologies, such as COREX, can be developed and applied to reduce energy consumption and emissions from energy use. More scrap steel can be gathered and used to make steel, reducing demand for pig iron (which requires lots of energy to make). These two variables are provided on the screen for users to make what-if inputs. All other things, such as building larger and more efficient furnaces/ovens; using dry coke quenching, powder coal injection in BFs, continuous casting, and direct rolling; establishing management centers; and increasing heat recovery, are combined into a single variable, *annual iron steel energy efficiency improvement*.

Using combinations of what-if changes, we developed four scenarios: Baseline, Optimistic, Pessimistic, and External Aid. The following tables summarize the demand, production, energy use, and emission situations of the scenarios for 2015 and 2030.

Table 1: Scenario results in 2015

	Unit	Baseline	Optimistic	Pessimistic	External Aid
I. Cement					
Total demand	Ton/Yr	1.58E+09	1.27E+09	1.92E+09	1.58E+09
Urban residential	Ton/Yr	5.10E+08	4.04E+08	6.25E+08	5.10E+08
Rural residential	Ton/Yr	1.72E+08	1.20E+08	2.28E+08	1.72E+08
Infrastructure	Ton/Yr	5.38E+08	4.49E+08	6.28E+08	5.38E+08
Commercial	Ton/Yr	1.91E+08	1.51E+08	2.34E+08	1.91E+08
Other	Ton/Yr	1.73E+08	1.44E+08	2.01E+08	1.73E+08
Total production	Ton/Yr	1.59E+09	1.27E+09	1.93E+09	1.59E+09
Rotary	Ton/Yr	1.24E+09	1.24E+09	1.49E+09	1.31E+09
Vertical	Ton/Yr	3.48E+08	3.20E+07	4.36E+08	2.80E+08
Total energy use	Mtce/Yr	185.95	134.00	233.78	183.21
Per ton energy use	Tce/Yr	0.117	0.105	0.121	0.115
Per ton rotary	Kgce/Yr	108.01	104.25	111.89	108.01
Per ton vertical	Kgce/Yr	148.58	143.40	153.91	148.58
Total CO_2 emission	Ton/Yr	1.08E+09	7.91E+08	1.38E+09	1.07E+09
Per ton CO_2 emission	Ton/Ton	0.679	0.622	0.719	0.674
Per ton rotary	Ton/Ton	0.670	0.642	0.698	0.670
Per ton vertical	Ton/Ton	0.783	0.752	0.815	0.783
Per ton process	Ton/Ton	0.368	0.351	0.385	0.368
Per ton energy	Ton/Ton	0.311	0.271	0.334	0.306
II. Steel					
Total demand	Ton/Yr	5.76E+08	4.75E+08	6.63E+08	5.76E+08
Urban residential	Ton/Yr	1.48E+08	1.21E+08	1.75E+08	1.48E+08
Rural residential	Ton/Yr	1.46E+07	1.06E+07	1.88E+07	1.46E+07
Infrastructure	Ton/Yr	8.97E+07	7.54E+07	9.87E+07	8.97E+07
Commercial	Ton/Yr	5.52E+07	4.53E+07	6.55E+07	5.52E+07
Mechanical industry	Ton/Yr	7.62E+07	5.90E+07	8.80E+07	7.62E+07
Automobile	Ton/Yr	2.76E+07	2.76E+07	2.76E+07	2.76E+07
Other	Ton/Yr	1.64E+08	1.36E+08	1.89E+08	1.64E+08
Total steel production	Ton/Yr	5.76E+08	4.75E+08	6.63E+08	5.76E+08
BOF	Ton/Yr	4.13E+08	3.00E+08	5.12E+08	4.13E+08
EAF	Ton/Yr	1.63E+08	1.75E+08	1.51E+08	1.63E+08
Total iron production	Ton/Yr	4.10E+08	2.83E+08	5.23E+08	4.10E+08
COREX production	Ton/Yr	1.83E+07	2.04E+07	1.21E+07	2.25E+07
Total energy use	Mtce/Yr	282.75	193.70	374.84	282.08
Per ton energy use	Tce/Yr	348.84	275.31	412.19	348.01
Total CO_2 emission	Ton/Yr	7.90E+08	5.41E+08	1.05E+09	7.88E+08
Per ton CO_2 emission	Ton/Ton	1.373	1.140	1.579	1.369

In 2015, the differences among the scenarios are obvious. In 2030, their differences are even bigger.

Table 2: Scenario results in 2030

	Unit	Baseline	Optimistic	Pessimistic	External Aid
I. Cement					
Total demand	Ton/Yr	1.13E+09	6.59E+08	1.93E+09	1.13E+09
Urban residential	Ton/Yr	3.66E+08	2.46E+08	5.24E+08	3.66E+08
Rural residential	Ton/Yr	1.05E+08	6.04E+07	1.69E+08	1.05E+08
Infrastructure	Ton/Yr	4.02E+08	2.01E+08	8.03E+08	4.02E+08
Commercial	Ton/Yr	1.37E+08	9.19E+07	1.96E+08	1.37E+08
Other	Ton/Yr	1.20E+08	6.02E+07	2.41E+08	1.20E+08
Total production	Ton/Yr	1.14E+09	6.62E+08	1.94E+09	1.14E+09
Rotary	Ton/Yr	1.14E+09	6.62E+08	1.92E+09	1.14E+09
Vertical	Ton/Yr	0.00E+00	0.00E+00	2.47E+07	0.00E+00
Total energy use	Mtce/Yr	104.98	54.75	201.60	104.98
Per ton energy use	Tce/Yr	0.092	0.083	0.104	0.092
Per ton rotary	Kgce/Yr	92.46	82.71	103.29	92.46
Per ton vertical	Kgce/Yr	0.00	0.00	142.38	0.00
Total CO_2 emission	Ton/Yr	6.13E+08	2.92E+08	1.26E+09	6.13E+08
Per ton CO_2 emission	Ton/Ton	0.540	0.440	0.649	0.540
Per ton rotary	Ton/Ton	0.579	0.498	0.663	0.579
Per ton vertical	Ton/Ton	0.000	0.000	0.772	0.000
Per ton process	Ton/Ton	0.321	0.267	0.374	0.321
Per ton energy	Ton/Ton	0.220	0.173	0.275	0.220
II. Steel					
Total demand	Ton/Yr	4.52E+08	2.97E+08	6.97E+08	4.52E+08
Urban residential	Ton/Yr	1.01E+08	7.37E+07	1.34E+08	1.01E+08
Rural residential	Ton/Yr	9.65E+06	6.04E+06	1.44E+07	9.65E+06
Infrastructure	Ton/Yr	7.23E+07	4.02E+07	1.20E+08	7.23E+07
Commercial	Ton/Yr	3.77E+07	2.76E+07	5.01E+07	3.77E+07
Mechanical industry	Ton/Yr	7.61E+07	3.80E+07	1.52E+08	7.61E+07
Automobile	Ton/Yr	2.64E+07	2.64E+07	2.64E+07	2.64E+07
Other	Ton/Yr	1.29E+08	8.47E+07	1.99E+08	1.29E+08
Total steel production	Ton/Yr	4.52E+08	2.97E+08	6.97E+08	4.52E+08
BOF	Ton/Yr	2.52E+08	1.06E+08	5.04E+08	2.52E+08
EAF	Ton/Yr	1.99E+08	1.91E+08	1.92E+08	1.99E+08
Total iron production	Ton/Yr	2.34E+08	7.82E+07	5.08E+08	2.34E+08
COREX production	Ton/Yr	3.26E+07	2.77E+07	2.09E+07	3.69E+07
Total energy use	Mtce/Yr	143.70	53.96	344.04	143.16
Per ton energy use	Tce/Yr	206.25	91.66	354.42	205.41
Total CO_2 emission	Ton/Yr	4.01E+08	1.51E+08	9.61E+08	4.00E+08
Per ton CO_2 emission	Ton/Ton	0.889	0.508	1.380	0.885

These tables show that the futures can be very different, depending on the paths (or policies) we choose. For instance, in 2015, cement demand could be 1.92 billion tons for Pessimistic or 1.27 billion tons for Optimistic, and their CO_2 emissions could be 1.38 billion tons or 791 million tons. Because of technology differences, per ton CO_2 emission could be 0.719 tons for Pessimistic or 0.622 tons for Optimistic. In 2030, the differences between these scenarios become even more significant. Cement demand could be 1.93 billion tons for Pessimistic or 659 million tons for Optimistic, a difference of almost three times. The difference in their CO_2 emissions is even bigger, 1.26 billion tons for Pessimistic or 292 million tons for Optimistic. Because of technology differences, per ton CO_2 emission could be 0.649 tons for Pessimistic or 0.44 tons for Optimistic. Steel demands and emissions for the scenarios show similar trends in 2015 and 2030.

With the model on your PC, you can easily make your own scenarios. While it is not possible to predict which scenario is most likely to occur, it makes sense to investigate their impacts and identify key fields where the Chinese government, civil society, and international organizations can work together to make bigger improvements.

V.2 Recommendations

WWF could either put money directly into these industries, as in the External Aid scenario, or work with the Chinese government and civil society to make policy shifts and improve public awareness.

As a result of the huge size of these two industries in China, billions of dollars could be injected from outside without significant improvements, as the External Aid scenario shows. It could be that we have yet to find the most cost-effective technology in which to invest, which might generate much better results. At this stage, we simply do not know if investing directly is the right way to go. We also noticed that during 2003–2006, Chinese public and private sources invested about US$30 billion annually in iron and steel and about US$6 billion in cement. For four years in a row from 2004 to 2007, annual rotary cement production capacity increased by over 100 million tons. Does this mean the Chinese can basically afford the new technologies? We do not know.

With its global prestigious position and reputation, WWF could certainly explore ways to work with or influence the Chinese government and/or private parties to make policy adjustments and improve public awareness in sustainable development. The model disclosed that per capita living space is a really important factor in reducing future emissions. In addition, the Chinese government is very strict in its land policy in defending its 120 million hectares of farmland. This creates a common ground for WWF and the Chinese government to cooperate in adjusting and promoting the social value of living conditions: comfortable and compact, rather than large and luxurious.

Another area in which WWF might contribute is technology transfer. Many technologies, such as COREX in iron-making, alternative fuel use in cement kilns, or reducing the clinker content in cement without lowering its quality, could be prohibitively expensive for China and other countries. If more countries could work together to develop and share these technologies, it would be a win-win situation for all. It is not an easy job to achieve this cooperation, but WWF could take the lead in this effort.

V.3 Further work

This model could become a practical tool to help Chinese policy-makers, the general public, and international organizations see what they can do to address the climate change issue in cement-and steel-related fields. In order to do that, we may need to:

1. have the model reviewed by experts, especially Chinese experts and WWF China,

2. update the model as needed and with more recent and accurate data,

3. have a workshop to train and distribute the model, and

4. publish papers in China and internationally.

This model uses inputs from T21 China. The outputs from this model, such as cement and steel production, may feed back into T21 China to affect its performances, such as the construction industry, GDP, employment, and national CO_2 emissions. With further research to quantify the linkages (or feedback effects), we can fully incorporate the cement and iron and steel sectors into the T21 China model.

This report is accompanied by a model package that can be installed and run on your PC, so users can build their own combinations of policy assumptions and develop their own scenarios.

This model uses inputs from the T21 China model, such as urban and rural population, GDP, government expenditures, and automobile sales. The results of this model for cement and steel demand could also affect many upstream and downstream sectors in T21 China, such as the mining industry and the residential construction industry. The size of these effects (or feedbacks) needs to be estimated, quantified, and linked back into T21 China.

Acknowledgments

Mr. Hefeng Tong of ISTIC designed the model structure with me, collected and organized most of the data, visited Chinese experts with me in Beijing, and reviewed earlier versions of the model.

Professor Michael Rock was the first person who introduced me to this field. His paper (Reference 1) was the starting point of my work. During the development of the model he provided me with many valuable questions, suggestions, and comments. Most of them are reflected in this paper and in the model.

Dr. Kejun Jiang provided Mr. Tong and me with insights about the conditions, policies, and future trends of the iron and steel industry. He answered lots of our questions and offered us his book (*Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China,* in Chinese), which is probably the most comprehensive and authoritative source of data in this field, although a bit outdated (it was published in 2001).

Professor Yuansheng Cui provided Mr. Tong and me with insights about the conditions, policies, and future trends of the cement industry. He answered lots of our questions and offered us the book he edited (*Cement Industry Towards Sustainability,* in Chinese) as well as several important papers.

Dr. Jed Shilling, chairman of MI Board, participated in all our meetings with WWF and provided many valuable questions, suggestions, and comments. I especially benefited from his careful review of this report.

Attachments

1. Model package
2. Script
3. PC living area computation.xls
4. CementComputation WQ.xls
5. SteelComputation WQ.xls

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Appendix: Guide to Navigating the China Cement and Steel Model, Version 4

A. Introduction

The China Cement and Steel Model is an analytical tool for strategy development and policy analysis for the future (to 2030). It gets input, such as gross domestic product and government expenditures, from the T21 China model developed in mid-2008.

B. System Requirements

- System requirements necessary
  - PC format
  - 50 MB of hard disk space
  - 512 RAM
  - Windows 98 or later

C. Installation Instructions

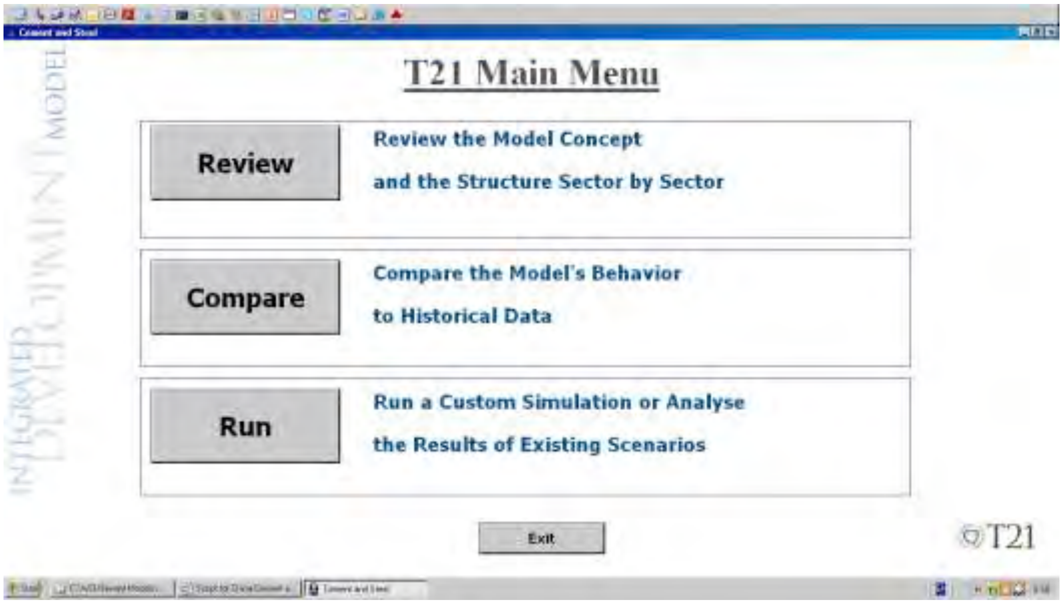
- With the ChinaCementSteelV4.exe file in your drive, double-click on that file name.
- You will be led through the installation processes.
- Target directory – here is where you indicate where the model will reside (the default is C:\Program Files\Venapp\ChinaCementSteelV4). It is important to remember where you install the model.
- Program menu choice – choose where you'd like the model icon to reside (a common place is Venapp).

D. Installing and Launching the Demo Model

- Install the demo model (see instructions above).
- To launch the demo, click on the ***Start Menu,*** select ***Programs,*** select ***Venapp*** (if that's where you saved it), and click the icon that displays ChinaCementSteelV4.
- Click on that file name.
- The model will open to the following screen:

Navigation Tutorial

Click anywhere or press any button to continue from the opening screen to the Main Menu:



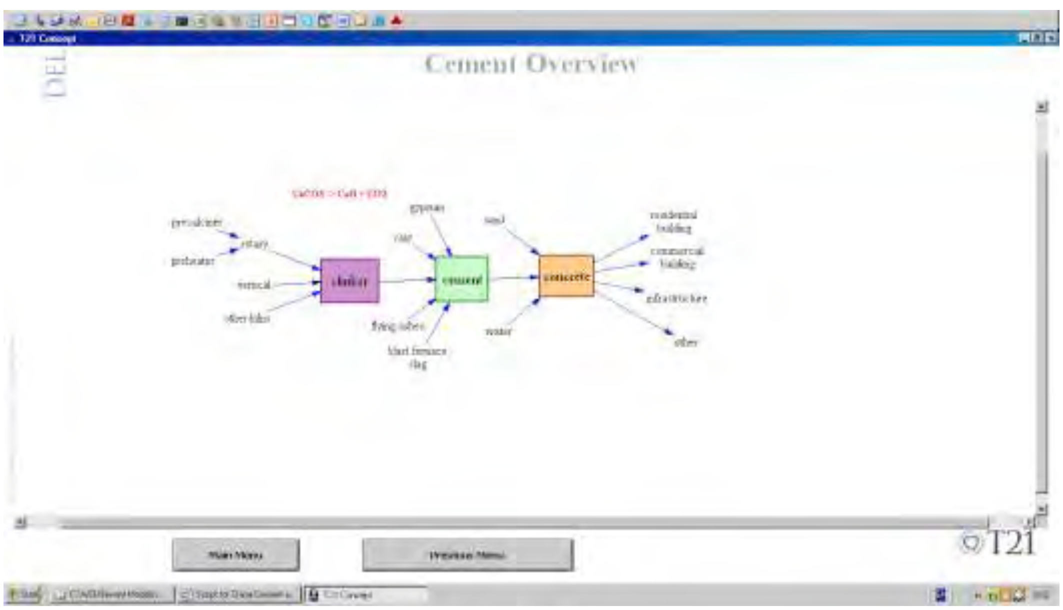
The Main Menu is the launch site to begin navigating through the model. To begin your launch you need to know where each button will take you, and that is where we begin.

1. **Main Menu First Button – Review of Model Structure**

This button allows you to study the basic concept and structure of the model. It does so by showing you sketches of the model components and their relationships.

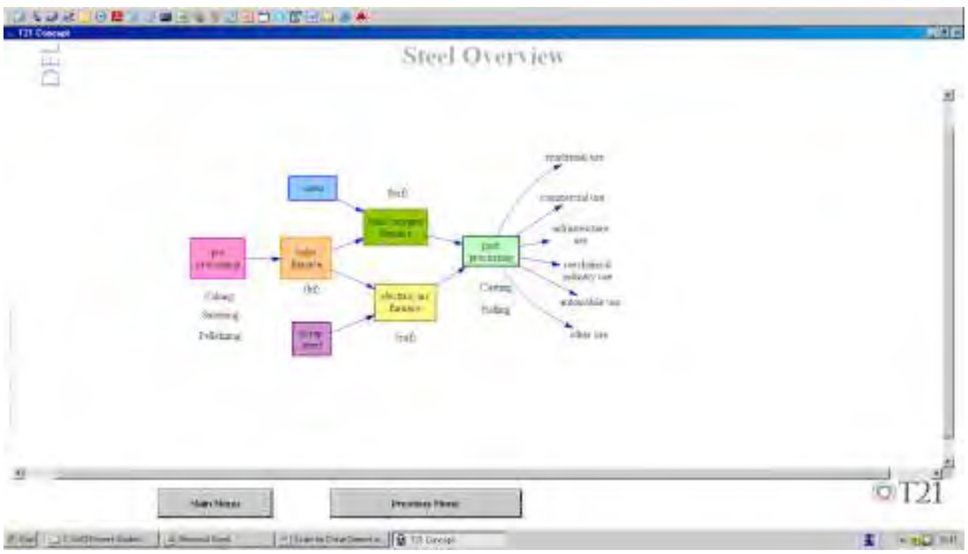
- Once you've clicked the ***Review*** button, the following Concept and Components menu will appear as shown below. There are three buttons in it: ***Cement Concept, Steel Concept,*** and ***Components (Sectors)***.

- Click the ***Cement Concept*** button, and the following concept screen will appear:



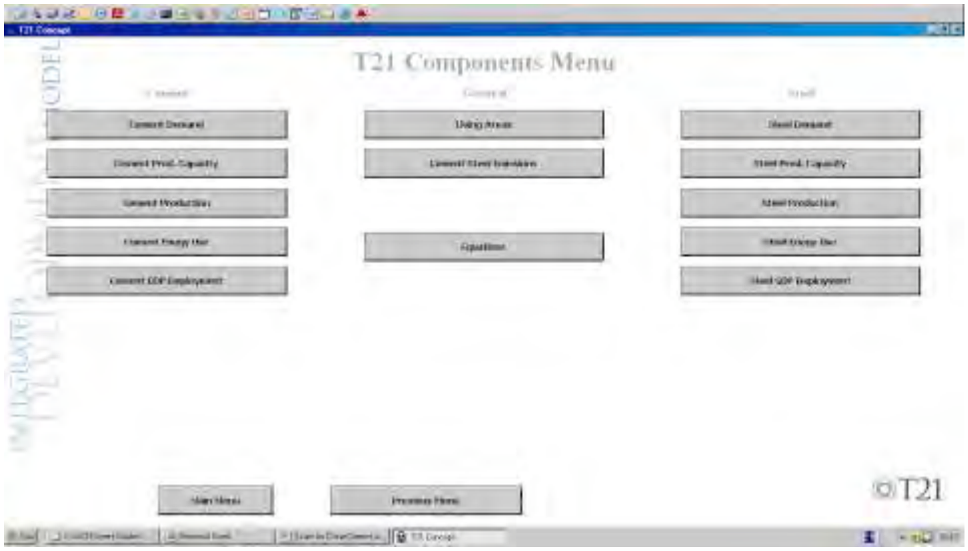
- This is the process overview of cement making and using, from left to right. Kilns for making clinker can be generally classified into rotary, vertical, and other (which is low in efficiency and is dying out). Modern rotary kilns have precalciners and preheaters to improve their efficiency. From clinker to cement, some additives are necessary, such as gypsum and clay. Recently it became apparent that many other things can be used as additives without compromising the quality of cement, such as blast furnace slag (or BFS, a by-product when making iron in a blast furnace) and flying ashes (or FA, a by-product from burning coal for power generation). Producing concrete from cement is usually carried out at the construction site, and more things need to be added and mixed well, such as water and sand. The right side shows the major users of cement (or concrete): residential and commercial buildings and infrastructure construction.

- When you finish examining the cement process, click the ***Previous Menu*** to return to the ***Concept and Components*** menu, then click the second button: ***Steel Concept***. You will see the following graph:

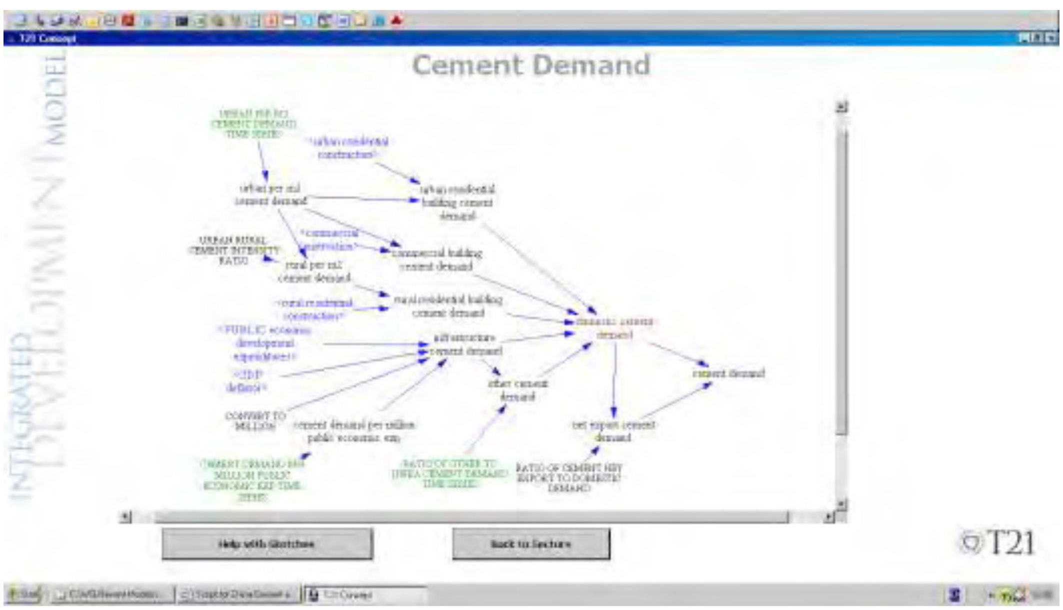


- This is the process overview of steelmaking, from left to right. For a blast furnace (BF) to make pig iron, iron ore and coal need preprocessing, mainly coking, sintering, and pelletizing. COREX (among several others) is a new technology that can make iron directly from iron ore and coal at a higher energy efficiency (and generate less CO_2). There are primarily two ways to make crude steel, with a basic oxygen furnace (BOF) and an electric arc furnace (EAF). A BOF needs iron from either a BF or COREX, while an EAF primarily uses scrap steel. After the BOF and EAF, crude steel is processed by casting and rolling to become a steel product. The right side shows the major users of steel.

- After you finish examining the steel process, click the ***Previous Menu*** to return to the ***Concept and Components*** menu, then click the third button: ***Components (Sectors)***. You will see the following graph:

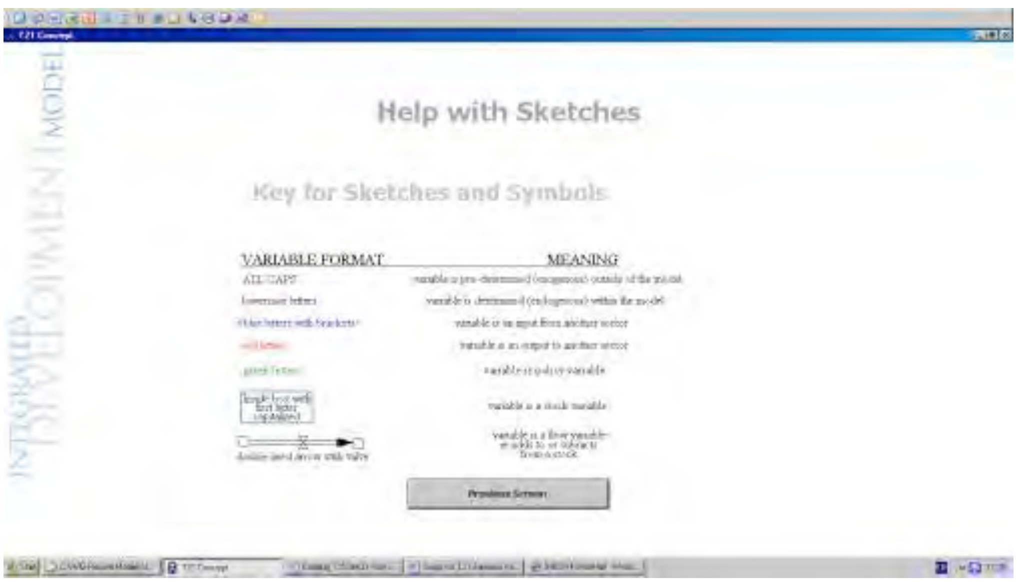


- You can click on any of the 13 buttons in the top half of the screen to see how each sector is modeled. And you can examine the equation of any variable by clicking the button in the center: ***Equations*.** Suppose you click the ***Cement Demand*** button on the top left; the following graph will appear:



- The arrows connecting the variables represent causality. The head of the arrow points to the consequences, which is the left-hand side of the equation. The tail of the arrow points to a cause, which is on the right-hand side of the equation.

- The color of a variable shows whether it is a common variable (black), an input variable from another sector (blue), an output variable that will be used by other sectors (red), or a policy variable whose value can be changed to represent various policy options (green). For example, from the sketch you can see that *urban residential construction* is an input variable, while *cement demand* is an output variable.
- From right to left, you can see how *cement demand* is modeled one level at a time. First cement demand is *domestic cement demand* plus *net export cement demand*. *Domestic cement demand* has five components: *urban residential building cement demand, rural residential building cement demand, commercial building cement demand, infrastructure cement demand,* and *other cement demand. Urban residential building cement demand* is further modeled with *urban residential construction* and *urban per square meter (m^2) cement demand. Urban residential construction* is a blue variable and is modeled in another sector with the ***Living Areas*** button.
- You can click the ***Back to Sectors*** button and then examine other sectors in the same way.
- Or you can click on the ***Help with Sketches*** button at the bottom of the screen to display a key explaining the meaning of the symbols, colors, and fonts used in the sketches (as below):

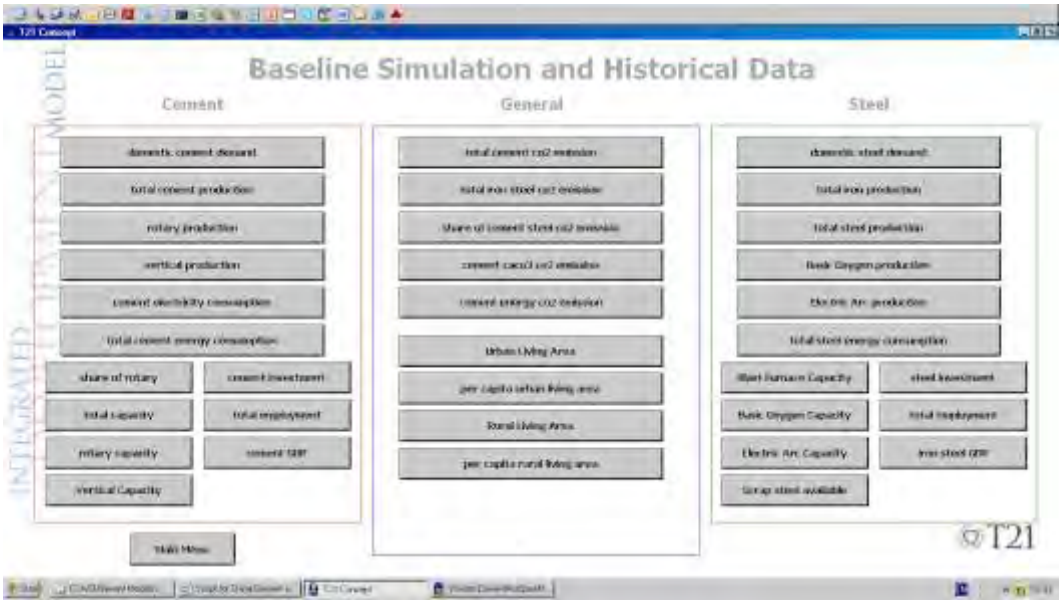


- Click on the ***Main Menu*** button when you finish examining all the sectors.

2. Main Menu Second Button – Compare

This button will compare the model's baseline results with historical data.

- Click on the ***Compare*** button, and a screen as below will appear. Indicators (variables) are grouped into three boxes. The first box is for cement. The second is for general, including emissions and living areas, and the third is for steel.



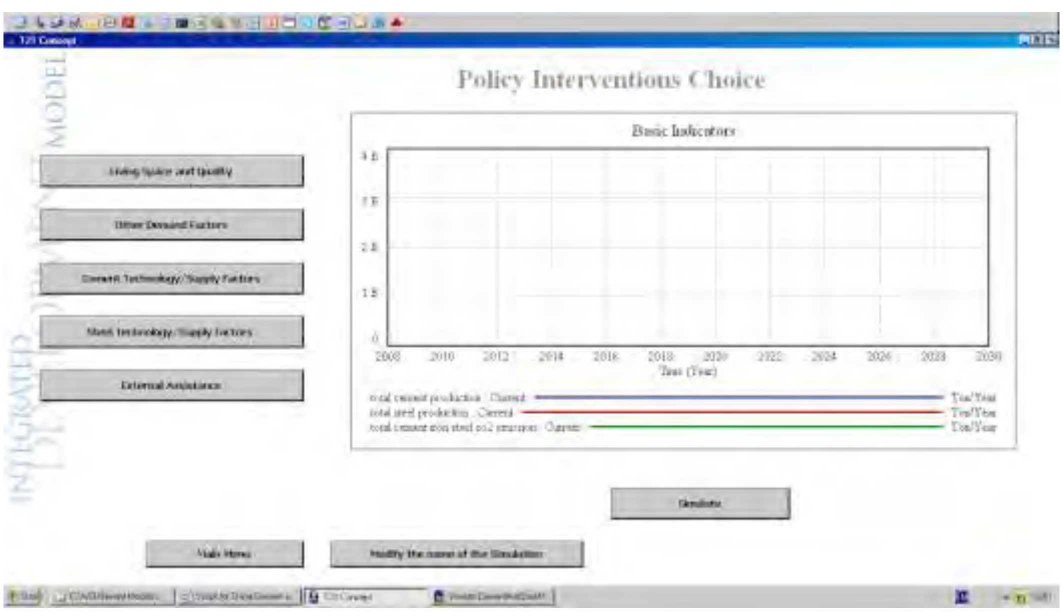
- Click on any buttons except the bottom one, and you will see a graph showing both the baseline results from the model and the historical data, if available. Suppose you click on the ***Total Cement Production*** button (second in the left box); a graph will appear that includes both the baseline model results and the historical data. The red line is data from China, available from 1990 to 2007, and the blue line is the simulation results from the model, which is calibrated to the data and projected out to 2030.

- The model baseline simulation is compared with actual historical data to validate the model and its ability to reflect the “reality” of the country. Notice how the model calculations of the past (blue line) correspond to the available historical data (red line).

- Similarly, you can look at comparisons of other indicators.
- You can view results in the table form by clicking the ***View as Table*** button, or return to the previous screen by clicking the ***Previous Screen*** button.
- When you have finished exploring the baseline simulation and historical data, click on the ***Main Menu*** button to return to the Main Menu. We continue with the third button.

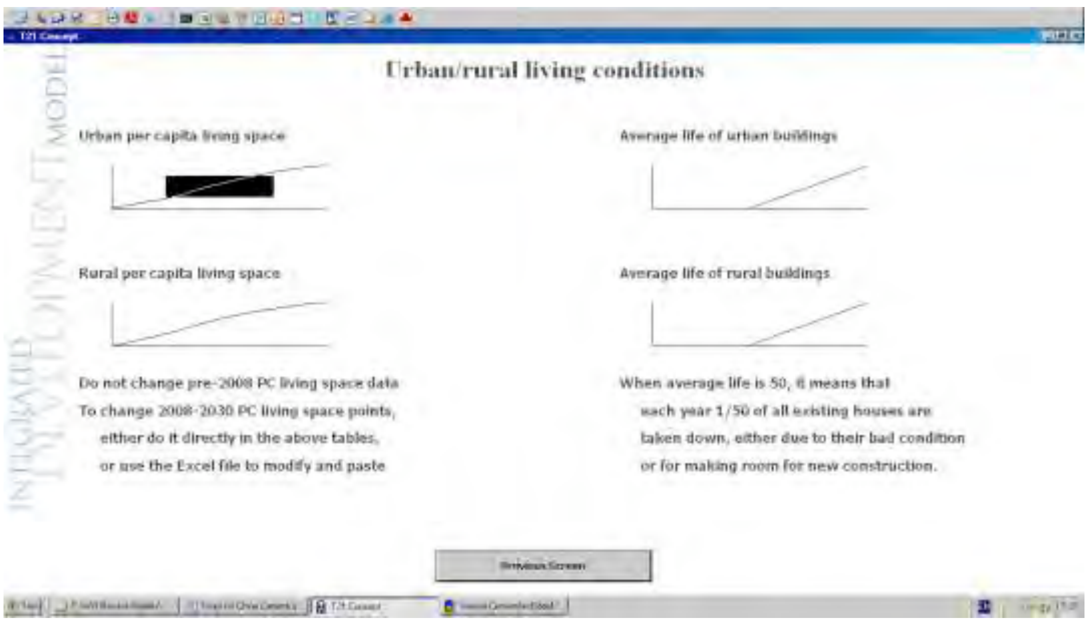
3. Main Menu Third Button – Run

- With this button, you can create your own scenarios by making policy choices and then simulate to 2030. You can compare your scenarios with each other, or with the baseline scenario, to find the best policy for the country.
- Click on the ***Run*** button, followed by the ***Create and Name the Simulation*** button (top one).
- At this point a window will pop up and you will be asked to either select an existing scenario or create a new scenario that will be saved to a file for future reference. Either type in a name of your choice in the File Name box or select any of the existing scenarios (files), and then click on the ***Save*** button.
- Assume you entered (created) Current and then clicked on the ***Save*** button.
- If Current already exists, Vensim will ask you if you want to overwrite the existing file Current.vdf (the extension .vdf is automatically added by Vensim). Click ***Yes.***
- You will now see a screen titled Policy Interventions Choice.

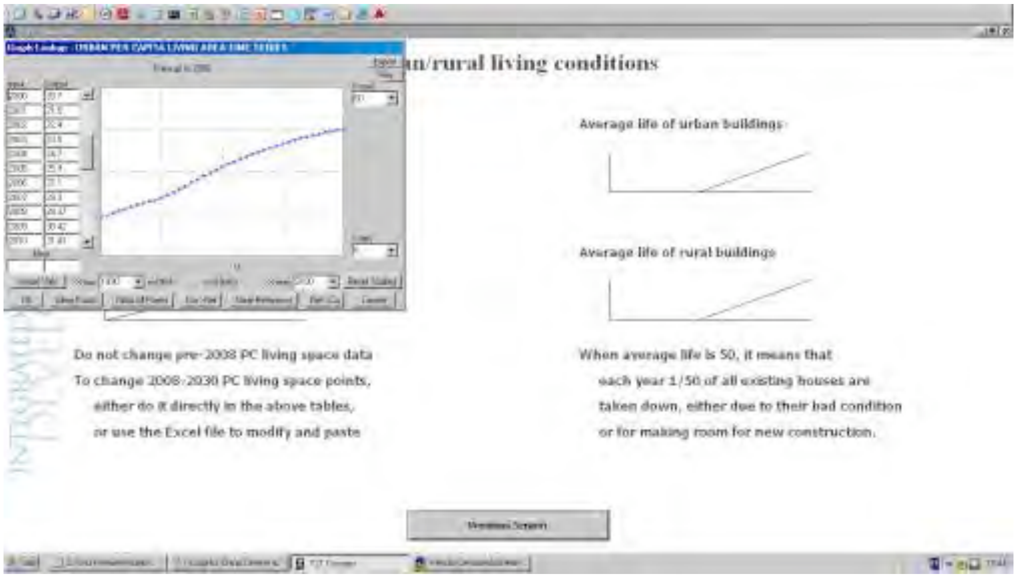


- On the left are five policy buttons. The first two provide the major factors (variables) that will affect the future demand of cement and steel. The next two (third and fourth) include important supply and technology factors that will affect per ton cement/steel energy demand and emissions. The fifth button provides two uses for foreign assistance.

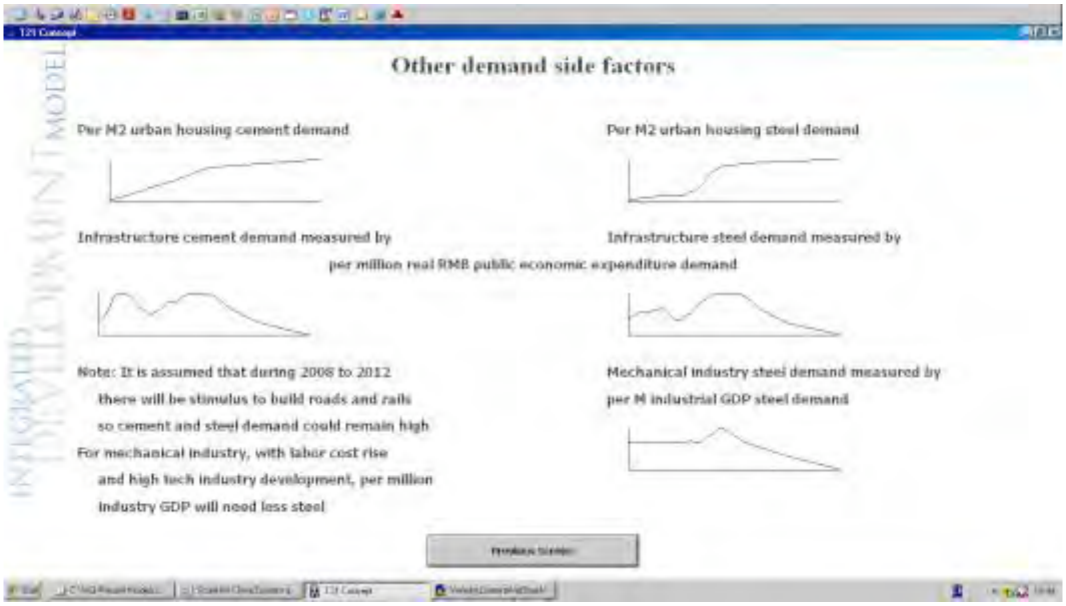
- Click on the ***Living Space and Quality*** button, which allows you to modify per capita living area parameters to see the consequences for future cement and steel demand.
- This will bring up a screen that contains four policy variables. The two left ones represent urban and rural per capita living spaces, and the two right ones represent the quality of urban and rural houses (in how long they will last). The pre-2008 values of per capita living spaces are based on historical data, while the post-2008 values are for the baseline but are available to the users to make changes.



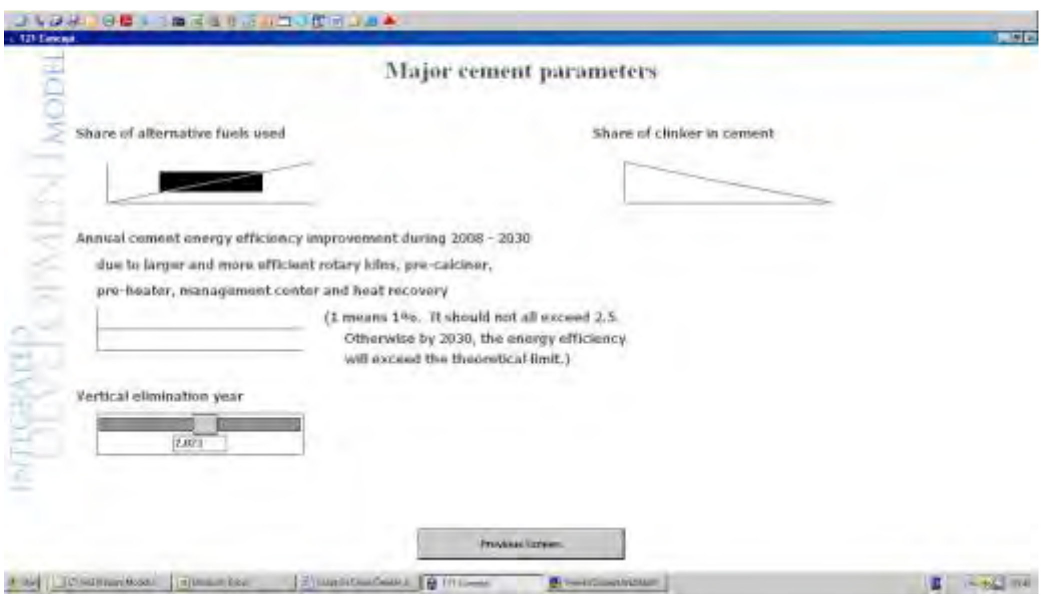
- Click the center of the *urban per capita living space* box, and a graph input box will appear in the top left of the screen. You can modify the numbers in the Output column (second column from left), such as for 2008, change 29.37 to 29.6, followed by pressing the key ***Enter,*** meaning increasing per capita living space in 2008 from 29.37 square meters to 29.6 square meters. You can also make your policy choices by dragging a point up or down. After making your changes to all the years from 2008 to 2030, click the ***OK*** button. As changing each point in this way is rather tedious, you can use the Excel file "PC living area computation.xls" to make changes quickly (by specifying only the 2030 value) and then paste (import) to this graph.



- Similarly, you can make changes to *rural per capita living space*.
- The variable *average life of urban buildings* needs a little explanation. Over the last 30 years or so, China has gone through massive residential housing construction. Because of lack of land and the bad conditions of existing houses, many houses were taken down, and sometimes the whole community was demolished to make room for new residential buildings. And increasingly these buildings are high-rise apartments. According to our estimate, from 1990 to 2007, each year about one-fiftieth (or 2 percent) of existing houses in urban areas were taken down, indicating an average life of 50 years. In the future, however, this fraction could become smaller, as there are fewer low-quality houses available, meaning that average life could become longer. In the baseline, it is assumed that the average life will be 70 years in 2030 for urban houses and 60 years for rural houses. If the existing houses could be maintained so they lasted longer than 70 and 60 years, it would mean big savings of cement and steel in the future. You can make changes to the right-hand variables in a similar way to the previous ones.
- After making your desired changes to the four variables, click on the ***Previous Screen*** button to return to the policy screen, and click the second button, ***Other Demand Factors***. A screen will appear as below:



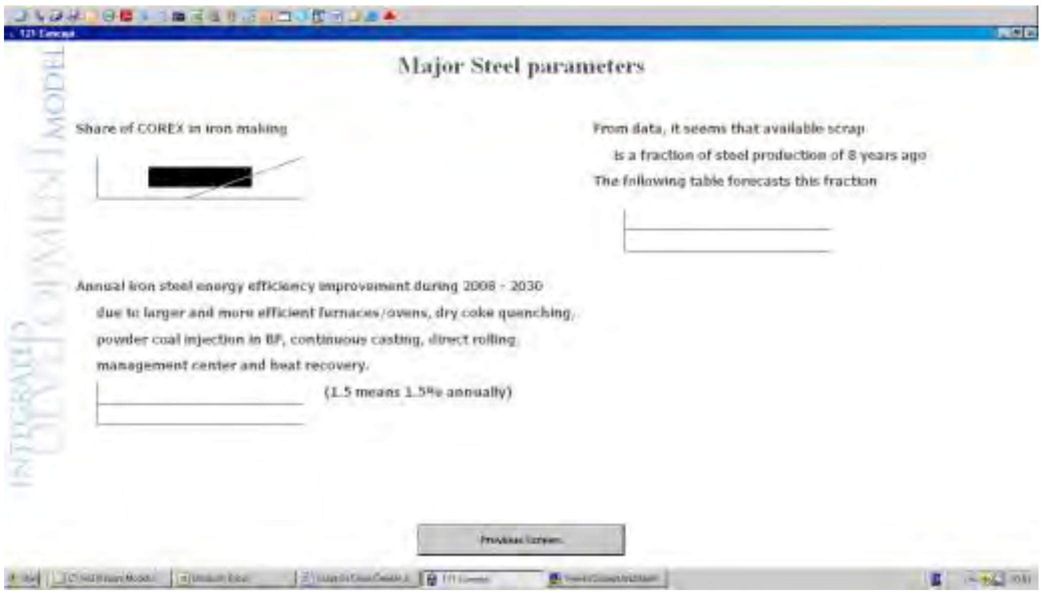
- The left two variables contribute to future cement demand, while the right three contribute to future steel demand. You can modify them in the same way as explained above. After making your desired changes to the variables, click on the ***Previous Screen*** button to return to the policy screen, and click the third button, ***Cement Technology/Supply Factors***. The following screen will appear:



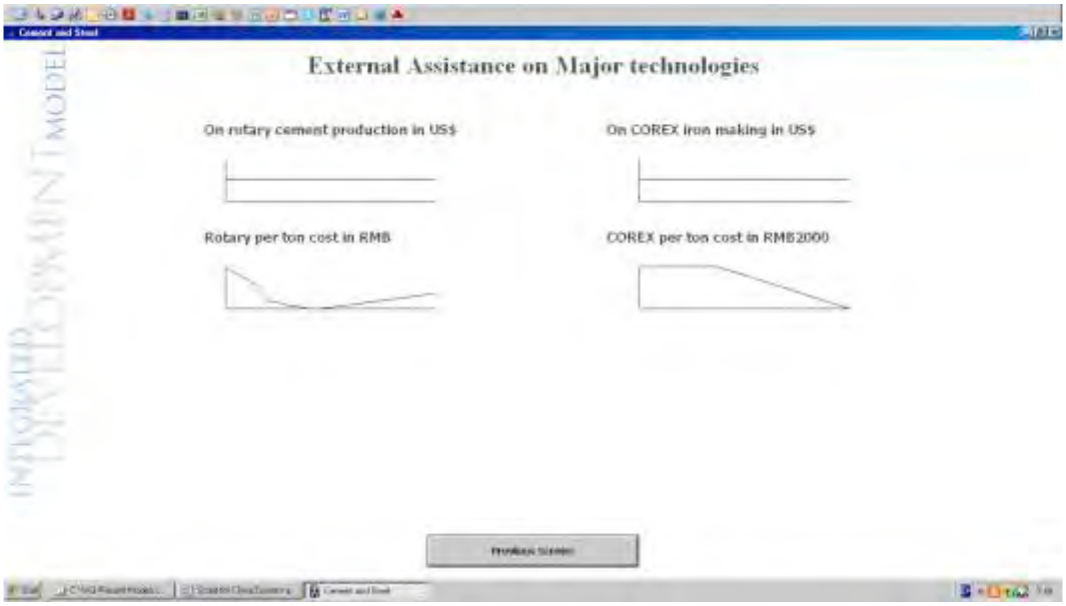
- On the cement production and technology side for energy saving and emission reduction, there are many things one can do, such as using alternative fuels to reduce emissions, reducing share of clinker in cement to save energy, building larger and more efficient rotary kilns with precalciners and preheaters, establishing management centers, and increasing heat recovery.

The two shares of alternative fuels and clinker in cement are provided in the first row for users to modify, and all the other factors are combined into an annual energy efficiency improvement during 2008–2030. To change that efficiency improvement, you can do similarly as you did to *urban per capita living space.* To change the *vertical elimination year,* you can either drag the slider or type a number into the number box.

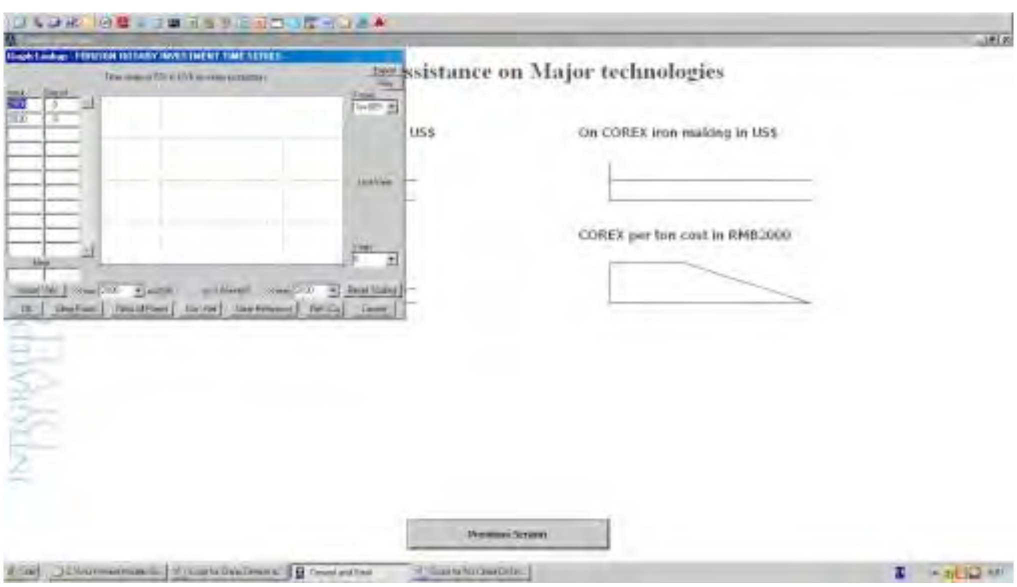
- After making your desired changes to the three variables, click on the ***Previous Screen*** button to return to the policy screen, and click the fourth button, ***Steel Technology/Supply Factors***. A screen will appear as below:



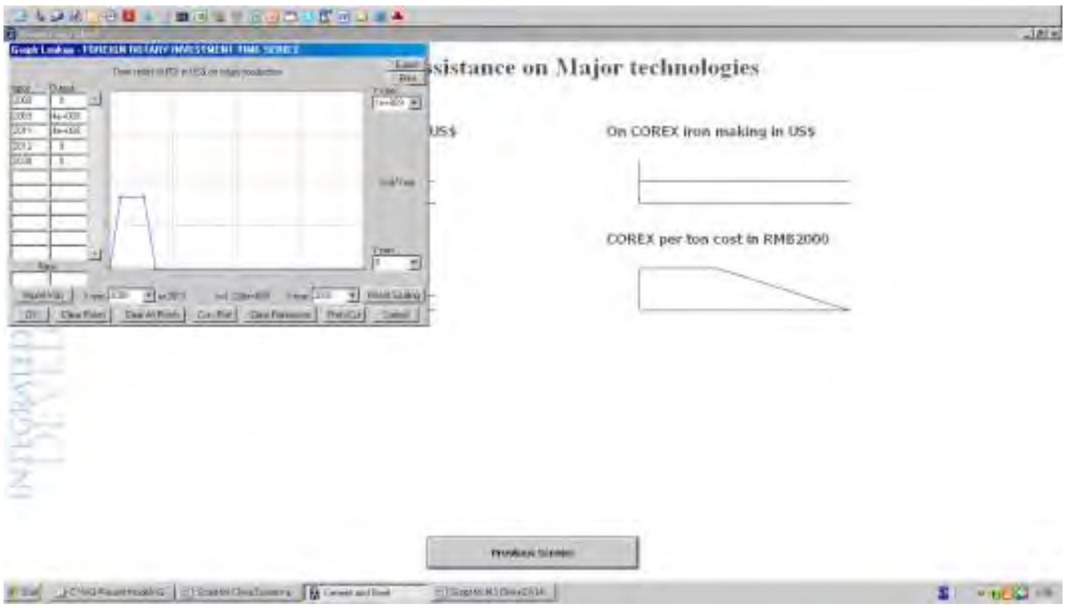
- On the steel production and technology side for energy saving and emission reduction, there are lots of things one can do, such as adopting advanced direct reduction iron-making technology like COREX (which is still quite expensive), making more scrap steel available to increase the steelmaking from an EAF to reduce energy use; building larger and more efficient furnaces/ovens; using dry coke quenching, powder coal injection in a BF, continuous casting, and direct rolling; establishing a management center; and increasing heat recovery. The share of COREX in iron making and the availability of scrap steel as a fraction of production eight years ago are provided in the first row for users to modify, and all the other factors are combined into an annual energy efficiency improvement during 2008–2030, which can be changed like the previous button.
- After making your desired changes to the three steel technology variables, click on the ***Previous Screen*** button to return to the policy screen, and click the fifth button, ***External Assistance***. A screen will appear as below:



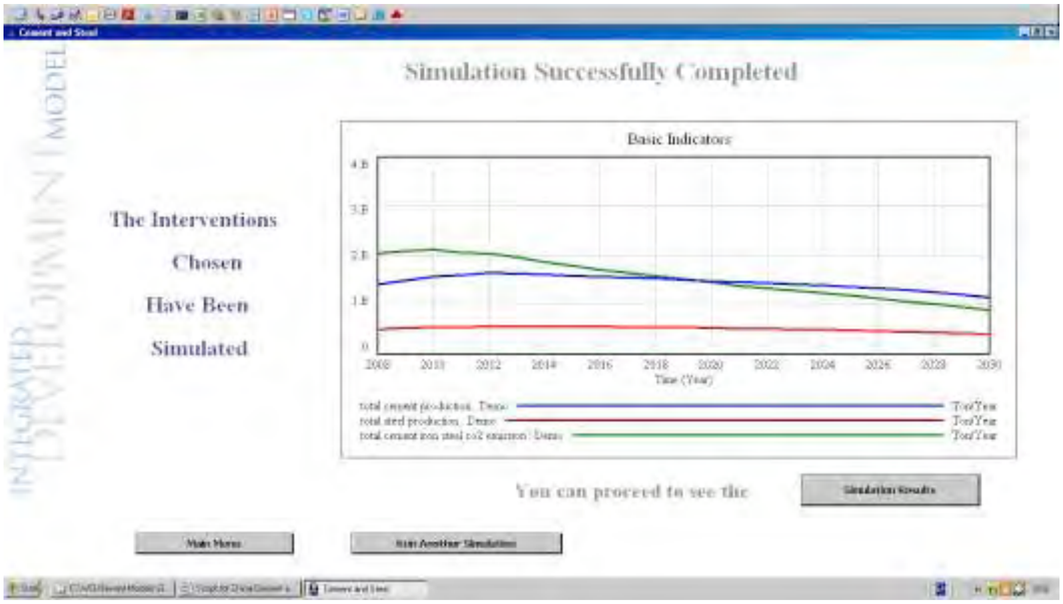
- Two technologies have known prices, so we can test how external financial assistance for them can help save energy and reduce emissions. In the cement sector, the rotary system with precalciner and preheater cost about 250 renminbi (RMB) per ton in 2008 (i.e., for a rotary system with 1-million-ton annual capacity, the cost is 250 million RMB in 2008). In the baseline, it is assumed that this price will stay constant in real value, while in nominal value, it will rise about 5 percent per year. In the steel sector, COREX had a price of 3,100 RMB per ton a few years ago. With technology advances, this price is assumed to decrease in the future.
- To test how external financial assistance in rotary systems can help, click the center of the top left variable, and a graph input box will appear in the top left of the screen, as below:



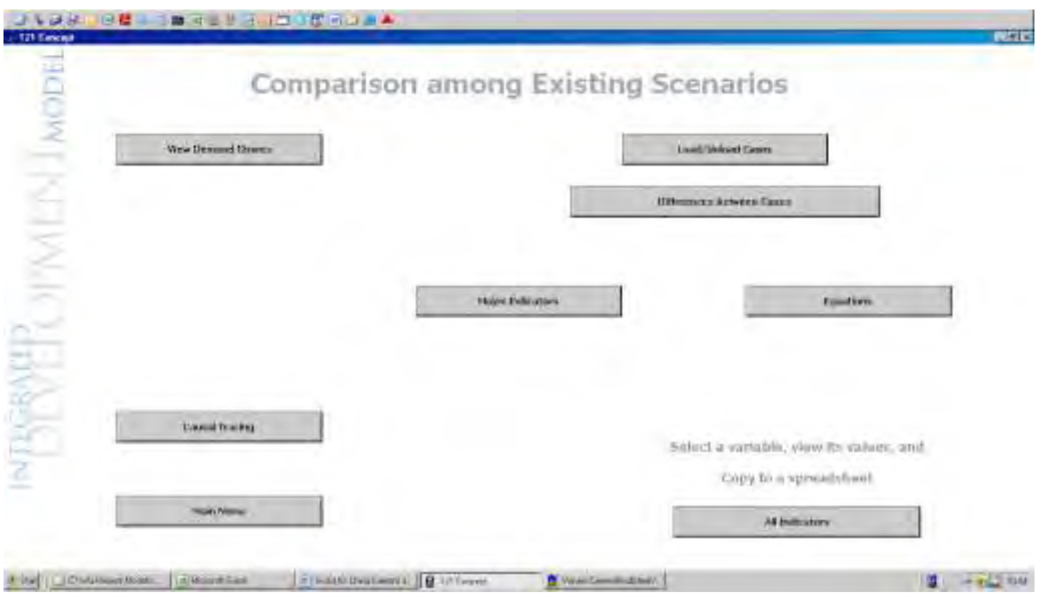
- In the baseline we assume that there will be no external assistance. If now we assume that US$400 million will be used each year from 2009 to 2011, we need to add three points, for 2009, 2011, and 2012, to the graph. To add a point to the graph, you can enter your desired policy choice, such as 2009 and 4e8 (meaning US$400 million) in the boxes below the word *New* (remember to press ***Enter*** after typing 4e8). After entering all three points, the screen will look as follows:



- Click the ***OK*** button in the lower left corner to return to the previous screen, and you can continue to modify external assistance in COREX and the prices of rotary systems and COREX.
- You can change multiple policies in all the areas (buttons) as well see the results of combinations of policy changes. But it is preferable to initially change only one policy or a small set of policies at a time to better understand their specific impacts. Then look at combinations of policy changes to see their interactions. You should give each scenario a different name so they can be compared later.
- Click on the ***Previous Screen*** button and then the ***Simulate*** button to simulate the model to 2030. In a few seconds you will see three lines from 2008 to 2030. These three lines are three variables selected from a few hundred variables to represent your scenario. They are total cement production, total steel production, and total cement and steel CO_2 emissions.

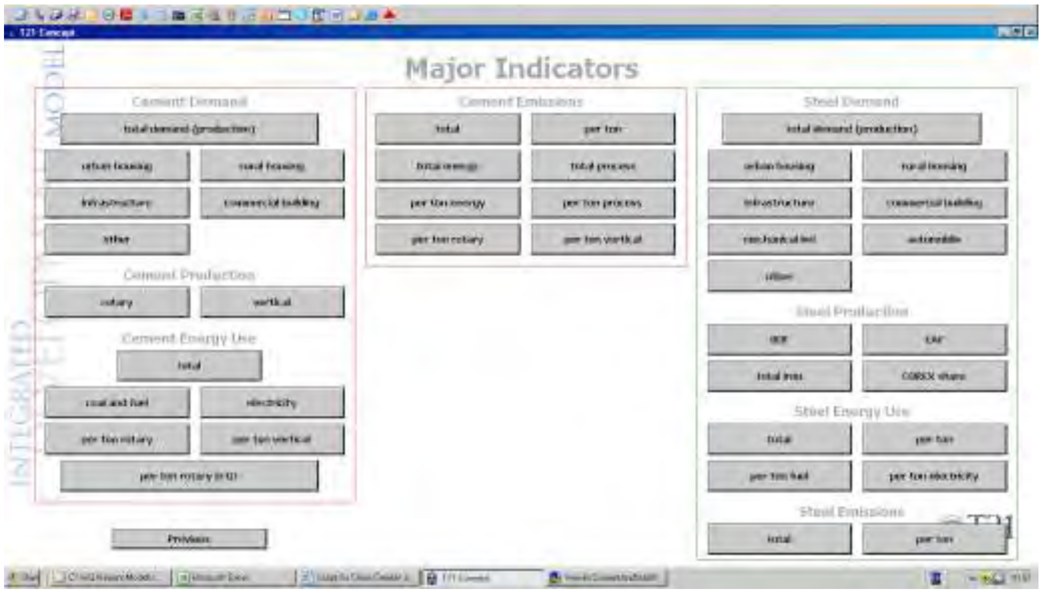


- Click on the ***Simulation Results*** button at the lower right of the screen and the following screen will appear:



- You can also access the same screen from the Main Menu, the third button, by choosing *View the results of existing scenarios*.
- First click on the ***Load/Unload Cases*** button to load the scenarios you want to compare. Move scenarios you want to load to the right-hand side of the window that will appear, and keep unwanted scenarios to the left-hand side. Suppose you loaded two scenarios: Current and Baseline (Baseline is under the folder "history").

- Then click the ***Major Indicators*** button, and the following screen will appear:



- Major indicators are classified into four groups for cement and steel: demand, production, energy use, and emissions (in central column). Click on each of them to see the difference between your scenario (be it Current or some other name you choose) and the model baseline. You can also click on the ***View as Table*** button to view their numeric values and then click the ***Copy to Clipboard*** button to paste the comparison results into an Excel file.
- Click on the other buttons to see the comparison for other major indicators.
- When you have finished, click on the ***Previous*** button to return to the Comparison among Existing Scenarios screen.
- The button on the upper left, ***View Demand Shares,*** allows you to examine the shares of all demand components for cement and steel in any scenario (only one scenario at a time).
- The button on the lower right, ***All Indicators,*** allows you to examine the behavior of all the other variables, in either graphical or tabular form.
- The button on the lower left, ***Causal Tracing,*** allows you to examine the causes of each variable.
- You can continue to create more scenarios by going back to the Main Menu and clicking the third button and then compare their results, as already explained.

You will now have completed an initial round of making a scenario(s). The runs (scenarios) that you have made will be saved when the application is closed and will be available for future use of the application.

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