MODELING OF THE INTERACTIONS BETWEEN SECTORAL CO2 EMISSIONS AND ENERGY EFFICIENY UNDER CO2 EMISSION RESTRICTION POLICIES

Kemal Sarıca[1], Nihan Karali[1]

[1] *Department of Industrial Engineering, Boğaziçi University, 34 342, Bebek, Istanbul, Turkey*

ABSTRACT

The purpose of this study is to understand the dynamics of carbon dioxide (CO2) emission restrictions and energy price policies on two highly energy intensive sectors of industry; iron&steel industry and cement industry over a 12 year period. Model is designed so that critical decisions such as growth and efficiency investments are based upon profit and extra costs incurred due to CO2 emissions. The profit margin, CO2 cost over revenue and Energy Cost Share in Total Annual Production are important key variables in the model. This study, giving attention to the economical and energy-emission policy aspects, aims to analyze the causal relationships and the feedback structures among industry's production capacity, investments on new and energy efficient technologies, financial burden, and CO_2 emissions.

Keywords: Sectoral Emission, Energy Efficiency, Emission Restriction, Energy Cost

1. INTRODUCTION

The purpose of this study is to understand the dynamics of carbon dioxide (CO2) emission restrictions and energy price policies on two highly energy intensive sectors of industry; iron&steel industry and cement industry over a 12 year period.

According to some experts, world energy consumption is expected to be 40% higher in 2020 than it is today. If no action is taken, these trends are likely to lead to supply interruptions, security risks of fossil fuel dependence, and price shocks caused by limited fossil fuel resources. Moreover, current level and profile of energy production mainly contributes to enormous emissions of CO_2 (and other greenhouse gases) into the atmosphere, leading to the likelihood of serious climate changes in the not too distant future. Being strong proponent of the Kyoto Protocol, the European Union (EU) calls its members to adjust for an EU-wide

---

[1] Corresponding author. Tel.: +90-212-3597072; fax: +90-212-2651800.
E-mail addresses: saricake@boun.edu.tr ; nihan.karali@boun.edu.tr

emission reduction obligation of 8 % for the first commitment period, 2008-2012. As an EU candidate country, with which accession negotiations have started (in October 2005), Turkey shall adopt the community acquis.

According to the “First National Communication of Turkey on Climate Change” report, Turkey’s energy and electricity consumptions have grown at an annual rate of 3.7% and 7.2%, respectively over the period 1990-2004. Moreover, total CO_2 emissions will increase at an average rate of 6.3% annually between 2003 and 2020 and will reach 604.63 million tons/year by 2020. In 2004, oil had the largest share of total final energy consumption with 37% while natural gas followed it with 23%. Hard coal, lignite and renewable (including hydroelectricity) also contributes energy consumption with shares of 16%, 11%, and 13% respectively. Transportation, industrial, and household/service sectors became the main energy demanding figures of the country over the past 20 years. The share of industrial sector in the total final energy consumption was 42% in 2004.

From this point of view, it is clear that it has vital importance to explore the impacts of emission restriction payments on Turkish industrial sectors. Therefore, it is significant to examine the dynamics of country’s main energy consumed sectors under certain emission restriction and energy price policies.

The main purpose of this paper is therefore to focus on a model that serves as a basis for establishing a reference projection of two main Turkish industries on energy use, economic growth and emission reduction by giving concern on energy efficient technologies.

This paper, giving attention to the economical and energy-emission policy aspects, aims to analyze the causal relationships and the feedback structures among industry’s production capacity, investments on new and energy efficient technologies, financial burden, and CO_2 emissions. By using Stella software, a stock-flow diagram of the system is constructed and dynamic behavior of the system variables is analyzed.

2. PROBLEM DEFINITION

Iron&steel and cement industry are chosen as the sectors that will be discussed in this paper because of their high-energy demand and their strong impact on climate change.

The basic production processes of steel industry such as arc furnaces, open-hearth furnace, or basic oxygen furnace are highly depended on energy usage which follows a wide fuel range. Average energy consumption between 2000 and 2005 is estimated 3.80 Mwh/ton. In 2000, 14.3 Mt (million tons) of crude steel was produced in Turkey. About 47% of energy consumed in the production of this amount came from electricity. Petroleum products followed electricity by 32% while natural gas had an 18% share. In 2000, the total amount of CO2 emissions, related to the direct use of energy in steel production, was estimated around 6.8 Mt.

In 2005, the total amount of CO2 emissions, related to the direct use of energy in steel production, was estimated 8.4 Mt while total production amount was 20.9Mt. The share of energy mix used in the production in the sector changed as 54% electricity, 15% petroleum products, and 28% natural gas. This is basically related with the increases in availability of natural gas.

Moreover, according to the projections of “First National Communication of Turkey on Climate Change” report crude steel production is expected to increase to 28.37 Mt in 2010, 32.36Mt in 2015, and 33.86Mt in 2020.

The cement industry is the second highest energy intensive sector with a unit energy consumption rate of 1.06Mwh/ton. In 2005, 67.8 Mt (million tons) cement was produced in Turkey. About 42% of energy consumed in the production of this amount came from petroleum coke, which faces the highest emission factor value among all fossil fuels. Lignite also had a 42% share while coal amounted the 13% of remaining. In 2005, the total amount of CO2 emissions, related to the direct use of energy in cement production, was estimated around 11.45 Kt (Kilo tons).

The purpose of this study is to model the *dynamic structure* that reflects the transition from old technologies to energy efficient technologies as emission restrictions put into board. The model is constructed from the view point of financial accounts. Capacity is depreciated with a fixed amount. Transition between old and new technologies, so the increase in sectoral efficiency index, totally depends on the financial burden of emission taxes and also the energy prices. Unit product price is used in the decision process of energy related payments.

The effect of most of the variables in both industrial sectors occurs in very short time periods. The production increases immediately as growth rate goes up, efficiency index is instantaneously formed by new technology investments due to added cost of both CO2 Emission deviation payment and high energy prices. Therefore, the time unit is chosen as year for this study and time horizon is determined as 12 years.

3. MODEL FORMULATION

In this section the dynamic hypothesis behind the model is discussed via causal loop diagrams. The first subsection gives the definitions of some key variables in the model, their effects on other variables, and effects of other variables on these variables.

3.1. Definitions of Variables

Production Capacity: ***(tons)***

- It is the physical capacity limitation of the sector determined by physical limits such as machinery, human resources, land area and etc.
- It is modeled as a stock and has inflow new capacity addition, and outflow depreciation.
- It has initial value of year 2000 production capacity limits.

New Capacity Addition: ***(tones/year)***

- Inflow of the Production Capacity stock. It occurs as a result of growth rate which is mainly determined by profitability of sector.
- It’s value is dependent on Production Capacity and growth rate.

Depreciation: ***(tons/year)***

- It is the natural degradation of physical production capacity.
- It increases as the Production Capacity increases by a multiplicative effect formulation.

Annual Production: ***(tons/year)***

- It is the physical production of sector using its' production capacity.
- It is a function of Production Capacity. It is determined by Capacity Utilization factor.
- Capacity utilization factor is constant for steel sector while it is a function of Unit Price for Cement sector.

Efficiency Index: ***(unitless)***

- It is modeled as a stock that reflects the energy efficiency of new capacity additions compared to base year 2000. It is the ratio of energy needed producing one unit product in year 2000 and current year. Efficiency index more(less) than 100 reflects the fact that new capacity additions will be less (more) energy efficient.
- It affects current average efficiency index value with a delay thus effecting overall efficiency of the sector.
- It has two inflows: Investment on Efficiency due to Energy Prices and Investment on Efficiency due to CO2 Cost.

Investment on Efficiency due to Energy Prices: ***(unitless)***

- It is one of inflow of Efficiency Index.
- Its' value is determined by ratio of annual energy cost to Total Annual Cost of Production.
- If the ratio is under a certain value it may lead to increase in efficiency index thus reducing efficiency.

Investment on Efficiency due to CO2 Cost: ***(unitless)***

- It is one of inflow of Efficiency Index.
- Its' value is determined by ratio of CO2 cost to Revenue.
- If the ratio is under a certain value it may lead to increase in efficiency index thus reducing efficiency.

Total CO2 Emission: ***(tones)***

- It is the sum of Annual CO2 emissions during simulation period. It determines the average annual CO2 emission.
- It is modeled as a stock. Inflow is Annual CO2 emission. It has no outflow.

Annual CO2 Emission: ***(tones)***

- It is the inflow of Total CO2 Emission. It is product of Annual Energy Consumption and Sector Specific CO2 Emission factor.
- Can be reduced by only reducing Annual Production and / or increasing efficiency (Current Energy Efficiency index).

Target Deviation: ***(tons)***

- It is the difference between Average Annual CO2 Emission and CO2 Cap Level.
- Used for determining Reduction Cost of CO2.

CO2 Cap Level: ***(tones/year)***

- It is CO2 cap level of the specific sector.
- It is 8% below from the year 2000 thousand emission level of the sector.

Revenue: ***(YTL)***

- Sum of financial transaction of sector via the sales of produced good. Measured in terms of real prices based on year 2000.
- It is the product of unit price and Annual Production.

Profit: ***(YTL)***

- Net financial gains of sector after costs are dropped down from the revenue.
- Accounted costs are Total Cost of Annual Production and CO2 Cost

Growth Rate: ***(%)***

- It is the ratio of capacity expansion to the current Physical Capacity levels.
- It is calculated by the product of target growth rate and Profit effect on Growth.

3.2. Dynamic Hypothesis and Causal Loop Diagrams

Model design and construction is based upon following principles and assumptions:

Model is designed so that critical decisions such as growth and efficiency investments are based upon profit and extra costs incurred due to CO2 emissions. The profit margin, CO2 cost over revenue and Energy Cost Share in Total Annual Production are important key variables in the model.

Model horizon is kept short since our main objective is to cover possible responses of energy intensive sectors in Turkey in near 10-12 year horizon with possible policy implementations such as energy prices, emission restriction levels and CER/VER Prices. Also short time horizon includes some advantages such as possible model simplifications. This may become important in the long run such as emission factor of energy used by the sector which is currently determined by historical data and possible future trends.

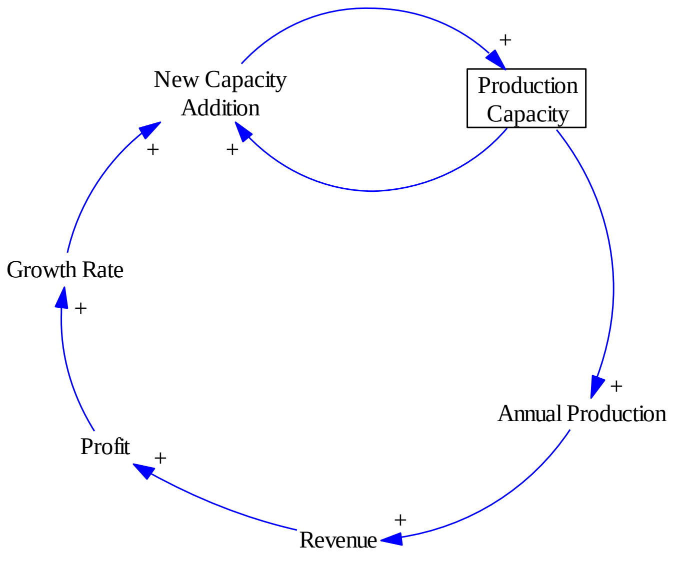


Figure 1 Main Growth Loop of the model

Figure 1 displays the self reinforcing growth loop of a general sector. As new capacity is added to Production capacity, Annual Production increases. Increase in annual production leads to more revenue and more profit. Increase in profit leads higher growth rate and more New Capacity addition. This loop is the main driving power of a sector without CO2 and energy price effects.

Figure 2 displays the self balancing loop of CO2 emission and efficiency improvement loop. As the energy consumption per unit production increases Annual energy consumption increases leading to higher Total CO2 Emission. This increase in Total CO2 emission levels increases average annual CO2 emission that pushes the current deviation level from base year emissions to higher levels (Target Deviation from Base year CO2 Level). Thus reduction cost of CO2 emissions by purchasing CER/VER certificates becomes more costly. This leads to investment on efficiency improvements due to CO2 emission which decreases efficiency index values. This decrease, with a delay, will decrease the average efficiency index value thus reducing Energy Consumption per unit production.

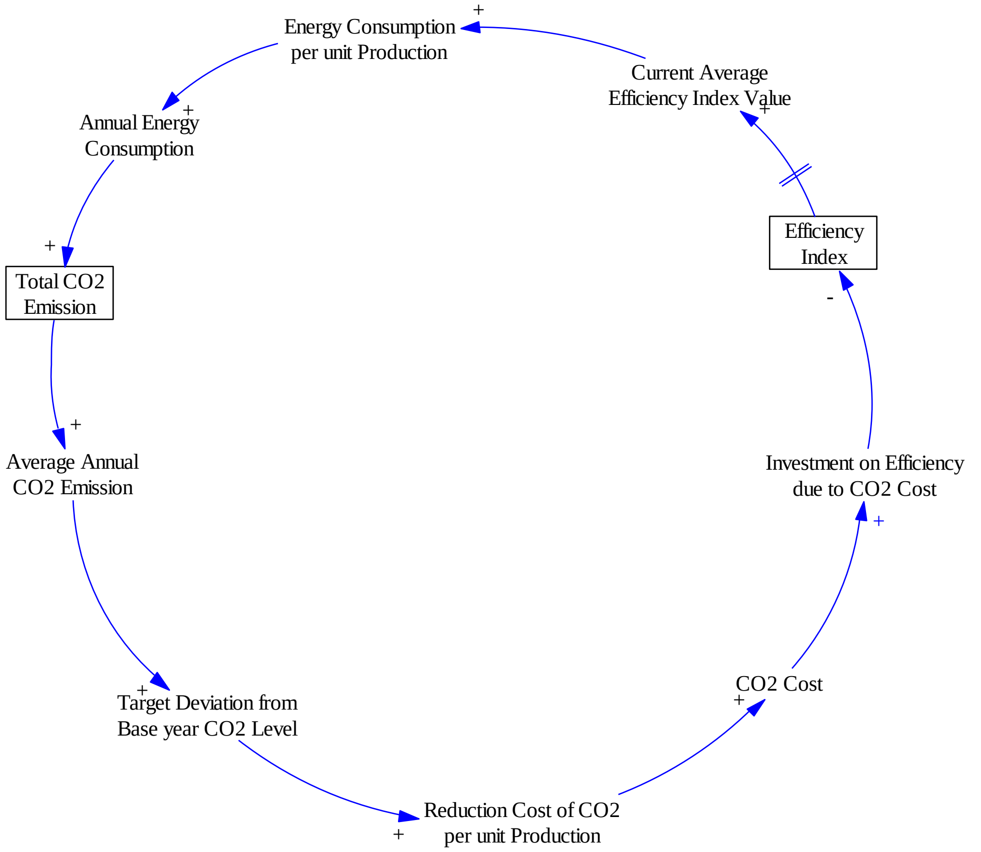


Figure 2 CO2 Emission - Efficiency Improvement Loop

Figure 3 shows two loops. First loop is Production - CO2 emission interaction balancing loop. Increase in Production Capacity leads to higher Annual Production. This increases annual energy consumption which directly increases average annual CO2 emission. This leads to higher deviation from the base year CO2 level. Therefore CO2 Cost decreases profit of the sector. Low profit level decreases growth rate, growth rate decreases Production capacities. Lower Production capacity decreases Annual Production.

Second loop is Production – Energy Price interaction self reinforcing loop. Increase in annual production cost leads to higher energy cost in annual production cost, thus increases energy cost share in total production cost. This trigger increases the investment on efficiency due to energy prices. Energy efficiency index decreases due to investments. With a delay average efficiency index value decreases leading to decrease in annual energy consumption. With same interactions of the first loop after Annual energy consumption, Annual Production increases.

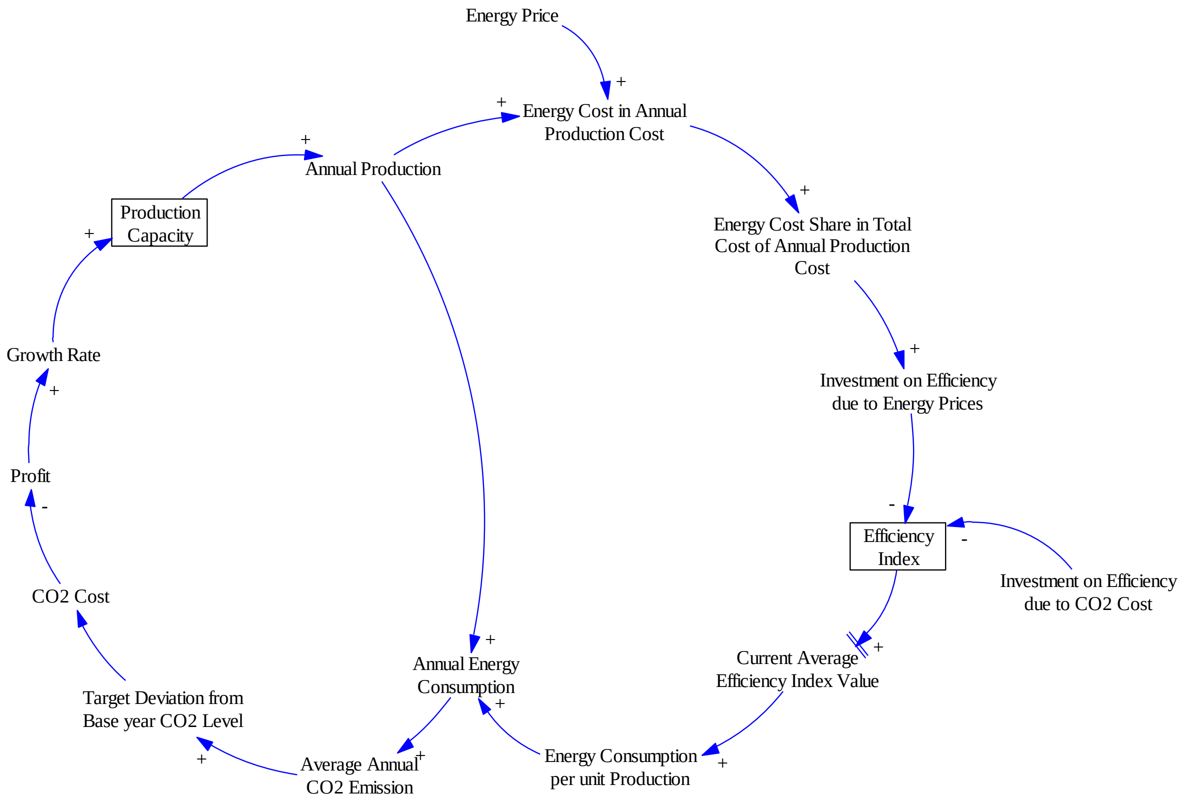


Figure 3 Production - CO2 emission and Production - Energy Price Interaction loops

Overall causal-loop diagram of model can be observed in Figure 4. This figure shows all relationships between variables. In addition to increase in capacity due to new capacity addition, there is a depreciation rate which is fixed at a certain amount. Target growth rate, energy price, unit production cost, CER/VER prices, capacity utilization rate, profit level per unit production, base year energy consumption per unit production, and emission factor are the sector specific exogenous variables of the model.

Exogenous variables are obtained analyzing the past six-year data of each sector. Energy prices and emission factors are the weighted average of sector specific primary energy resource prices and emissions, respectively.

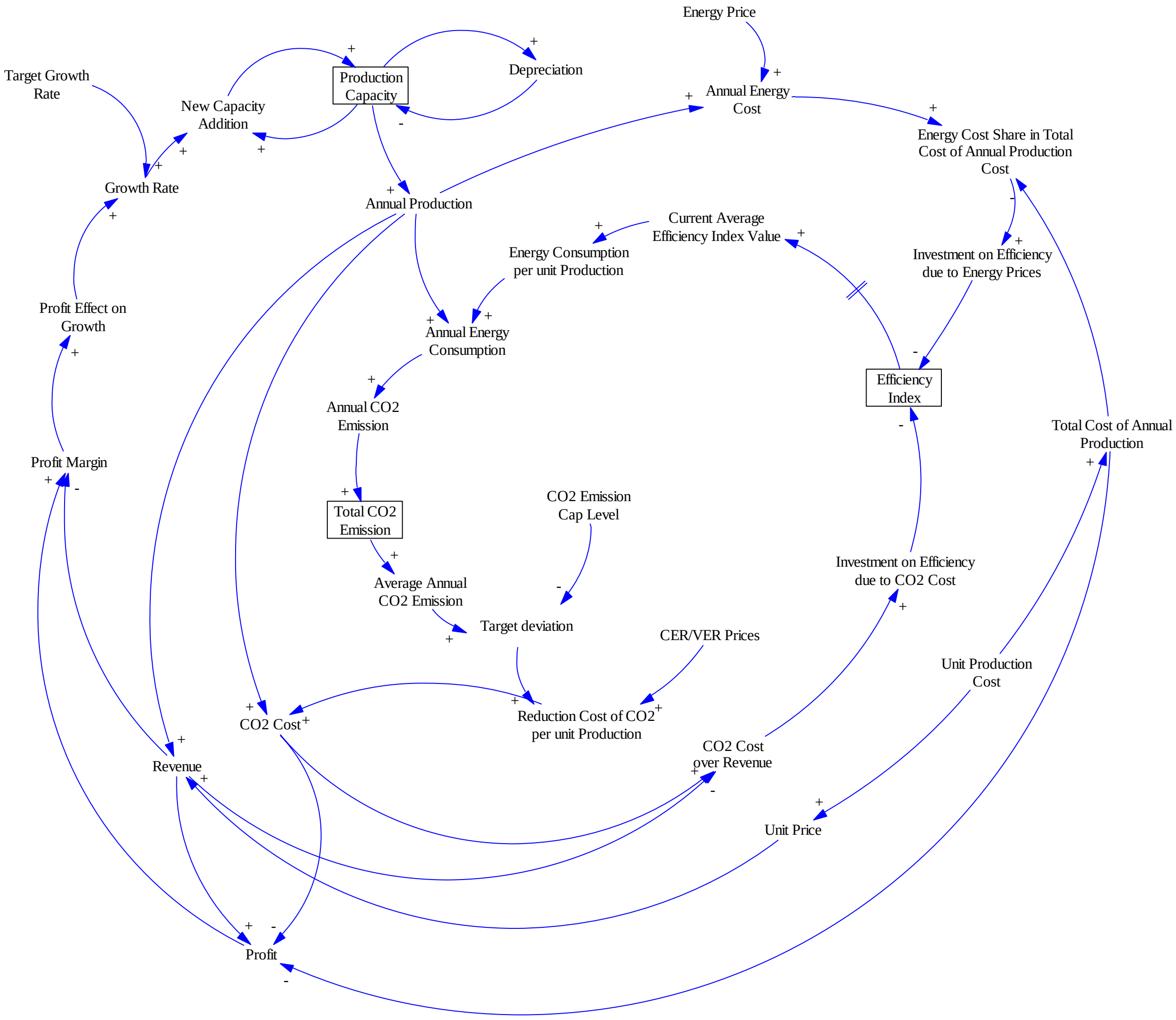


Figure 4 Overall causal loop diagram of the model

4. FORMAL MODEL

4.1. Stock - Flow Diagrams

Capacity is the main stock variable of the model. It is one of two drivers determining annual production levels. New capacity addition and deprecations are the flows interacting with this stock. New capacity addition is the product of sector growth rate and stock value while depreciation flow is the product of stock value and a constant rate. Efficiency Index is the second stock of the model. It affects the efficiency levels of new capacity additions. Net inflow is sum of efficiency index change due to CO2 Emissions and efficiency index change due to energy prices. These flows are constructed as graphical functions which are depended on Investment on efficiency Improvement and Energy Cost Share in Total Production, respectively. Efficiency Index X Capacity stock is used as a memory tool for the calculation of Current Average Efficiency Index Value. Total CO2 Emission Stock sums up the annual CO2 emission values caused by the energy consumption of the sector. There is only inflow, no outflow. Inflow of this stock is obtained by the multiplication of sector specific emission factor with annual energy consumption of related sector. Profit effect on Growth and Investment on Efficiency Improvement are also represented as graphical functions. All energy units are represented as Mwh. Main assumptions and graphical functions of the model are given in Table 1 & 2 and Figure 6 and 7, respectively.

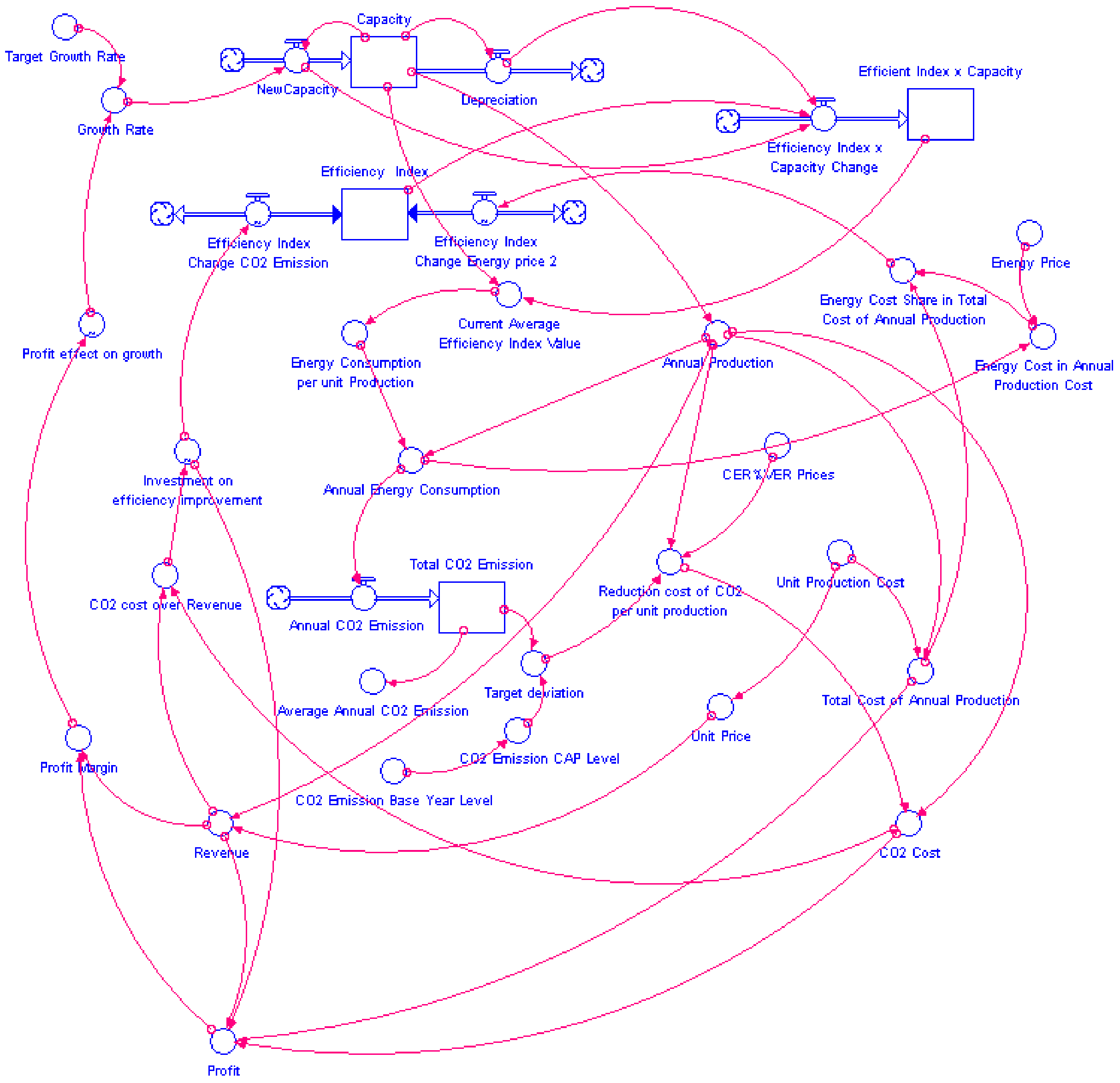


Figure 5 Stock Flow Diagram of the Model

Table 1 Base Year Data

BaseYear Data (2000)	**Iron&Steel Sector**	**Cement Sector**
Capacity *(Million tons)*	443	64
Emission factor *(ton CO2/Mwh)*	0.38	0.33
Energy Consumption per unit production *(Mwh/ton)*	4.19	1.09
Energy Price *(YTL)*	31.1	13.0
Unit Production Cost *(YTL/ton)*	143.0	28.9

Table 2 Base Year Assumptions

Base Year Assumptions:	**Iron&Steel Sector**	**Cement Sector**
Depreciation rate	1/30	1/30
Initial Efficiency Index	100	100
CER/VER Prices *(YTL)*	6.67	6.67
Emission Restriction Level *(%)*	8.0% below the base year	8.0% below the base year
Average Energy Price *(YTL)*	32.3	13.0
Average Target Growth Rate *(%)*	12.5%	1.7%
Average Capacity Utilization *(%)*	86%	58%
Profit Level per Unit Production	18%	100%

All prices of model are in YTL form and based on year 2000. They also are kept constant for time window. When the past data of the iron&steel sector is analyzed, it is observed that capacity utilization rate is nearly constant for the time horizon. Besides, unit production price and profit have negligible impacts on capacity utilization. Growth rate of capacity expansion, independent from price dynamics, is also found nearly constant for the time horizon. Nevertheless, profit margin and growth rate interaction is found significant. Therefore, it is constructed as average of past data changing with profit margin (see also Figure 6). Other graphical functions of iron&steel model, representing certain relationships, are also illustrated in Figure 6.

Dynamics of cement sector differs from the iron&steel sector in a few aspects. Capacity utilization rate is not constant in this case. A causal relationship is found between unit product price and utilization rate. Real prices, which are discounted to year 2000, of unit products are nearly constant overtime. Graphical functions of cement model, representing certain relationships, are also illustrated in Figure 7.

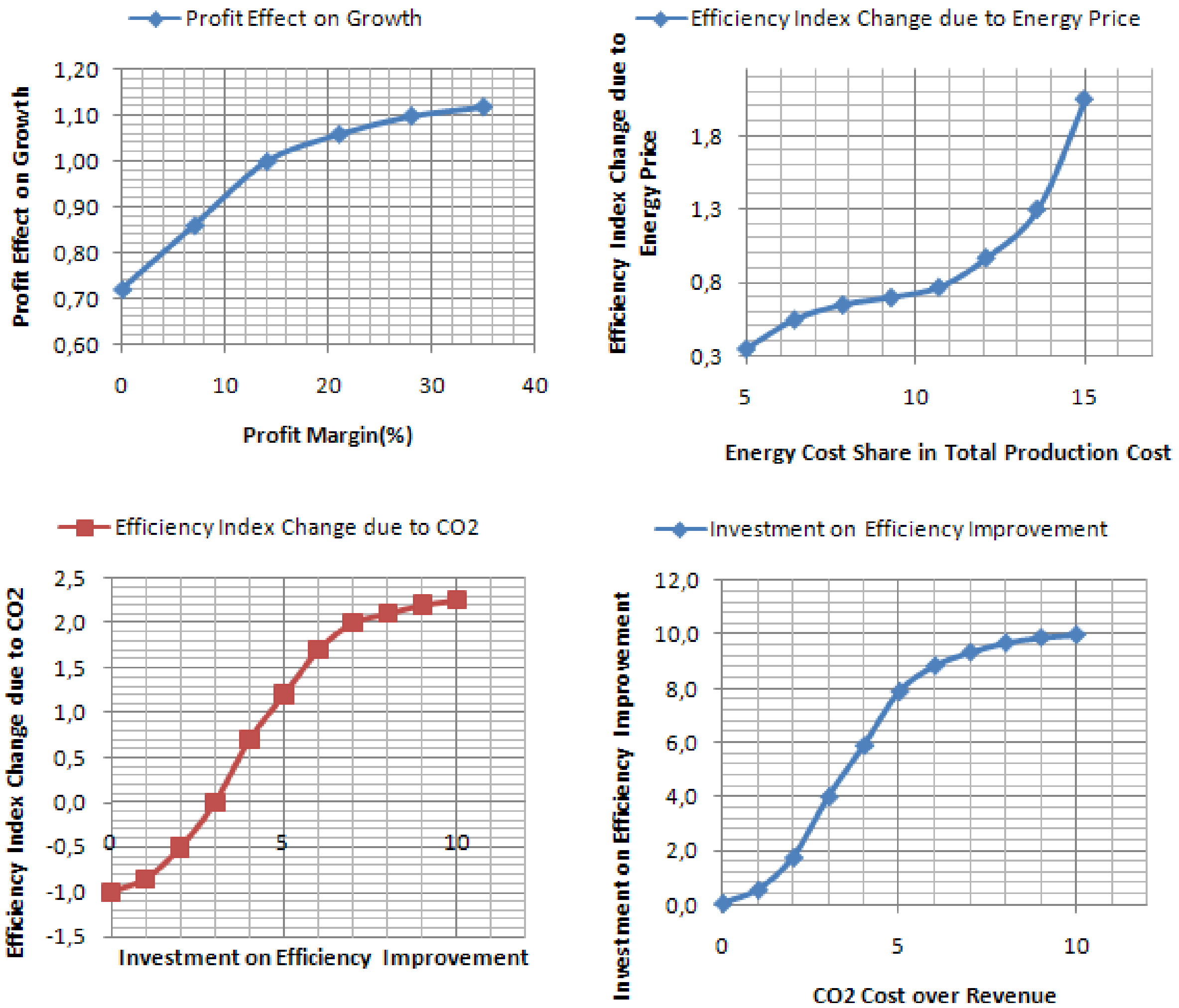


Figure 6 Graphical Functions of Iron&Steel Industry

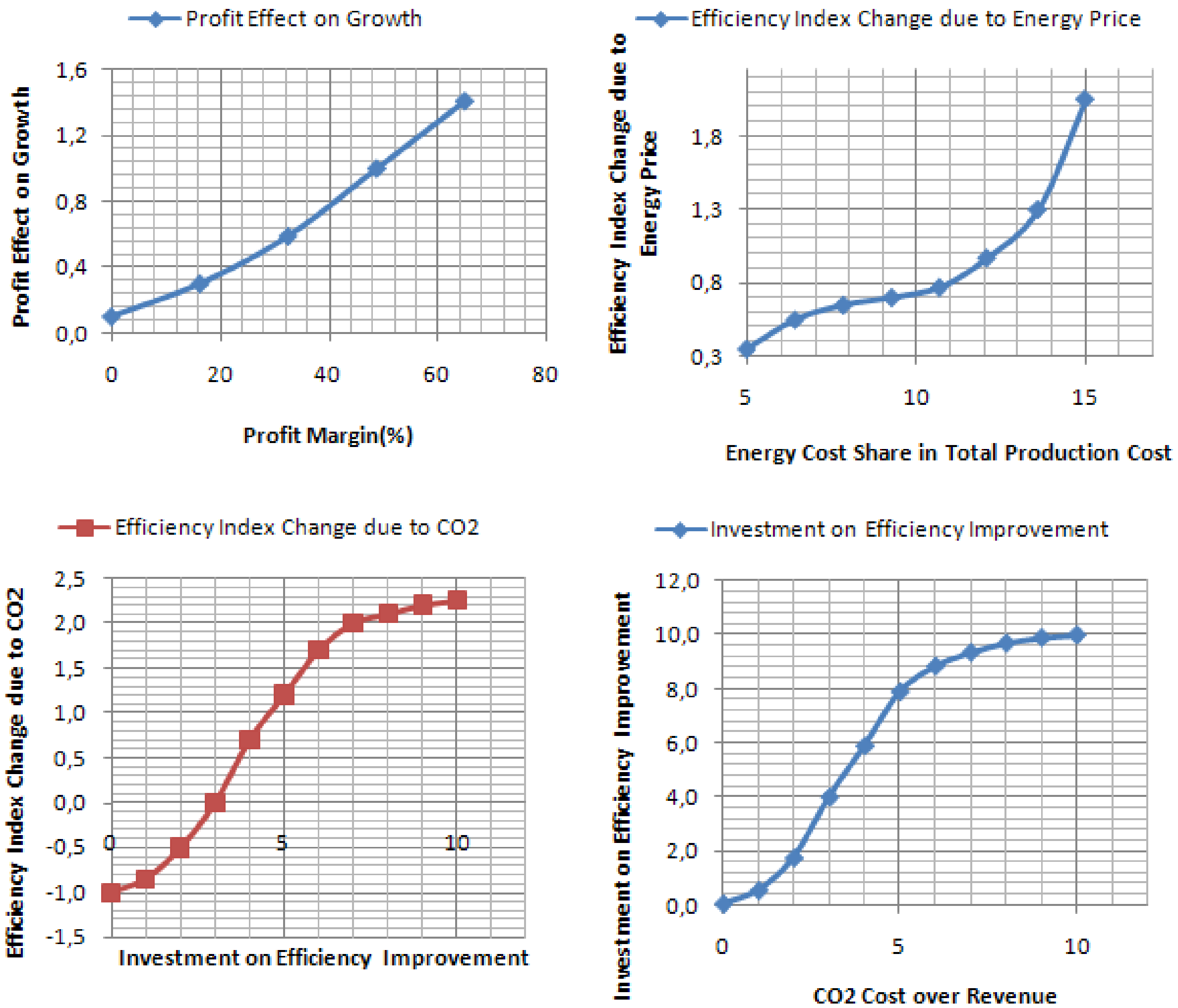


Figure 7 Graphical Functions of Cement Industry

5. MODEL CALIBRATION AND VERIFICATION

The model is calibrated for a reference scenario with year 2000 being the base year (there were no extra ordinary political, social or economic events that could affect energy consumption habits or economic balances in year 2000) and solved in one year time steps. Results for the first period are compared with actual realizations, verifying the dynamic behavior pattern. Production, capacity, and unit price dynamics between 2000 and 2005 are compared with the actual dynamics. Pattern similarities are recognized.

5.1. Base Case Scenario Results

Base Case scenario data and assumptions are listed in Table 1 & 2.

5.1.1. Iron&Steel Sector

As can be seen from Figure 8, capacity continuously grows over the time horizon. However, there is a clear reduction in capacity change percentage due to decline in profit margin levels caused by additional CO2 emission restriction costs.

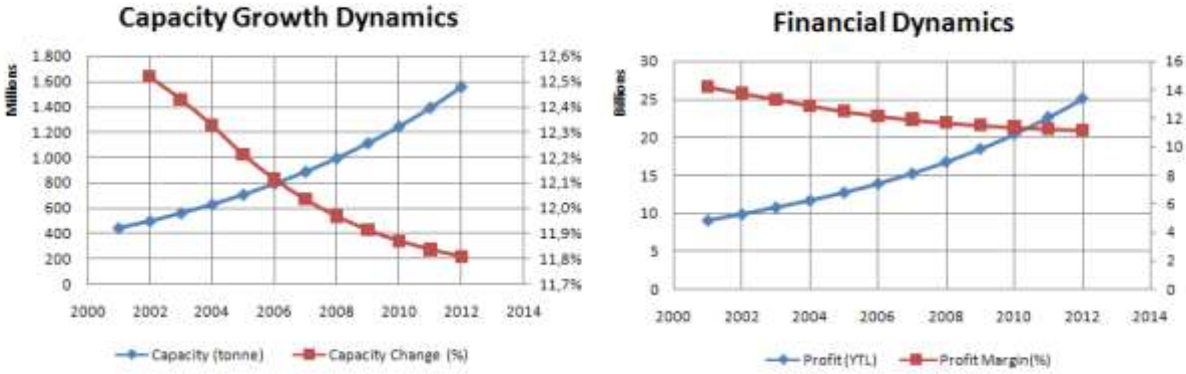


Figure 8 Capacity Growth and Financial Dynamics of Base Scenario for Steel Sector

CO2 emission dynamics shows a different pattern than growth dynamics. It increases over time horizon as capacity increases, but change in increase rate (CO2 Emission Change) is in opposite direction. This is clearly because of increase in efficiency index (see also Figure 9). The model prefers not to invest on efficiency improvement even though CO2 emissions restriction costs are on board.

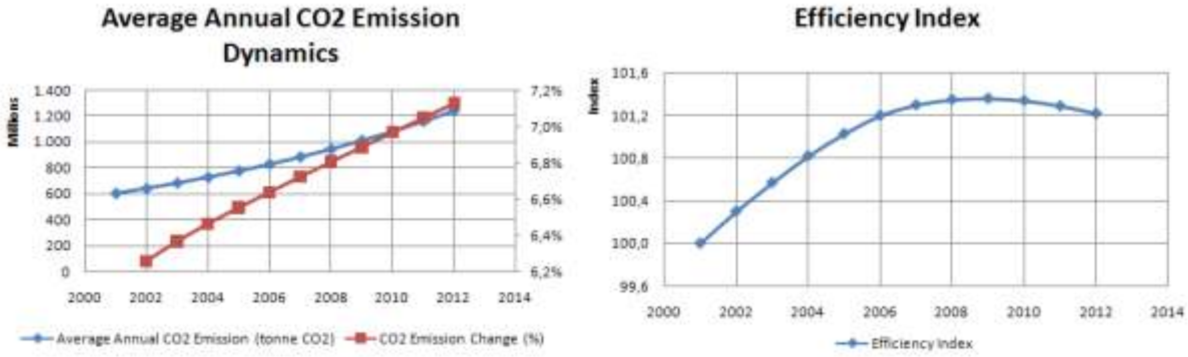


Figure 9 CO2 Emission and Efficiency Index Dynamics

5.1.2. Cement Sector

Capacity dynamics of cement sector (Figure 10), with a smaller growth rate, are similar to the iron&steel sector dynamics. Capacity continuously grows over the time horizon and capacity change percentage reduces due to decline in profit margin levels caused by additional CO2 emission restriction costs.

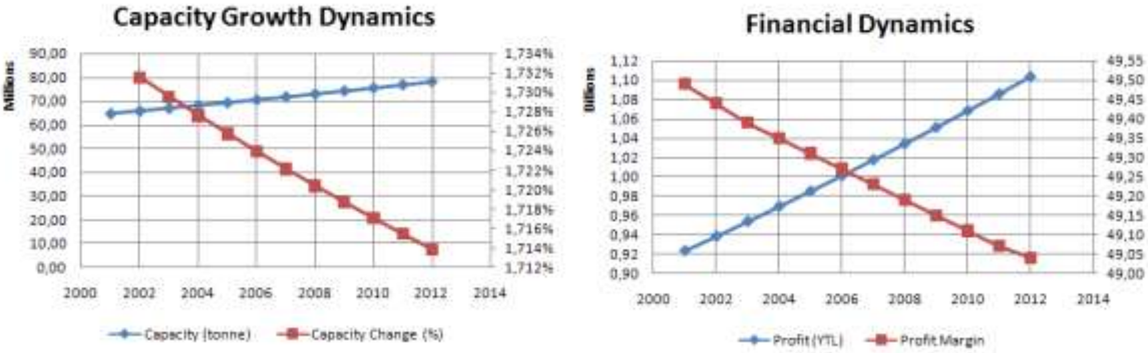


Figure 10 Capacity Growth and Financial Dynamics of Base Scenario for Cement Sector

CO2 emission increases over time horizon as capacity increases, as it happens in steel case. However, efficiency index dynamics shows a different pattern than steel case. Efficiency index value improves slowly due to its high sensitivity to energy price which is 50% of unit production cost in base case data (see also Figure 11).

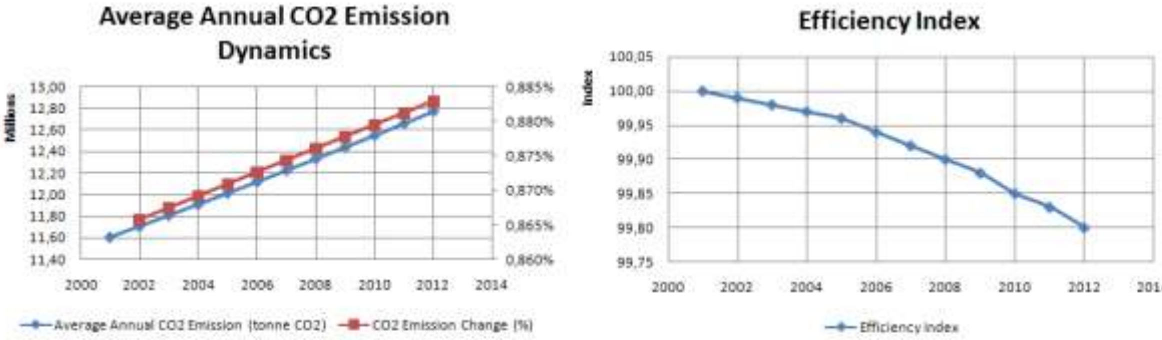


Figure 11 CO2 Emission and Efficiency Index Dynamics

6. SCENARIO ANALYSIS

In addition to the base case scenario, two other scenarios including different CER/VER prices, different energy prices, and different emission restriction levels are defined as shown in Table 3.

Table 3 Scenario Definitions

Scenario	Description
Base Case	*Business-As-Usual*
Scenario2	Base Case + Doubling in *CER/VER Prices* + Doubling in *Energy Prices*
Scenario3	Scenario2 + 20% Decrease in CO2 Emission Restriction Level

6.1. Iron&Steel Sector

Scenario Analysis starts with the annual profit dynamics. As Figure 12 illustrates, Scenario2 and Scenario3 lead to serious decreases in profit values. Besides, between 2001 and 2008, profit levels stay almost constant. Only after year 2008, increase with a lower slope compared to Base Case in profit can be seen. Moreover, both scenarios have the same profit patterns with a bias. It is clear that decrease in CO2 emission restriction level does not lead any pattern change.

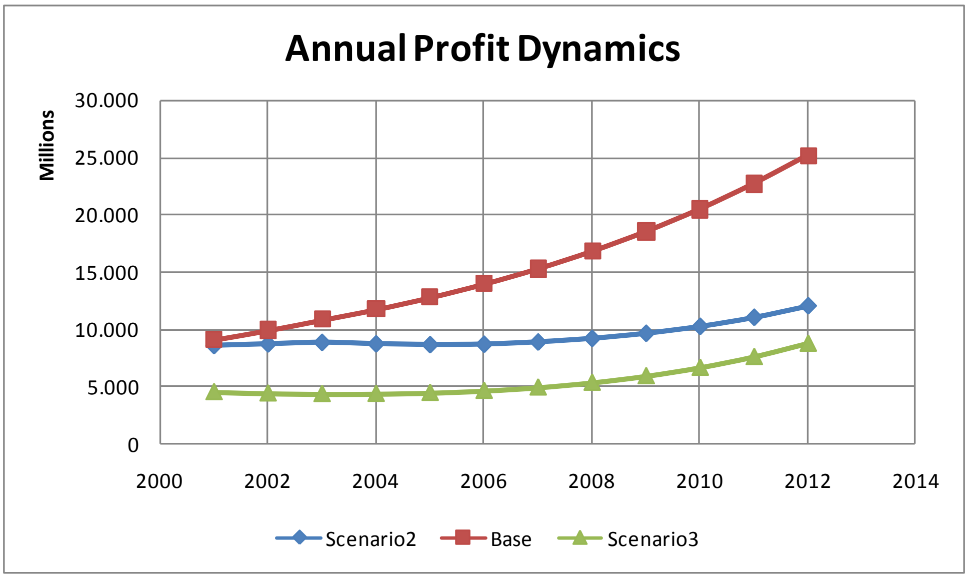


Figure 12 Profit Dynamics of Steel Sector for Three Scenarios

Also annual profit change (%), which is the change of profit in two successive years, shows that Scenario2 and Scenario3 causes some decreases in profit values in the beginning of the time horizon. The difference between the patterns of Scenaro2 and Scenario3 occurs because of difference in the initial restriction levels. Scenario 3 has greater profit change values than Base Case at the late periods of time horizon (see Figure 13).

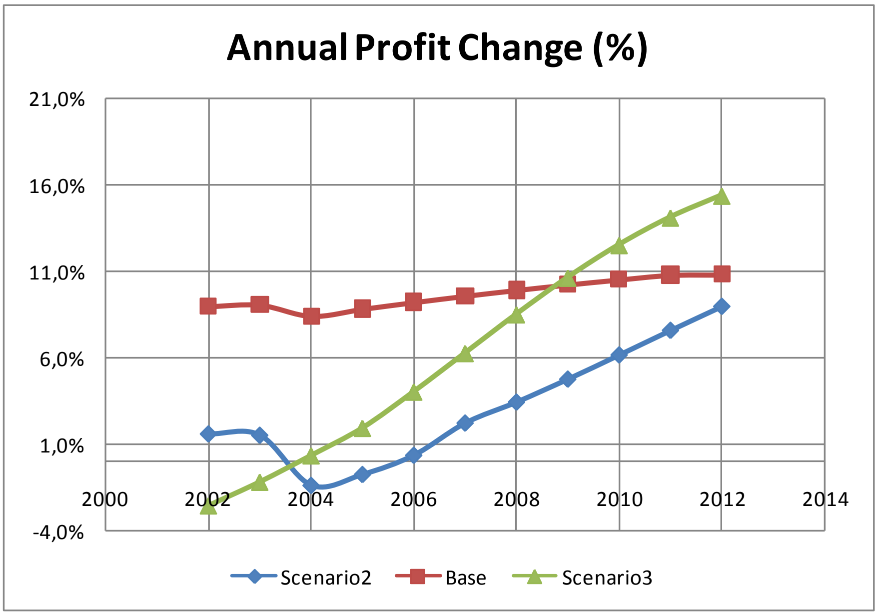


Figure 13 Change in Annual Profits of Steel Sector for Three Scenarios

Higher energy and emission related prices (CER/VER and energy prices) lead to more investments on efficiency which improves (decreases) efficiency index value in Scenario2 compared to Base Case (see Figure 14). In Scenario3, additional burden of reduced restriction level on Scenario2 causes more investment on efficiency.

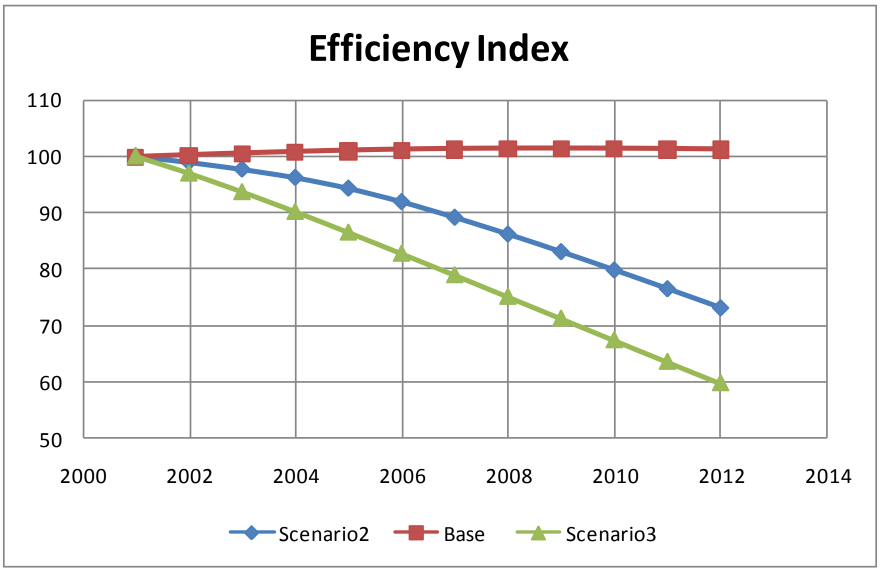


Figure 14 Efficiency Index of Steel Sector for Three Scenarios

Energy consumption per unit production decreases since efficiency improves in Scenario2 and Scenario3. Figure 15 shows how efficiency index penetrates energy consumption per unit production with a delay. The first four years it is almost constant because of the time delay occurring in the investment on new physical capacity.

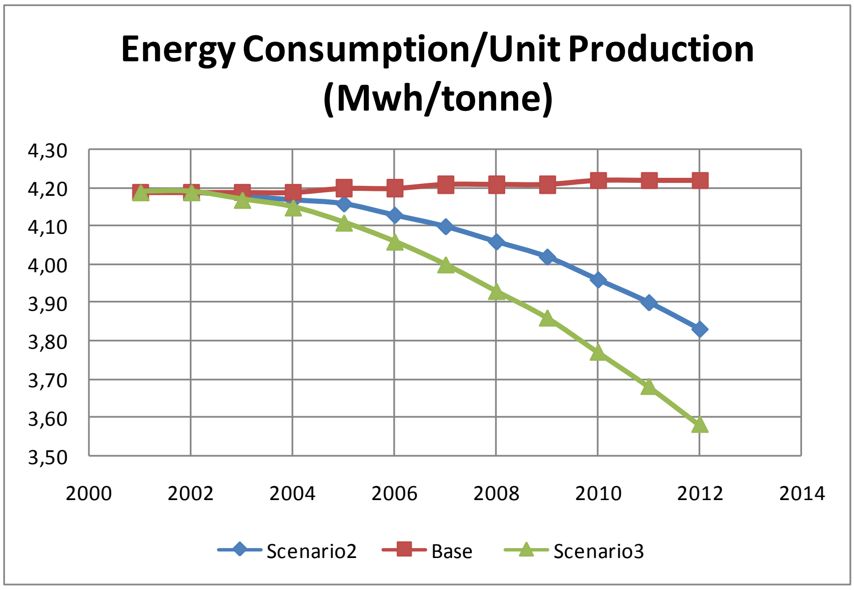


Figure 15 Energy consumption per unit production of Steel Sector for Three Scenarios

Percent change in CO2 emission levels decreases as efficiency improves in Scenario2 and Scenario3. Figure 16 clearly illustrates the positive impact of CO2 emission restriction levels on CO2 Emission dynamics when Scenario2 and Scenario3 are analyzed.

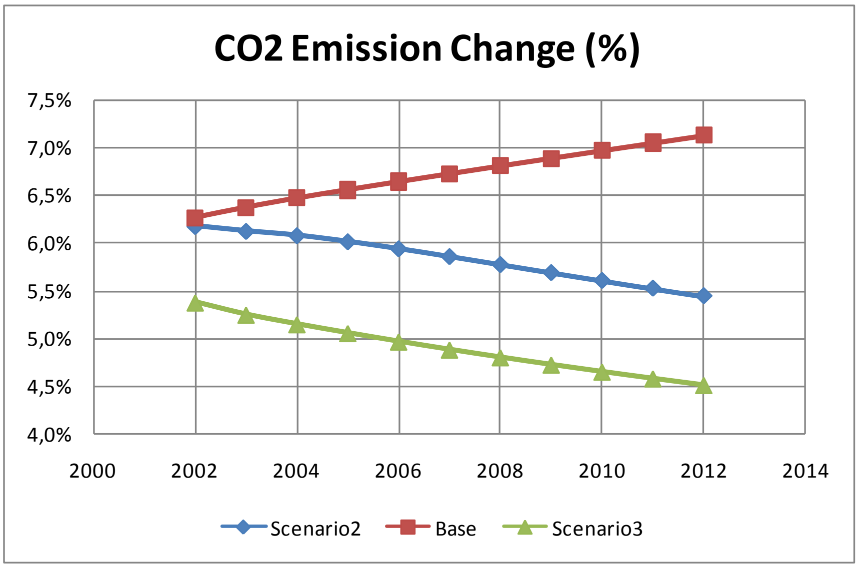


Figure 16 CO2 Emission change of Steel Sector for Three Scenarios

6.2. Cement Sector

As can be seen in Figure 17, Scenario2 and Scenario3 lead to serious decreases in profit values but not in patterns compared to Base Case. When Scenario2 and Scenario3 are compared within themselves, the clear difference of profit values caused by reduced CO2 emission restriction level can be observed.

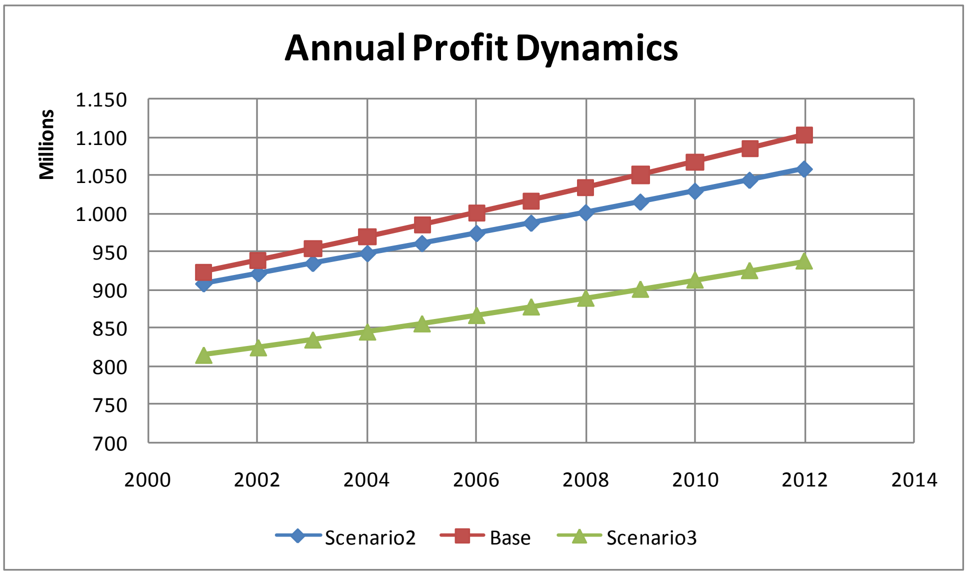


Figure 17 Profit Dynamics of Cement Sector for Three Scenarios

Higher energy and emission related prices (CER/VER and energy prices) lead to more investments on efficiency which improves (decreases) efficiency index value in Scenario2 compared to Base Case (see Figure 18) as it happens in steel case. In Scenario3, additional burden of reduced restriction level on Scenario2 causes more investment on efficiency.

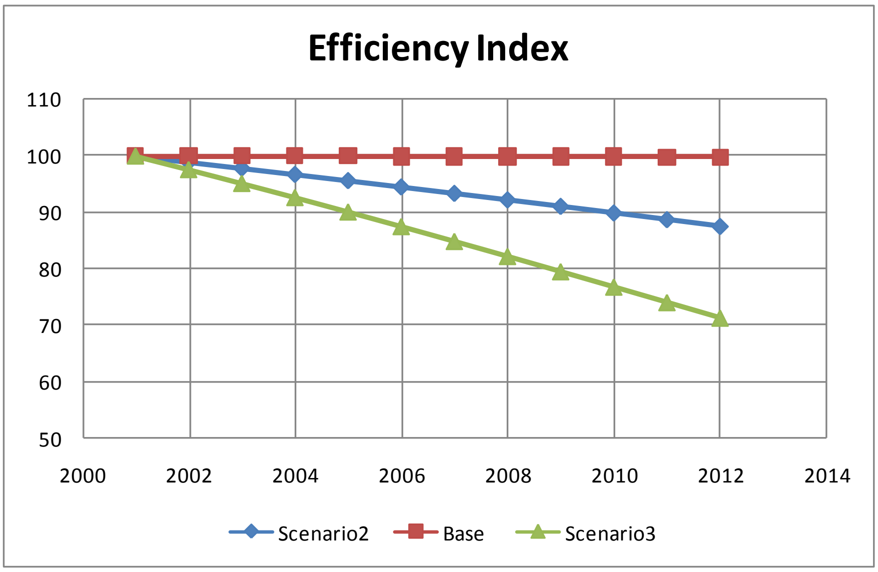


Figure 18 Efficiency Index of Steel Sector for Three Scenarios

There is a negligible decrease (compared to steel case) in energy consumption per unit production value because of Scenario2 and Scenario3 effects (see Figure 19).

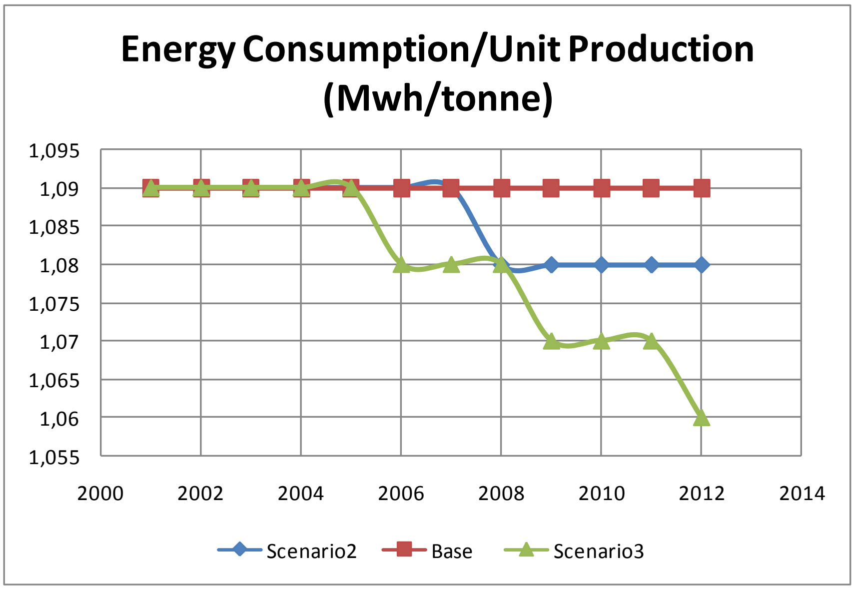


Figure 19 Energy consumption per unit production of Steel Sector for Three Scenarios

Percent change in CO2 emission levels decreases in small steps as efficiency improves in Scenario2 and Scenario3. Figure 20 clearly illustrates the positive impact of CO2 emission restriction levels on CO2 Emission dynamics when Scenario2 and Scenario3 are analyzed like in steel case.

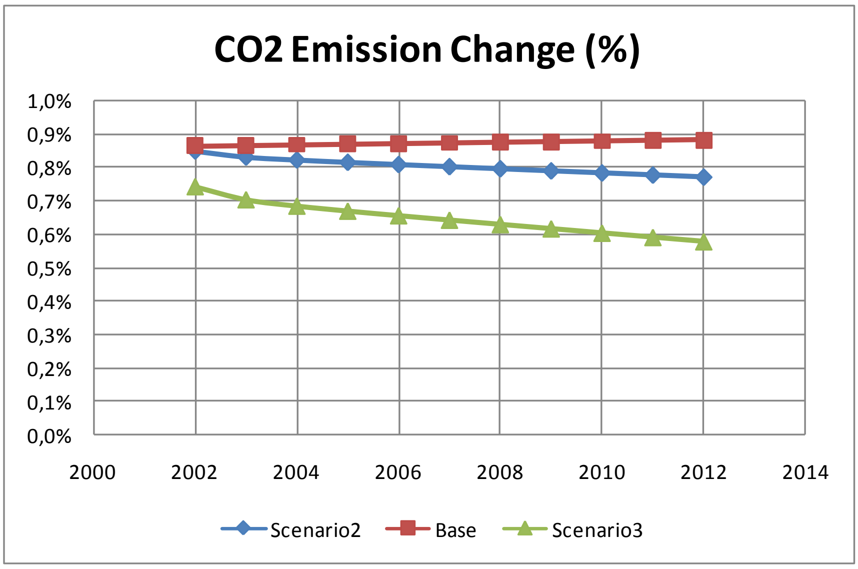
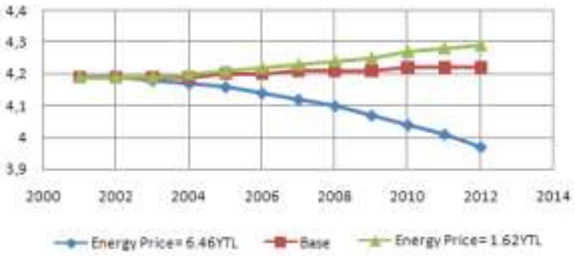


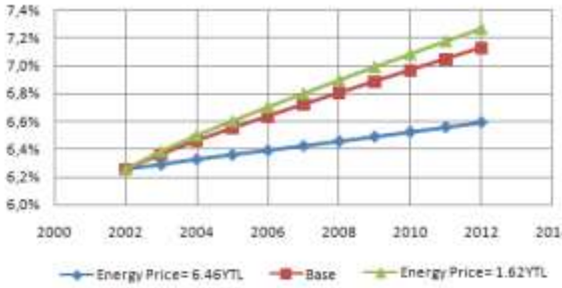
Figure 20 CO2 Emission change of Cement Sector for Three Scenarios

7. MODEL SENSITIVITY TO KEY PARAMETERS

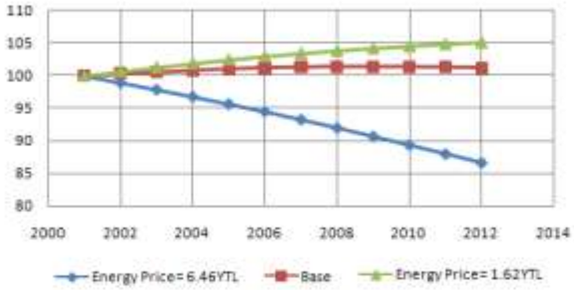
For model sensitivity analysis the model which is calibrated for steel sector is used. Model sensitivity to energy & CER/VER prices and CO2 emission restriction levels, as well as to the capacity utilization is explored. As expected, the lower the energy price, the higher value is placed on the energy consumption/unit production and CO2 emission growth (Figure 21). Moreover, increase in energy price has a positive influential impact on efficiency improvement (lower efficiency index value).



a. Energy Consumption/Unit Production (Mwh/tonne)



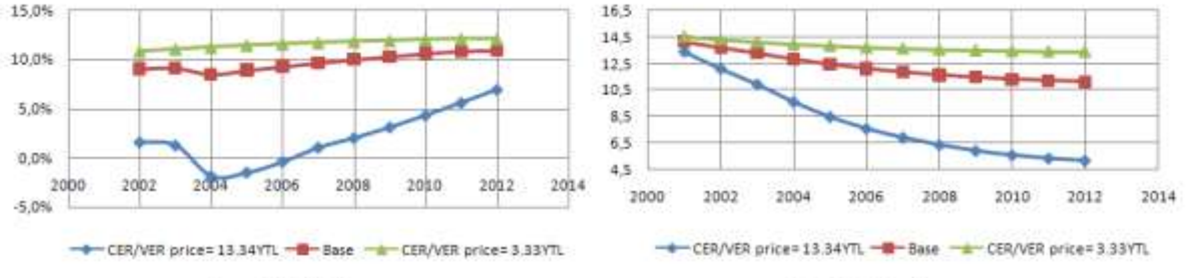
b. CO2 Emission Change



c. Efficiency Index

Figure 21 Sensitivity to Energy Price Change

Increase in CER/VER price leads to a decrease in absolute value of profit at the beginning of the period. Later on increase rate of profit accelerates continuously (see also Figure 22.a). Furthermore, the higher the CER/VER price, the lower the profit margin is. Similar to ‘energy price’ case, decrease in CER/VER price value causes higher efficiency index values. However, it is clearly observed in Figure 22.c, there is a delayed effect of CER/VER price on efficiency index value compared to ‘energy price’ case. CER/VER price is also the only single effect among the other discussed that can achieve important decline in annual increase rate of CO2 Emission (see Figure 22.d).



a. Annual Profit Change

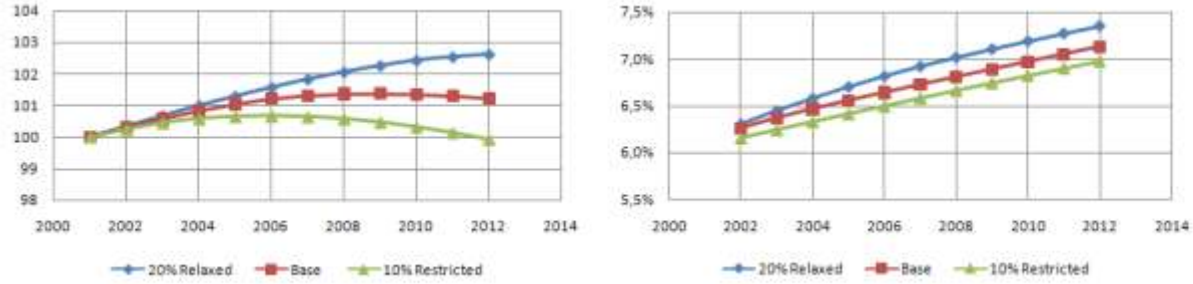
b. Profit Margin

c. Efficiency Index

d. CO2 Emission Change

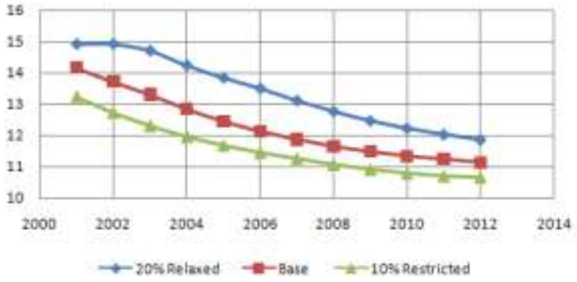
Figure 22 Sensitivity to CER/VER Price Change

CO2 emission restriction level is another factor that has direct impacts on model dynamics. The higher the restriction level, the higher efficiency index (lower improvement in efficiency) is (see Figure 23.a).



a. Efficiency Index

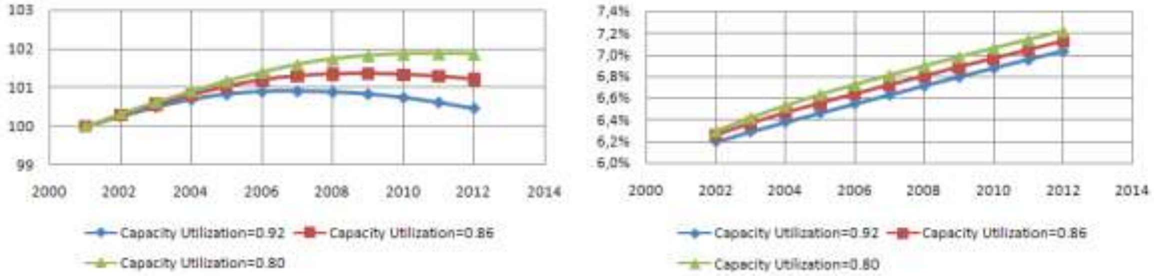
b. CO2 Emission Change



c. Profit Margin

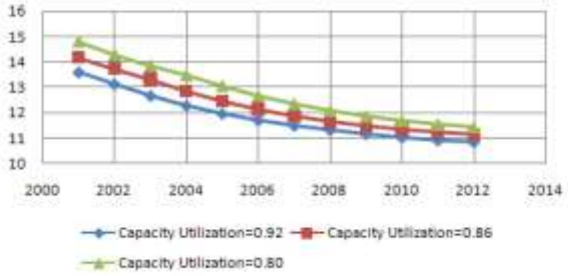
Figure 23 Sensitivity to CO2 Emission Restriction Level Change

Moreover, the lower the capacity utilization rate, the higher value is placed on the efficiency index value (see Figure 24.a). Among the three efficiency patterns, the one that has the highest capacity utilization rate achieves to turn down the growing trend in 12 year period. Further investigation also may show us decreasing trends of two other patterns that may reveal the delaying effect of capacity utilization rate.



a. Efficiency Index

b. CO2 Emission Change



c. Profit Margin

Figure 24 Sensitivity to Capacity Utilization Rate

8. CONCLUSION

This study analyzes the economical and energy-emission related policy aspects of the industrial sector of Turkey; and aims to analyze the causal relationships and the feedback structures among industry's production capacity, investments on new and energy efficient technologies, financial burden, and CO_2 emissions. The model takes efficiency improvement into consideration. The interactions between the CO2 emissions and efficient technology investment depend on the price of energy and CO2 emission payment (CER/VER prices). In addition to a Base Case Scenario, two energy-emission related scenarios are defined restricting CO_2 emissions under higher CER/VER and energy price trajectories.

The model simulation shows that in any case it is not possible to achieve the target emission levels (8% below the base year levels). For steel case, the most influential factor on CO2 emission reduction is found as CER/VER price. Energy price follows it as the second driver factor. CO2 emission restriction level does not have a comparable impact on CO2 emissions as much as energy price and CER/VER prices do. Profit margin decay rate is mainly dependent on CER/VER price changes. Restriction level changes create significant biases but the pattern stays unchanged.

Cement industry is less responsive to restriction and price scenarios relative to steel industry. This is because of less energy intensive production and less emission factor composition of primary energy resources.

As a further research, it is possible to apply the model to more sectors of industry. Moreover, to get an insight about the interactions and linkage among three or more sectors a redesigned version the existing model can be constructed and analyzed.

REFERENCES

Barlas, Y. (1996). Formal Aspects of Model Validity and Validation in System Dynamics. System Dynamics Review, Vol. 12, No. 3, pp.183-210.

DÇÜD (2007). Turkish Iron and Steel Producers Association, In Internet http://www.dcud.org.tr/bulten.asp.

EUROSTAT (2007). Energy Yearly Statistics 2005.

Ministry of Environment and Forestry (2007). First National Communication of Turkey on Climate Change Report.

ODYSSEE (2007). Energy Efficiency Indicators of Europe http://www.odyssee-indicators.org/Indicators/Energy%20saving.html.

Sterman, J. (2000). Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin McGraw-Hill.

TÇMB (2007). Turkish Cement Manufacturers' Association, In Internet http://www.tcma.org.tr/index.php?lang=EN.