System Dynamics Modeling of Energy Consumption in the Colombian Industrial Sector

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Abstract

A System Dynamics model specially built to analyze energy policies in the Colombian industrial sector is presented. The model allows to simulate two main aspects of industrial energy consumption: line production and boilers. The decision processes takes into account all energy alternatives and selects the most economic one. Decision are made based on economic terms where variables such as investment, tariffs, energy consumption and maintenance are taken into account. The model allows to examine several aspects such as: alternatives on technology diffusion, energy consumption growth and effects of pricing policies on diverse energetic demands. The model was applied to the energy consumption of the industrial sector in the Medellín Metropolitan Area, Colombia. Results are included.

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1. INTRODUCTION

Industrial energy consumption represents about 35% of total energy consumption in Colombia. The industrial energy market split in 1992 was:

14.6% Natural gas
11.7% Oil
34.8% Coal
16.0% Wood
11.1% Electric energy
7.0% Oil derivatives
4.8% Other sources

The electric energy participation in the industrial energy market has not changed significantly during the last five years.

Energy planning needs decision support systems based on detailed modelling of different interrelationships between diverse economic sectors, energy subsectors, energy demand and energy alternative sources, so decisions can be made trying to understand a large number of possible consequences.

Few developments have been reported on energy planning applications using system dynamics methods such as Ford (1990), Naill (1977), Naill (1992), Naill et al (1992) and Sterman (1984).

Because of its complexities sometimes it is best to model the national energy sector by subsectors (i.e. industry, residential and transportation). In the case of the industrial sector there are important differences that have to be taken into account. A national single global energy model can then be developed by coupling several subsectorial regional models. With this respect some work has been done by Dyner et al (1990, 1993).

The Colombian electric energy sector accounts for about 30% of the country external debt. The Colombian government is also driving the country into an open economy. The industrial sector then has to improve its production efficiency in order to be competitive with foreign industries. Energy efficiency in the colombian industrial sector has two main aspects:

- To decrease electric energy future needs.
- To improve production efficiency.

Efforts have to be made oriented to electric substitution by more efficient and/or less expensive alternatives. Least cost planning when all possible alternatives are considered, or made available, should be the objective of the industrial sector development. Alternatives such as energy conservation and to improve electric energy efficiency should be considered.

In most industrial processes there are two different aspects to be considered for energy efficiency decisions. The first one is the production machinery lines which in most cases only use electricity. The energy alternatives in this case are reduced to change machines actually in use for more efficient ones. The alternative machines will increase the rate of production to electric energy consumption. The second aspect is the self energy generation process. Some industrial processes needs steam that could be generated using different energy sources such as coal, natural gas, oil, and others. Industrial boilers can also be used for self electric energy generation if it is less expensive than the one offered by the public utilities. In this second aspect the electric energy alternatives are the energy sources that could be used by the boilers (coal, oil, oil derivatives, natural gas, and wood).

It is useful to develop decision models to analyze electric energy consumption dynamics in the industrial sector. These models should be able to predict future consumptions and the success of massive energy efficiency and/or energy conservation programs. A first approximation to this approach is presented in this paper.

2. THE COLOMBIAN INDUSTRIAL SECTOR

Figure 1 shows the energy consumption by sectors, where it is shown that the industrial sector energy consumption represents 35.9 % of total energy consumption. Figure 2 shows the electric energy consumption by sectors, where it is shown that the industrial sector electric energy consumption represent 27.9 % of total electric energy consumption.

The most important industries in colombian industrial sector are:

- Food, beverages and tobacco
- Fabrics and clothes
- Shoes and leather
- Furniture
- Paper and printing
- Chemicals
- Cement
- Ceramics, glasses and others
- Steel and Iron
- Machinery and equipments

The electric energy consumption of this subsector are shown in Figure 3. The most important industries from the electric energy consumption point of view are food, beverage and tobacco (19.2%), steel and iron (16.6%), chemicals (16.4%) and fabrics and clothes (13.6%). The energy consumption for two of these industries are shown in figures 4 and 5 that shows that the industrial energy consumption is strongly dependent on the type of industry. While for the food, beverage and tobacco industry the electric energy consumption is 8.2 %, for the textile (fabrics) and clothing industry it is 20.3 %.

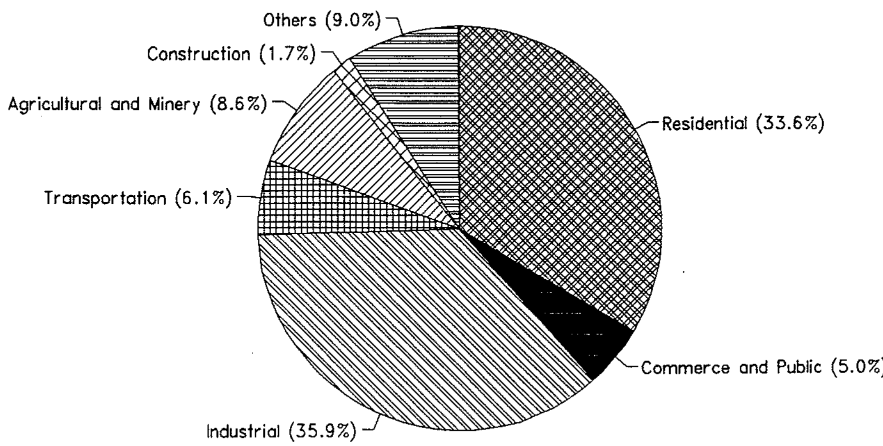

FIGURE 1. Colombian energy consumption by sectors in teracalories.

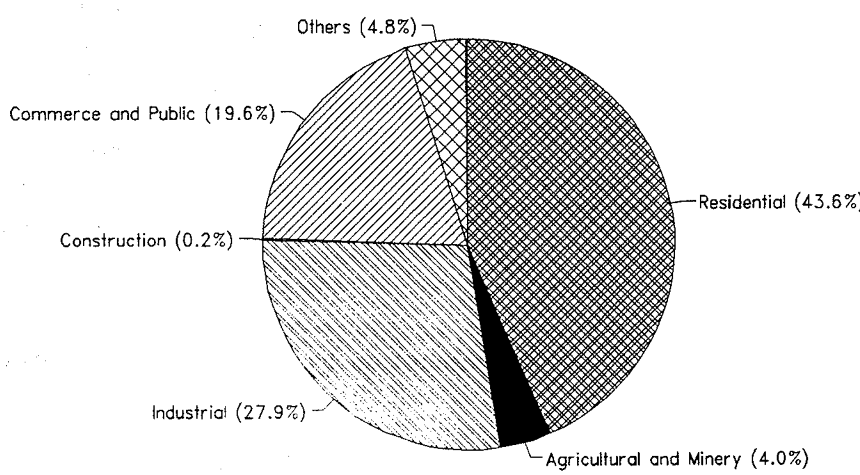

FIGURE 2. Colombian electric energy consumption by sectors in Giga Watt Hours.

Econometric relationships produced the following results:

- Textile:

$$CONT = \exp(6.9334) * \left(\frac{GNPT}{NUTT}\right)^{(0.8038)} * TARIF^{(-0.456)} * PRICE^{(2.26)}$$

- Beverage

$$CONB = \exp(3.9342) * \left(\frac{GNPB}{NUTB}\right)^{(0.4828)} * TARIF^{(-0.582)} * PRICE^{(0.505)}$$

Where GNP represents the gross national product, TARIF the electric energy tariff, and PRICE the price for the alternative energy source (substitution). These results show again the electric energy consumption differences in the different industrial subsectors.

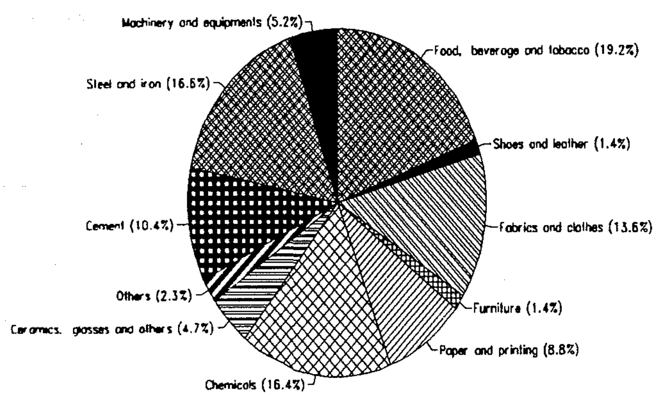

FIGURE 3. Industrial electric energy consumption by sub-sectors (Giga Watts Hours).

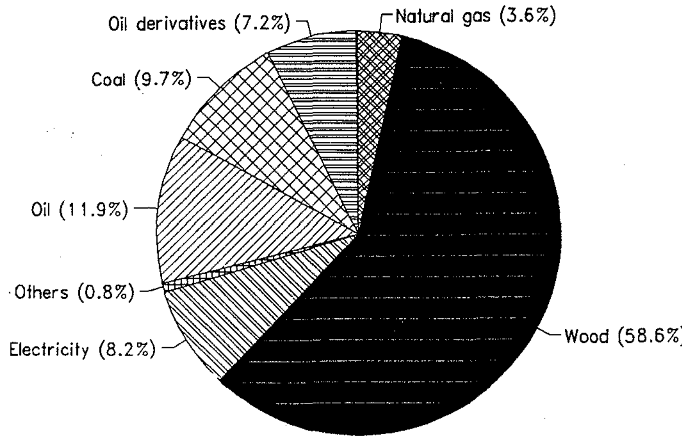

FIGURE 4. Energy consumption in the food, beverage and tobacco industrial subsector (Teracalories).

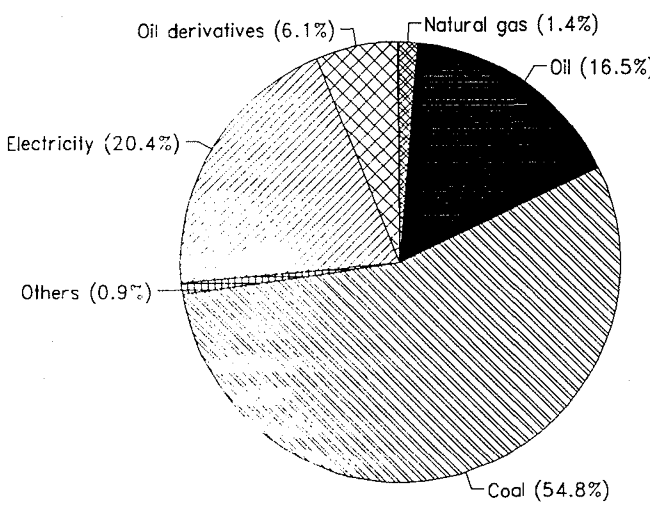

FIGURE 5. Energy consumption in the fabrics and clothes industrial subsector (Teracalories).

3. A MODEL FOR INDUSTRIAL ENERGY DYNAMICS

The causal diagram in Figure 6 represent a fairly general dynamics for the energy consumption of the Colombian industrial energy sector. The energy consumption in the industrial sector is controlled by economic variables, the availability of energy resources and the industrial development. As it can be seen in Figure 6 as more electric energy needs for production lines the electricity consumption increase, contributing to energy availability exhaustion and increasing electric energy conservation measures. The electric energy conservation measures diminishes the electric energy needs. This is a negative cycle controlling the electric energy consumption growth. Electric energy consumption is also controlled through the cost of electricity. When electric energy availability decreases the energy cost increases diminishing industrial development incentives and future electric energy needs. The diagram shows that in the case of production lines the electric energy alternatives are to continue using the machines in use or to change for more efficient ones. The decision is made using the annual equivalent cost criteria.

The cycles for the boilers are similar to the ones described above for the production lines. In this case, as an example, the energy alternatives included are natural gas and coal. Other energy alternatives for the boilers are oil, oil derivatives (fuel oil and diesel oil), wood and electricity.

A System Dynamics model was developed based on the described causal diagram of Figure 6. The model assumes that all decisions are made under the least cost principle. Any industry will always choose the least cost option considering all available energy alternatives. In its decision all economic variables such as tariffs, investments, maintenance costs, and others, are taken into account.

As stated before there are two main different industrial processes for energy consumption efficiency analysis: production lines and boilers. For production lines the energy alternatives in most cases are to continue utilizing the equipment presently in use or to change this equipment for a more e: y (electric) efficient one. For the boilers the decision involves to change the boiler in use for a more energy efficient equipment, and also the use of a cost efficient energetic source.

Least cost decisions are done for each industry. The least cost decision criteria is represented by the annual equivalent cost. The option with the lowest annual equivalent cost will be selected.

4. PRELIMINARY RESULTS

Several energy alternatives were analyzed for the two main processes in the industrial sector: production lines and boilers. The different industrial subsectors were modeled separately and the results for some cases are shown in Figures 7 and 8. Figure 7 shows that a program of electric efficiency will significantly affect the electric energy consumption. This kind of program will not only reduce electric energy consumption but will also make the national industry more competitive. The electric energy efficiency program needs to be carefully analyzed as an important energy alternative for the industrial sector.

Figure 8 shows that a natural gas availability for the industrial sector will induce the change of coal by natural gas as main fuel for the boilers. This is an expected decision because of the large gas reserves recently found in Colombia and the government efforts to make gas available for all the country. A national gas distribution grid is under construction.

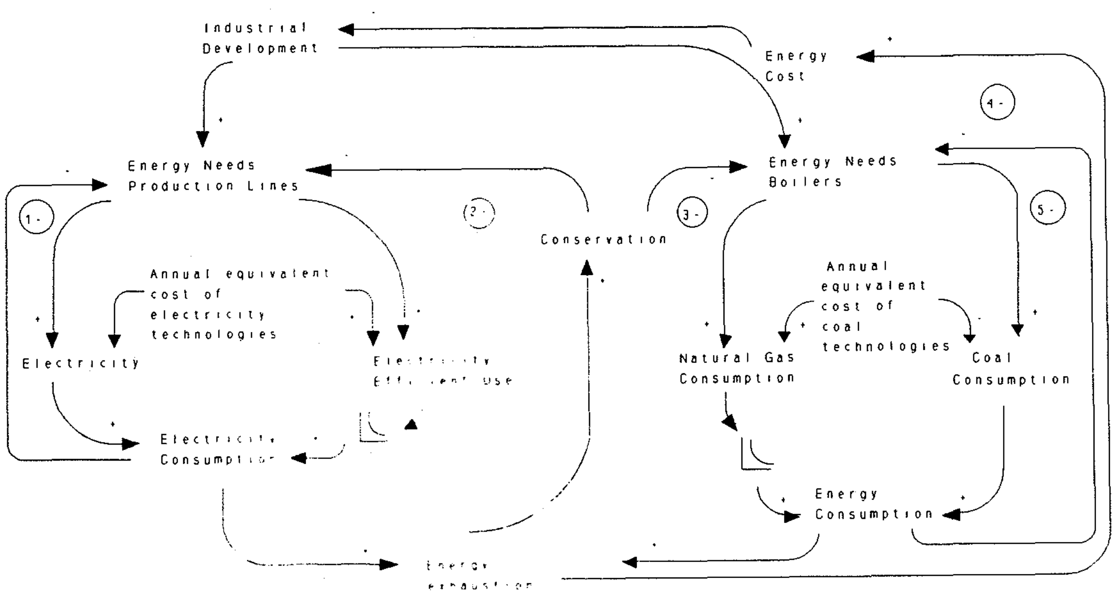

FIGURE 6. Energy consumption dynamics of colombian industrial sector.

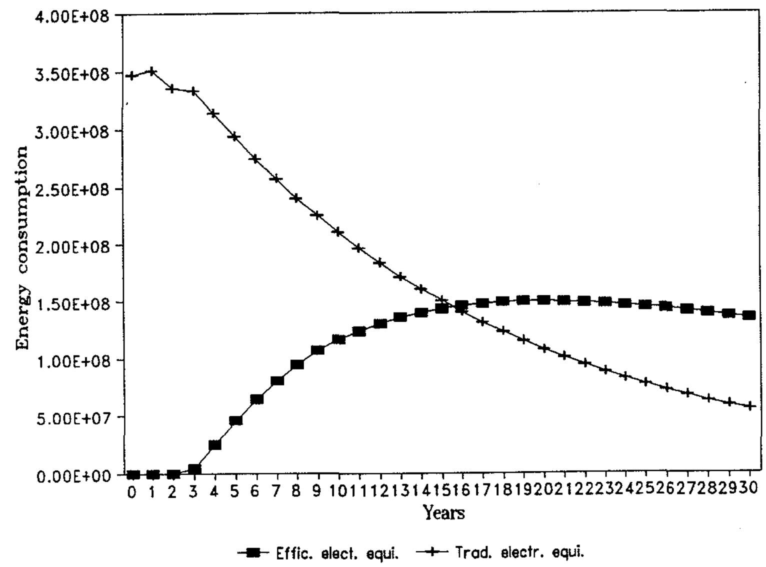

FIGURE 7. Energy consumption dynamics for production lines.

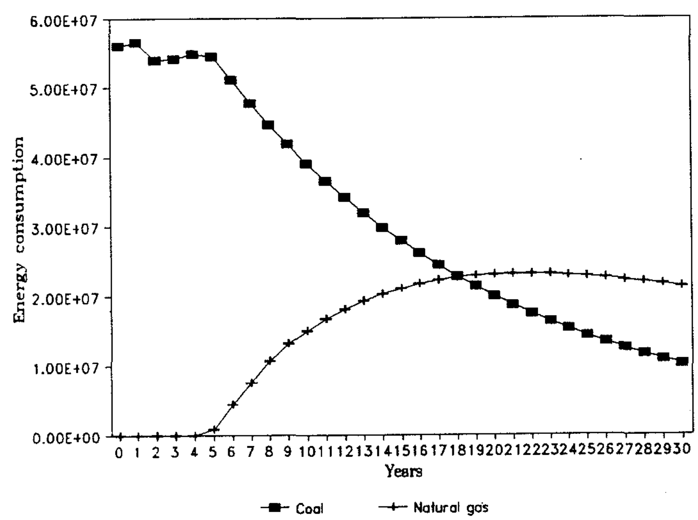

FIGURE 8. Energy consumption dynamics for boilers.

5. ELEMENTS FOR ENERGY POLICES AND CONCLUSIONS

From previous discussions, analysis and results the following elements for energy policies and conclusions are presented:

- An electric energy efficiency program for most industries seems to be adequate and will be clearly financed by the savings in electric energy consumption.

- The national gas program will transform the industrial energy consumption composition Natural Gas will substitute most of coal use in the industrial sector. Gas participation in the industrial sector energy consumption composition will not affect electric energy consumption.

- Combined national gas supply and electric energy efficient program will represent important savings for the industrial sector, increasing its competitiveness with foreign industries.

- The model has to be improved including more detailed aspects of the different industrial subsectors. The presented results are preliminary results.

- System Dynamics proves to be appropriate to support integrated energy planning issues. the model developed is fairly general and may be adequate for preliminary results for energy consumption at industrial subsectors.

6. ACKNOWLEDGEMENTS

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