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OPERATIONS STRATEGY AND ENVIRONMENTAL MANAGEMENT IN COSTA RICAN ELECTRICITY POWER SECTOR: A SYSTEM DYNAMICS APPROACH

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INTRODUCTION

By 1999, an almost totally integrated electricity power monopoly shows the Costa Rican government responsible for 92% of total generation, 100% of transmission and 82% of commercialisation. The performance level is, in general terms, good. The electrification level is 93.25%, one of the highest in Latin America; electricity losses are around 11%, one of the lowest in that region of the world; and the tariffs are reasonable. However, future electricity generation and demand are important concerns of the government due to: (a) the fact that between 35% and 47% of the total government investment during last 10 years has been directed to this national sector; (b) the increasing investment demands of other Costa Rican sectors; and (c) the accumulated debt of the electricity sector is so big that during some years the money required to pay the interests was bigger than the total income of the sector.

As a result, new legislation pursuing private investment at the generation level, within certain limits, has been passed. The purpose of this paper is to show how not only private investment will help Costa Rica to decrease its electricity debt, while coping with the increasing requirements of the customers, but also how the interaction of this action with the correct management of operational as well as environmental issues will benefit the country.

There is a long tradition of System Dynamics models applied to the electricity power industry (Aslam & Saeed, 1995; Barton & Bull, 1986; Bunn, Larsen & Vlahos, 1997; Coyle, 1996; Dyner & Bunn, 1997; Ford, 1990a; Ford, 1990b; Ford, 1997a; Ford, 1997b; Ford & Bull, 1989; Ford, Bull & Naill, 1987; Grupo de Dinámica de Sistemas de la Universidad de Sevilla, 1993; Larsen & Bunn, 1999; Lyneis, 1997; Naill, 1992), which are very helpful in recognising several feedbacks present in this sector. Unfortunately, this is insufficient to solve the specific case of Costa Rica. As Larsen & Bunn (1999) have pointed out, each country faces different market and industry structures, each holding different amounts of natural resources and generation technologies. This situation leads to the combination and/or invention of models suited to the needs of each country. The case of Costa Rica is no exception.

THE PURPOSE OF THE MODEL

The aim of the proposed model is to show, in an aggregated and strategic level, the interrelationships among operations strategy issues (i.e., capacity, technology, vertical integration, quality and production planning), environmental management issues (i.e., conservation and efficiency programs, and losses management), investment, debt, prices, cost, demand and forecasts; and how these variables might interact with new regulation encouraging private power generation. This paper extends the idea proposed by Pérez Ríos (1999), who pointed out that the turbulence of the environment stimulates the combined use of different methodologies to tackle complex issues.

THE MODEL

Figure 1 shows the interrelationships among several strategic issues considered by the model, from a highly aggregated perspective. For example, legislation and customers influence the strategy of the electricity power sector, which influences its operations strategy and its environmental management. Operations strategy is practised through a number of decision categories including capacity, facilities, production control and planning, technology, vertical integration and quality (Wheelwright & Hayes, 1985). These decision categories are also influenced by decisions related to environmental management issues. The interrelationships among these decision categories will determine the level of performance and competitiveness of the electricity power sector in terms of the well known distinctive competences of price, quality, reliability and flexibility (Wheelwright, 1984).

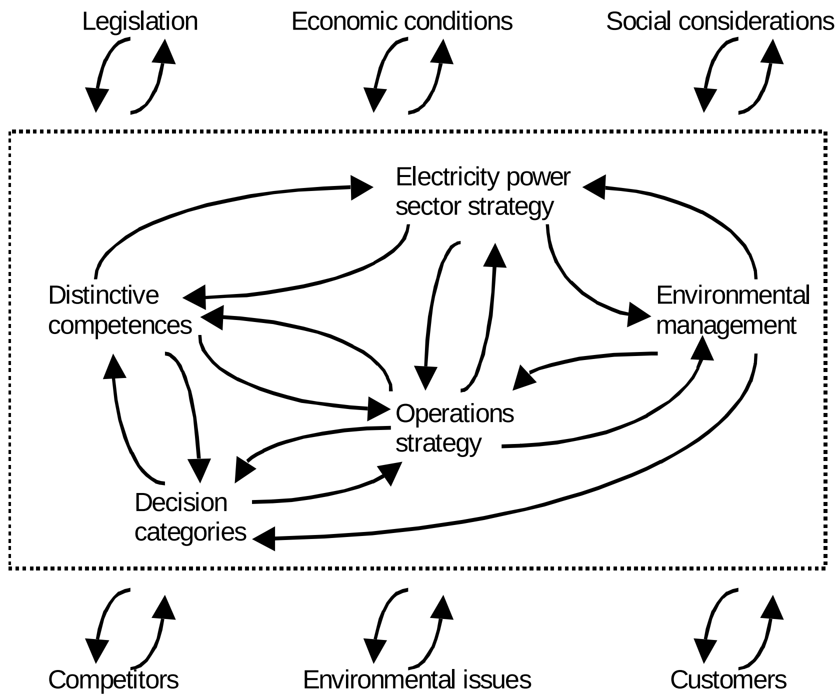


FIGURE 1. Strategic issues from an influence diagram perspective.

Figure 2 shows the interrelationships among the decision categories (the current version of the model does not take into account either organisation or labour, which are proposed as future areas of research).

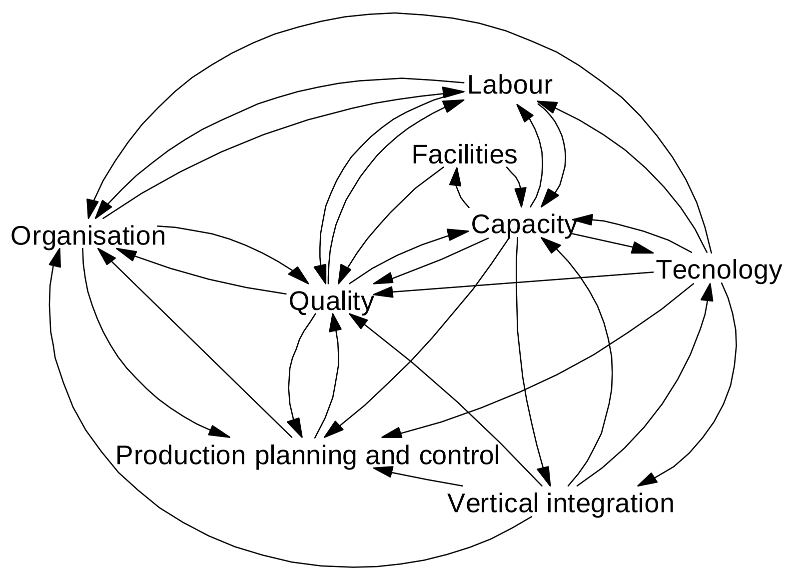


FIGURE 2. Influence diagram reflecting the interrelationships among the decision categories.

The general structure of the model is shown in Figure 3 (the detailed model is available from the author). It shows, among others, some of the interrelationships already mentioned.

As illustrated in Figure 3, the model is organised into six sectors:

1. Demand sector; computes the total demand based on type of customer, number of customers, kWh per customer, and effect of price elasticity.
2. Generation sector; determines the mix of generated power (from hydroelectric plants, thermoelectric plants, geothermal plants, wind generation plants and private generation plants), taking into account losses in transmission and distribution, available capacity, costs and load factors. It also dispatches the available generation to meet load.
3. Installed capacity sector; keeps track of the installed capacity, by generation source. It also considers depreciation and the reserve margin.
4. Cash flow sector; computes income, costs, debt, investment, interests and interest payments.
5. Demand forecast sector; calculates the expected demand in the medium and long term (i.e., five and ten years in advance, respectively).
6. New capacity addition sector; represents the construction and addition of new capacity, taking into account demand forecasts, installed capacity, expansion plans and the construction of capacity by private generators (who are not supposed to provide, according to the new regulation, more than 30% of the total demand).

The System Dynamics model was built using Powersim Constructor 2.51, and the tuning and optimisation was achieved using its companion software Powersim Solver 2.0.

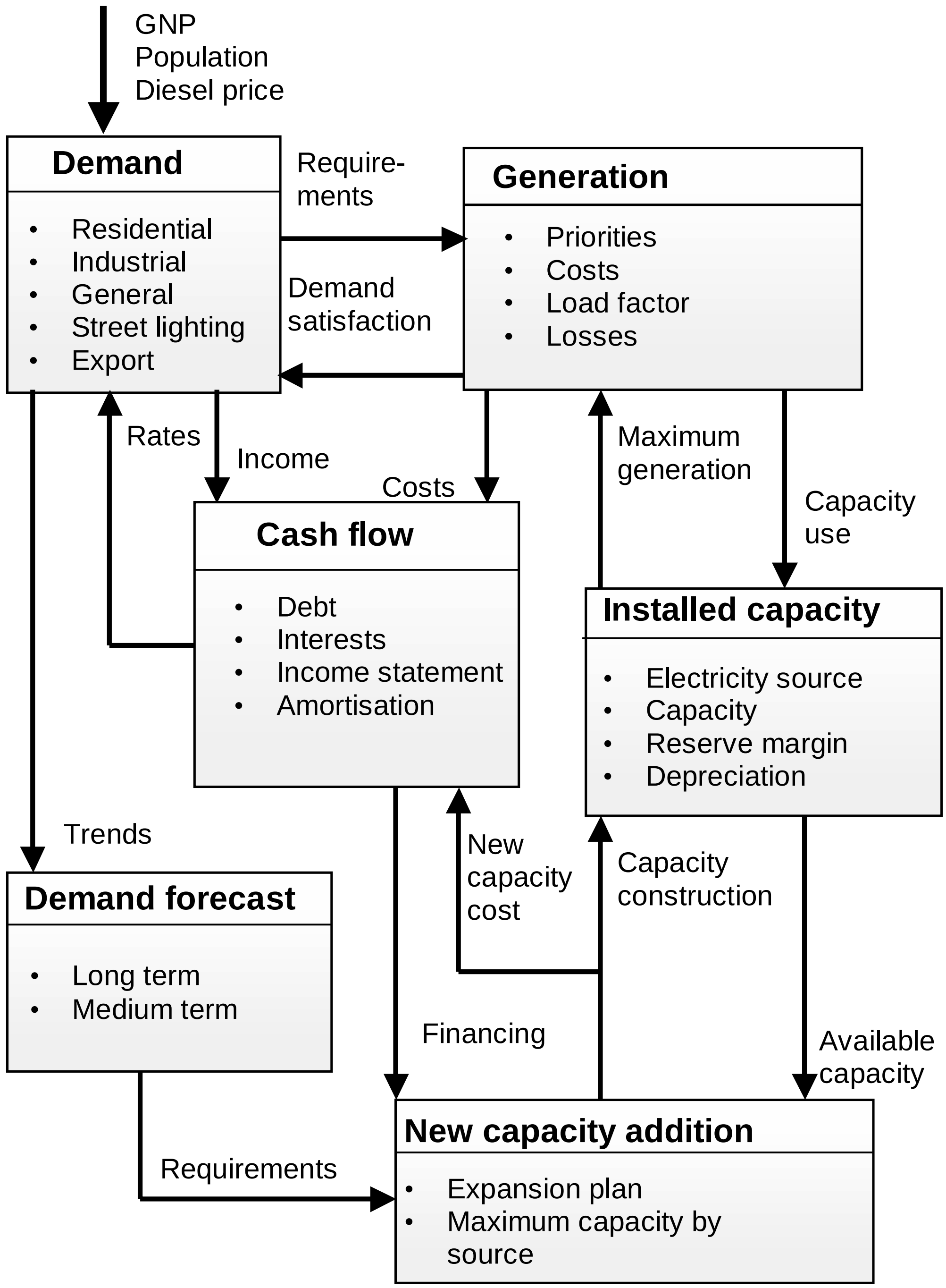


FIGURE 3. General structure of the model.

MODEL USEFULNESS

The model had to "pass" the complete set of tests proposed by Forrester & Senge (1996/1980), which deal with structure, behaviour and policy implications. Furthermore, the set of summary statistics for evaluating the historical fit of System Dynamics models proposed and explained by Sterman (1984) was used, as shown below.

MODEL TUNING

The model assumes that parameters such as losses, margin reserve and load factor are constant, whereas it can be observed that the values of these parameters change within certain intervals. Figure 4 shows the combined evolution of the real electricity generation (historical), that simulated by the model (simulated), and that tuned by Powersim Solver 2.0. Figure 5 shows the combined evolution of the installed capacity case.

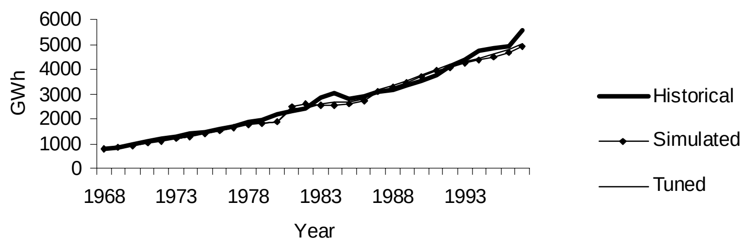


FIGURE 4. Historical, simulated and tuned generation data series.

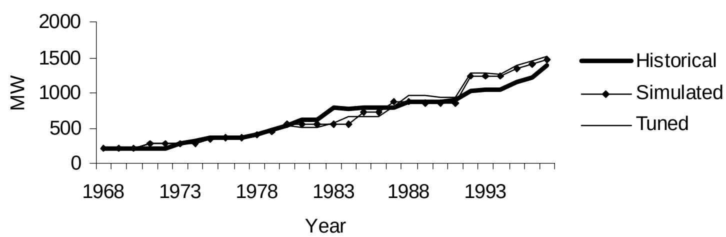


FIGURE 5. Historical, simulated and tuned capacity data series.

Table 1 shows the numerical results obtained for the generation demand case. Summary statistics are calculated for both the simulated and the tuned data series.

TABLE 1. Summary statistics: simulated and tuned electricity generation

	Simulated	Tuned
N	30 years	30 years
R^2	0.98096	0.98370
Mean square error (MSE)	47820	32786
Root mean square error (RMSE)	219	181
Root mean square percent error (RMSPE)	0.07024	0.05804
Theil´s inequality coefficient (U)	0.07336	0.06075
Bias (U^m)	0.22992	0.09438
Variation (U^s)	0.09070	0.03718
Covariation (U^c)	0.67937	0.86843

Table 2 shows the summary statistics obtained for the installed capacity case. Values are calculated for both the simulated and the tuned data series.

TABLE 2. Summary statistics: simulated and tuned installed capacity

	Simulated	Tuned
N	30 years	30 years
R^2	0.93955	0.94130
Mean square error (MSE)	10727	13687
Root mean square error (RMSE)	104	117
Root mean square percent error (RMSPE)	0.13335	0.14206
Theil´s inequality coefficient (U)	0.14065	0.15887
Bias (U^m) (fraction of MSE)	0.01809	0.06203
Variation (U^s) (fraction of MSE)	0.23573	0.34349
Covariation (U^c) (fraction of MSE)	0.74617	0.59448

In both cases the numerical results allow the reliability of the model's behaviour to be determined.

RESULTS

One of the purposes of the model is to generate insights in the analysis of several policy implications. In this section some simulations are presented in order to illustrate the nature of the results of the model.

Two cases are explored: (a) the impact of two different capacity expansion plans in the total debt of the sector, one without more private generation investment, and the other finding the optimum level of private generation investment, given certain legal restrictions; and (b) the impact of a sensitivity analysis in the result obtained in (a).

Figure 6 shows the results of the first case, where the total debt of the electricity monopoly might go from $725 millions in 1998 to $1069 millions in year 2020, if private investment is suspended in 1998. On the other hand, if private generation investment achieves a rate of approximately 30 MW/year, which is not contrary to the new legislation requiring that total private generation be less than 30% of total demand, and assuring full use of the private installed capacity, the total debt of the Costa Rican government participation in the electricity power industry might go from $725 millions in 1998 to $227 millions in year 2020. This optimum private investment rate was found using the *Optimize* task of Powersim Solver 2.0.

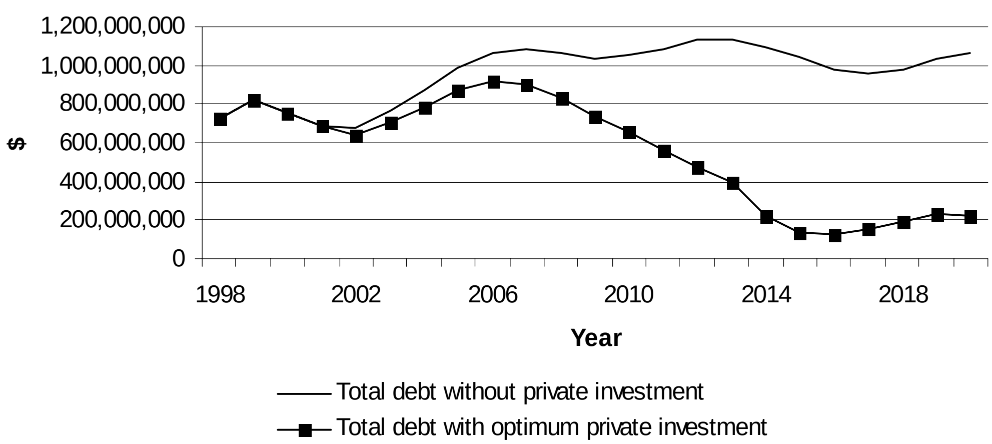


FIGURE 6. Comparison of the evolution of the total electricity debt under two extreme scenarios.

Figure 7 shows how sensitive the "savings" obtained in the previous case are. As explained before the model assumes that parameters such as losses, margin reserve and load factor are constant along the simulation period, but actually the values of these parameters change within certain intervals. The *Assess Risk* task of Powersim Solver 2.0 is used, which allows for defining the assumptions of the already mentioned parameters as statistical functions rather than specified values. By using the historical ranges of these parameters, assuming triangular distributions for all of them, it was possible to find the range that the total debt will fall between with 100% certainty.

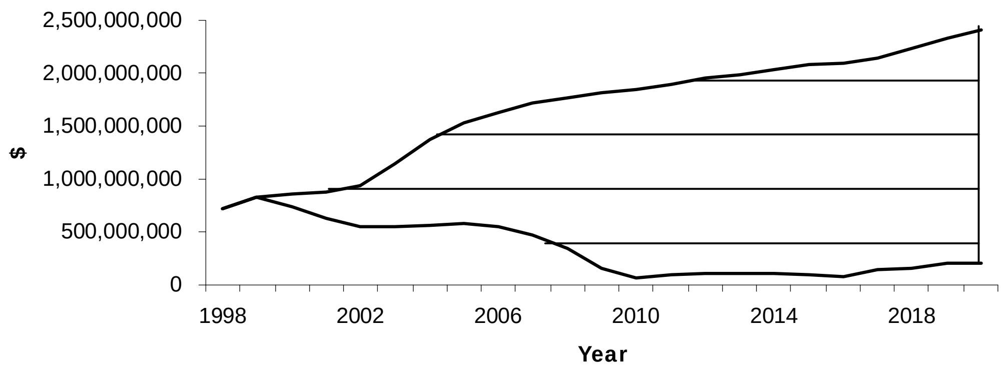


FIGURE 7. Range that the total debt will fall between with 100% certainty.

These results show that the Costa Rican government would be mistaken to assume that private power generation will solve its debt problem. If the government does not manage its electricity operations carefully the expected benefits of new legislation might simply evaporate.

ELSECDYN: A MICROWORLD

A microworld (Morecroft, 1988; Senge, 1990) of the electricity sector of Costa Rica was built using Powersim Constructor 2.51. The purpose of this microworld, called ELSECDYN (an acronym for Electricity Sector Dynamics), is to aid different stakeholders (i.e., legislators, managers, engineers, policy makers, among others) to understand several interrelationships in the sector, and to give them the means to experiment with the design of social and business policy in the safety of a simulated environment.

Four of several control panels are shown in Figures 8, 9, 10 y 11. Figure 8 shows the main control panel, where decisions related to several parameters can be changed before or during the simulation.

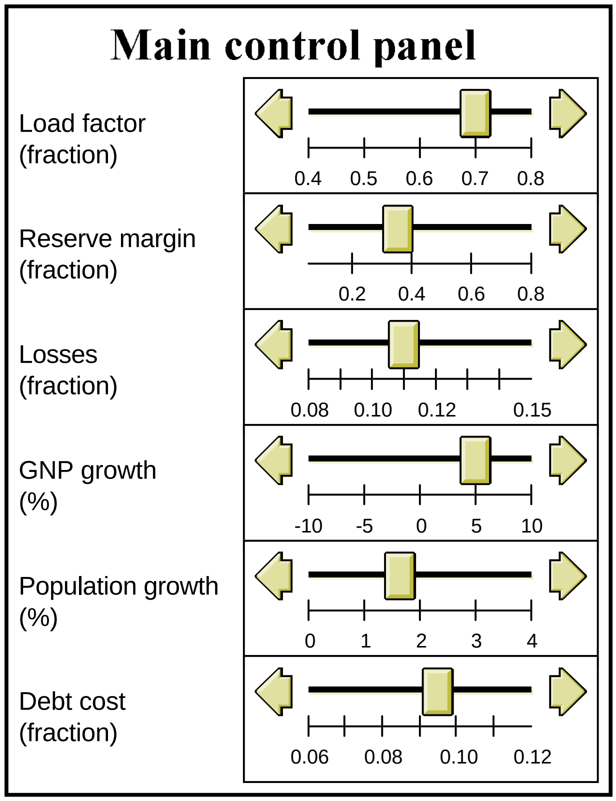


FIGURE 8. Main control panel.

Figure 9 shows the control panel related to electricity costs classified by source of generation (private generation is included as a special "source"), which allows for different assumptions about these costs to be tested.

Figure 10 shows the demand multipliers, which allow experimenting with different than expected growth rates in residential, industrial and general electricity demand sectors.

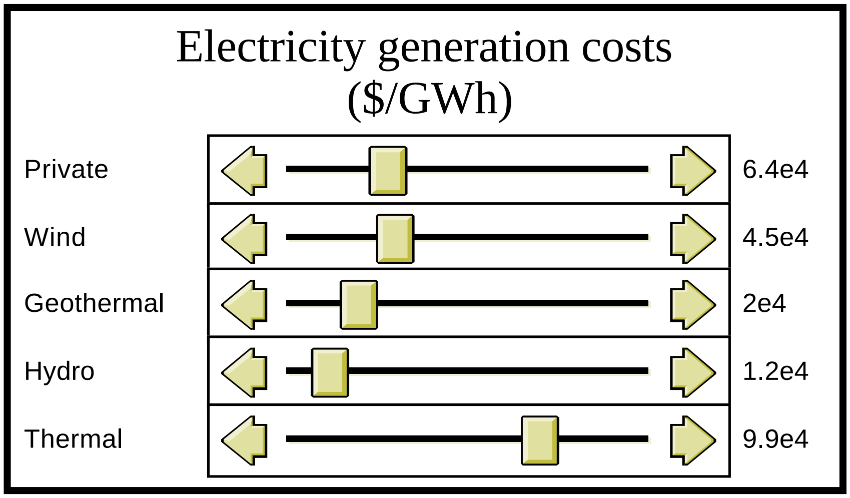


FIGURE 9. Electricity generation costs panel.

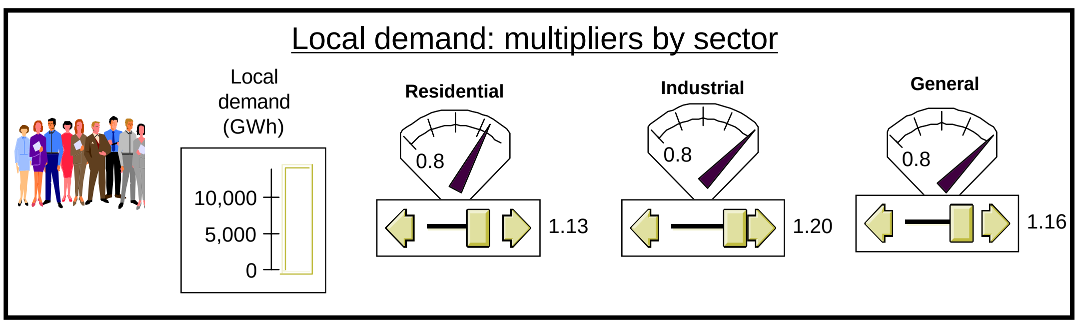


FIGURE 10. Demand multipliers.

Figure 11 shows the control panel dealing with export demand and private power generation demand. This panel allows the users to see, for example, the impact in the Costa Rican electricity power sector, of exporting electricity to other Central American countries.

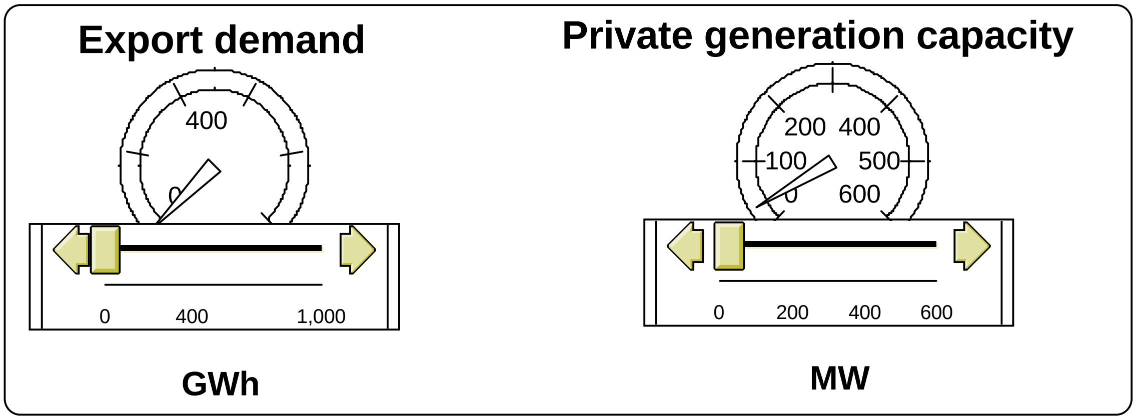
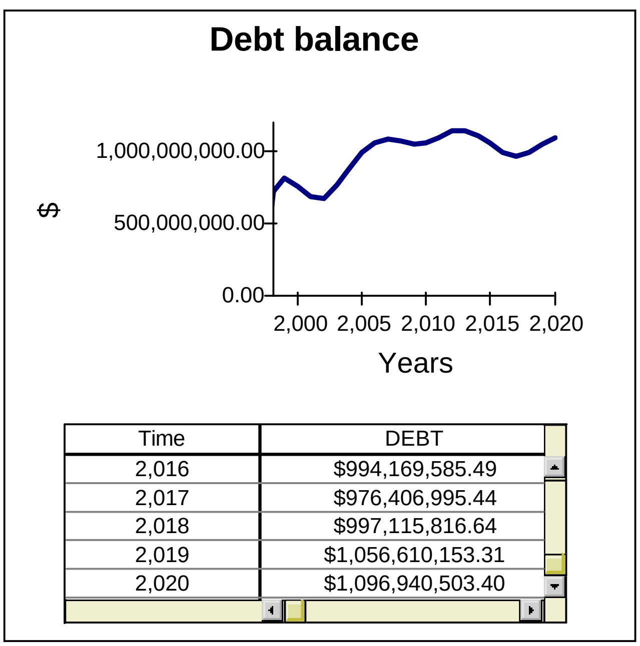


FIGURE 11. Export demand and private generation demand panel control.

ELSECDYN allows the effects of changes in many parameters in several parts of the electricity sector to be seen. Some of these parts can be as diverse as total generation costs, accumulated debt of the government participation in the electricity sector, annual interests charge, total generation, installed capacity and unmet demand. Figure 12 shows an example of the simulated results of the electricity sector debt balance, in both graphic and table form.



Time	DEBT
2,016	$994,169,585.49
2,017	$976,406,995.44
2,018	$997,115,816.64
2,019	$1,056,610,153.31
2,020	$1,096,940,503.40

FIGURE 12. Electricity sector debt balance simulated results.

CONCLUSIONS

The System Dynamics model of the Costa Rican electricity power sector, allows, following structural and behavioural validation, the simulation of several policies intended to improve the overall management of this national sector.

It was shown how simply launching new legislation will not provide sustainable solutions to the electricity debt problem of Costa Rica, because the interaction of other variables might well counteract the expected results of the new regulation.

It was also found that there is an unquestionable relationship between strategic and operational issues. Typically, only one of such approaches (strategic or operational) is pursued. However, this paper shows how the strategic issues are actually achieved when confronted with day to day operations.

It is normal to define common sense strategic paths, but the experimentation of how such strategic options can develop along time can be enhanced if a System Dynamics model is defined, validated and used as a testbed of the different strategic options.

Finally, it was shown how the use of tools such as tuning, optimisation, and risk assessment can help in designing better models for policy making.

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