PRODUCT POLICY IMPACT IN THE LIFECYCLE OF LIGHT BULBS THROUGH SYSTEMS DYNAMICS

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Abstract:
Like any other Electric and Electronic Equipment (EEE), light bulbs have significant environmental impacts throughout their lifecycle. The stages of production, use and end of life are considered for Bogota City in this paper. The middle class population is studied. The main variables are: raw materials recycled material, purchase criteria, formal and informal channels for recycling, recycling process and landfill. A system dynamics approach is used to model the behaviour of the system, considering different Integrated Product Policies (IPP), which contributes to minimize environmental impacts. The evaluated policies are: 1. Intra-Technological Energy Efficiency Change; 2. Energy cost variation; 3. Recycled materials incorporation, 4. Hazardous materials elimination, and 5. Recycling consumer tax. The best results on energy consumption reduction and amount of recycled material are outcomes of the synergy of all the policy instruments. The economical instrument shows good results in both variables in the case of single policy evaluation.

Keywords: Integrated product policy (IPP), Systems Dynamics, Lifecycle, Energy Efficiency, Waste Electric and Electronic Equipment (WEEE), Electric and Electronic Equipment (EEE).

1. INTRODUCTION

Whereas the environmental impact of most products is produced during the stages of resource use, production, transport and end of life, light bulbs produce their highest environmental impact during the use stage; it can rise up to 90% depending on the lamp type [5]. In the specific case of light bulbs lifecycle, three essential aspects have been identified as significant concerns: 1) excessive and inefficient use of natural resources in manufacturing and disposal processes; 2) the generation of big amounts of residues; and 3) the production of dangerous waste, which is harmful both for health and the environment [8].

In Colombia the most common light bulbs used at the household are: incandescent, compact fluorescent, tubular fluorescent, halogen, which they are moving to LED and Tubular LED. Illumination can be responsible for 50 % of the household energy bill in Colombia. [18]. The light bulbs compositions are 63% in glass, 18% in metals, 10% of plastic, 8% of electronic parts and 2%

others [5]. Mercury is a hazardous waste in some light bulbs. The amount of mercury in a fluorescent lamp varies, depending on the type of lamp, manufacturer and data of manufacture, but typically ranges from 1.7 milligrams to 15 milligrams; some older bulbs may contain 50 milligrams of mercury or more [7]. For this reason, it is important to reduce the use of hazardous substances in the manufacturing stage [2]. Most of these materials can be recovered by means of a technical process, not yet implemented in Colombia.

Currently, Bogota has a population of about 8 million people distributed in 6 social strata. Informal recycling is preponderant on recycled channel. As for laws about waste, there is regulation only for hospital residues; on pesticides, batteries, pharmaceutical products and light bulbs there are voluntary, not obligatory agreements in order to assure their collection in a defined location. Concerning legislation on energy efficiency, in Decree 2105 of 2007 general provisions were enacted to promote practices for the purposes of rational and efficient use of energy. The Decree 2331 of 2007 and Decree 895 of 2008 established that replacing low-efficiency light sources in all public institutions were required. The Decree 3450 of 2011 prohibited the importation, marketing and use of low-efficiency light sources. The Technical Regulation of Electrical Installations was updated in 2008 and the Technical Regulations for Lighting and Street Lighting were updated in 2010. This did not affect directly the residential sector and therefore we can state that no administrative instruments were applied to the residential sector.

In the case of electrical and electronic equipment (EEE), Instruments of Integrated Product Policy (IPP) can affect the usage stage by affecting energy consumption and the end of life stage by managing hazardous components, because they cause considerable environmental and health impacts. The analysis of user behaviour regarding the purchase, utilization and disposal of light bulbs and the application of the IPP are the central purposes of this study in order to show alternatives that may allow preventing and mitigating the environmental impact of these products.

Previous studies have addressed the interactions among the different components involved in the life cycle of appliances. In the case of TV sets, the return of recycled materials to the productive cycle is so low that it does not exert any significant influence on the system. However, the implementation of recycling promotion policies takes these materials to the formal recycling channels [17]. Regarding freezer lifecycle, which was analysed due to its elevated usage and disposal impact, information labels give the highest contributions to reduce energy consumption. On the other hand, recycling taxes guarantee that the highest amounts of Waste Electric and Electronic Equipment (WEEE) flow through formal channels, thus leading to higher recovery rates [15].

In this context, the current paper proposes a light bulb lifecycle model that describes and analyses five economic, administrative and informative policy instruments that allow modelling different environmental impact scenarios. The evaluated policies are: 1. Intra-Technological Energy Efficiency Change, 2. Energy cost variation 3. Recycled materials incorporation, 4. Hazardous materials elimination, and 5. Recycling Consumer Tax. These policies are evaluated by means of a dynamic systems model in order to know their influence in the life cycle model of light bulbs in Bogotá.

2. STATE OF THE ART

The environmental impact of a product can be prevented and mitigated by means of administrative, informative and economic policy instruments applied throughout the different stages of the product's lifecycle. A literature review revealed that the most commonly employed administrative instruments are: 1) the banning of hazardous substances, and 2) minimum recycling or establish rate standards. Ecologic and energy efficiency labels are frequently used as informative instruments, among others. On the other hand, the dominant economic instruments are upstream and downstream taxes [1], [4], [11], [13]. Three additional instruments are of common use regarding energy efficiency: the variation of the energy price depending on consumption (economic instrument), the installation of meters that provide the user with immediate consumption feedback and the use of energy efficiency labels, (informative instruments) [10].

In order to develop the model, different studies on energy efficiency and WEEE were reviewed. Georgiadis et al., Eichner et al. and Gottberg et al. have analysed environmental sustainability strategies (legislation and green image), working features of the supply chain, and impacts on environmental sustainability [6]. The lifecycle of EEE has also been explored in variable preference and uniform demand scenarios [7]. Consumer behaviour has been observed to be irrational, since energy cost increases determined turning off or eliminating bulbs considered as not indispensable, at the expense of investing in more efficient bulbs [14]. The disposition of the EEE generates an environmental impact, which is modelled considering the socio-economic behaviour of the population in the phases of use and disposal [5], [12], [15], [17].

3. METHODOLOGY

A survey was used as the methodology for this study to characterize the population of Bogota concerning light bulbs lifecycle. The perception of Bogotá citizens was collected by applying 150 surveys in strata 1 to 6. Only the data from strata 3 and 4 was used for the model, because the purpose was to study the middle class, which corresponds to 45% of the Bogotá population [16]. Some of the results are: 67% of the population lives in a house, typical dwelling unit, while the remaining 33% live in flats. The monthly income of the surveyed population is distributed as follows: 32% in the range of $520 to $ 1,040 dollars, 31% of household income between $260 and $520 dollars, 11% in the range from $0 to $ 260, 16% from $1040 to $ 2080 and 10% over $ 2080. 76% of those surveyed expressed no knowledge of a waste separation program at a general level and the remaining 24% said that separation programs are carried out within the city. To quantify how important the issue of waste separation is for the population, assigning a value from 1 to 6 to it, where 1 is the most significant category, 61% gives a score of 1-2: 37 % rating 1 and 24% rating 2. 12% of the population says that the separation of waste in the household is not important with a rating of 6. The rest of the population assigns values between 3, 4 and 5 with proportions of 15%, 7% and 5%.

As for the industry of light bulbs, the population of Bogota has shown a significant progress in the importance given to the mitigation of environmental impact caused by the use of this product. Increasing the efficiency of luminaires to reduce energy consumption has been one way, but some of the components of the most common lamps used at home, classified as hazardous waste, have not adequate disposal.

In general it is evident that the 44.59% of the population acquires the lights in chain stores and 35.81% in small stores in the neighborhood. As for the light bulb purchasing criteria, 65% of the population considers cost and power as important criteria, 43% of respondents rated the design / shape / aesthetics as indifferent criteria. Finally in terms of consumer habits 37.41% of the surveyed population uses only compact fluorescent-type lamps, 4.76% uses incandescent lamps, 28.57% uses a mixture of incandescent lamps and compact fluorescent at home, 10.88% mix tubular lamps, compact fluorescent and incandescent light bulbs.

The system dynamics model to describe the life-cycle assessment of the luminaries in Bogota was built. Choosing to use the tool of system dynamics was due to the complexity of the reporting system and the different characteristics of the social (taxes, price, recycled, etc.) that is analysed. In the following sections model details are given and the different scenarios are explained.

4. DESCRIPTION OF THE MODEL

The objective of the current study is to analyse the lifecycle of light bulbs in Bogota by modelling the behaviour and interaction among components within a 50 years horizon. People are featured by their purchasing decisions based on product price, thus dismissing cost-benefit relations implied in future projections. The model analysed six light bulb technologies of common use in this city: Incandescent, Compact fluorescent, Tubular fluorescent, Halogen, LED and Tubular LED.

The model intended to represent the relation between energy consumption and light bulb type in their lifecycle that are affected by consumer behaviour in terms of purchase and usage decisions. The modelling was carried out through system dynamics, an analysis tool that allows observing interactions among variables as they change through time, thus facilitating the understanding of cause – effect relationships, as well as through the scrutiny of subsystems and their feedback relationships. The aforesaid interactions can be assessed through a causal and a Forrester diagram (Figures 1 and 2), which allow observing how population growth directly increases energy consumption, the number of light bulbs in use, the amounts of recycled materials and of those disposed in landfills, light bulb production with recycled materials and, in general, all flows in the model. It is also believed that the landfill has a certain capacity and the energy it produces is used in gas and this affects the price of energy and therefore energy consumption at home.

- Overall Causal Diagram

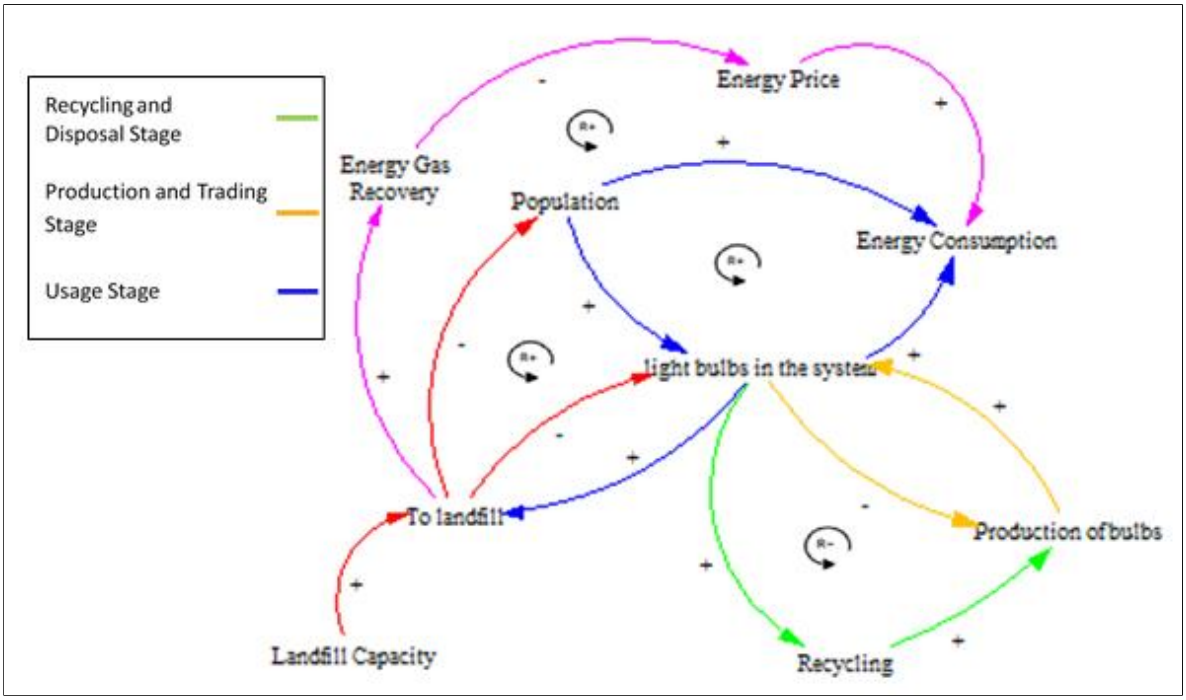

Figure 1. Overall Causal Diagram

- Overall Forrester Diagram

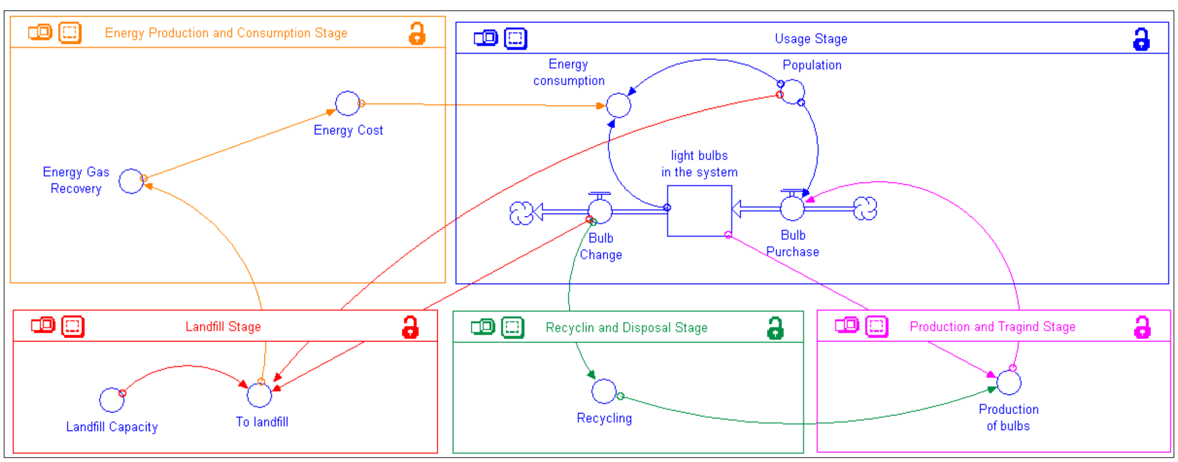

Figure 2. Overall Forrester Diagram

Production and marketing stage

The production and marketing stage considers locally manufactured light bulbs made from new and recycled materials as well as imported ones. The production process uses recycled materials obtained from the end-of-life stage of these products. The marketing and distribution process includes exports and domestic sales, which directly affect the purchase habit, mainly through sale price and bulb technical features. Figure 3 illustrates this stage, specifying the relationships between variables.

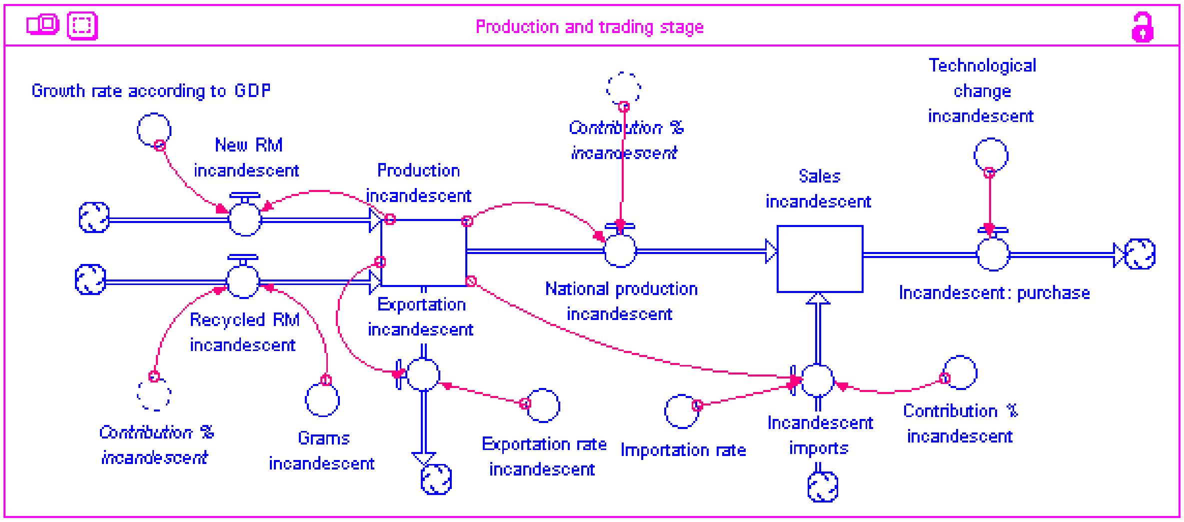

Figure 3. Forrester Diagram of the Production and Marketing Stages.

The relationships depicted in the Forrester diagram above can be expressed by the following equations:

Production = Production with raw material + Production with recycled material - Exports

Sales = National Production + Imports – Bulbs purchase

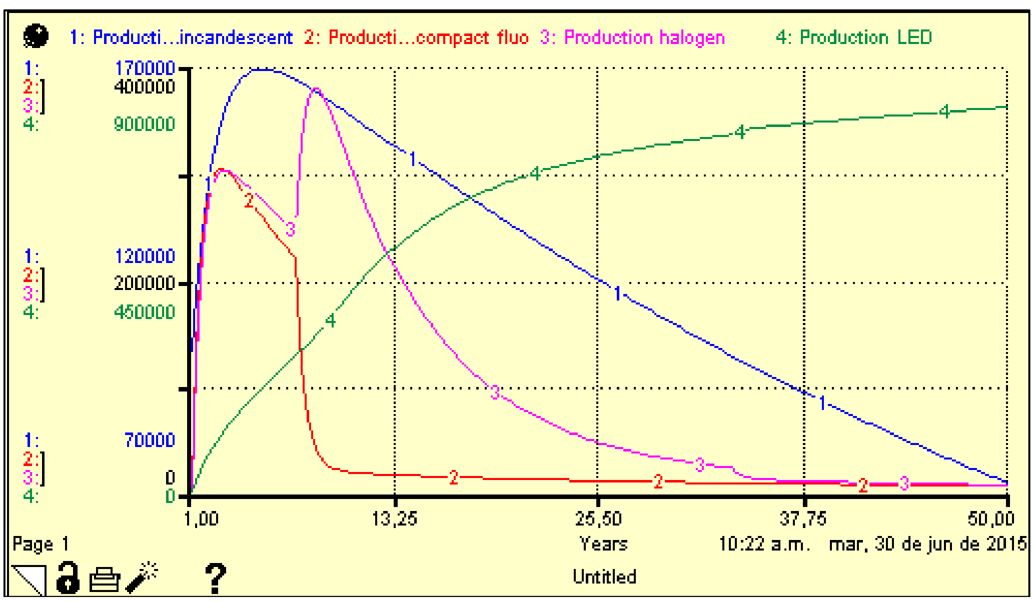

Figure 4. Production Curves of the Studied Bulb Types.

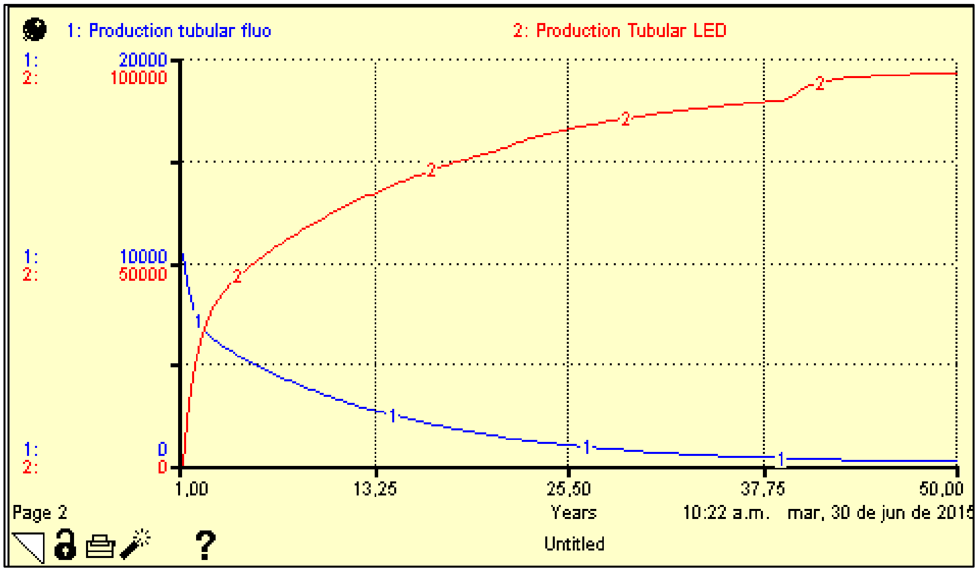

Figure 5. Production Curves of the Studied Bulb Types.

Figures 4 and 5 shows production behaviour as measured in units of each bulb type. In general, production tends to grow during the first years, and then declines. The latter periods are those usually employed for this type of analysis, since they mark the moment when the system reaches certain stability. The model allows demonstrating how the useful life of the bulbs goes from just months to quinquennium by switching from incandescent to LED technology. Results are showed in two graphs because the software only allows to model five light bulb technologies.

Usage stage

At this stage, energy consumption, which depends on bulb type, also changes as a function of consumer behaviour. The latter is affected by technological choice when it is time to change bulbs at home and a new technology is available. Figure 6 illustrates this stage: lighting change is strongly affected by the habit of use, thus allowing moving the system through the migration to more efficient technologies.

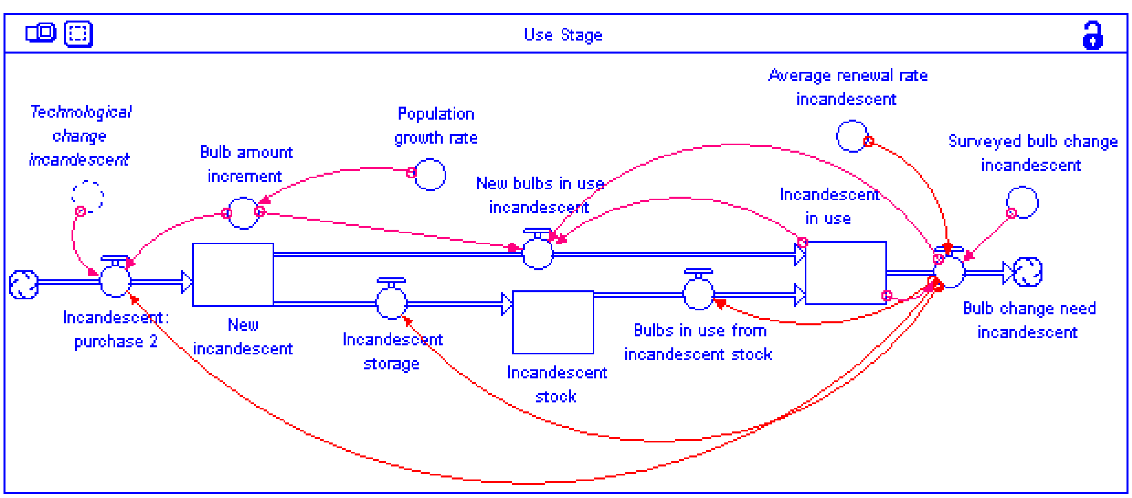

Figure 6. Forrester Diagram of the Usage Stage.

The behaviour of the studied bulbs, including the ways they enter and exit the system, are represented by the following equation:
Light bulbs in the system = In Use + In Stock – Bulb Change

Figure 7 shows the behaviour of the amounts of the studied bulb types within a horizon of simulation. It can be deduced that, given the purchase and use habits, as well as the technological changes, at the end of the period under analysis the most representative bulbs in the market are LED ones, although the system was initially dominated by compact fluorescent and incandescent lamps. In the transient part of the process, incandescent and compact fluorescent lamps give way to halogen and LED ones.

This is so because, despite their elevated unit cost, the latter have greater energy efficiency and lower environmental impact. For their part, halogen bulbs have lower environmental impact than compact fluorescent ones, which contain mercury.

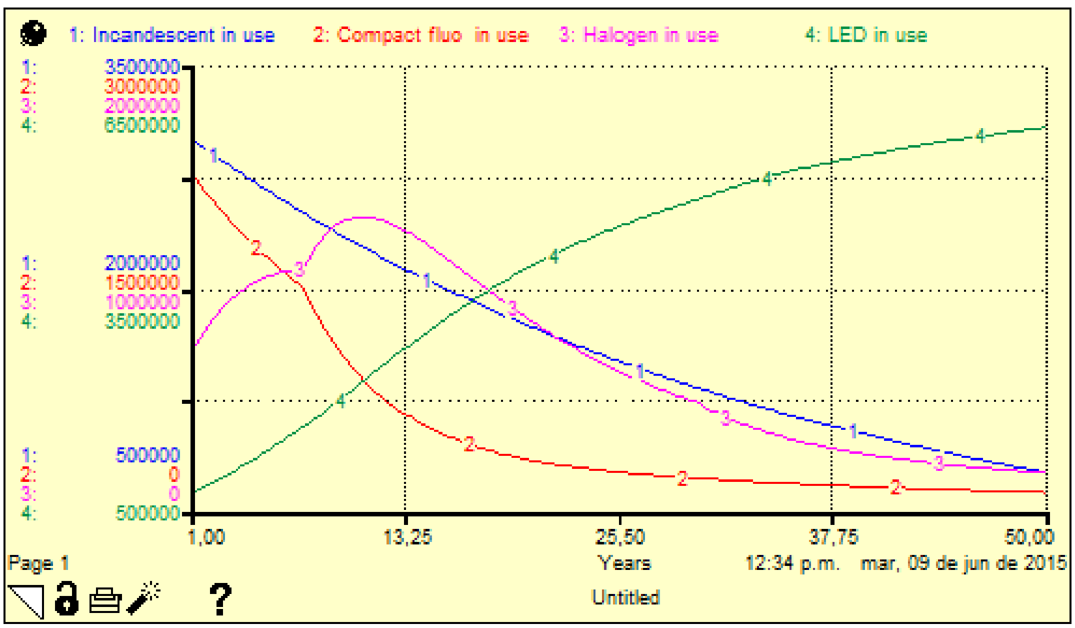

Figure 7. Consumption Curves of the Studied Bulb Types.

Regarding energy consumption, Figure 8 shows a steady increasing trend in this parameter during the 50 years of the analysis, as expected from the sustained increase of the population and the consequent need to use more and more light bulbs.

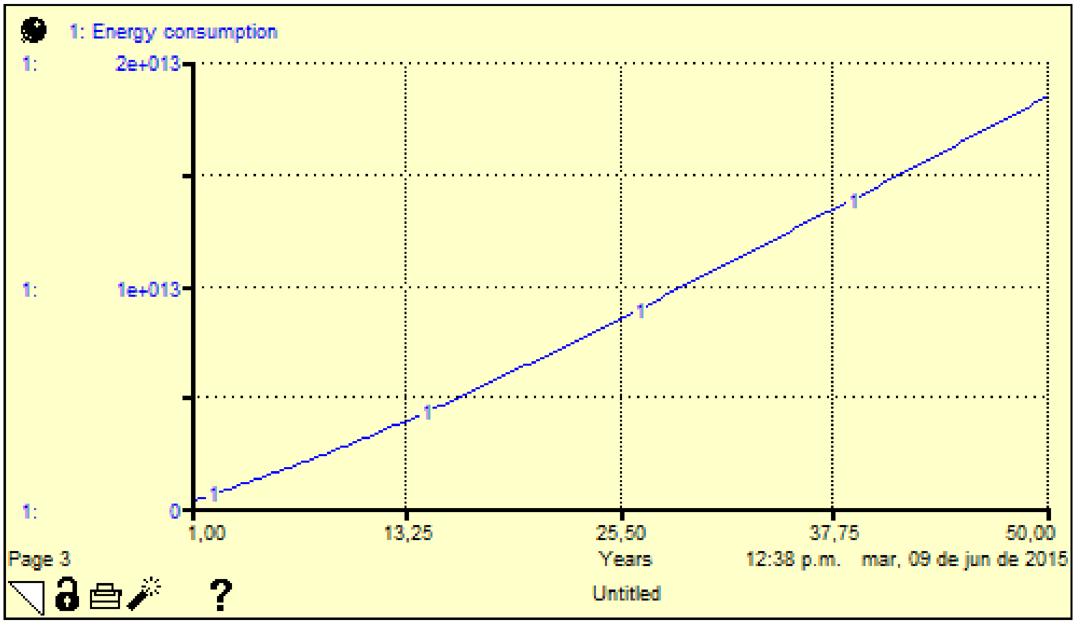

Figure 8. Total Power Consumption during the period under analysis.

End-of-life stage

This stage analyses the destination of recycled and hazardous materials. Both product categories contain two fractions, namely those that can (and cannot) be returned to the production process. Naturally, the non-recyclable fractions require especially adequate handling. Formal or informal channels can undertake the entire process. The former are in charge of formally constituted companies, which meet the required standards for handling bulbs. In turn, informal channels are in the hands of common people without any training for the task, determining a more negative impact on the environment. Figure 9 illustrates the relationships involved in this stage.

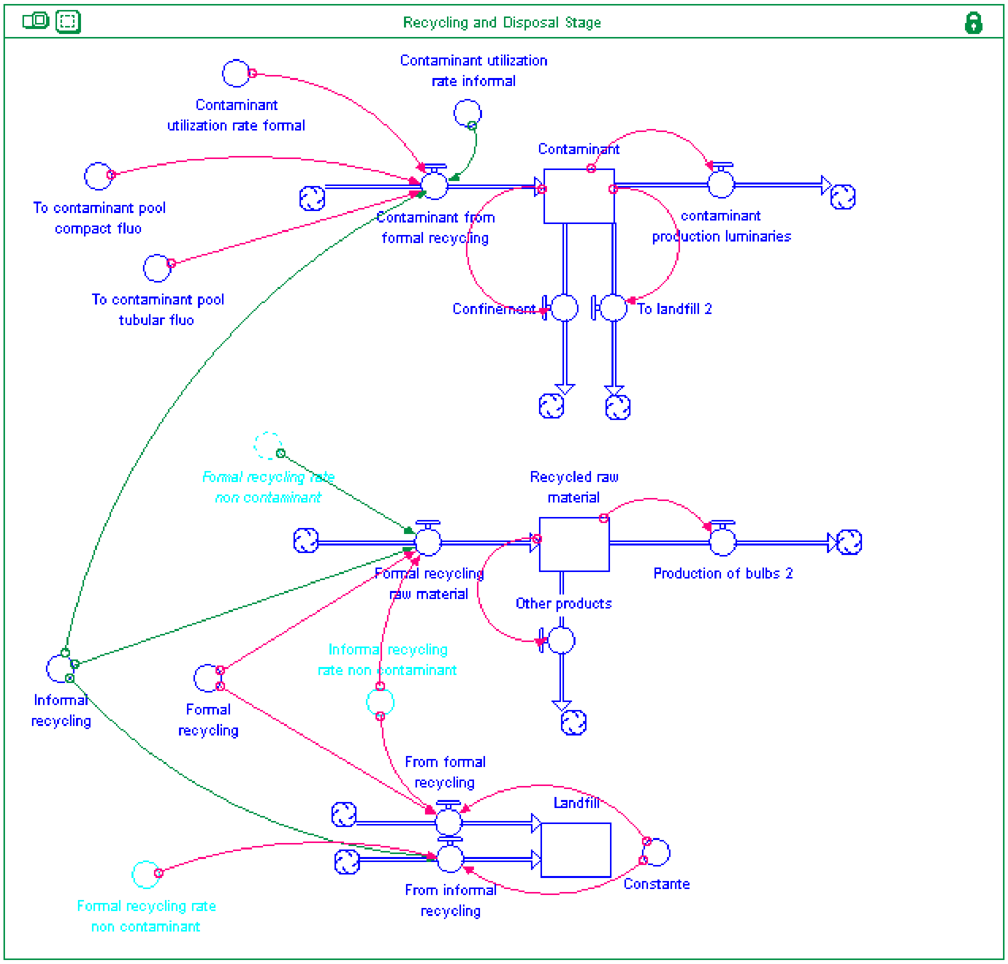

Figure 9. Forrester Diagram of Recycling and Final Disposal Stages.

The relationships depicted in the Forrester diagram above can be expressed by the following equations:

Landfill = From formal recycling + From informal recycling

Recycled material = From recycling - Intended for bulb production - Sent to landfill

Contaminant = From recycling - Intended for bulb production - Sent to landfill - Sent to confinement

The landfill capacity is determined up to 8.750 tones and when the capacity reaches 70% this should increase the amount of recycled material and energy prices will decrease because energy can be obtained from landfill, particularly gas.

4. VALIDATION OF THE MODEL

To perform the validation of the model two scenarios were analysed, one under current price conditions, and the other with the price of energy increased at inflated values on the order of thirteen thousand pesos (37 times), and the energy consumption observed behaviour as shown in Figure 10.

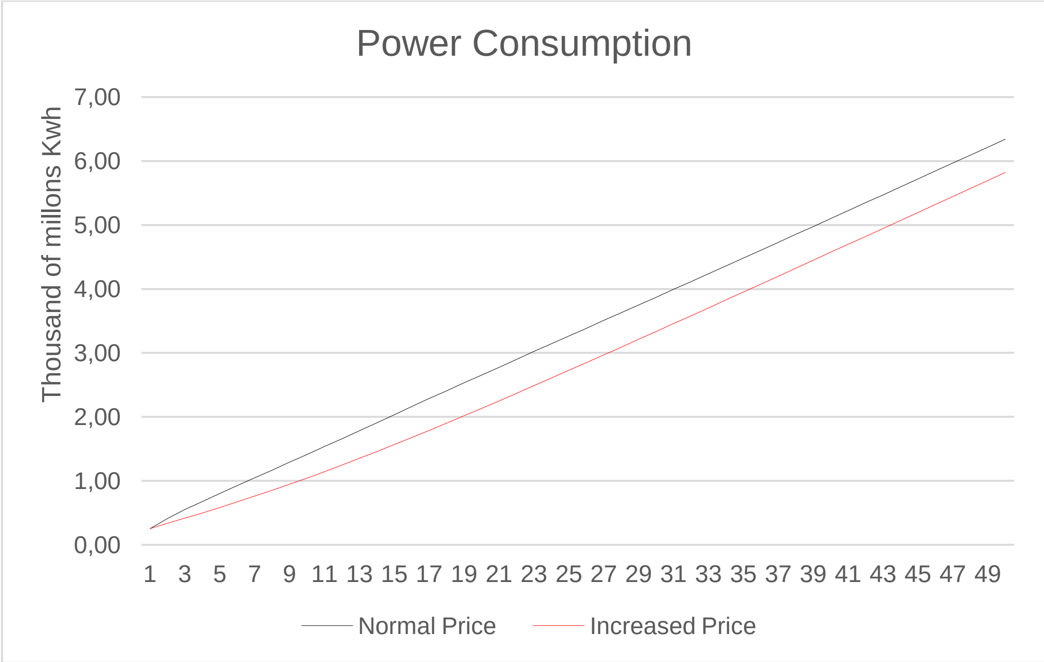

Figure 10. Total Power Consumption.

It is observed that the energy consumption is reduced when the price is increased, showing that the model is sensitive to the price of energy, so that the consumer has the option of reducing the lights-on hours or migrating to a light bulb with more efficient technology. This technology migration is differentiated according to the type of luminaries, as shown in Figure 11 and 12.

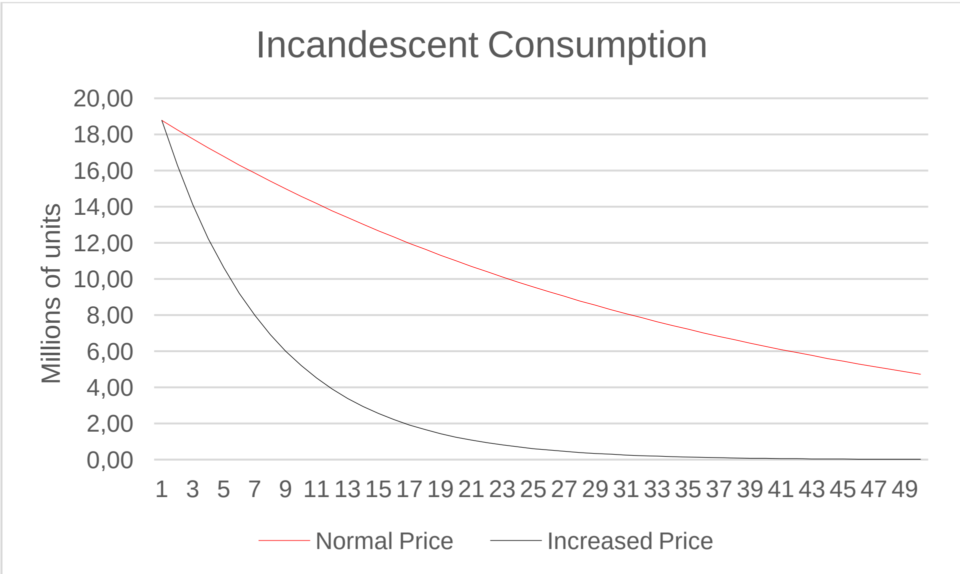

Figure 11. Incandescent Energy Consumption under the two scenarios.

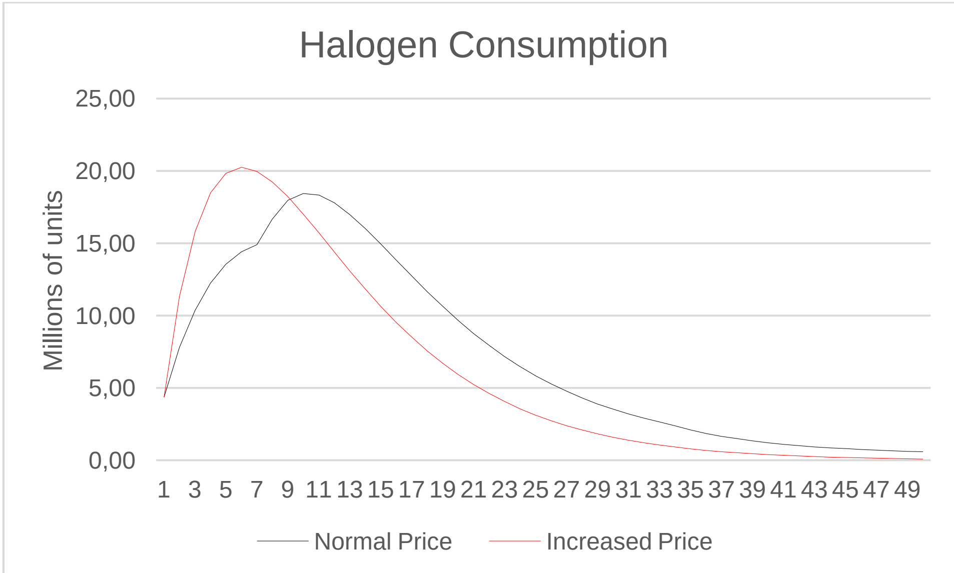

Figure 12. Halogen Energy Consumption

The model was run under the effect of extreme values, which allowed both checking for its sensitivity and robustness and identifying the parameters that define the behaviour of the system. First, the variables "recycling rate" and "discount on bulb price", which are present in the "recycled materials incorporation instrument", were taken to values of 95% and 46%, respectively, while maintaining the proportions established by the policy in question. Under the effect of these increments, consumption underwent a considerable increment, which shows the sensitivity of the model with respect to the variables that define the policy instrument, as shown in Figure 13.

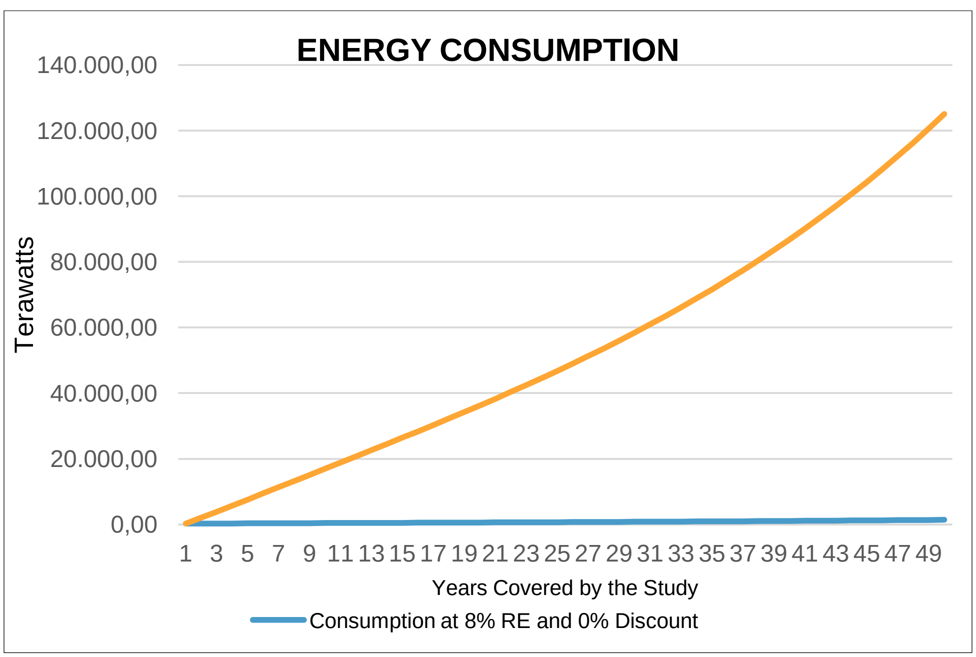

Figure 13. Energy Consumption.

Another sensitivity analysis of the model focused on the reaction of power consumption per bulb in face of changes in power cost, which was initially increased by 100%, and then reduced in the same proportion. That is, the minimum power cost was COP$ 3.572,3 ($1,34 US), and the maximum was COP$ 35.723 ($13,38 US). Consumption per bulb remained constant, i.e., consistent with the initial conditions, after power cost reduction. In turn, the increment in power cost reduced consumption per bulb by approximately 63%, as shown in Figure 14.

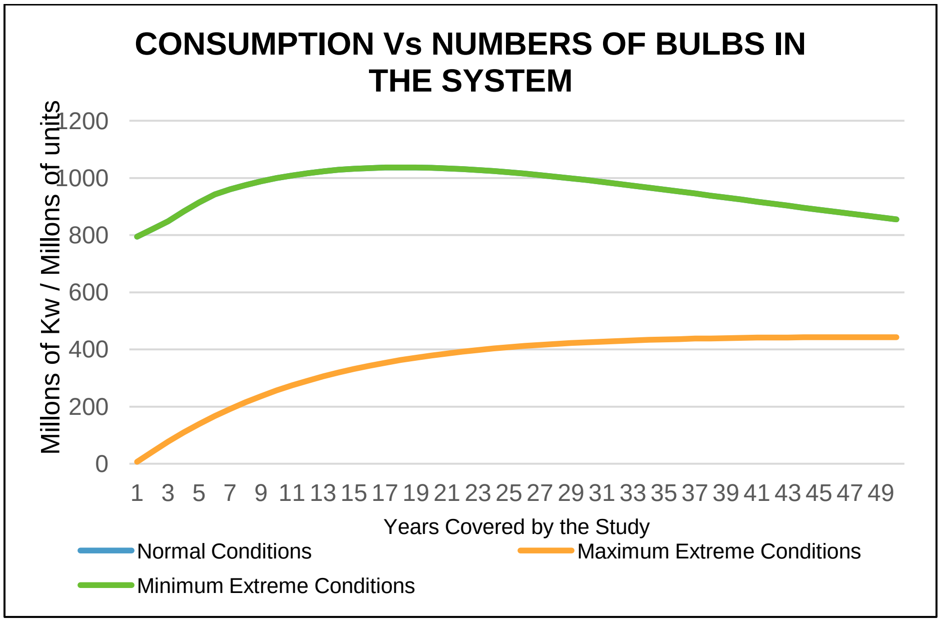

Figure 14. Consumption Vs. Number of Bulbs

5. IMPLEMENTATION OF POLICY INSTRUMENTS.

There is policy instruments associated with the adequate management of products at different stages of the lifecycle. These instruments are administrative, informative, and economical and they are applied in order to mitigate the impact to the environment. The obligations established by law, the restriction of hazardous substances, the establishment of extended producer responsibility, standards of minimum content of recycled material, standards for capacity planning in manufacturing networks and systems recovery and recycling collection are found among administrative policies instruments. The instruments of economical policy are taxes "up stream" and "down stream", which affect the producer and the user respectively, and subsidies for meeting goals of administrative instruments. Among the instruments of information policy, eco-labels that give consumers information about the components that has the product in the whole life cycle are found. In terms of energy efficiency, policy instruments such as eco-design, energy efficiency labels, regulations, minimum consumption by type of lighting, real-time meter consumption, and kilowatt-hour tariff increase according to consumption levels. The model with five policy instruments is analysed.

Hazardous materials elimination

At the end of life phase, the policy of disposal of hazardous substances, specifically mercury gas, which is present in the manufacture of compact fluorescent lamps and fluorescent tubular, is evaluated. This policy seeks to eliminate this type of light bulbs of the market, within a 8 years horizon as application deadline, which corresponds to 2023 in the simulation. There is a small increase in the halogen light bulb, due to the migration of compact fluorescent to the next more efficient technology, which is also closer in cost.

While it is important to highlight the growth of LED, because at the end of the simulation period this is the light bulb with greater use in Bogota household, a rapid drop in the number of compact fluorescent light bulb in use is evident, as well as other technologies, demonstrating the consequences of the effective implementation of this policy. See Figure 15.

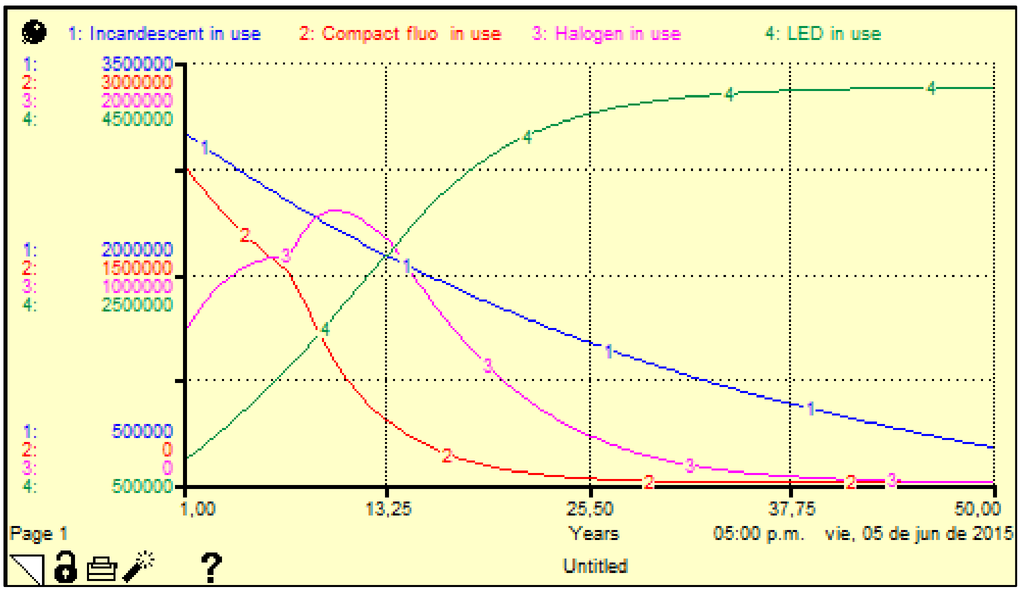

Figure 15. Number of Light bulbs in use by type of light bulbs.

Recycled materials incorporation.

In end of life subsystem, the impact of incorporating recycled materials in the production process is quantified in different scenarios as well as the price discount for producers. The government gives subsidies according to the recycling material recovery amount. It poses as current situation that only 8% of the light bulbs materials are recycled and producers have no incentive, so they do not transfer any discount to the consumer. While in the later stages an increase of 10% in the rate of utilization and a discount done is less than half the rate of use made arises, which means that if the rate of utilization is 28%, then discount made will be 13% corresponding to less than half of the total use rate. See Table 2 and graphs 16.

	Reincorporated rate	Discount
Initial Situation	8%	0%
Scenario 1	28%	13%
Scenario 2	48%	23%
Scenario 3	68%	33%

Table 1. Material Reincorporated to the production process Vs. Discount.

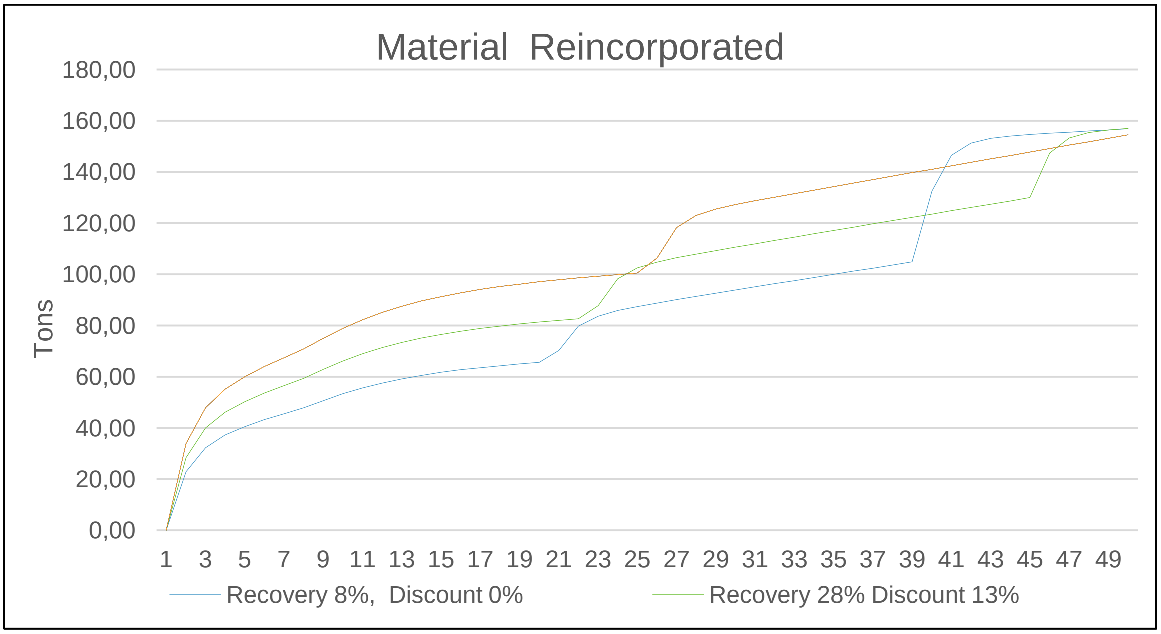

Figure 16. Material Reincorporated to the production process to encourage producers.

Figure 16 show that the higher incentive to incorporate recovered materials in the production process, the faster the growth rates, but the same final value is reached. Recovery of 48% does not increase the growth rate.

Recycling consumer tax

The price of each light bulb is increased by 10% on account of material recovery logistics operations. In addition, a fixed value is added to the compact and tubular fluorescent light bulbs price, due to hazardous material recovery. See Figure 17.

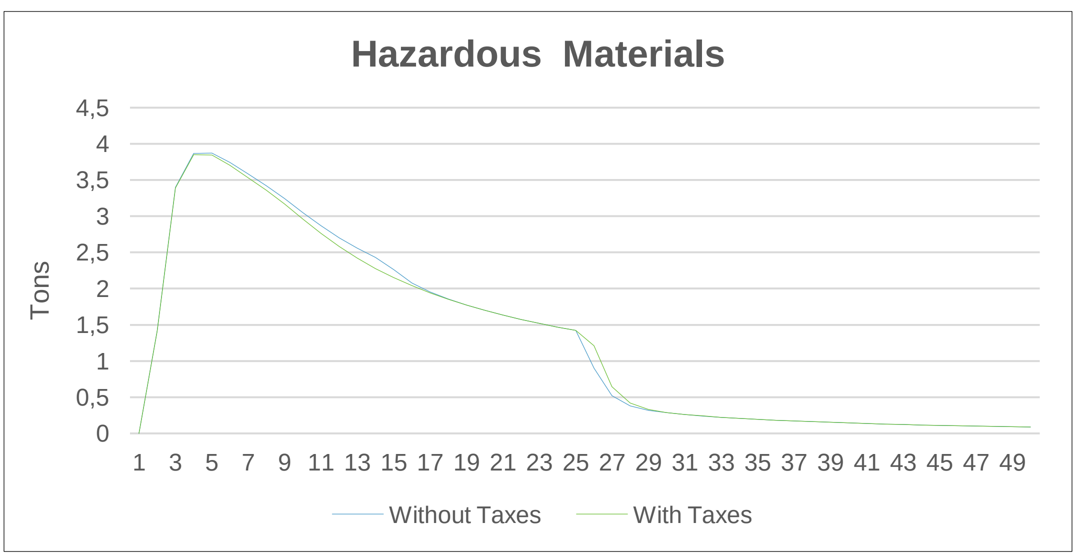

Figure 17. Amount of Hazardous Materials

The hazardous materials recovery has a similar behaviour in both scenarios due to the rapid migration from low energy efficient light bulbs to more efficient ones.

Energy cost variation

Subsystem usage behaviour is seen in energy consumption as a function of the variation in the cost of energy; the behaviour of the model is analysed in terms of purchasing and disposition of light bulbs. The energy cost is increased by 10%, 20%, 30% and 40%. Then, household energy consumption behaviour is influenced in a small percentage by the energy cost variation, due to the low energy price.

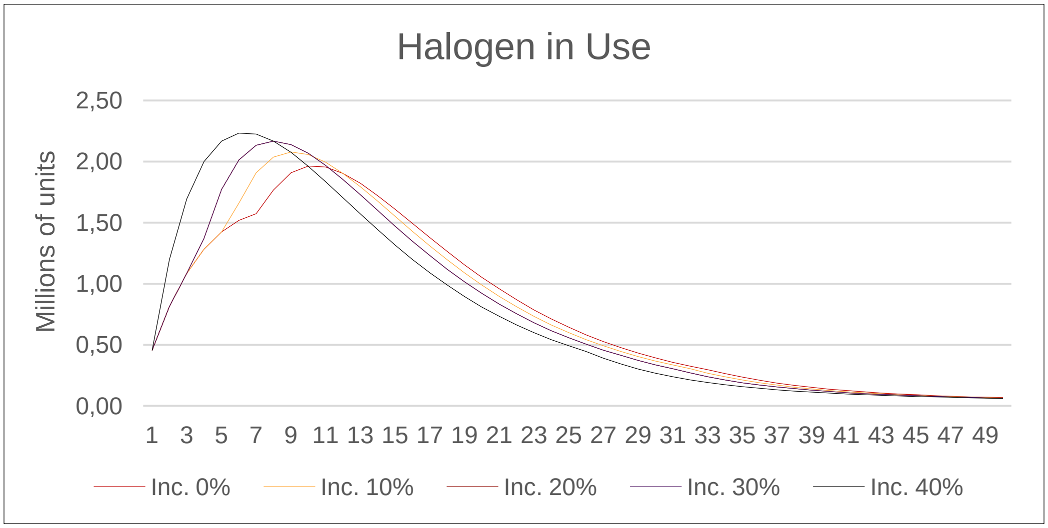

Figure 18. Power Consumption Halogen Light bulbs varying the Price of Energy.

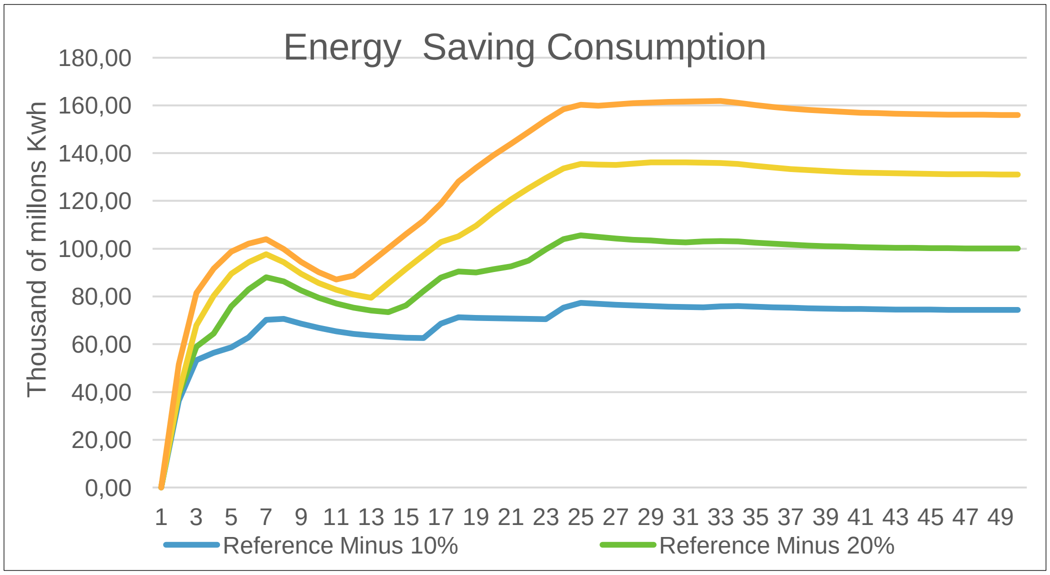

Figure 19. Energy Saving Consumption

Since the model includes the possibility of a fast migration to more efficient light bulb technologies, users do not decrease the amount of lights bulbs or the use patterns. They simply move to a better-labelled bulb and an energy saving potential appears.

Intra-Technology Energy Efficiency Change

In the production subsystem, consumption label regulations are applied to each light bulb type. The modelled regulation established three energy efficiency categories: label C indicates the average efficiency available in the marketing; label B, a relatively increased efficiency (20%); and label A, the maximum efficiency available in the market (50%). The price of the light bulbs in the different labels is considered as shown in Table 2.

Light Bulb	Light Bulb Cost		
	Label C	Label B	Label A
Incandescent	$ 0,56	$ 0,75	$ 0,86
Compact Fluorescent	$ 4,50	$ 5,25	$ 6,11
Tubular Fluorescent	$ 1,87	$ 2,40	$ 3,00
Halogen	$ 6,00	$ 6,75	$ 7,68
LED	$ 10,68	$ 11,62	$ 12,93

Table 2. Energy Efficiency Label Vs. Cost of Lights.
Source: Current Market Prices (1 Dollar=2667.97 Colombian Pesos)

The potential energy savings are bigger as a more efficient light bulb is selected, as shown in Figure 20, although the average energy consumption keeps growing due to population growth.

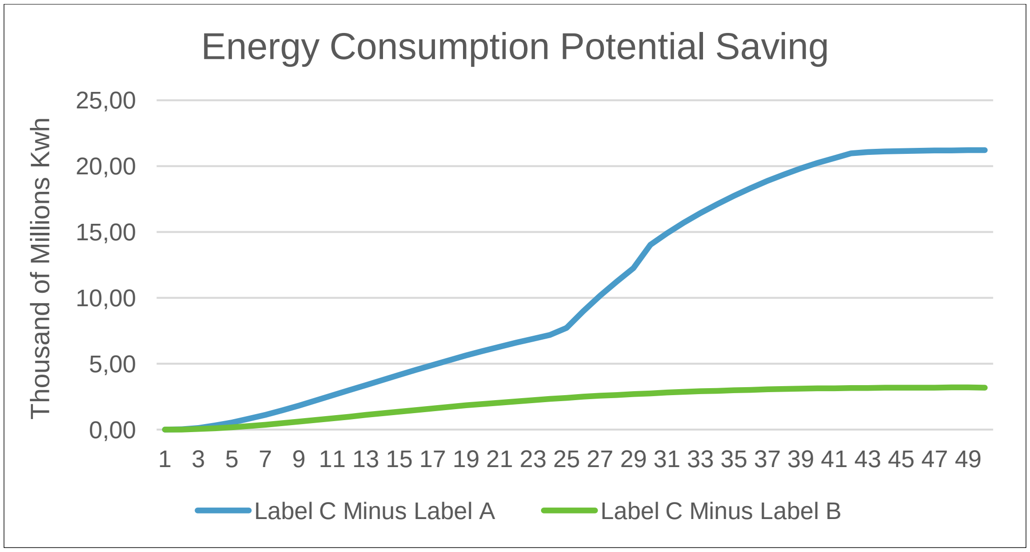

Figure 20. Energy Consumption Potential Saving.

6. ANALYSIS OF RESULTS AND SENSITIVITY ANALYSIS OF THE MODEL

To determine which policy instruments render better results in terms of both energy consumption and return of materials to the production process, the per cent improvement resulting from the application of each of the instruments was calculated upon the initial conditions of the system. The recycled materials incorporation instrument was found to determine a 36.8% increase in the amount of recycled materials. In assessing the percentage of improvement in terms of energy consumption, the latter was reduced by 4% as a result of the application of the energy cost variation instrument, as shown in Table 3.

Policy Instrument	Percentage of Improvement	
	Recycled Material	Energy Consumption
Intra-Technology Energy Efficiency Change	2,3790%	-0,0343%
Energy cost variation	**2,7881%**	**3,8838%**
Recycled materials incorporation.	**36,7378%**	**0,4841%**
Hazardous materials elimination	-0,4958%	1,2644%
Recycling consumer tax	2,2474%	-0,0037%

Table 3. Percentages of improvement by Policy Instruments.

Applying simultaneously the previous best policies (Recycled materials incorporation and Energy cost variation) in the model simulation, the recycled material grows as well as energy consumption decrease.

Policy Instrument	Percentage of improvement	
	Recycled Material	Energy Consumption
Energy cost variation And Recycled materials incorporation	38,94%	6,04%

Table 4. Percentages of improvement by Best Policy Instruments.

Simulating the model with the four policies, (*Variation in energy cost, recycled materials incorporation, Energy Efficiency Intra-Technological Change and Recycling Consumer tax),* a significant improvement in the consumption and recycled material is observed, 44,9% of recycled material and reduction of energy consumption in 7,5%, as shown in Table 5.

Policy Instrument	Percentage of improvement	
	Recycled Material	Energy Consumption
Energy cost variation, Recycled materials incorporation, Energy Efficiency Intra-Technological Change And Recycling consumer tax	44,85%	7,53%

Table 5. Percentages of improvement by Four Policy Instruments.

7. CONCLUSIONS

The synergy of different policy instruments gives the best result to the recycled material and energy consumption. Policy instruments applied in the first stage of the lifecycle produce a better result than those applied in the use and end of life stage.

Under the current conditions of the system, the diversity of bulbs of the same type with different levels of efficiency and very similar costs does not generate a significant variation in the system. In other words, inter-technology changes are not attractive to consumers. Contrastingly, power cost increment was found to affect consumption. When that increment is greater than 10% of the current power cost, consumption decreases, either by migration to more efficient technologies or by a drop in lights-on time. On the other hand, the policy of recycled materials incorporation to the manufacturing process and giving discounts on the price of bulbs encourages the purchase of these products and significantly reduces their environmental impact. For its part, the policy of hazardous materials elimination from the system succeeds by driving the production of compact fluorescent bulbs to zero. Finally, recycling consumer tax policy shows that the hazardous material is not sensitive to it, while the amount of clean material that is incorporated to the production process presents a significant increase over time.

It can be concluded that economic instruments produce the best results, if the single instrument is considered. Incorporating recycled material, which generates a win-win scenario for the consumer, the manufacturer and the environment can attain a reduction in bulb price. In turn, varying power cost, thus confirming that raising the price discourages demand, can successfully control energy consumption. Other policies facilitate faster technological changes, thus reducing the hazardous materials and remarking that the synergy resulting from the implementation of several policies with different purposes in the EEE cycle attains the best results in terms of reducing environmental impacts.

Future research may include the educational levels of the population, in order to model the intra-technology behaviour of the system in face of larger power differences among labels. Also, other socioeconomic strata may be included to attain a general model of the Bogotá population and determine whether there are variations between strata due to their contrasting socioeconomic conditions.

8. References

1. Calcott, P., & Walls, M. (2002). Waste, recycling, and “design for environment”: Roles for markets and policy instruments. Resource and energy economics, 27(4), 287-305.
2. Comisión Europea, 2001. Política de producto integrada. Online: *http://ec.europa.eu/environment/ipp/home.htm. Consulted on 2014.05.22.).*
3. Comisión Europea, 2010. Consumo y Producción sostenibles, más inteligente y más limpio. Online: *http://ec.europa.eu/environment/eussd/pdf/brochure_scp/kg006508ES_2.pdf. Consulted on: 2014.05.22).*
4. Eichner, T., & Runkel, M. (2005). Efficient policies for green design in a vintage durable good model. Environmental and Resource Economics, 30(3), 259-278
5. ELCFED, (2008). The life cycle of a lamp. Online: http://www.elcfed.org/documents/050301%20DYK%20the%20potential%20of%20energy%20savings%20of%20an%20energy%20efficient%20lamp.pdf. Consulted on: 2014-12-13.

6. Elshkaki, E. v. (2005). Dynamic stock modelling: A method for the identification and estimation of future waste streams and emissions based on past production and product stock characteristics. *Energy*, 1353–1363
7. EPA, 2009. Fluorescent Lamp Recycling. Online http://www.epa.gov/osw/hazard/wastetypes/universal/lamps/lamp-recycling2-09.pdf. Consulted on: 2015-01-30
6. Georgiadis, P. M. (2009). Environmental and economical sustainability of WEEE closed-loop supply chains with recycling: a system dynamics analysis. *The International Journal of Advanced Manufacturing Technology*, 475–493.
7. Georgiadis P., A. E. (2010). The impact of two-product joint lifecycles on capacity planning of remanufacturing networks. *European Journal of Operational Research*, 420–433.
8. Gottberg, A., Morris, J., Pollard, S., Mark-Herbert, C., & Cook, M. (2006). Producer responsibility, waste minimisation and the WEEE Directive: case studies in eco-design from the European lighting sector. *The Science of the Total Environment*, *359*(1-3), 38–56.
9. Greening L., Greene, D., Difiglio, C. (2000). Energy efficiency and consumption-the rebound effect-a survey. *Energy Policy 28 389-401*.
10. Khetriwal, D. S., Kraeuchi, P., & Widmer, R. (2009). Producer responsibility for e-waste management: key issues for consideration–learning from the Swiss experience. Journal of Environmental. Management, 90(1), 153-165.
11. Khetriwal, D., Kraeuchi, P., & Schwaninger, M. (2005). A comparison of electronic waste recycling in Switzerland and in India. Environmental Impact Assessment Review, 25(5), 492-504.
12. Lee, T. K. (2005). Resource Cyclical Dynamics of Electric and Electronic Equipment Waste.
13. Lindhqvist, T., Manomaivibool, P., & Tojo, N. (2008). La responsabilidad extendida del productor en el contexto latinoamericano. Online: http://www.basuracero.org/sitio/admin/archivos/la-responsabilidad-extendida-d.pdf . Consulted on: 2015-09-23
14. Panzone, L., (2013). Saving money vs investing money: Do energy ratings influence consumer demand for energy efficient goods?. *Energy Economics 38, 51–63s* .
15. Rodríguez LA, González N, Reyes L, Torres A. (2013) Sistema de gestión de residuos de aparatos eléctricos y electrónicos. Enfoque de dinámica de sistemas. *Revista Facultad de Ingeniería Sistemas y Telemática. Universidad ICESI Vol 11, No 24 (2013) 39-53.* ISSN: 1692-5238
16. Secretaria Distrital de Planeación. (2011). Viviendas, Hogares y Personas por Estrato. Online: http://www.sdp.gov.co/PortalSDP/InformacionTomaDecisiones/Estadisticas/ProyeccionPoblación. Consulted on: 2015-01-20
17. Schröter, T. S. (2005). A system dynamics model for strategic management of spare parts in closed-loop supply chains. *The 23rd International Conference of the System Dynamics Society.*, 1–13.
18. UPME, 2007. Alumbrado interior de edificaciones. Online: http://www.upme.gov.co/Docs/Alumbrado_Residencial.pdf. Consulted on: 2014-11-12.