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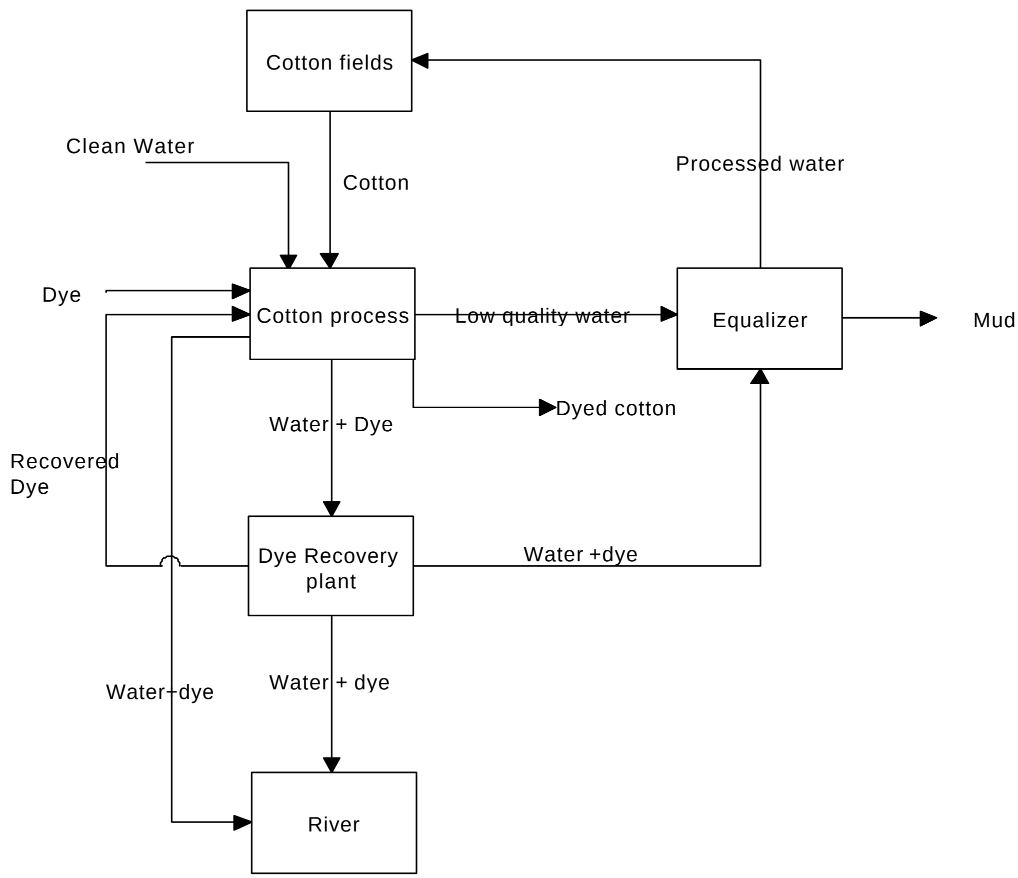
MODELLING ECOINDUSTRIAL PARK RESPONDS TO DIFFERENT ENVIRONMENTAL POLICIES

PURPOSE OF THE MODEL

The main purpose of this paper is to point out how modelling can be useful either as a tool to design environmental policy or as a helpful tool for enterprise management.

In this case, we are going to analyze an ecoindustrial park respond to different economic environmental policies developed by the administration. We will notice, on the one hand, how this tool could be useful to managers who wanted to adapt industrial processes to minimize the costs to fulfill environmental legislation. On the other hand, modelling could help public administrators to design efficient and fair environmental policies, as well as to obtain an estimation of the results of their further implementation.
We will model processes shown in the following diagram:



Cotton fields
Clean Water
Cotton
Processed water
Dye
Cotton process
Low quality water
Equalizer
Mud
Dyed cotton
Water + Dye
Recovered
Dye
Dye Recovery
plant
Water +dye
Water+dye
Water + dye
River

DESCRIPTION OF THE MODELLED PROCESSES

Cotton processing is the main activity of our ecoindustrial park, which essentially consists on a mechanical manipulation and a dyeing procedure.

This process requires *cotton*, *clean water* and *dyes*, as inputs, and as outputs it generates two residual flows: one of *low quality water* (from the mechanical process) and another of *mixed water and dyes*. Obviously, it also generates a product (dyed cotton), which is the original cotton and a fraction of the initial quantity of dyes.

The *processing plant* is located close to the river. Since it is cheaper to dump wastes to the river (externalizing environmental costs), than to recover them, and the enterprise wants to minimize costs, the river is the destination of the mixed and dyes flow if there is not environmental policy against it. Nevertheless, if administration develops some environmental policy (taxes, regulation or whatever), the situation may change, and it will not be so clear for the industry that the cheapest thing to do is to pour everything to the river. Then managers will have to decide whether it is cheaper to keep on dumping (and face the penalties) or it is more interesting to carry wastes to recovery plants (and assume these additional costs).

To model this situation we have supposed the existence of two recovery installations. One of them, owned by the cotton processing enterprise, is a *dye recovery plant*. This plant is used or not depending on the environmental administrative policy against dumping to the river. The more severe it is, the more the plant is going to be used.

This plant will recover an important amount of dyes but, despite these are valuable raw materials, it is far more expensive to recover dyes than to dump them and buy new ones, if there is no environmental policy.

On the other hand, *low quality water* and the output water of the *dye recovery plant* (still with some dyes remaining in it) are carried to an *equalizer*, in order to increase their quality. The equalizer outputs are a water flow used to irrigate the nearby cotton fields and a flow of toxic *muds*. These toxic *muds* have to be carried to a legal dumping ground.

We have supposed that the *equalizer* is an independent enterprise, so it charges a price to the cotton processing enterprise for every processed kilogram.

At this point, we will notice how a policy subsiding equalization will comparatively make cheaper the process of dye recovery, so dumping to the river will diminish. Moreover, we will also notice that, if *mud* generation is taxed, dye recovery cost will increase as well as the quantity of mixed water and dyes dumped to the river.

MODEL DEVELOPMENT[1]

In this part of the paper, it is going to be explained the internal structure of the model, as well as different enterprise behaviours related with several environmental administrative policies.

1. COTTON PROCESSING COSTS WITHOUT ENVIRONMENTAL ADMINISTRATIVE POLICY

The quantity of processed cotton is the main data of the model. If we suppose, as it has been done in this case, that rates among cotton, water and dyes are constant[2], cotton defines the process needs for the rest of raw materials and, therefore, it also defines the cotton plant effluents. In our example, we have supposed a daily processing of 2000 kilograms of cotton.

In relation to dyes, as it has already been said, we can either buy or recovery them, but the addition of both quantities has to remain constant in relation with the quantity of processed cotton. In our example, we have supposed that 0.01 *kg of dyes* are needed *per kg of cotton*. Moreover, a fraction of such dyes (20% in this case) is considered to remain with the clothes due to the dyeing process. These dyes have to be replaced as well as those dumped to the river or those remaining in the equalizer *muds*.

In relation to the amount of needed clean water, it has to be said that, like the use of dyes, is proportional to the quantity of cotton processed[3]. Half of the water used gets dirty due to the mechanical processes done in the plant and it goes to the *equalizer*. The other half is mixed with dyes and it can be either poured to the river or carried to the *dye recovery plant*.

Carrying the water to the *dye recovery plant* has an important cost, but it saves a relevant fraction of dyes to be purchased. On the other hand, the cost of dumping polluted water to the river depends almost strictly on the severity of the environmental administrative policy.

In the model it has been defined the *Fraction of water and dyes poured to the river* (F) parameter, which can vary between 0 and 1. As its name says, this parameter indicates the fraction of the *water and dyes mixed* (output flow from the cotton processing plant) that is dumped to the river. The rest of this flow is carried to the dye recovery plant

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1. The program used to develop this model is Stella 5.0 for Windows.
2. We have considered that this is a consistent hypothesis in a short-term period like the one considered.
3. To be consistent, water is also measured in kilograms.

Certainly, this variable is the most important one in the model because it allows the user to know the *cost per kg of processed cotton*, depending on which environmental behaviour the enterprise adopts (F from 0 to 1), given an environmental administrative policy. In a short-term period, as the one studied, this would be the main variable for the enterprise to minimize the cost to fulfill the legislation.

Let us consider now the *dye recovery plant*. When F=0, all the *mixed water and dyes* are carried to the recovery plant and when F=1 everything is dumped to the river. An important part of these dyes (50% in our example) are recovered in the plant, and the rest of dyes, as well as all the amount of water, are carried to the *equalizer*.

The equalizer also receives the *low quality water* flow. The process inside the equalizer is supposed to generated muds (15% of the total inflow), but the rest is considered to become water clean enough to irrigate the nearby cotton fields.

We have supposed that the equalizer is owned by an enterprise different from the one processing cotton. This is relevant in two ways: on the one hand, the equalizing cost is the result to multiply the quantity carried to the equalizer by the price per kg, which is a magnitude not fixed by the processing cotton enterprise, but fixed by the equalizer owners. On the other hand, any environmental policy taxing the equalizer will not directly affect the cotton cost per kg, but indirectly through the equalizing cost.

In conclusion, the cotton processing cost is defined by the addition of the following aspects:

COTTON PROCESS
- Cost of different raw materials (cotton, water and dyes),
- Fixed costs of the process,
- Other variable costs of the cotton process,
- Dumping water and dyes to the river cost[4].

DYE RECOVERY PROCESS
- Using the dye recovery plant cost (proportional to the quantity).

EQUALIZING PROCESS
- Using the equalizer cost (proportional to the quantity):
    - Carrying and irrigating the cotton fields cost,
    - Carrying and dumping equalizer muds cost,
    - Other variable costs of the process.

A part from these aspects, the cotton cost per kg will be also significantly influenced by the environmental policies developed by the administration, as we can see in the following chapter.

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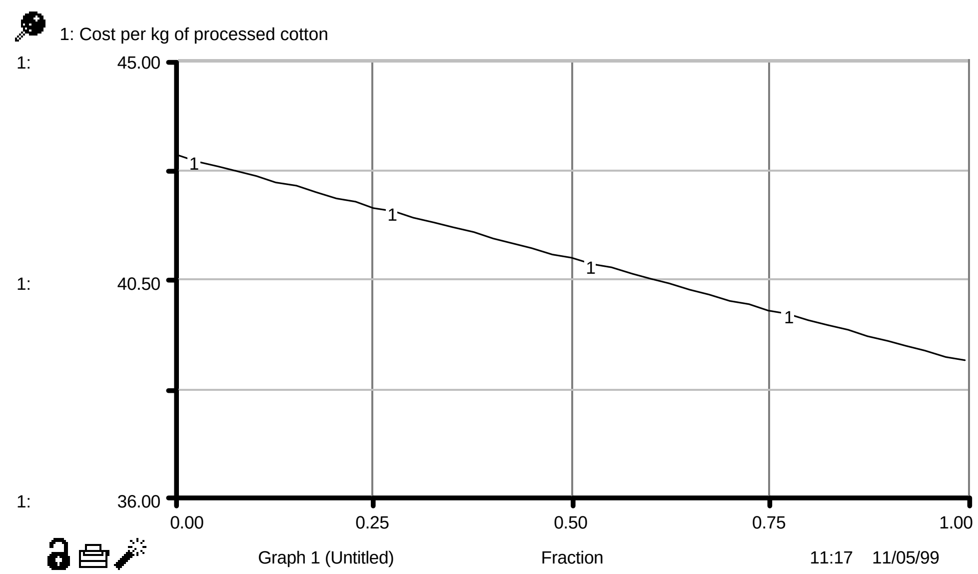
4. Referred to the cost of physical dumping, not to the cost derived from the application of any environmental policy.

2. ANALYSIS OF THE ECOINDUSTRIAL PARK RESPOND TO DIFFERENT ENVIRONMENTAL POLICIES

At each of the following cases, we have run the model and studied the evolution of the cotton cost per kg, for all the allowed F values (between 0 and 1).
It would be interesting to find the F value that minimizes the cotton cost per kg, and discuss how this result is modified if environmental policy changes.

1. Without any environmental administrative policy

Let us suppose, to begin with, that there is no environmental administrative policy. We run the model and obtain a linear behaviour of the cotton cost per kg, depending on F. The minimum cost (p=38.75 m.u./kg[5]) would be obtained for F=1, that is to say, everything dumped to the river. The maximum cost would be obtained for F=0, everything carried to the dye recovery plant. These results are completely coherent with the ones we could have guessed, because if no environmental policy exists, the cheapest attitude for the enterprise is to externalize as much costs as possible.



2. With a proportional tax against dumping to the river

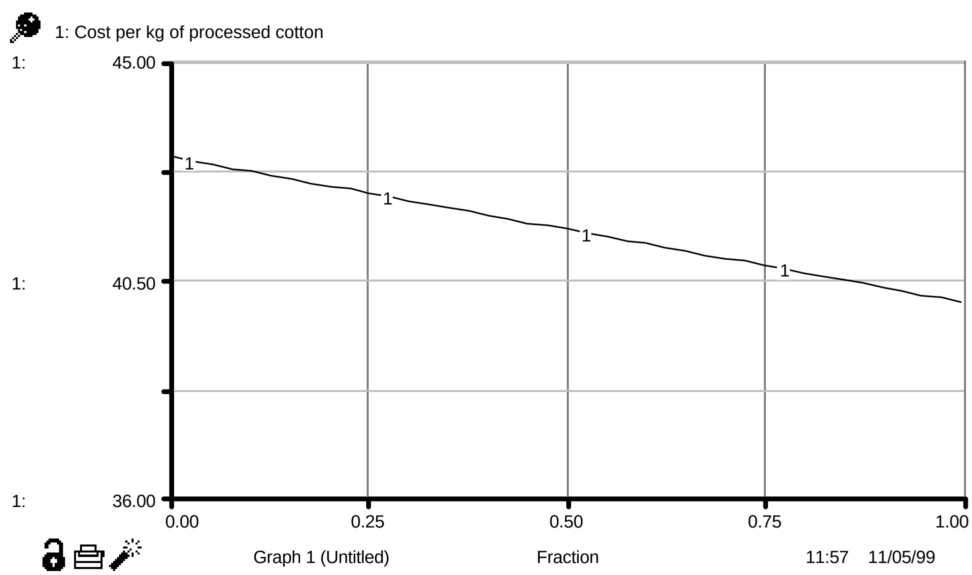
In this case, we suppose that the Administration establishes a proportional tax to the amount of water and dyes poured to the river. This defines another linear cost function, depending on F, which has to be added to the one obtained in the first case.

5. Monetary units per kilogram, given certain per-kilo prices for raw materials and other estimated variable and fixed costs of the process.

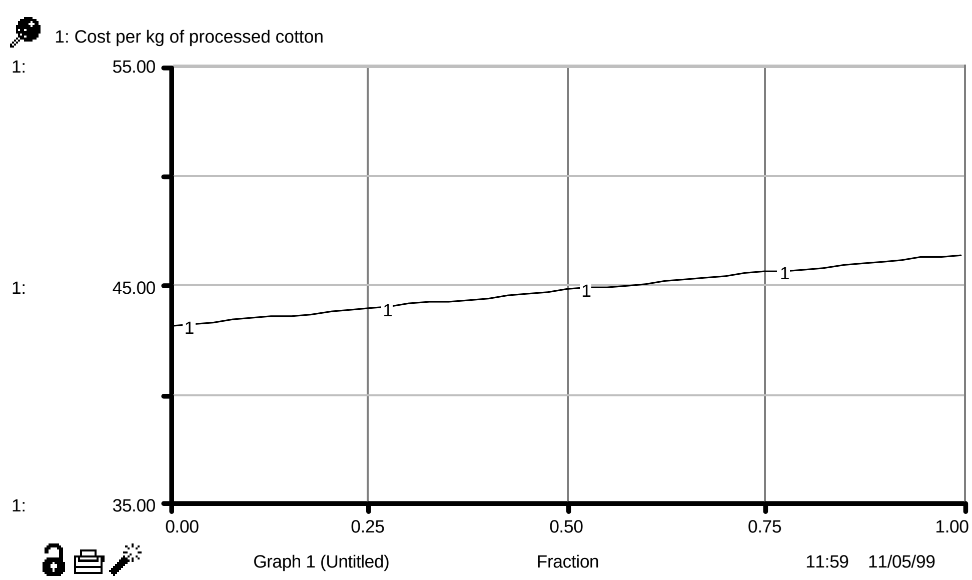
If these additional costs are higher than the ones of the dye recovery plant, then the minimum cotton cost per kg is going to be obtained for F=0: all mixed water and dyes are carried to the recovery plant. If these additional costs are not high enough to compensate these recovery costs, the minimum cost will remain for F=1, everything to the river.

This is a quite simple case, not according to reality, where even a low tax may have some effect. However, these results can be explained because two linear function are added (first case cost + proportional tax), so the minimum cost will be obtained either for F=0 or for F=1.

For a low *proportional tax value* like 0.05, for example, we obtain the minimum *cotton cost per kg* (p=40.00 m.u./kg) for F=1, total dumping.



On the other hand, for a higher *proportional tax value*, like 0.03, minimum *cotton cost per kg* (p=43.00 m.u./kg) is obtained for F=0.



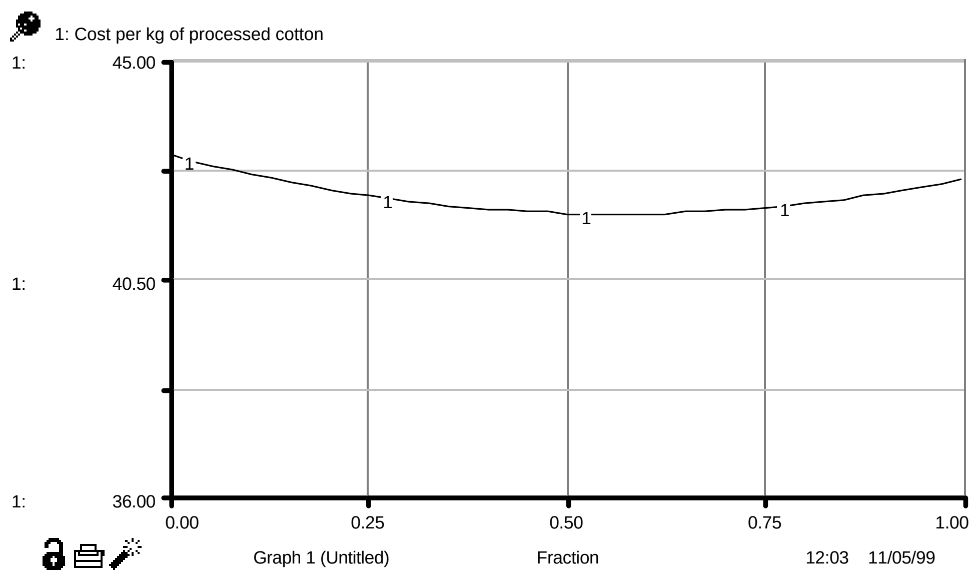
3. With a marginally increasing tax against dumping to the river

Let us suppose that Administration decides to implement a *marginally increasing tax* to water and dyes poured to the river, instead of the *proportional tax* we have just studied in the previous case.

We define a linear marginal tax, increasing as the quantity dumped to the river increases. The integral of this linear function, for a fixed cotton production, depends on F^2. This is the amount of money that cotton-processing enterprise has to face, depending on its environmental behaviour F.

In this case, it can be guessed that the total cost depending on F may be obtained as the addition of a linear function (first case) plus the non linear function just explained.

Running the model it can be obtained the minimum price (p=41.80 m.u./kg) for F=0.55[6]. This price is cheaper than the one obtained for F=0 (maximum recuperation) because marginally increasing tax do not affect significantly the first quantities of pollution emitted. The more we approach F=1, the higher tax effects become, because of its marginally increasing characteristics.



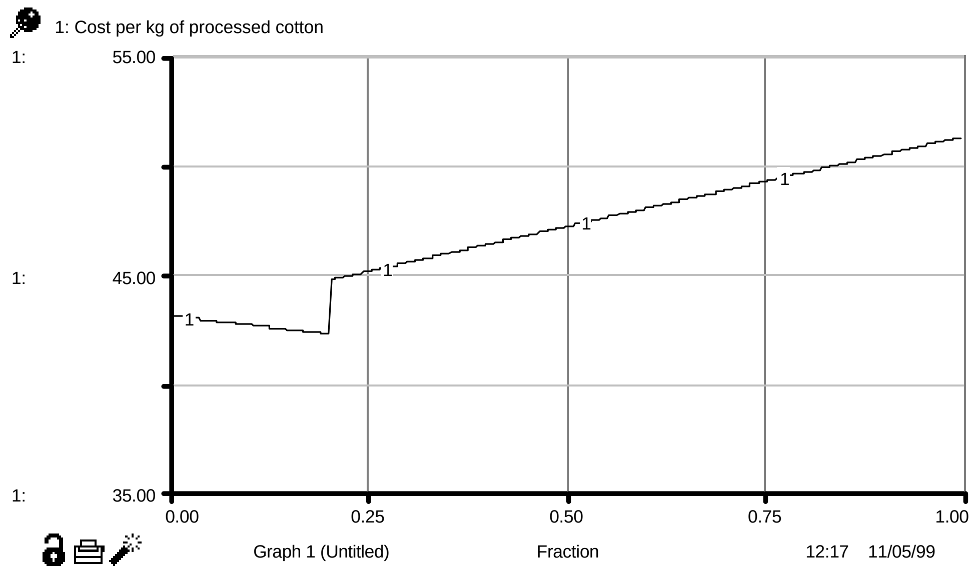
4. Existence of environmental regulation against dumping to the river

In this case, Administration fights dumping to the river with an environmental standard, instead of using taxes. If the quantity dumped to the river is allowed by the standard, enterprise has to pay nothing. Otherwise, it has to face a high

6. These results are obtained defining the marginally increasing tax as 0,15/25000*water_and_dyes_to_the_river. Changing the slope value it can be noticed how F also changes, obtained either more dumping or more dye recuperation.

penalty (higher than dye recovery cost), which is proportional to non-allowed emissions.

Running the model the minimum cost (p=42.15) it is found for F=0.2, which corresponds with the maximum contamination allowed, given a fixed cotton production[7]. This value is the same obtained in case 1 for F=0.2, because in neither one of the situations there is any tax increasing costs.



5. With a marginally increasing tax against dumping to the river and a proportional tax against equalizer muds

This case is similar to case 3, but moreover we have to add costs derived from the proportional *tax against mud generation* in the equalizer.

Muds are toxic, so it is coherent to charge them. Anyway, it has to be emphasized that, in our study, muds these muds are obtained in a recovery process, so it is fairer and more efficient to tax direct dumping to the river than dumps or any other aspect related with recuperation processes.

Running the model switching on this new tax, we can notice how equalizing cost increases and, indirectly, so does the dye recovery process. That is why the F optimal value obtained in this case is higher than the one obtained in case 3, so a greater fraction of mixed water and dyes are dumped to the river. For the *tax against mud generation* defined, minimum price (p=43,33 m.u./kg) is obtained for F=0.725.

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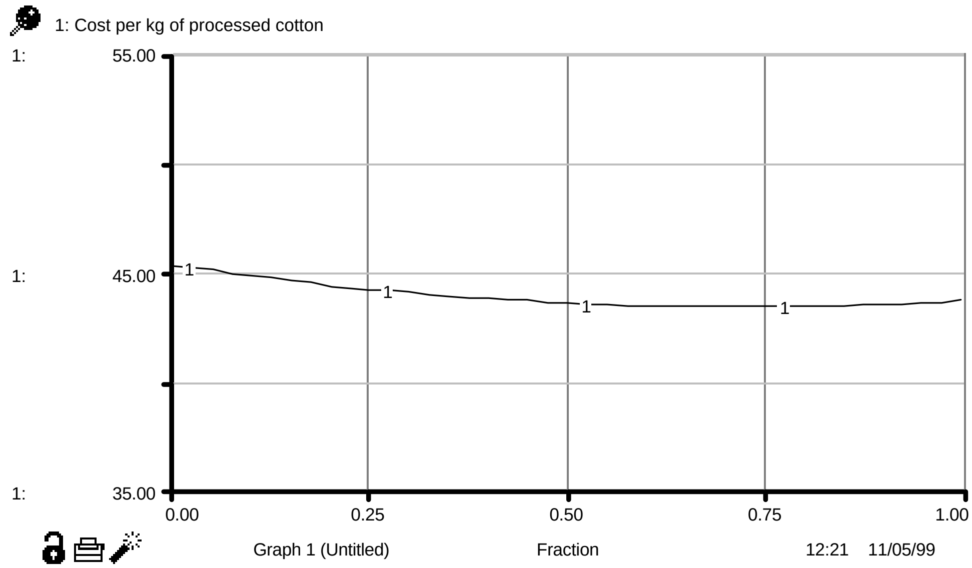
7. If the amount of processed cotton was increased, remaining the standard fixed, a lower F optimal value would be obtained and vice versa. In our example, allowed contamination is 10000 kg/day.

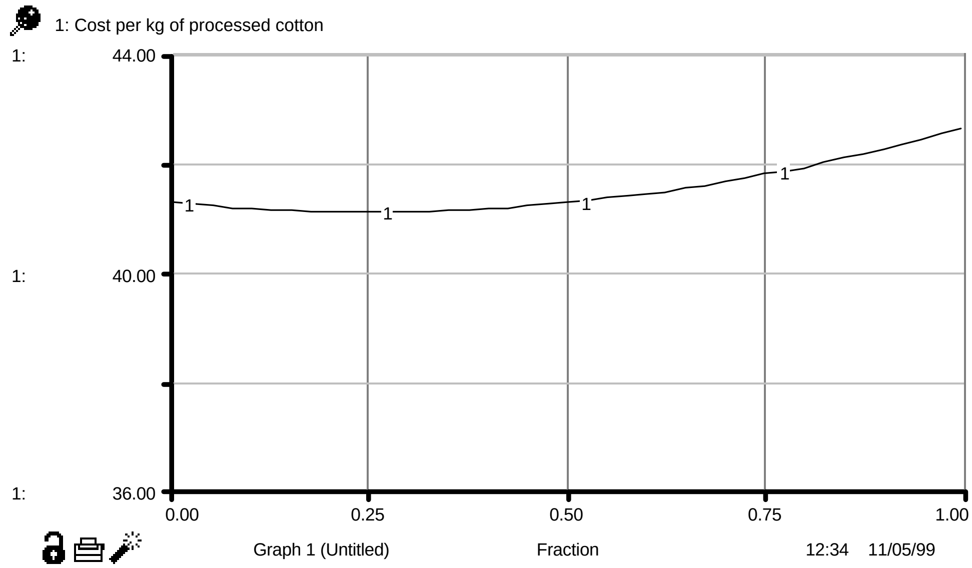


6. With a marginally increasing tax against dumping to the river, a proportional tax against equalizer muds and a subsidy to the amount carried to the equalizer

This case is similar to case 5, but moreover Administration decides to subsidy the processing cotton enterprise in a marginally increasing relation to the quantity of wastes carried to the equalizer.

It has to be emphasized that this is a subsidy to the cotton processing enterprise and not to the equalizer itself, which has slightly different effects. It also has to be pointed out that this kind of subsidies can have hardly justification in reality, because they transfer public resources to a polluting enterprise, which is a quite arguable policy.

Having added this new subsidy and running the model, it can be noticed that recovery processes become cheaper and, therefore, cotton cost per kg diminishes for every F value. Moreover, we can observe that F optimal value (F=0.25) is much lower than in case 5, as well as the minimum cotton cost per kg obtained (p=41.08).



Finally, it has to be remarked that this model can deal with several other combinations of the policies studied in the previous cases. Especially interesting may be those combinations entailing both regulatory standards and environmental taxes, because this is quite likely to happen in real policy.

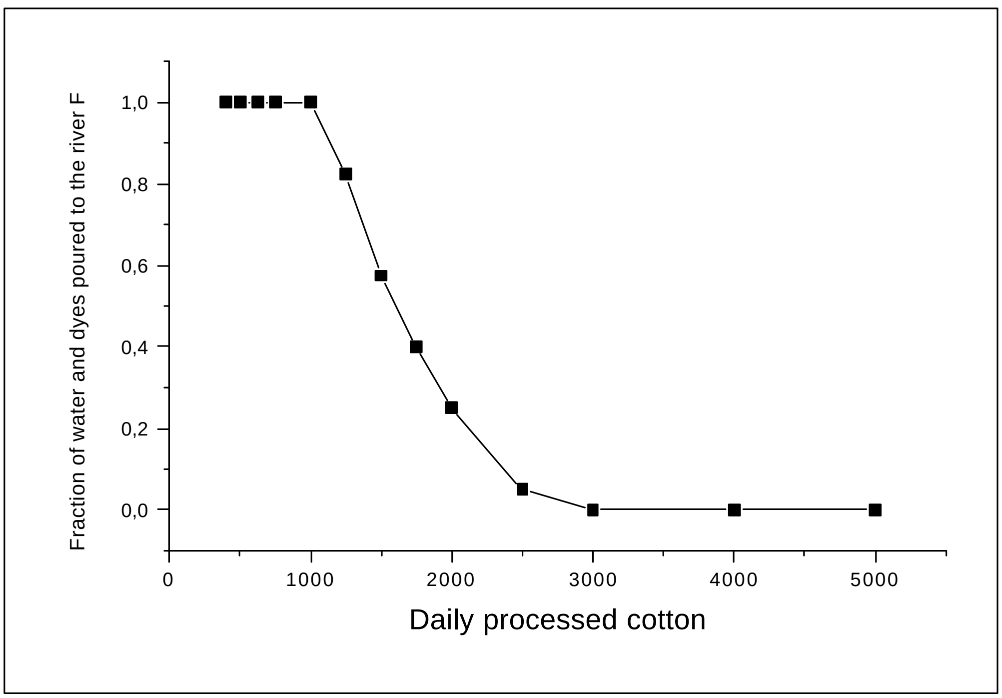
It is also interesting to notice that we could keep on increasing the model, trying to approach real complexity. For example, we could model the cotton fields (seasons, needs of water or fertilizers,...), we could analyse hypothetical investment to reduce dye generation, we could model with more detail some of the economical aspects,... That probably would have the advantage to obtain more accurate results, but on the other hand it would be more difficult for the model users to guess and to understand enterprise responds.

PRODUCTION SCENARIOS

To finish the model description, we want to assess what happens for different production levels[8], in the last explained case (6).

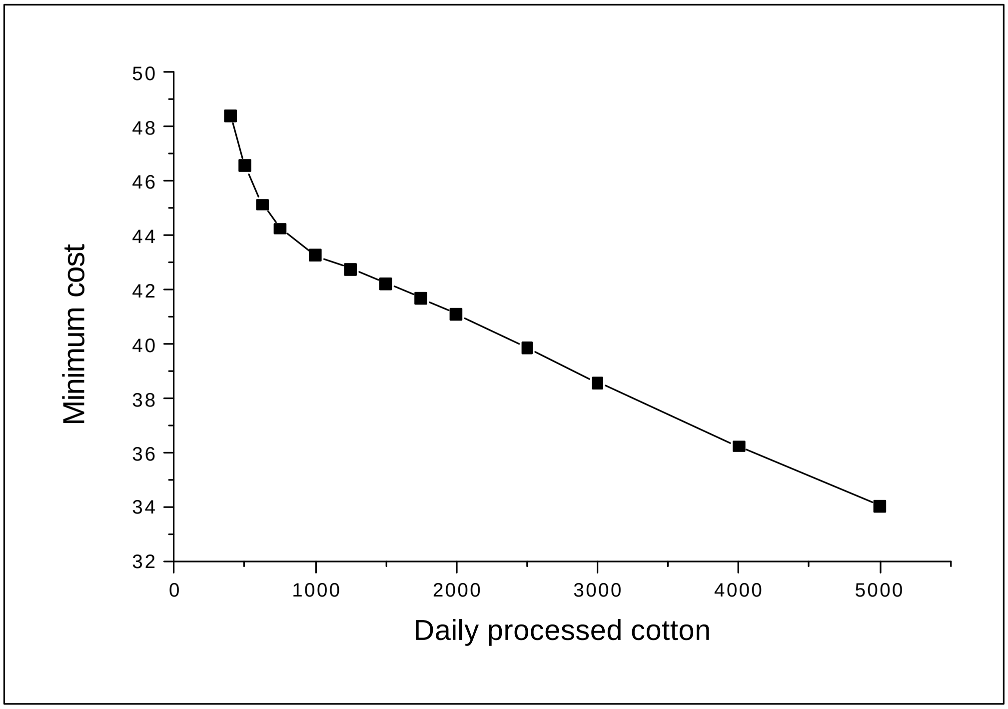
For different amounts of processed cotton, we get different results of minimum cost and optimal F, as it is shown in the following table and graphic:

Processed cotton (kg/day)	Minimum cost	F
400	48,42	1
500	46,56	1
625	45,13	1
750	44,24	1
1000	43,25	1
1250	42,75	0,825
1500	42,23	0,575
1750	41,67	0,4
2000	41,08	0,25
2500	39,83	0,05
3000	38,58	0
4000	36,24	0
5000	34,04	0



8. Since now, we have considered a daily processing of 2000 kg of cotton.

In the graphic it can be noticed how little productions are not as affected as the bigger ones by the tax against dumping to the river, because of its marginally increasing character. Therefore, under a certain production level, enterprise would not use the dye recovery plant and, on the other hand, beyond a certain production level nothing would be poured to the river.



On the other hand, it can be observed that, the greater the production gets, the fewer the costs per unit of processed cotton become. This happens mainly due to the existence of an important fixed costs.