Design and planning of the bioethanol supply chain via simulation-based optimization: *The case of Argentina*

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Introduction

Agentina's National Law #26093 (2006)

Provides the framework for investment, production, and marketing of biofuels.

Establishes a minimum content of biofuels in gasoline and diesel.

>5%

Current situation*

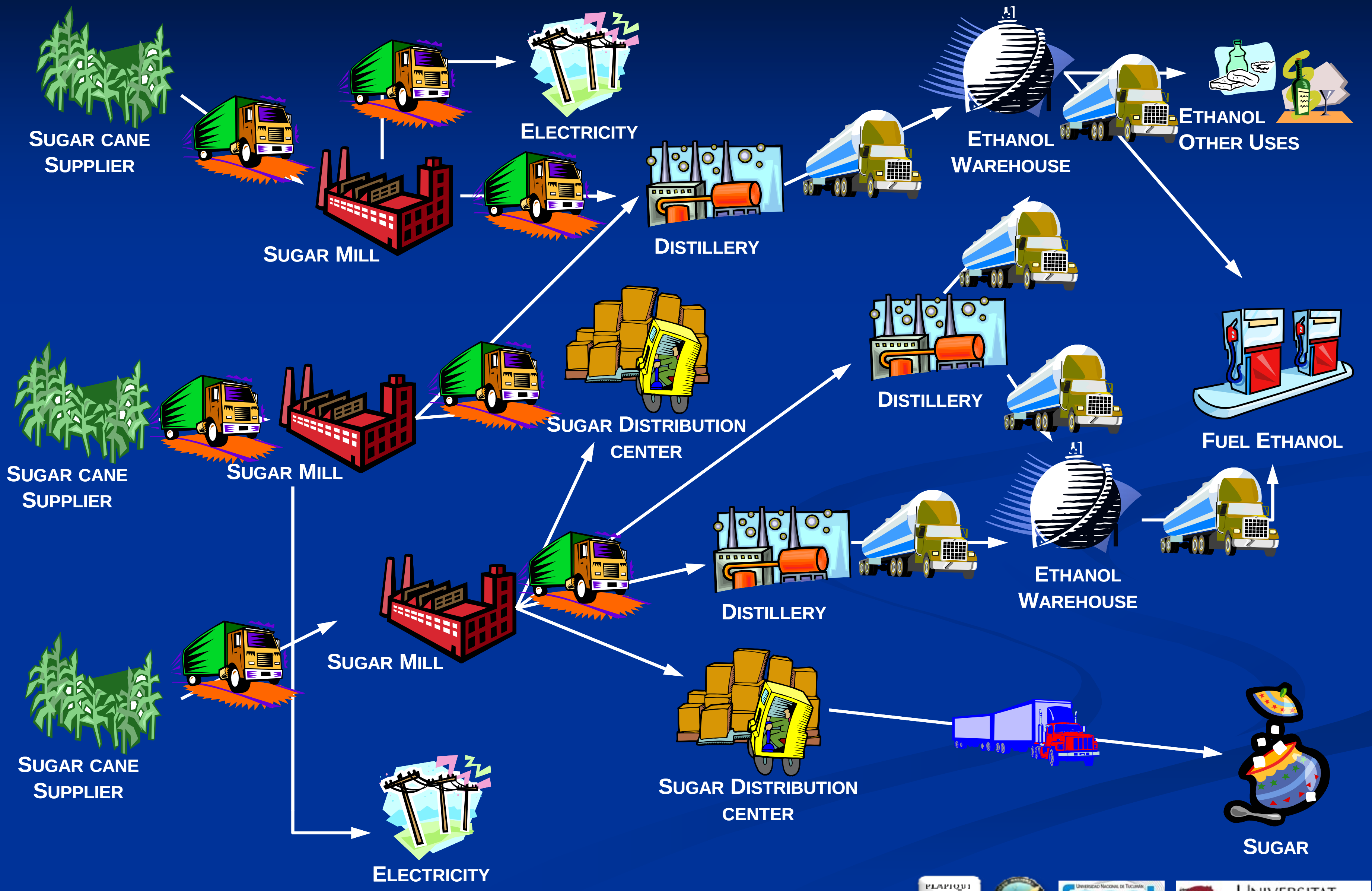
Ethanol from sugarcane
23 sugar mills
120000tn/d process capacity
→ **only 3% of content**

Expansion needed!

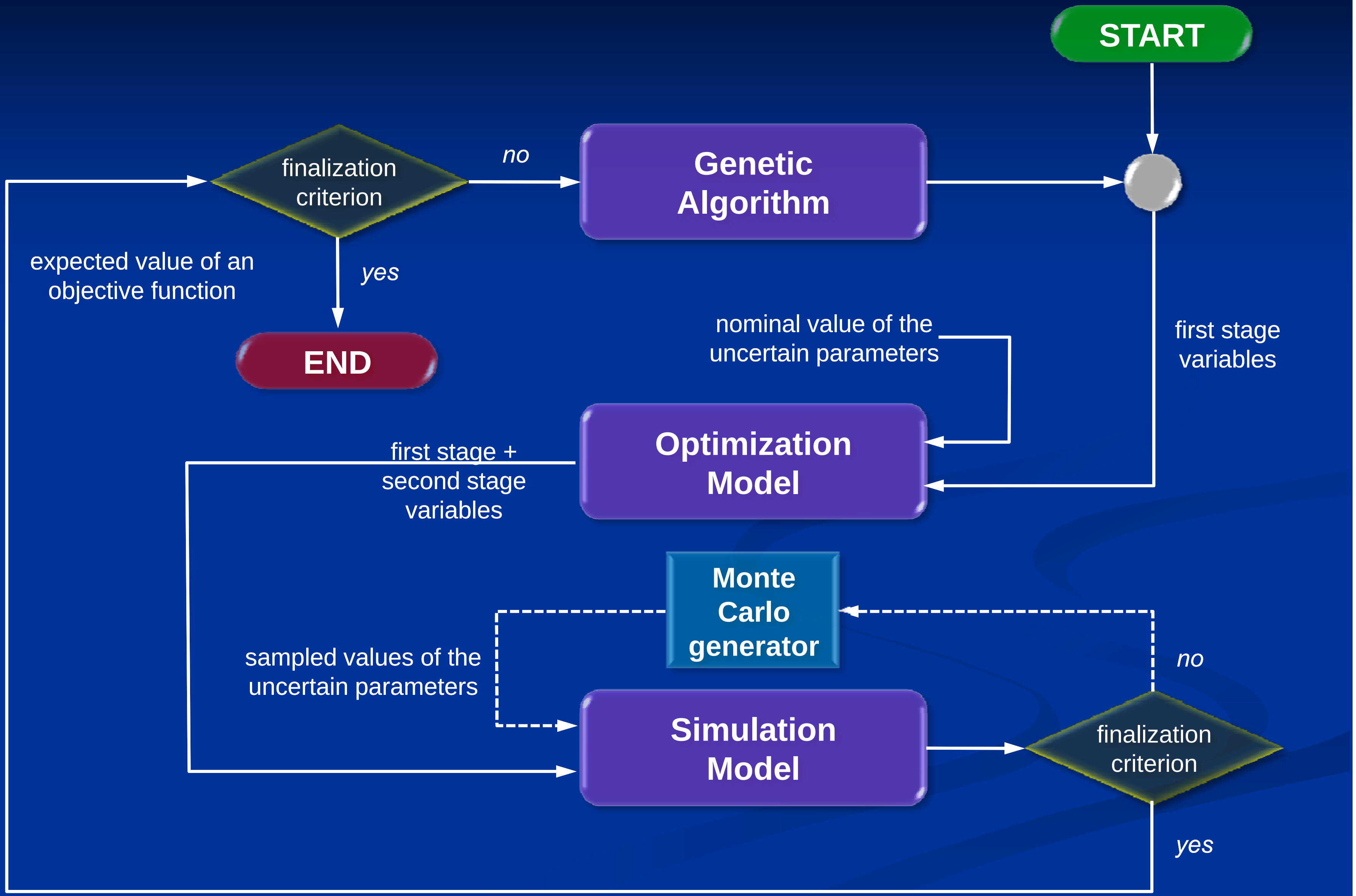
*Perez et al, (2011), *Biocombustibles en la Argentina y Tucumán, cifras de la industria en el período 2009-2011*, Reporte Agroindustrial, 52.

The Biofuel Supply Chain

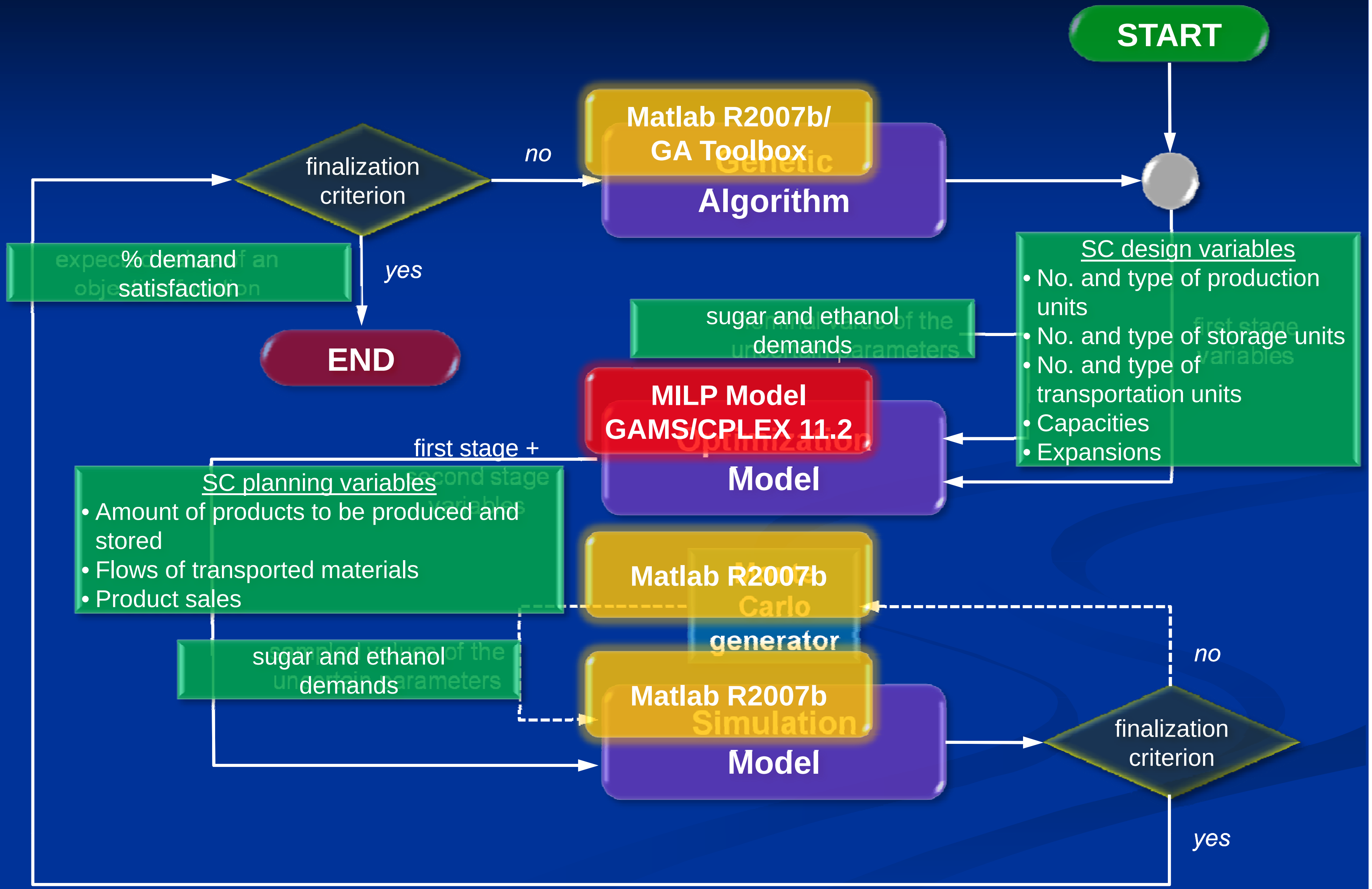
Kostin et al, (2012), *Design and planning of infrastructures for bioethanol and sugar production under demand uncertainty*, ChemEngRes, 90, 359-376.



Simulation-based Optimization (SbO)



Simulation-based Optimization (SbO) – The Biofuel Supply Chain



Supply Chain MILP Model

Sets

t	periods (year)
i	materials
IM	subset of *i*, raw materials
g	regions
s	storage technologies
IS	subset of *s*, storage technologies for material *i*
p	production technologies
l	transportation types
IL	subset of *i*, transportation types for material *i*

Parameters

ρ_{pi}	mass balance coefficients
τ_{pg}	minimum desired fraction of technology *p* on region *g*
$CapCrop_{gt}$	maximun sugarcane's production on region *g* on period *t*
NP_{pgt}	number of production units of technology p on region g on period t (first stage variable)
SD_{igt}	product *i*'s demand on region *g* on period *t* (sampled)

Variables

CF_t	cash flow of period *t*
DTS_{igt}	inventory of material *i* on storage *s* on region *g* on period *t*
NPV	supply chain total net present value
$PCap_{pgt}$	production capacity of technology *p* on region *g* on period *t*
$PCapE_{pgt}$	expansion of production capacity of technology *p* on region *g* on period *t*
PE_{ipgt}	material *i* produced by technology *p* on region *g* on period *t*
PT_{igt}	material *i* produced on region *g* on period *t*
PU_{igt}	material *i* purchased on region *g* on period *t*
$Q_{ilgg't}$	flow of material *i* from region g to region *g'* by transport *l* on period *t*
$SCap_{sgt}$	storage capacity of technology *s* on region *g* on period *t*
ST_{isgt}	inventory of material *i* on storage *s* on region *g* on period *t*

$$\max NPV = \sum_t \frac{CF_t}{(1+ir)^{t-1}}$$

Supply Chain MILP Model

Mass balance constraints

$$\sum_{s \in IS(i,s)} ST_{isgt-1} + PT_{igt} + PU_{igt} + \sum_{i \in IL(i,l)} \sum_{g' \neq g} Q_{ilg'gt} =$$

$$= \sum_{s \in IS(i,s)} ST_{isgt} + DTS_{igt} + \sum_{i \in IL(i,l)} \sum_{g' \neq g} Q_{ilgg't} + W_{igt} \qquad \forall i,g,t$$

$$PT_{igt} = \sum_{p} PE_{ipgt} \qquad \forall i,g,t$$

$$PE_{ipgt} = \rho_{pi} PE_{i'pgt} \qquad \forall i,p,g,t \quad \forall i' \in IM(i,p)$$

$$DTS_{igt} \leq SD_{igt} \qquad \forall i,g,t$$

Capacity constraints

$$PU_{igt} = CapCrop_{gt} \qquad i = sugarcane \quad \forall g,t$$

$$\sum_{s \in IS(i,s)} ST_{isgt} \leq SCap_{sgt} \qquad \forall s,g,t$$

$$\tau_{pg} PCap_{pgt} \leq PE_{ipgt} \leq PCap_{pgt} \qquad \forall i,g,t$$

$$PCap_{pgt} = PCap_{pgt-1} + PCapE_{pgt} \qquad \forall p,g,t$$

$$\underline{PCap_p} NP_{pgt} \leq PCapE_{pgt} \leq \overline{PCap_p} NP_{pgt} \qquad \forall p,g,t$$

SbO of the Argentina's Biofuel Supply Chain

Uncertain parameters were sampled considering a perturbation with a probability distribution of *N*(1,30%) for the sugar demand, and *N*(1,5%) for the ethanol demand.

The time horizon for the design and planning was set at 3 years.

The finalization criterion for the inner loop was for the Monte Carlo generator to take 100 samples.

The finalization criterion for the outer loop was to test 40 generations of 100 individuals each.

Objective function of the outer loop:

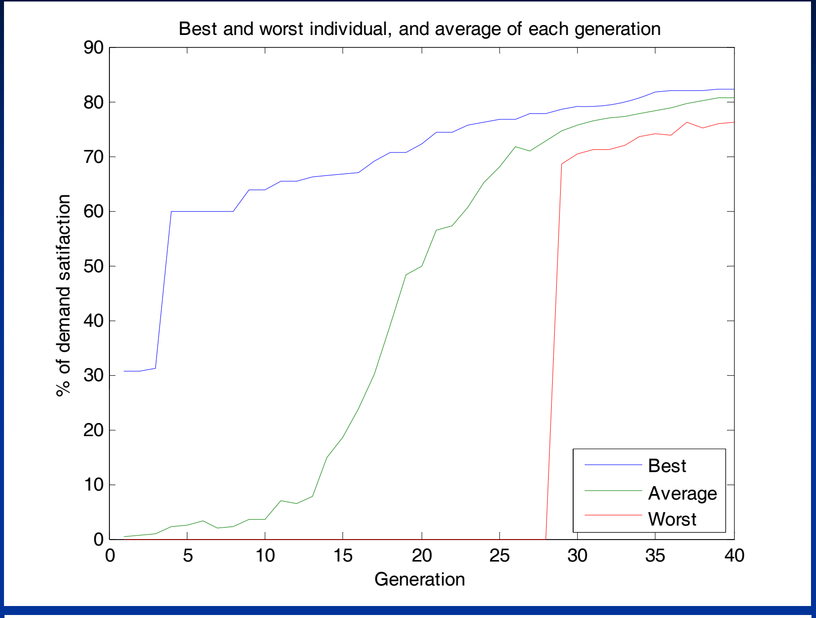
$$\max E\left[\sum_{i}\sum_{g}\frac{\text{Fullfiled}\,SD_{ig}}{SD_{ig}}100\%\right]$$

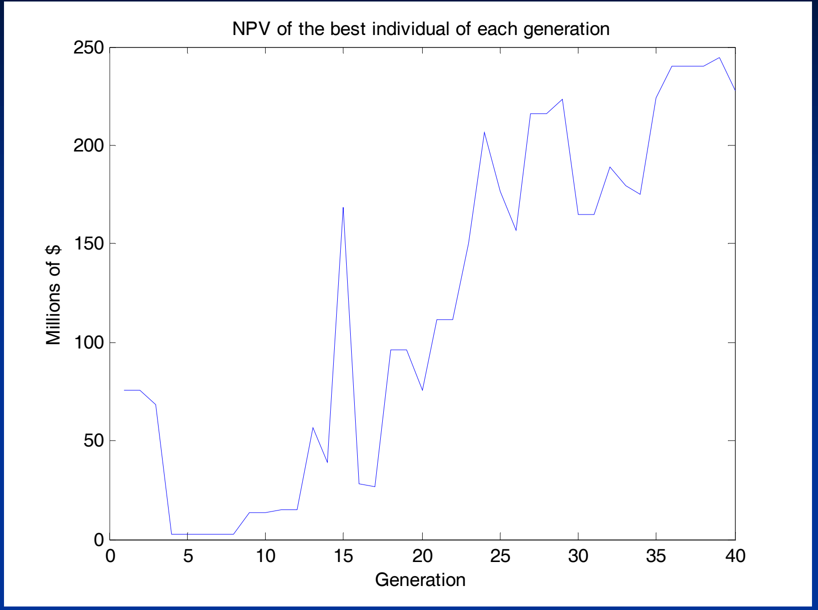
Individuals with a negative objective function were assigned a value of 0.

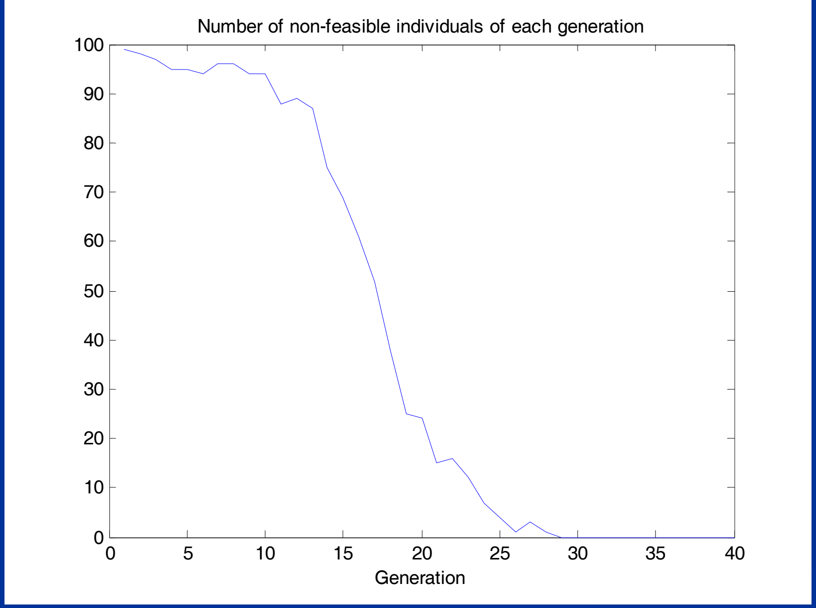
SbO solution statistics

Population	100
Generations	40
Objective function (best individual)	82.17%
NPV (best individual)	$227.7 millions
Best individual found at generation	38
Tried combinations	100x41 = 4100
Unique combinations	3975 (1627 not valid)
Average CPU time per MILP solving*	0.846 seconds
Total CPU time*	61 minutes 1.47 seconds
* SbO run on a Pentium D 945 desktop PC with 1GB of RAM	
Average number of uncertain parameters per run	*70*

SbO solution statistics







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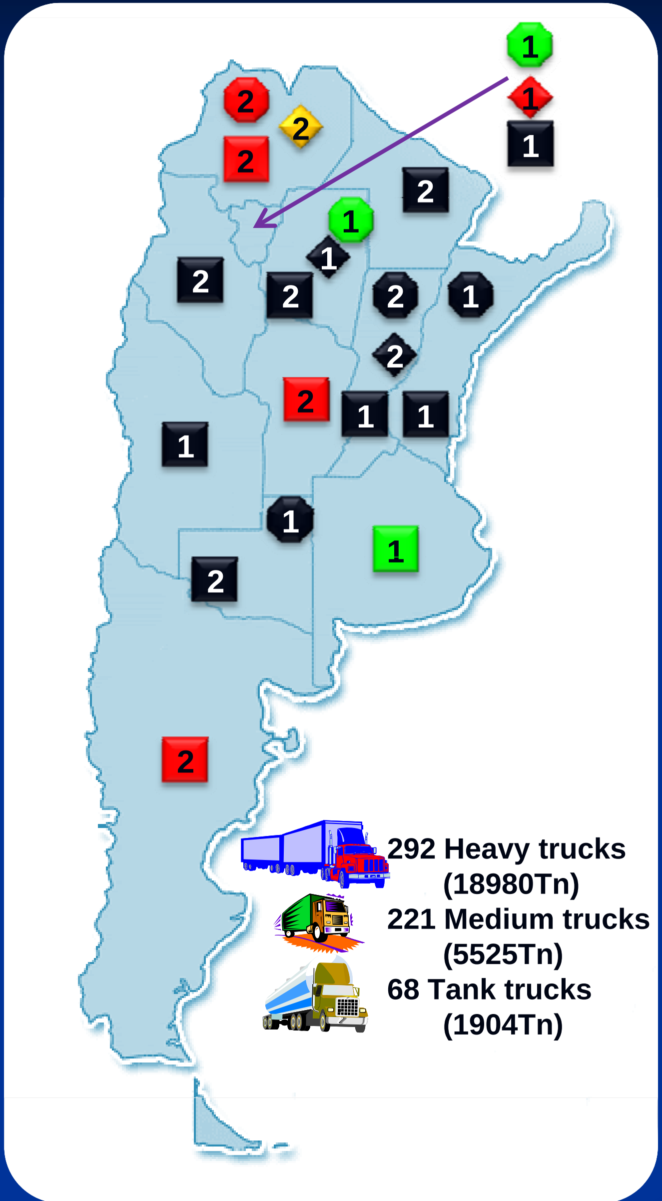
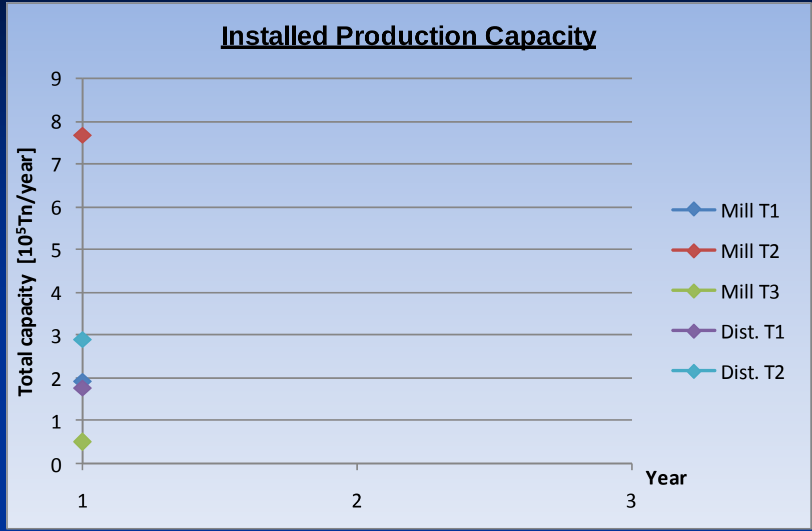
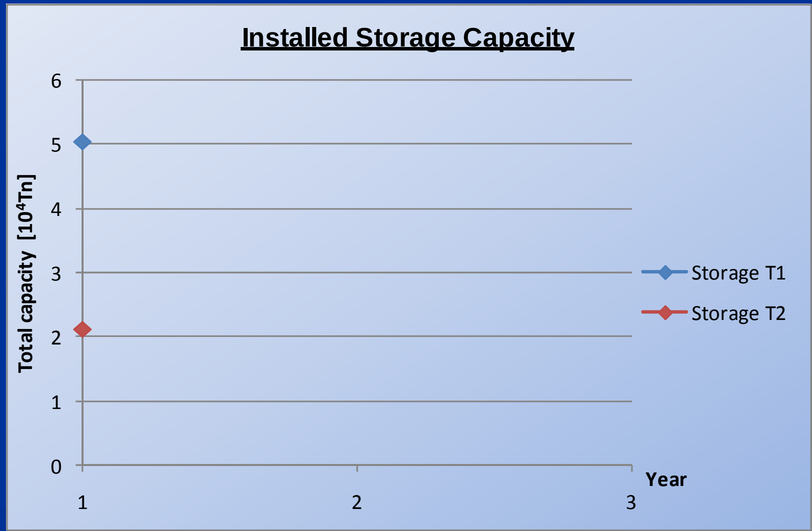
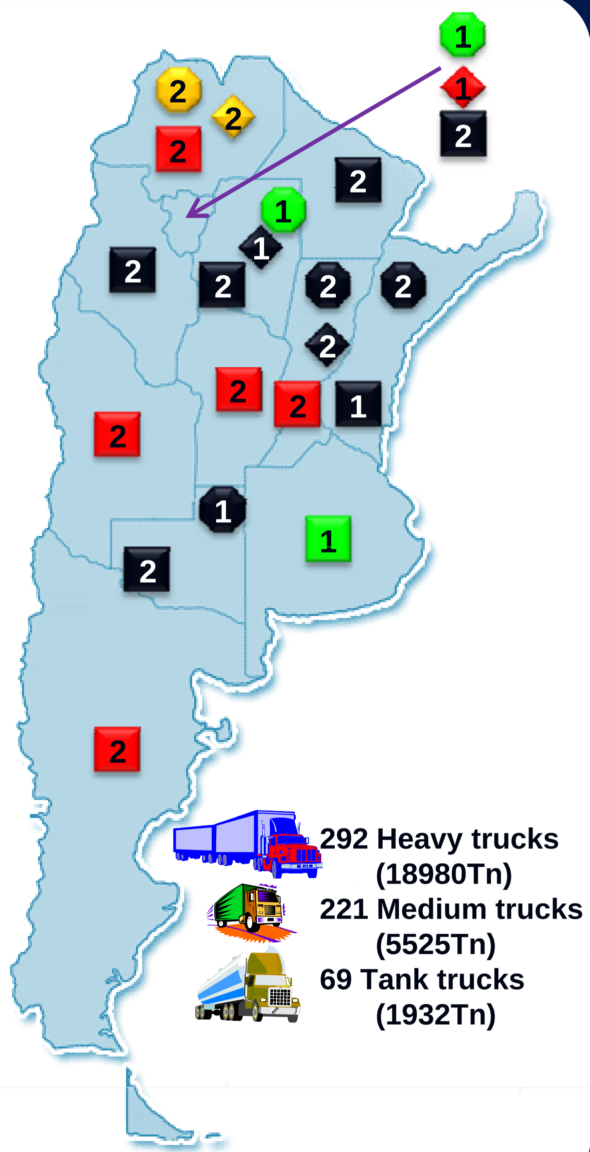
SbO Results – Best solution – Year 1

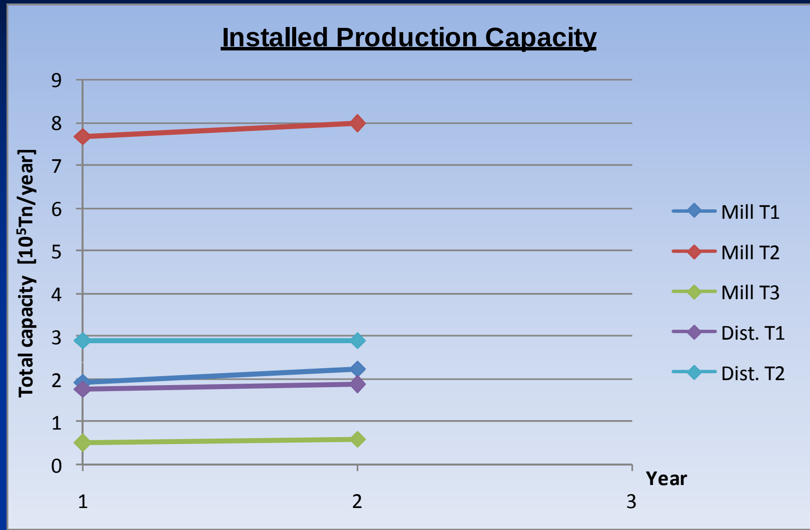


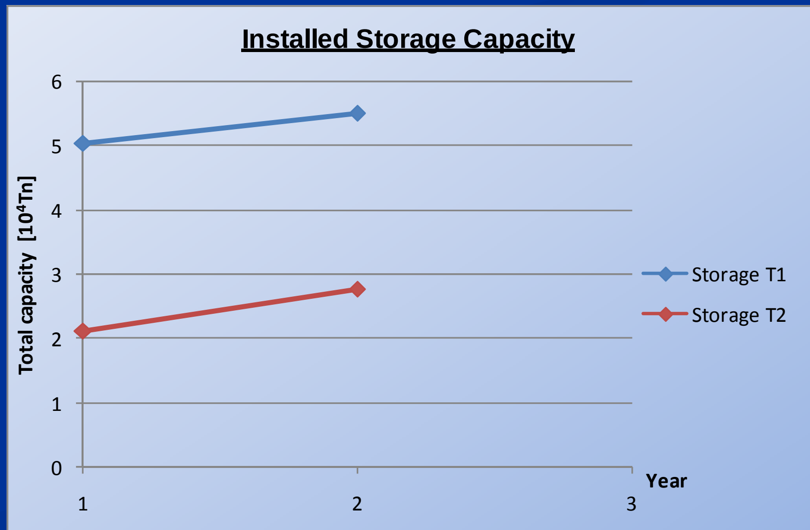




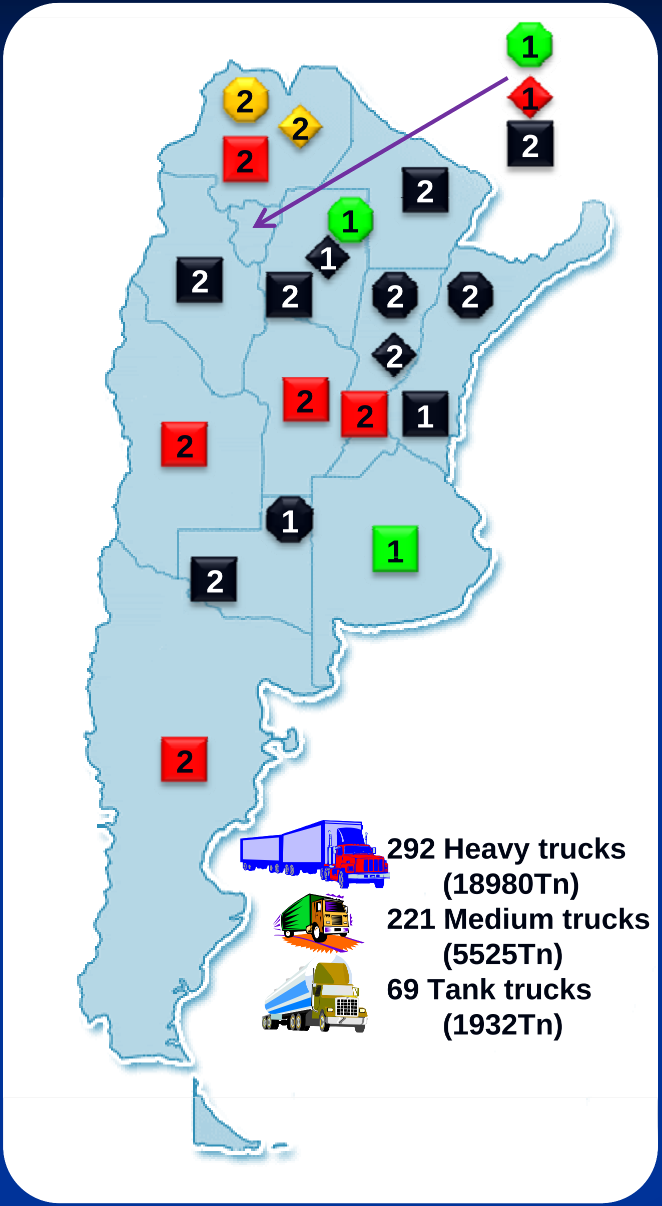
SbO Results – Best solution – Year 2

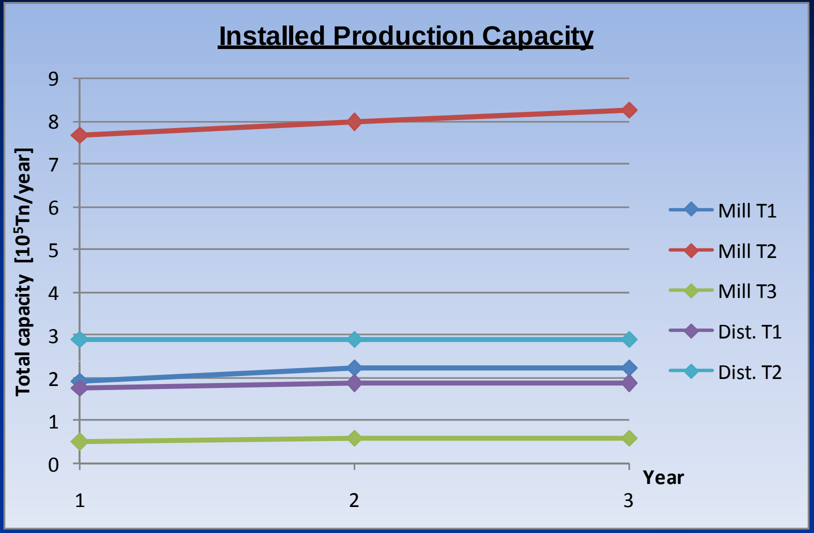


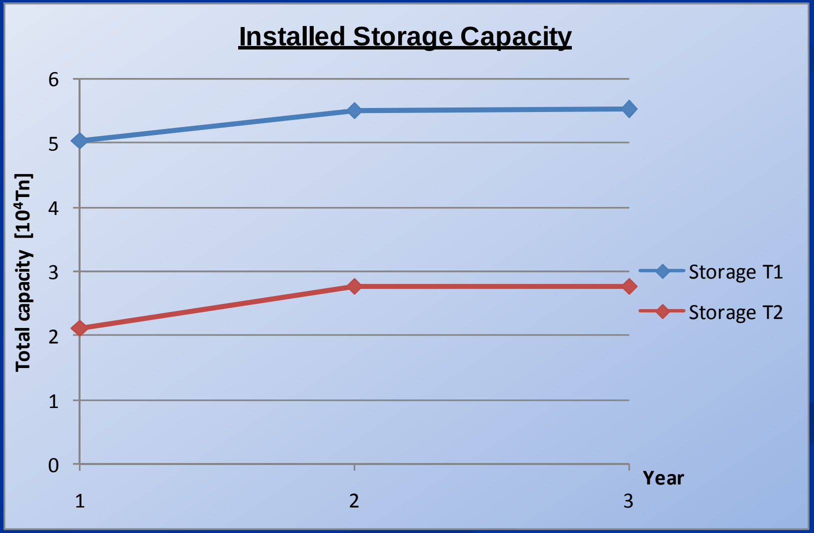




SbO Results – Best solution – Year 3







Conclusions

- ✓ A SbO strategy has been implemented to solve the problem of optimal design of the sugar/ethanol SC in Argentina under parametric uncertainty.
- ✓ The strategy is a two level optimization framework that combines MILP solving with Monte Carlo simulation and Genetic Algorithms.
- ✓ The proposed framework handles around 70 uncertain parameters (the products demands for each region and time period) and geographically distributes production/ storage/ distribution nodes in Ar-gentina, considering different technologies.
- ✓ The model decides the production/storage capacities of the nodes, the quantity of transport units and the period in which each installation and/or expansion should be made.
- ✓ The proposed SbO strategy combines two objective functions, CSat and NPV, thus allowing increasing both although it was expected them to be opposite.

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