Optimal Planning of Drinking Water Production

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Abstract

The water system is one of the most important issues for life and the planetary ecosystem, which is widely recognized by society and synthesized as one of the current research problems of the United Nations. One of the problems involved with this system is related to the treatment of water in treatment plants in a context of sustainable development. This article focuses on the problematic of the raw water treatment system for purification, through a mathematical programming model and a solution procedure for the optimal planning of the treatment system in its different steps and in a two objectives context. The linear model considers two objectives, the first maximizes profits and the second minimizes emissions of pollutants. As restrictions are considered: mass balances, production capacities of the different stages of water production in their different conditions, supply of water, demand and the permissible technical levels of pollutants, which are proposed in a generic manner, independent of the technologies and productive alternatives. The model by its nature allows to solve almost any instance of the problem in excellent CPU times.

Keywords: optimal planning, production and treatment of drinking water, linear programming.

1. Introduction

The concept of sustainable development, promulgated since the 80's, began to gain importance using the foundations established by global environmental initiatives as a result of the evidence of pollution spread around the globe. Defined for the first time in the Brundtland Report (UN, 1987), as part of the work of the United Nations World Commission on Environment and Development (created in 1983), it was assumed as the 3rd Principle of the Rio Declaration in 1992 that says: "The development that responds equitably to the needs of present and future generations" (UN, 1992).

The term environmental impact refers to "any type of alteration in the biotic, abiotic and socioeconomic environment that is adverse or beneficial, total or partial, that may be attributed to the development of a project, work or activity (Colombian Ministry of the Environment and Sustainable Development

Decree 2140 of 2014). Well now, the environmental impact assessment can be defined as the identification and assessment of the potential impacts (effects) of the activities or actions that are carried out and that can generate changes on the physical-chemical, biotic, cultural and socioeconomic components of a particular territory.

The treatment of water to make it potable and adequate for human consumption and agricultural and industrial use, is a central issue for human health and the sustainability of the planet (UN, 2015a, 2015b). The treatment systems are an essential part of the public drinking water home service, whose purpose is the municipal distribution of water fit for human consumption, including its connection and measurement. The system has complementary activities such as collecting water and its processing, treatment, storage, driving and transportation.

The planning of water production is framed in a context of tactical-operational decision that seeks to satisfy the regulatory requirements and at the same time increase the efficiency of the system. Production planning is likely to be assisted by support systems for decision making that allow to maximize the flow of material and minimize waste emissions, the latter in order to be in line with contemporary requirements for sustainability.

The literature presents a significant number of articles that deal with the design of water treatment plants. However, the review carried out showed that despite the importance of the tactical-operative theme that concerns this article, related to the optimal planning of an existing and functioning system, this has not been addressed yet. In summary, the literature has focused on the strategic planning of the water treatment system to make it potable, there being a tacit deficiency in the literature in the development of support systems for its tactical-operative planning.

The processes related to water treatment depend on the technology used and the condition of the raw water, which is the input to be treated. The system can be represented by linked steps of the process, associated with treatment units. Each treatment unit generates a particular transformation of inputs that allows achieving a certain marginal improvement in water quality; the process continues until the last treatment unit allows to reach a water quality that conforms to international regulatory requirements. In this regard, a typical process such as a Potable Water Treatment Plant - PTAP or a less conventional process, contemplates a set of works, equipment and materials necessary to carry out the processes that allow compliance with drinking water quality standards; any treatment system is composed of desandering tanks, pre sedimentators, zone of rapid mixture, tanks of mechanical flocculation, sedimentation, filtration, tanks of storage, areas of disinfection and stations of pumping.

This article presents an approach to a linear mathematical programming model to plan the production of drinking water. The modeling involves the relevant factors for the optimal planning of the treatment plant in any of its possible steps. The linear model contemplates two objectives, maximizes profits and minimizes pollutant emissions. As restrictions are considered: mass balances, production capacities of the different stages of water production in their different conditions, supply of raw water, demand of water treated and the permissible technical levels for contaminants.

2. Literature Review

The United Nations Conference on the Human Environment, First Earth Summit, held in Stockholm in 1972, states that the earth's natural resources, including air, water, land, flora and fauna, must be preserved for the benefit of present and future generations through careful planning (UN, 1972). The Rio + 20 Conference, abbreviated name of the United Nations Conference on Sustainable Development (UN, 1972); celebrated twenty years after the Earth Summit in Rio in 1992 (UN, 1992, 1997), states in its report "The future we want", that the participants "renew their commitment to ensuring the promotion of an economic, social and environmental sustainable future for the planet". Finally, the draft final document of the United Nations summit for the adoption of the post-2015 development agenda, the Millennium Declaration (UN, 2015; NU, 2015), establishes 17 global objectives to eradicate poverty, protect the planet and ensure prosperity for all, that includes the objective of "Clean water and sanitation", that seeks to "Guarantee the availability of water and its sustainable management and sanitation at a global level".

With regard to sustainability in the treatment of water for purification, Lemos et al. (2013) studied the environmental impact derived from the urban water treatment system using the life cycle analysis (LCA) methodology, which includes not only the productive process of treatment that concerns this work but the entire system, that includes stages such as collecting and distributing raw water, collecting, treating and disposing of wastewater and water management. The work also considered the energy production, in this regard, it was identified that this process has the greatest environmental impact.

The work of Kawamura (2000) presents the foundations for the design and operation of facilities for water treatment. On the other hand, there are a good number of articles for strategic contexts of planning water treatment systems. In this regard, some of the most recent works include sustainability considerations such as the work of Ahn and Kang (2014), who present an optimization model that integrates a genetic algorithm with a linear mathematical programming model for the strategic planning of the treatment system of water in a sustainable context. In the same line Koleva et al. (2017) develop a non-linear mixed whole programming model (MINLP) for the design of the water treatment system in sustainable contexts, supplied by alternatives of water sources, specifically seawater or surface water.

With regard to support systems for tactical planning, Mirsepassi (2004) develops a system based on neural networks that learns the non-linear relationships of the plant to provide operational patterns for alum and polymer dosages that facilitate decision making in the treatment of water in plants. Pulluru and Akkerman (2017) developed a mixed model of decision, which allows, with regard to the tactical context, the integrated programming of water plants through a batch process, and in the strategic context the selection of technology, The work seeks the efficiency of the process through the reuse of water resources to reduce their consumption. Apart from these two works, no other works were found that dealt with the tactical decision context of our optimization problem or that linked sustainability considerations.

MODEL

Sets

I: Input set

$I(k)$: Sets of inputs used in stage k

K: Set of stages (treatment units)

$\bar{I}$: Sets of inputs that integrate water

$\underline{I}$: *Set of inputs that are not part of the water*

Parameters:

B_i^k: Rate of production of type *i* pollutants in stage *k*

C_i^k: Unit cost of input *i* used in stage *k*

C^k: Unit income of water in stage *k*

D_i^k: Amount of pollutant *i* per unit of water produced in the stage *k*

E^k: Water production capacity of stage *k*

O: Raw water supply in the initial stage

Q: Demand for drinking water in the final stage

$\underline{H_i^k}$: Lower bound of type *i* contaminant allowed in stage *k*

$\overline{H_i^k}$: Upper bound of type *i* contaminant allowed in stage *k*

$\underline{\alpha_i^k}$: Minimum level of input *i* associated with stage *k*

$\overline{\alpha_i^k}$: Maximum level of input *i* associated with stage *k*

$\underline{\beta_i^k}$: Minimum level of water loss in stage *k*

$\overline{\beta_i^k}$: Maximum level of water loss in stage *k*

Variables:

v_i^k: Amount of type *i* pollutant produced in stage *k*

w_i^k: Amount of type *i* input not absorbed by water in stage *k*

y_i^k: Amount of input type *i* absorbed by water in stage *k*

r_i^k: Amount of type *i* input used to treat water in stage *k*

x^k : Amount of water produced in stage *k*

z^k : Loss of water in stage *k*

Objective functions

Objective 1: Minimization environmental impact

$$Min\ U: \sum_{k \in K} \sum_{i \in I(k)} D_i^k\, x^k \qquad (1)$$

Objective 2: Maximization utilities

$$Max\ Z: \sum_{k \in K} C^k (x^k - z^k) - \sum_{k \in K} \sum_{i \in I(k)} C_i^k\, r_i^k \qquad (2)$$

Constrains:

Raw water supply:

$$x^1 \leq O \qquad (3)$$

Production capacity:

$$x^k \leq E^k \qquad k \in K \qquad (4)$$

Balance of the inputs that are part of the treated water:

$$r_i^k = y_i^k + w_i^k \qquad i \in I(k), k \in K \qquad (5)$$

Balance of water mass:

$$x^k = \sum_{i \in I(k)} y_i^k + x^{k-1} - z^k \qquad k \in K \qquad (6)$$

Generation of pollutants:

$$v_i^k = D_i^k x^k \qquad i \in I(k), k \in \mathrm{K} \qquad (7)$$

Demand for drinking wáter:

$$x^n \geq Q \qquad (8)$$

Bounds:

$$\underline{\alpha_i^k} \leq r_i^k \leq \overline{\alpha_i^k} \qquad i \in I(k), k \in K$$

$$\underline{\theta_i^k} \leq y_i^k \leq \overline{\theta_i^k} \qquad i \in I(k), k \in K$$

$$\underline{\beta_i^k} \leq z^k \leq \overline{\beta_i^k} \qquad i \in I(k), k \in K$$

$$\underline{\varphi_i^k} \leq w_i^k \leq \overline{\varphi_i^k} \qquad i \in I(k), k \in K$$

$$\underline{H_i^k} \leq v_i^k \leq \overline{H_i^k} \qquad i \in I(k), k \in K$$

$$0 \leq x^k \qquad k \in K$$

3. Results

The execution of the model was carried out with the help of commercial software LINGO 9 operated on an Intel Core I5-3470 CPU at 3.2 GHz with 16 GB of RAM and a 64-bit operating system (Windows 8). 5 instances of the problem were modeled (1054, 2174, 3284, 4084 and 5104 non-negative linear variables). The bi-objective problem is solved by a *posteriori* method of ε-restrictions (Mavrotas, 2009). In it, one of the objective functions (considered more relevant) is optimized, while all other objective functions are considered constraints of the model. By generating a set of optimal solutions that allow a final choice, the method is considered to supply abundant information, thus avoiding weakly efficient solutions. The method is detailed in appendix. Table 1 shows the characterization of the parameters of the five executed instances.

Table 1. Output parameters of the ε-constraint method.

Variables	**1054**	**2174**	**3284**	**4084**	**5104**
Index and sets	**Amount**	**Amount**	**Amount**	**Amount**	**Amount**
Supplies	10	15	20	25	25
Stages	25	35	40	40	50
Parameters associated with inputs and stages	3	3	3	3	3
Parameters associated with stages	2	2	2	2	2
Dimensions associated with inputs and stages	6	6	6	6	6
Parameters				**Density function**	
Polluting production rate				U(4-12)	
Unit cost of the input				U(5-18)	
Amount of pollutant produced per unit of water				U(3-10)	
Unit water income				U(35-60)	
Water production capacity				U(900;1500)	
Lower limit of pollutant allowed				U(5-20)	
Upper limit of pollutant allowed				U(4000-7000)	
Minimum level of the input associated with the stage				U(50-80)	
Maximum level of the input associated with the stage				U(1200-1800)	
Minimum level of water loss				U(5-20)	
Maximum level of water loss				U(800;1400)	

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The Table 2 shows steps 1 and 2 of the ε-constraint method, which allow the estimation of the optimal and nadir values of the two objective functions. Said values are necessary to proceed to step 3, see appendix, which is of fundamental importance for the current application.

Table 2. Output parameters of the ε-constraint method

Variables	1054				2174			
Parameters	*Θopt*	*Πopt*	*Θnadir*	*Πnadir*	*Θopt pt*	*Πopt*	*Θnadir*	*Πnadir*
Objective function	33678,90	360701,53	778070,78	-189420,73	52200,05	327649,86	1603865,33	-391938,38
CPU time (seconds)	0	1	0	0	0	0	0	0
Binary variables	0	0	0	0	0	0	0	0
Number of constraints (Non-negativity constraints not included)	2054	2054	2055	2055	4274	4274	4275	4275
Memory used (K)	418	422	422	423	858	865	865	865

Variables total	3284				4084			
Parameters	*Θopt*	*Πopt*	*Θnadir*	*Πnadir*	*Θopt pt*	*Πopt*	*Θnadir*	*Πnadir*
Objective function	75407,67	223933,30	2460083,16	-621669,25	99426,92	61459,15	2990313,80	-761084,42
CPU time (seconds)	0	0	0	0	0	0	0	0
Binary variables	0	0	0	0	0	0	0	0
Number of constraints (Non-negativity constraints not included)	6484	6484	6485	6485	8084	8084	8084	8084
Memory used (K)	1295	1305	1306	1306	1610	1623	1623	1623
Variables total	5104							
Parameters	*Θopt*	Parameters	*Θopt*	Parameters				
Objective function	114154,57	74702,03	3771373,99	-963080,87				
CPU time (seconds)	0	0	0	0				
Binary variables	5104	5104	5104	5104				
Number of constraints (Non-negativity constraints not included)	0	0	0	0				
Memory used (K)	10104	10104	10105	10105				

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In order to calculate the efficient frontier, the incremental step value of parameter ε was set at 0.05. Consequently, 105 optimal estimates were solved for the two objective functions, 21 for each instance. The solution is shown below.

Table 3. Efficient frontier and performance indicators

Variables	1054					2174					
ξ	*Θ*	*Π*	*φ1*	*φ2*	CPU time (seconds)	*ξ*	*Θ*	*Π*	*φ1*	*φ2*	CPU time (seconds)
0	33678,9	-185224,73	1	0	0	0	52200,05	-391938,38	1	0	0
0,05	59548,19	-161914,62	0,97	0,1	0	0,05	112301,71	-355958,97	0,96	0,05	0
0,1	92978,86	-134408,51	0,92	0,1	0	0,1	182947,48	-319979,56	0,92	0,1	0
0,15	127126,38	-106902,39	0,87	0,2	0	0,15	255356,25	-284000,15	0,87	0,15	0
0,2	162067,96	-79396,28	0,83	0,2	0	0,2	328553,39	-248020,74	0,82	0,2	0
0,25	197923,19	-51890,17	0,78	0,3	0	0,25	402190,01	-212041,32	0,77	0,25	0
0,3	234021,64	-24384,06	0,73	0,3	0	0,3	475832,31	-176061,91	0,73	0,3	0
0,35	270176,85	3122,06	0,68	0,4	0	0,35	549482,07	-140082,5	0,68	0,35	0
0,4	306640,03	30628,17	0,63	0,4	0	0,4	623131,84	-104103,09	0,63	0,4	0
0,45	343410,35	58134,28	0,58	0,5	0	0,45	696786,46	-68123,68	0,58	0,45	0
0,5	380180,68	85640,4	0,53	0,5	0	0,5	770449,58	-32144,26	0,54	0,5	0
0,55	416951	113146,51	0,49	0,6	0	0,55	844267,31	3835,15	0,49	0,55	0
0,6	453847,94	140652,62	0,44	0,6	0	0,6	918361,46	39814,56	0,44	0,6	0
0,65	490857,29	168158,74	0,39	0,7	0	0,65	993455,51	75793,97	0,39	0,65	0
0,7	528069,08	195664,85	0,34	0,7	0	0,7	1071327,87	111773,38	0,34	0,7	0

0,75	566798,16	223170,96	0,28	0,8	0	0,75	1150467,14	147752,8	0,29	0,75	0
0,8	605531,26	250677,08	0,23	0,8	0	0,8	1229607,58	183732,21	0,24	0,8	0
0,85	644552,39	278183,19	0,18	0,9	0	0,85	1309773,9	219711,62	0,19	0,85	0
0,9	684129,03	305689,3	0,13	0,9	0	0,9	1392266,92	255691,03	0,14	0,9	0
0,95	725749,4	333195,41	0,07	1	0	0,95	1475683,61	291670,44	0,08	0,95	0
1	778070,78	360701,53	0	1	0	1	1603865,33	327649,86	0	1	0
Variables	3284					4084					
ξ	Θ	Π	ξ	Θ	Π	ξ	Θ	Π	ξ	Θ	Π
0	75407,67	-621669,25	0	75407,67	-621669,25	0	75407,67	-621669,25	0	75407,67	-621669,25
0,05	160307,02	-579389,12	0,05	160307,02	-579389,12	0,05	160307,02	-579389,12	0,05	160307,02	-579389,12
0,1	266088,35	-537109	0,1	266088,35	-537109	0,1	266088,35	-537109	0,1	266088,35	-537109
0,15	373587,56	-494828,87	0,15	373587,56	-494828,87	0,15	373587,56	-494828,87	0,15	373587,56	-494828,87
0,2	481937,4	-452548,74	0,2	481937,4	-452548,74	0,2	481937,4	-452548,74	0,2	481937,4	-452548,74
0,25	590287,27	-410268,61	0,25	590287,27	-410268,61	0,25	590287,27	-410268,61	0,25	590287,27	-410268,61
0,3	700092,94	-367988,49	0,3	700092,94	-367988,49	0,3	700092,94	-367988,49	0,3	700092,94	-367988,49
0,35	811980,64	-325708,36	0,35	811980,64	-325708,36	0,35	811980,64	-325708,36	0,35	811980,64	-325708,36
0,4	924168,96	-283428,23	0,4	924168,96	-283428,23	0,4	924168,96	-283428,23	0,4	924168,96	-283428,23
0,45	1038287,05	-241148,1	0,45	1038287,05	-241148,1	0,45	1038287,05	-241148,1	0,45	1038287,05	-241148,1
0,5	1154950,93	-198867,98	0,5	1154950,93	-198867,98	0,5	1154950,93	-198867,98	0,5	1154950,93	-198867,98
0,55	1273248,13	-156587,85	0,55	1273248,13	-156587,85	0,55	1273248,13	-156587,85	0,55	1273248,13	-156587,85
0,6	1391739,07	-114307,72	0,6	1391739,07	-114307,72	0,6	1391739,07	-114307,72	0,6	1391739,07	-114307,72
0,65	1510397,77	-72027,59	0,65	1510397,77	-72027,59	0,65	1510397,77	-72027,59	0,65	1510397,77	-72027,59
0,7	1629608,18	-29747,47	0,7	1629608,18	-29747,47	0,7	1629608,18	-29747,47	0,7	1629608,18	-29747,47
0,75	1749509,66	12532,66	0,75	1749509,66	12532,66	0,75	1749509,66	12532,66	0,75	1749509,66	12532,66
0,8	1869610,77	54812,79	0,8	1869610,77	54812,79	0,8	1869610,77	54812,79	0,8	1869610,77	54812,79
0,85	1990018	97092,92	0,85	1990018	97092,92	0,85	1990018	97092,92	0,85	1990018	97092,92
0,9	2112004,07	139373,05	0,9	2112004,07	139373,05	0,9	2112004,07	139373,05	0,9	2112004,07	139373,05
0,95	2236364,58	181653,17	0,95	2236364,58	181653,17	0,95	2236364,58	181653,17	0,95	2236364,58	181653,17
1	2460083,16	223933,3	1	2460083,16	223933,3	1	2460083,16	223933,3	1	2460083,16	223933,3
Variables	5104										
ξ	Θ	Π	ξ	Θ	Π						
0	114154,57	360701,53	0	114154,57	360701,53						

0,05	259517,18	360701,53	0,05	259517,18	360701,53
0,1	427917,91	360701,53	0,1	427917,91	360701,53
0,15	599899,95	360701,53	0,15	599899,95	360701,53
0,2	774273,71	360701,53	0,2	774273,71	360701,53
0,25	949377,78	360701,53	0,25	949377,78	360701,53
0,3	1125046,41	360701,53	0,3	1125046,41	360701,53
0,35	1301381,86	360701,53	0,35	1301381,86	360701,53
0,4	1478098,66	360701,53	0,4	1478098,66	360701,53
0,45	1654909,09	360701,53	0,45	1654909,09	360701,53
0,5	1831971,65	360701,53	0,5	1831971,65	360701,53
0,55	2009190,24	360701,53	0,55	2009190,24	360701,53
0,6	2187064,07	360701,53	0,6	2187064,07	360701,53
0,65	2364988,19	360701,53	0,65	2364988,19	360701,53
0,7	2544113,07	360701,53	0,7	2544113,07	360701,53
0,75	2724440,80	360701,53	0,75	2724440,80	360701,53
0,8	2906939,67	360701,53	0,8	2906939,67	360701,53
0,85	3091539,45	360701,53	0,85	3091539,45	360701,53
0,9	3279405,40	360701,53	0,9	3279405,40	360701,53
0,95	3470903,26	360701,53	0,95	3470903,26	360701,53
1	3771373,99	360701,53	1	3771373,99	360701,53

[redacted]

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The CPU times for the solution of the instances of the problem show very good values due to the linear nature of the problem, the executed instances far exceed the practical instances of the problem, which is why the model is foreseen as a robust tool for the planning of water treatment plants. Once the efficient frontiers of a particular instance have been obtained, the decision makers will be able to identify which combination of optimal objectives is the one that best suits their administrative possibilities.

4. Conclusions

The model is a base that requires greater development and attention from the scientific community, this because although sustainable development is still an ambitious proposal, it is an interesting and desirable theoretical-conceptual approach, which needs to be understood as a paradigm that interweaves the dimension natural, the social dimension and the economic dimension in benefit of a better present and future of the planet.

By its nature, the linear model allows solving virtually any instance of the problem in excellent CPU times. The model represents perhaps the first approach to support the tactical decision-making process of raw water treatment systems for drinking water, which has also considered aspects of sustainability, which can be seen in the minimization of water waste and water use of inputs and contaminants. As a research perspective, the application of a solution procedure is proposed for the solution of the bi-objective problem. The model is a base that requires greater development and attention from the scientific community, this because although sustainable development is still an ambitious proposal, it is an interesting and desirable theoretical-conceptual approach, which needs to be understood as a paradigm that interweaves the natural, social and economic dimensions in benefit of a better present and future of the planet.

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APPENDIX

Below are the steps of this solution method:

Step 1: Determining the range of each objective function. Calculate the *s-optimal* and *s-nadir* values (respectively corresponding to the best and worst results accepted for each objective function). The calculation of the optimal values (*Θ^* optimal. *x_1^* optimal; *Π^* optimal. *x_2^*optimal) requires solving the model by optimizing each objective function separately. In turn, the calculation of the s-nadir values for each objective function uses the following equation:

Equation A1

$$\Theta^{\text{nadir}} = min\{\Theta|\Pi^{optimal} \; where \;\; x \ni X\}$$

$$\Pi^{nadir} = \boldsymbol{max}\{\Pi|\boldsymbol{\Theta^{optimal}} \; \boldsymbol{where} \;\; \boldsymbol{x} \ni \boldsymbol{X}\}$$

Step 2: Determining the belonging function of each objective function in question. In the current case study, the objective functions in question are environmental impact and total costs. The following equations ($\Phi(x)$) represent the degree of satisfaction of each objective function:

Equation A2

$$\Phi_1(x) = \begin{Bmatrix} 1. & si \;\; \Theta < \Theta^{optimal} & \\ \dfrac{\Theta^{nadir} - \Theta}{\Theta^{nadir} - \Theta^{optimal}}. & si \; \Theta^{optimal} \leq \Theta & \leq \Theta^{nadir} \\ 0. & si \;\; \Theta > \Theta^{nadir} & \end{Bmatrix}$$

$$\Phi_2(x) = \begin{Bmatrix} 1. & si \;\; \Pi < \Pi^{optimal} & \\ \dfrac{\Pi^{nadir} - \Pi}{\Pi^{nadir} - \Pi^{optimal}}. & si \; \Pi^{optimal} \leq \Pi & \leq \Pi^{nadir} \\ 0. & si \;\; \Pi > \Pi^{nadir} & \end{Bmatrix}$$

Step 3: A single objective must be used for the model, such that belonging function 1 (total cost) is kept as an objective function, while belonging function 2 (total time) is used as a constraint limited by a value epsilon (ε), which is described in step 4 (Equation A3).

Equation A3

$$\max \Phi_1(x)$$

$$s.a.\ \Phi_2(x) \geq \varepsilon$$

$$x \exists X$$

$$\varepsilon \exists [0.1]$$

By replacing the Equation A2 and Equation A3 in the belonging linear function, Equation A4 is obtained

$$\max \left[\frac{\Theta^{nadir} - \Theta}{\Theta^{nadir} - \Theta^{optimal}} \right]$$

$$s.a.\ \Pi \leq \Pi^{nadir} - \varepsilon\left(\Pi^{nadir} - \Pi^{optimal}\right)$$

$$x \exists X$$

$$\varepsilon \exists [0.1]$$

Step 4: Systematically varying (ε). The latter corresponds to the degree of satisfaction of the constrained objective function, which is associated to the belonging function of this objective ($\Phi_2(x)$. The latter is assigned to each solution generated along the set of efficient solutions within a [0.1] range.

Step 5: Based on the results obtained by the fluctuation of both epsilon (ε) and the acceptable degree of minimum variability (s), the decision-maker shall select a feasible segment and conduct a more detailed analysis for intermediate values of epsilon (ε) evaluated in step 4. Finally, the best scenario must be chosen.