مجله نخبگان علوم و مهندسی
Journal of Science and Engineering Elites
جلد ۵- شماره ۴- سال ۱۳۹۹
www.ElitesJournal.ir

A Fuzzy Goal-Programming Model for Optimization of Resilience and Sustainable Natural Gas Supply Chain: A Case Study

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Received: January 2020 Accepted: October 2020

Abstract

Resilience and sustainable supply chain has become an integral part of the corporate strategy. In this paper, a real case study of the natural gas supply chain has been investigated. Using concepts related to natural gas industry and the relations among the components of gas and oil wells, refineries, storage tanks, dispatching, transmission and distribution network, a seven-level supply chain has been introduced and presented schematically. The aim of this paper is to optimize a case study using a fuzzy goal programming multi-period and multi-product model considering recovery, environmental and economic costs, total revenue and service level as fuzzy goals and maximize the total degree of satisfaction of goals as objective function.

A small-sized problem was solved using GAMS 23.2.1 software and sensitivity analysis was conducted on its parameters. To the best of our knowledge, this is the first study that presents a fuzzy goal-programming model for the optimization of resilience and sustainable natural gas supply chain by trade-offs among recovery, environmental and economic costs, total revenue and service level approach in order to help decision makers make an optimal decision.

Keywords: Optimization, Resilience, Sustainable, Supply Chain, Fuzzy goal programming.

1- Introduction

Nowadays, companies have indisputable consequence on the economy of their countries [1]. On the other hand, competition between companies has been replaced by competition between supply chains. In other words, there is a network of companies converting raw materials into finished products and delivering them to end consumers [2]. Events leading to the stoppage in the flow of materials, even happening in a faraway area, can interfere the production process on a large scale. Such stoppages may be distributed along the supply chain, leaving extremely disagreeable effects. In a worst-case scenario, many companies fail to retain their productivity levels when a disruption occurs. Consequently, interrupted companies lose competitiveness [3]. In other words, if supply chain activities fail to resolve unforeseen disruptions appropriately, there will be potentially harmful consequences. Finally, it escalates the risk of business continuity, causing huge amounts of financial loss [4]. Supply chain resilience can define the capacity of disruptions and retaining the basic, structural supply chain tasks in the face of stoppages [5].

On the other hand, Sustainable development has become a major jargon in the business terminology. Influenced by sustainability practices through the integration of economic, environmental and social goals, professions extensively gain a competitive edge when sustainable supply chains are projected. Most organizations pay attention to the strategic importance of sustainable investments. In this environment, the development and availability of analytical models and decision support tools can help organizations make more effective, informed decisions [6]. In response, academic research has been developed on the design and management of sustainable supply chains over the past two decades [7-10]. Most efforts in sustainable supply chain have been orchestrated to mitigate the supply chain's burden of environmental responsibility in measuring greenhouse gas emissions and consumption of resources [11]. In terms of social sustainability, the focus has mostly been shifted on damages to human community health [12]. An evaluation involving the dimensions of sustainability is different from an evaluation of traditional business-oriented performance. When dimensions of sustainability are considered, the scope of evaluation should be expanded. In addition to its economic dimension, sustainable development covers environmental and social dimensions [13]. Despite the growing efforts in the design and management of sustainable supply chain, there is little known about the effects of sustainability dimensions on resilient supply chains. In a specific environment affected by frequent inevitable stoppages, sustainable supply chain management requires a sustainable modeling and analysis adaptable to that dynamic complexity. Static sustainability analysis is simple because the sustainable economic and non-economic performances of a supply chain can be influenced by interruptive events such as supply stoppage [6].

On the other hand, natural gas is one of the most substantial sources of energy for many residential, power plant, industry and commercial consumers throughout the world. It has an enormous and complex supply chain which is in need of manifold investments in all the levels of exploration, extraction, production, refinement, transmission, storage and distribution. In recent years, economic and environmental problems in the supply chain engrossed so much attention of researches. In other words, the two dimensions of the sustainable development such as environment and economy in the natural gas supply chain are very significant. Given that a number of researches have been conducted in recent years on the dimensions of sustainability and resilience in some levels of the supply chain, some dimensions of resilience such as the service level, or adequate inventory on the network and facilities and decreasing penalty per underutilized capacity, or recovery, and some dimensions of sustainability such as the environmental or social costs of greenhouse gas emissions, economic or supply chain costs, and total revenue earned in the consumption nodes at all levels and components of the natural gas supply chain, are investigated in the present study and provided as the contribution of this research while considering the trade-offs among them. This study presents a fuzzy-goal programming model for the resilience and sustainable natural gas supply chain in the Iranian gas industry, in a one-year time horizon, including maximizing the service level and total revenue and minimizing the recovery, environmental and economic costs in order to assess trade-offs among them and advice decision makers for the natural gas supply chain management.

The schematic representation of the natural gas supply chain under study in Iran is shown in Fig. 1. In this research, natural gas supply chain modeling was carried out in seven levels. At the first level, there are three types of suppliers, including gas collection wells, imports and storage tanks. The gas refineries, the compressor stations, the city-gate stations, the dispatching, the town bordering stations are at the second, third, fourth, fifth, and sixth levels, respectively. The nine groups of customers including: 1. Injection into the oil wells 2. The export of liquid and gas products, 3. Liquid and gas products for domestic use 4. Natural gas exports 5. Major industries 6. Power Plants 7. Small industries 8. Residential consumers and 9. Commercial consumers are at the seventh level. In the entire supply chain, gas is transmitted through pipelines of varying sizes, nodes and pressures, according schematic representation figure of the natural gas supply chain. Dispatching directorate through monitoring and using information from refineries, compressor stations and city-gate stations, balances the volume and pressure of the gas transmission lines in order to maintain resilience, sustainability, and customer demand throughout the supply chain [14, 15].

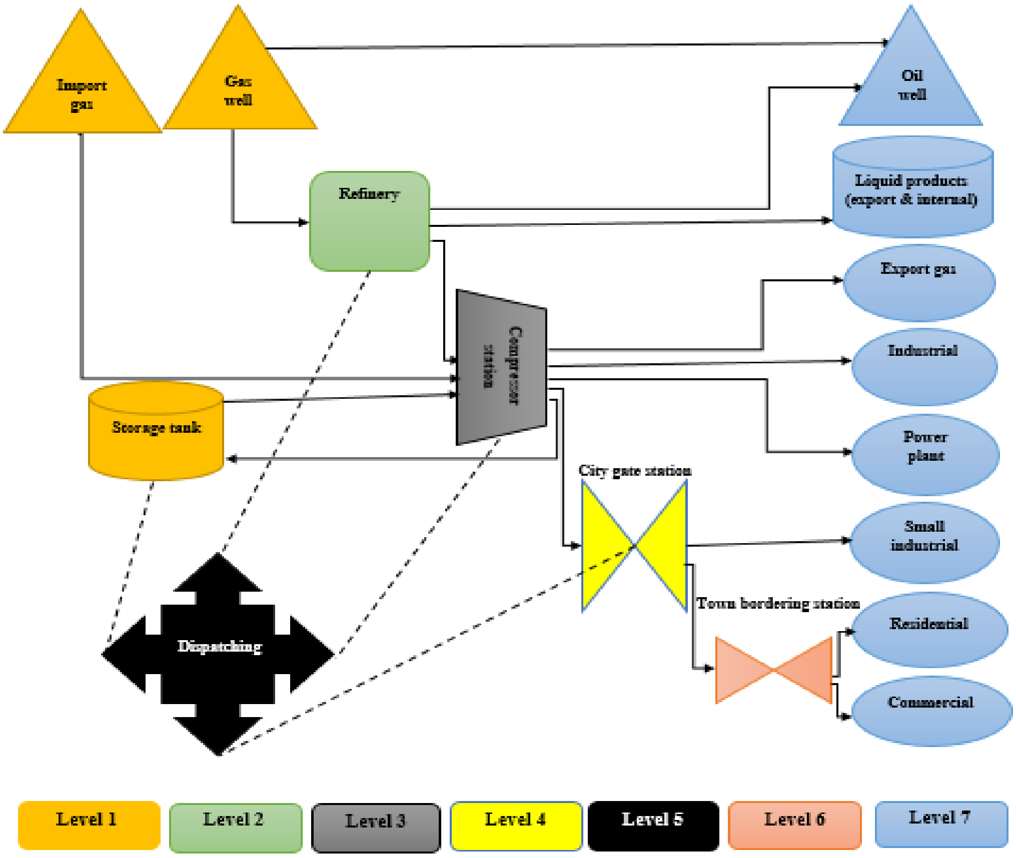

Fig. 1- Schematic representation of the natural gas supply chain

Therefore, the rest of the paper is organized as follows: In Section 2, literature review of resilience and sustainable supply chains. Section 3 presents mathematical modelling. In Section 4, case study is presented. Finally, the discussions with sensitivity analysis and conclusions are given in Sections 5 and 6, respectively.

2- Resilience and Sustainable Supply Chains

In recent years, several researches have surveyed the effects of the technical parameters on the natural gas supply chain. In their research, Nikbakht et al. proposed a framework for integrating the operational parts of natural gas transmission [16]. Pambour et al. presented a simulation motor for calculating the flow of gas in the supply chain and the network operations in case of gas crises in the future [17]. In their research, Ghaithan et al. developed a multi-objective integrated model for the medium-term tactical decision-making of the downstream oil and gas supply chain through an improved augmented ε-constraint algorithm [18]. Gohari Bahabadi et al. found that the South Pars gas field has the optimal production rate when the technical parameters are optimized due to operational and economic constraints [19].

Numerous attempts have been made to model the environmental and green areas of sustainable supply chain, involving disruptions in sustainable environmental and economic calculations during the design and management of sustainable supply chain [20]. Minimization of greenhouse gas emissions has so far been the most desirable environmental goal [21]. The optimal models for strategic supply chain design sought to balance the supply chain cost and CO_2 emissions [22-24]. Tactical and operational design tools for the emission-cost balance in supply chains [11, 25, 26]. Design and planning of closed-loop supply chains with a concentration on emission-cost of forward and reverse networks [27-29]. Apart from studies on the management and design of green supply chains, there have only been few attempts made to model the combined performance criteria in three dimensions of sustainability. In fact, there is no consensus on the measurement and reporting of supply chain social sustainability [30], which is a primary explanation for insufficient research in this area. On the other hand, Zhang et al. conducted several studies on optimal design and cost planning in supply chains, greenhouse gas emissions, lead time, and social and environmental performance criteria [31]. Boukherroub et al. studied supply chain planning problems from the perspective of employee distance to industrial sites and job stability as criteria for social performance [12]. As evident in these studies, the selection of social and environmental criteria combined in supply chain models is a special technical problem.

In recent years, several researches have surveyed the economic and environmental effects and sustainable aspects of the natural gas supply chain [12, 32-34]. In their research, Zamanian et al. developed natural gas supply chain and presented a fuzzy goal-programming model for optimization of sustainable natural gas supply chain by focusing on the environmental and economic costs and total revenue of gas products [14, 15].

The relevant literature suggests that sustainability and resilience have been explored independently [35, 36]. By the same token, the efforts made to model supply chains did not explicitly link the dimensions of resilience and sustainability. In fact, there are scenarios where the dimensions and effects of sustainability in supply chain capacity are inconsistent with unforeseen stoppages. For instance, the majority of sustainability capabilities serve to enhance efficiency in utilization of resources and mitigation of redundant protections (similar to inventory points and fewer storage areas across the supply chain). Although such practices may be environmentally consistent and economically viable, supply chains may be more vulnerable to stoppages due to limited accessibility to safety inventory to cope with variations in supply and demand [37]. Murino et al. proposed a supply chain model construction based on several factors including inventory level, number of suppliers and production rate through simulation software and promotion through analysis of critical outcomes and strengths in the supply chain [38]. Moreover, they argued that supply chain sustainability could be achieved through the functional tasks of resilience. Hanke and Krumme presented a conceptual model while demonstrating the complex relationships between risk, resilience, and sustainability in the supply chain [39].

In their research, Hawker and Edmonds showed that sustainability challenges the basic assumption of performance analysis seeking maximization of profits, not to mention that efficiency may serve as a trap for lower resilience in markets facing sudden changes [40]. Edgeman and Wu emphasized that strength, resilience, and sustainability of transcendental firms are crucial, desirable and complementary to various stakeholders [41]. Fahimnia and Jabbarzadeh investigated the relationship between resilience and sustainability at the design level of supply chains. Providing a multi-objective optimal model developing a sustainability performance scoring method and probabilistic fuzzy ideal planning approach, they managed to design a sustainable, resilient supply chain through dynamic sustainable performance analysis [6]. This approach could progress from static resilient supply chain toward dynamic analysis to deal with unpredictable disruptions in the supply chain. Zahiri et al. developed a linear multi-objective mixed-integer integrated resilient-sustainable planning model to design a supply chain under conditions of uncertainty [42]. In their research, they developed new benchmarks and imported them in the model for resilience and sustainability. Their new model integrated strategic and tactical decisions. Razmi et al. proposed a mix-integer linear programming (MILP) model optimizing the hydrogen supply chain network [43]. Karbassi Yazdi et al. presented a meta-heuristic Binary Particle Swarm Optimization (BPSO) algorithm to come with an optimized solution for ship routing and scheduling of Liquefied Natural Gas (LNG) transportation [44]. Furthermore, Pavlov et al. showed a problem of contingency plan optimization for seaport operations under supply and network structural dynamics [45]. Their research methodology is based on a structural dynamics control approach solved by mathematical programming.

Review of literature shows that in the scope of the resilience and sustainable development in the natural gas supply chain, no significant research has been conducted. Therefore, presenting a fuzzy goal-programming model for optimization of resilience and sustainable natural gas supply chain, by trade-offs among recovery, environmental and economic costs, total revenue and service level approach, in their all levels, would be very useful for gas industries management in order to help decision makers make an optimal decision. Finally, the contributions of this research, compared to the former researches, are as follows: 1. Consideration of the resilience aspect including the first and second goals and the sustainability aspect including the third, fourth and fifth goals in the proposed model, and trade-offs among them, 2. Application of fuzzy goal programming method of the proposed model, 3. A great compatibility of the proposed model and all its parameters with Iran's natural gas supply chain, 4. Considering the validity of the proposed model through the implementation and use of the actual parameters and the desired and optimal results of its outputs, 5. Considering the increase in the pressure of the oil wells and reservoirs through the injection of gas into them and, consequently, increasing their oil recovery while preserving the resilience and sustainability aspects of the natural gas supply chain. The key features of this model, along with previous studies are presented in Table 1.

Table 1- Classification and features of this study with previous studies

Reference articles	**Level of supply chain**			**Objective**		**Sustainability**			**Resilience**		**Solution method**
	Transport	Distribution	All	Single	Multi	Revenue	Economic	Environmental	Recovery	Service Level	
Tabkhi et al. [46]	✓			✓			✓				Branch and bound
Hamedi et al. [33]			✓	✓			✓				A hierarchic algorithm
Mahdavi et al. [47]		✓		✓			✓				Minimum spanning tree
Dos Santos et al. [48]		✓			✓		✓				Monte Carlo simulation
Santibanez-Gonzalez et al. [49]	✓				✓		✓	✓			Genetic Algorithm
Jamshidi et al. [50]	✓			✓			✓	✓			Hybrid genetic Taguchi algorithm
Azadeh et al. [51]			✓		✓		✓	✓			An interactive method resolution
Azadeh et al. [32]	✓				✓		✓	✓			ε-constraint algorithm
Ghaithan et al. [18]			✓		✓	✓	✓			✓	ε-constraint algorithm
Sapkota et al. [34]			✓		✓		✓	✓			A comparative assessment

Zamanian et al. [14]			✓		✓	✓	✓	✓			Fuzzy goal programming
Zamanian et al. [15]			✓		✓	✓	✓	✓	✓	✓	ε-constraint algorithm
This study			✓		✓	✓	✓	✓	✓	✓	Fuzzy goal programming

3- Mathematical Modelling

The proposed model consists of sets and indices, decision variables, parameters, goals and constraints (mathematical model), and problem solving approach.

Sets and indices

w: Set of gas wells
a: Set of importations
r: Set of refineries
y: Set of compressor stations
s: Set of storage tanks
g: Set of city gate stations
b: Set of town bordering stations
o: Set of oil wells
e: Set of exportations
el: Set of equal liquid products
d: Set of industrial customers
p: Set of power plant customers
l: Set of residential customers
f: Set of commercial customers
m: Set of small industrial customers
t: Time period
i: Starting nodes $i \in \{w \cup a \cup r \cup y \cup g \cup b \cup s\}$
j: Finishing nodes $j \in \{r \cup y \cup g \cup o \cup e \cup d \cup p \cup s \cup b \cup l \cup f \cup m\}$

Decision variables in period *t:* Transported gas volume from:

xwr_{wrt}: Gas well to the refinery
xwo_{wot}: Gas well to the oil well
xry_{ryt}: Refinery to the compressor station
xro_{rot}: Refinery to the oil well
xay_{ayt}: Importation to the compressor station
xys_{yst}: Compressor station to the storage tank
xsy_{syt}: Storage tank to the compressor station
xye_{yet}: Compressor station to the exportation
xyd_{ydt}: Compressor station to the industrial customer
xyp_{ypt}: Compressor station to the power plant customer
$xyy'_{yy't}$: Compressor station to the another compressor station
xyg_{ygt}: Compressor station to the city-gate station
xgm_{gmt}: City-gate station to the small industrial customer
xgb_{gbt}: City-gate station to the town bordering station
xbl_{blt}: Town bordering station to the residential customer
xbf_{bft}: Town bordering station to the commercial customer
SLG_t: Service level gas in period t
SL: A minimum target for the service level

Capacity parameters in period t:

oc_{ot}: Delivery capacity of oil well
wc_{wt}: Gas well
ac_{at}: Importation
rc_{rt}: Refinery
yc_{yt}: |Compressor station
gc_{gt}: City-gate station
bc_{bt}: Town bordering station
sc_{s}: Storage tank(constant)

Fuel parameters: Fuel consumption coefficient of:

β_r: Refinery
β_y: Compressor station
β_g: City-gate station

Volume parameters: Decreased volume coefficient consequence of liquids analysis in the refinery as equal liquid product:

α_1: Type one
α_2: Type two
α_3: Type three
α_4: Type four
α_5: Type five

Percent parameters: Percent of α as equal liquid product type:

α_{3i}: Three for internal consumption $\alpha_{3i\%} + \alpha_{3e\%} = 1$
α_{3e}: Three for exportation consumption
α_{4i}: Four for internal consumption $\alpha_{4i\%} + \alpha_{4e\%} = 1$
α_{4e}: Four for exportation consumption

Demand parameters in period t: Demand volume of:

od_{ot}: Oil well
ed_{et}: Exportation
dd_{dt}: Industrial customer
pd_{pt}: Power plant customer
ld_{lt}: Residential customer
fd_{ft}: Commercial customer
md_{mt}: Small industrial customer
eld_{rt}: Equal liquid products in the refinery

Route parameters

d_{ij}: length of the unique route between node *i* and node *j*
h_{ij}: Hardness coefficient of the unique route between node *i* and node *j*
Λ_{ij}: If there is a unique route between node *i* and node *j*, *1* otherwise *0*
Q_{ij}^{Min}: Minimum flow unique route between node *i* and node *j*
Q_{ij}^{Max}: Maximum flow unique route between node *i* and node *j*

Greenhouse gas emissions parameters: Average amount of greenhouse gas emissions produced by:

gw: Gas well per unit
gr: Refinery per unit
gy: Compressor station per unit
gg: City-gate station per unit

gb: Town bordering station per unit
go: Oil well per unit
gd: Industrial customer per unit
gp: Power plant customer per unit
gl: Residential customer per unit
gf: Commercial customer per unit
gm: Small industrial customer per unit
gs: Storage tank per unit
$g\alpha_{3i}$: Equal liquid product type three per unit
$g\alpha_{4i}$: Equal liquid product type four per unit

Cost parameters in period *t*

cw_{wt}: Cost of supply by gas well per unit
ca_{at}: Cost of supply by importation per unit
cr_{rt}: Cost of production by refinery per unit
cy_{yt}: Operation cost of compressor station per unit
cg_{gt}: Operation cost of city gate station per unit
cb_{bt}: Operation cost of town bordering station per unit
cs_{st}: Operation cost of storage tank per unit
ct: Transportation cost per product unit per distance unit
sc: Social cost caused by per unit of greenhouse gas emissions (Convert parameter)

Penalty parameters: Penalty per underutilized capacity unit of:

c_1: Gas well
c_2: Refinery
c_3: Compressor station
c_4: City-gate station
c_5: Town bordering station

Price parameters in period t: Selling price of:

Pwo_{wot}: Gas product by gas well for oil well per unit
Pro_{rot}: Gas product by refinery for oil well per unit
Pye_{yet}: Gas product by compressor station for exportation per unit
Pyd_{ydt}: Gas product by compressor station for industrial customer per unit
Pyp_{ypt}: Gas product by compressor station for power plant customer per unit
Pgm_{gmt}: Gas product by city gate station for small industrial customer per unit
Pbl_{blt}: Gas product by town bordering station for residential customer per unit
Pbf_{bft}: Gas product by town bordering station for commercial customer per unit
$P\alpha_{1t}$: Equal liquid product as type one per unit
$P\alpha_{2t}$: Equal liquid product as type two per unit
$P\alpha_{3it}$: Equal liquid product as type three for internal consumption per unit
$P\alpha_{3et}$: Equal liquid product as type three for exportation per unit
$P\alpha_{4it}$: Equal liquid product as type four for internal consumption per unit
$P\alpha_{4et}$: Equal liquid product as type four for exportation per unit

Aspiration level, lower and upper tolerance parameters for goals:

AL_1: Aspiration level for the service level
AL_2: Aspiration level for the recovery costs
AL_3: Aspiration level for the environmental or social costs
AL_4: Aspiration level for the economic costs
AL_5: Aspiration level for the total revenue of gas products

ε_1: The lower tolerance limit for the service level
ε_2: The upper tolerance limit for the recovery costs
ε_3: The upper tolerance limit for the environmental or social costs
ε_4: The upper tolerance limit for the economic costs
ε_5: The lower tolerance limit for the total revenue of gas products

3.1 Mathematical Model

This natural gas supply chain is formulated in terms of the dimensions of resilience such as the service level and penalty per underutilized capacity, or recovery costs and sustainability such as the environmental and economic costs and total revenue.This study presents a fuzzy goal-programming model for optimization of resilience and sustainable natural gas supply chain in the Iranian gas industry, including maximizing the service level and total revenue and minimizing the recovery, environmental and economic costs in the consumption nodes at all levels and components of the natural gas supply chain in a one-year time horizon, in order to assess trade-offs among them and advice decision makers for the natural gas supply chain management. Goals and constraints of the proposed model are presented as follows:

G_1: Maximizing the service level gas in period t (Goal 1)

$$G_1 = SL \tag{1}$$

$$G_2 = \left(\sum_w\sum_r\sum_t xwr_{wrt} + \sum_w\sum_o\sum_t xwo_{wot} - \sum_w\sum_t wc_{wt}\right)C_1 +$$
$$\left(\sum_r\sum_y\sum_t xry_{ryt} + \sum_r\sum_o\sum_t xro_{rot} + \sum_w\sum_r\sum_t xwr_{wrt} \times (\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\beta_r) - \sum_r\sum_t rc_{rt}\right)C_2 +$$
$$\left(\left(\sum_y\sum_{\acute{y}}\sum_t xy\acute{y}_{y\acute{y}t} + \sum_y\sum_g\sum_t xyg_{ygt} + \sum_y\sum_s\sum_t xys_{yst} + \sum_y\sum_e\sum_t xye_{yet} + \sum_y\sum_d\sum_t xyd_{ydt} + \sum_y\sum_p\sum_t xyp_{ypt}\right) + \right.$$
$$\left(\left(\sum_r\sum_y\sum_t xry_{ryt} + \sum_a\sum_y\sum_t xay_{ayt} + \sum_s\sum_y\sum_t xsy_{syt} + \sum_{\acute{y}}\sum_y\sum_t x\acute{y}y_{\acute{y}yt}\right) \times \beta_y - \sum_y\sum_t yc_{yt}\right)C_3 + \tag{2}$$
$$\left(\sum_g\sum_m\sum_t xgm_{gmt} + \sum_g\sum_b\sum_t xgb_{gbt} + \sum_y\sum_g\sum_t xyg_{ygt} \times \beta_g - \sum_g\sum_t gc_{gt}\right)C_4 +$$
$$\left(\sum_b\sum_l\sum_t xbl_{blt} + \sum_b\sum_f\sum_t xbf_{bft} - \sum_b\sum_t bc_{bt}\right)C_5$$

G_3: Minimizing the environmental costs of emission of greenhouse gases (Goal 3) (3)

$$G_3 = \mathrm{sc}\Bigg\{ gw\left[\sum_w\sum_r\sum_t xwr_{wrt} + \sum_w\sum_o\sum_t xwo_{wot}\right] + gr\left[\sum_r\sum_y\sum_t xry_{ryt} + \sum_r\sum_o\sum_t xro_{rot}\right]$$

$$+ gy\Bigg[\sum_y\sum_{\acute{y}}\sum_t xy\acute{y}_{y\acute{y}t} + \sum_y\sum_g\sum_t xyg_{ygt} + \sum_y\sum_s\sum_t xys_{yst}$$

$$+ \sum_y\sum_e\sum_t xye_{yet} + \sum_y\sum_d\sum_t xyd_{ydt} + \sum_y\sum_p\sum_t xyp_{ypt}\Bigg] +$$

$$gs\left[\sum_s\sum_y\sum_t xsy_{syt}\right] + gg\left[\sum_g\sum_b\sum_t xgb_{gbt} + \sum_g\sum_m\sum_t xgm_{gmt}\right] +$$

$$gb\left[\sum_b\sum_l\sum_t xbl_{blt} + \sum_b\sum_f\sum_t xbf_{bft}\right] + go\left[\sum_w\sum_o\sum_t xwo_{wot} + \sum_r\sum_o\sum_t xro_{rot}\right] +$$

$$\Bigg[gd\sum_y\sum_d\sum_t xyd_{ydt}$$

$$+ gp\sum_y\sum_p\sum_t xyp_{ypt}$$

$$+ gl\sum_b\sum_l\sum_t xbl_{blt} + gf\sum_b\sum_f\sum_t xbf_{bft} + gm\sum_g\sum_m\sum_t xgm_{gmt}$$

$$+ \left(g\alpha_{3i}\sum_w\sum_r\sum_t xwr_{wrt} \times \alpha_{3i}\right) + \left(g\alpha_{4i}\sum_W\sum_r\sum_t xwr_{wrt} \times \alpha_{4i}\right)\Bigg]\Bigg\}$$

G_4: Minimizing the economic costs (Goal 4)

$$G_4 = \sum_w\sum_r\sum_t xwr_{wrt}\,(cw_{wt} + d_{wr}h_{wr}ct) + \sum_w\sum_o\sum_t xwo_{wot}(cw_{wt} + d_{wo}h_{wo}ct) +$$
$$\sum_r\sum_y\sum_t xry_{ryt}(cr_{rt} + d_{ry}h_{ry}ct) + \sum_r\sum_o\sum_t xro_{rot}(cr_{rt} + d_{ro}h_{ro}ct) +$$
$$\sum_a\sum_y\sum_t xay_{ayt}(ca_{at} + d_{ay}h_{ay}ct) + \sum_y\sum_{\acute{y}}\sum_t xy\acute{y}_{y\acute{y}t}(cy_{yt} + d_{y\acute{y}}h_{y\acute{y}}ct) + \quad (4)$$
$$\sum_y\sum_g\sum_t xyg_{ygt}(cy_{yt} + d_{yg}h_{yg}ct) + \sum_y\sum_s\sum_t xys_{yst}(cy_{yt} + d_{ys}h_{ys}ct) +$$
$$\sum_s\sum_y\sum_t xsy_{syt}(cs_{st} + d_{sy}h_{sy}ct) + \sum_y\sum_e\sum_t xye_{yet}(cy_{yt} + d_{ye}h_{ye}ct) +$$

$$\sum_{y}\sum_{d}\sum_{t} xyd_{ydt}(cy_{yt}+d_{yd}h_{yd}ct) + \sum_{y}\sum_{p}\sum_{t} xyp_{ypt}(cy_{yt}+d_{yp}h_{yp}ct) +$$
$$\sum_{g}\sum_{m}\sum_{t} xgm_{gmt}(cg_{gt}+d_{gm}h_{gm}ct) + \sum_{g}\sum_{b}\sum_{t} xgb_{gbt}(cg_{gt}+d_{gb}h_{gb}ct) +$$
$$\sum_{b}\sum_{l}\sum_{t} xbl_{blt}(cb_{bt}+d_{bl}h_{bl}ct) + \sum_{b}\sum_{f}\sum_{t} xbf_{bft}(cb_{bt}+d_{bf}h_{bf}ct)$$

G_5: *Maximizing the total revenue of gas products* (*Goal* 5)

$$\begin{aligned} G_5 = &\left(\sum_{w}\sum_{o}\sum_{t} xwo_{wot} \times Pwo_{wot}\right) + \left(\sum_{r}\sum_{o}\sum_{t} xro_{rot} \times pro_{rot}\right) + \\ &\left(\sum_{y}\sum_{e}\sum_{t} xye_{yet} \times Pye_{yet}\right) + \left(\sum_{y}\sum_{d}\sum_{t} xyd_{ydt} \times pyd_{ydt}\right) + \\ &\left(\sum_{y}\sum_{p}\sum_{t} xyp_{ypt} \times Pyp_{ypt}\right) + \left(\sum_{g}\sum_{m}\sum_{t} xgm_{gmt} \times pgm_{gmt}\right) + \\ &\left(\sum_{b}\sum_{l}\sum_{t} xbl_{blt} \times Pbl_{blt}\right) + \left(\sum_{b}\sum_{f}\sum_{t} xbf_{bft} \times pbf_{bft}\right) + \\ &\left(\sum_{w}\sum_{r}\sum_{t} xwr_{wrt} \times \alpha_1 \times P\alpha_{1t}\right) + \left(\sum_{W}\sum_{r}\sum_{t} xwr_{wrt} \times \alpha_2 \times P\alpha_{2t}\right) + \\ &\left(\sum_{w}\sum_{r}\sum_{t} xwr_{wrt} \times \alpha_{3e} \times P\alpha_{3et}\right) + \left(\sum_{W}\sum_{r}\sum_{t} xwr_{wrt} \times \alpha_{3i} \times P\alpha_{3it}\right) + \\ &\left(\sum_{w}\sum_{r}\sum_{t} xwr_{wrt} \times \alpha_{4e} \times P\alpha_{4et}\right) + \left(\sum_{W}\sum_{r}\sum_{t} xwr_{wrt} \times \alpha_{4i} \times P\alpha_{4it}\right) \end{aligned} \quad (5)$$

Equation (1) refers to the service level at consumption nodes along the supply chain.
Equation (2) refers to the penalty per underutilized capacity along the supply chain or recovery costs. This goal is considered as the fines resulting from the use of low-capacity equipment or gas transmission at total levels, and each section of it is as follows:
2-1: The gas transmission or capacity of equipment form gas wells to oil wells and refineries and the associated shortage penalty
2-2: The gas transmission or capacity of equipment form refineries to oil wells and compressor stations and the associated shortage penalty
2-3: The gas transmission or capacity of equipment form compressor stations to another Compressor stations, city-gate stations, storage tanks, exportations, industrials and power plants and the associated shortage penalty
2-4: The gas transmission or capacity of equipment form city-gate stations to town bordering stations and small industrials and the associated shortage penalty
2-5: The gas transmission or capacity of equipment form town bordering stations to residential and commercial customers and the associated shortage penalty
Equation (3) refers to the costs of emission of greenhouse gases along the supply chain, or environmental cost. This goal is considered as the average amount of emission of greenhouse gases at all levels of the supply chain including supply and demand by gas wells, oil wells,

refineries, equal liquid products type three and four, compressor stations, storage tanks, industrials, power plants, city-gate stations, town bordering stations, small industrials, residential customers and commercial customer.
Equation (4) refers to the economic costs along the supply chain. This goal is considered as the cost of supplying at each level and the cost of transmission to the next level and each section of it is as follows:
4-1: Supply cost by gas wells and transmission to the refineries
4-2: Supply cost by gas wells and transmission for sour gas injection to oil wells
4-3: Production cost by refinery and transmission to the compressor stations
4-4: Supply cost by importations and transmission to the compressor stations
4-5: Production cost by refinery and transmission for sweet gas injection to the oil wells
4-6: Operation cost of compressor station y and transmission to other compressor Stations ŷ

4-7: Operation cost of compressor station and transmission to city-gate stations, storage tanks, exportations, industrials and power plants
4-8: Operation cost of storage tank and transmission to compressor stations
4-9: Operation cost of city-gate station and transmission to town bordering station and small industrials
4-10: Operation cost of town bordering station and transmission to residential and commercial customers
Equation (5) refers to the total revenue of gas products along the supply chain. This goal is considered as the price of gas products and each section of it is as follows:
5-1: Selling price of gas product by gas wells for oil wells
5-2: Selling price of gas product by refineries for oil wells
5-3: Selling price of gas product by compressor stations for exportations, industrials, and Power plants
5-4: Selling price of gas product by city gate stations for small industrials
5-5: Selling price of gas product by town bordering stations for residential and commercial customers
5-6: Selling price of equal liquid products as type one and two for exportation
5-7: Selling price of equal liquid products as type three and four for internal consumption
5-8: Selling price of equal liquid products as type three and four for exportation

Constraints of the proposed model are presented as follows:

$$\sum_{w} xwo_{wot} + \sum_{r} xro_{rot} \geq od_{ot} \qquad \forall o,t \tag{6}$$

$$\sum_{y} xye_{yet} \geq ed_{et} \qquad \forall e,t \tag{7}$$

$$\sum_{y} xyd_{ydt} \geq dd_{dt} \qquad \forall d,t \tag{8}$$

$$\sum_{y} xyp_{ypt} \geq Pd_{pt} \qquad \forall P,t \tag{9}$$

$$\sum_{b} xbl_{blt} \geq ld_{lt} \qquad \forall l,t \tag{10}$$

$$\sum_{b} xbf_{bft} \geq fd_{ft} \qquad \forall f,t \tag{11}$$

$$\sum_{g} xgm_{gmt} \geq md_{mt} \qquad \forall m,t \tag{12}$$

$$\sum_{w} xwr_{wrt} \times (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4) \geq eld_{rt} \quad \forall r,t \tag{13}$$

Constraints (6) – (13) guarantee demand satisfaction for each oil well, exportation, industrial, power plant, residential, commercial, small industrial and equal liquid products, respectively.

$$\sum_{r} xwr_{wrt} + \sum_{o} xwo_{wot} \leq wc_{wt} \qquad \forall w,t \tag{14}$$

$$\sum_{y} xay_{ayt} \leq ac_{at} \qquad \forall a,t \tag{15}$$

$$\sum_{y} xry_{ryt} + \sum_{o} xro_{rot} + \sum_{w} xwr_{wrt} \times (\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5) \leq rc_{rt} \qquad \forall r,t \tag{16}$$

$$\sum_{g} xyg_{ygt} + \sum_{s} xys_{yst} + \sum_{e} xye_{yet} + \sum_{d} xyd_{ydt} + \sum_{p} xyp_{ypt} + \sum_{\acute{y}} xy\acute{y}_{y\acute{y}t} \leq yc_{yt} \quad \forall y,t \tag{17}$$

$$\sum_{b} xgb_{gbt} + \sum_{m} xgm_{gmt} \leq gc_{gt} \qquad \forall g,t \tag{18}$$

$$\sum_{l} xbl_{blt} + \sum_{f} xbf_{bft} \leq bc_{bt} \qquad \forall b,t \tag{19}$$

$$\sum_{y}\sum_{\acute{t}=1}^{t} xys_{ys\acute{t}} - \sum_{y}\sum_{\acute{t}=1}^{t} xsy_{sy\acute{t}} \geq o \qquad \forall s,t \tag{20}$$

$$\sum_{y}\sum_{\acute{t}=1}^{t} xys_{ys\acute{t}} - \sum_{y}\sum_{\acute{t}=1}^{t} xsy_{sy\acute{t}} \leq sc_s \quad \forall s,t \tag{21}$$

Each gas well, importation, refinery, compressor station, city-gate station, town bordering station and storage tank capacity are represented by constraints (14) – (21), respectively.

$$\sum_{w} xwr_{wrt} = \sum_{y} xry_{ryt} + \sum_{o} xro_{rot} + \sum_{w} xwr_{wrt} \times (\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\beta_r) \qquad \forall r,t \tag{22}$$

$$\begin{aligned}\left(\sum_{r} xry_{ryt} + \sum_{a} xay_{ayt} + \sum_{s} xsy_{syt} + \sum_{\acute{y}} x\acute{y}y_{\acute{y}yt}\right) = \\ \sum_{g} xyg_{ygt} + \sum_{s} xys_{yst} + \sum_{e} xye_{yet} + \sum_{d} xyd_{ydt} + \sum_{p} xyp_{ypt} + \sum_{\acute{y}} xy\acute{y}_{y\acute{y}t} + \\ \left(\sum_{r} xry_{ryt} + \sum_{a} xay_{ayt} + \sum_{s} xsy_{syt} + \sum_{\acute{y}} x\acute{y}y_{\acute{y}yt}\right) \times \beta_y \qquad \forall y,t\end{aligned} \tag{23}$$

$$\sum_{y} xyg_{ygt} = \sum_{b} xgb_{gbt} + \sum_{m} xgm_{gmt} + \sum_{y} xyg_{ygt} \times \beta_g \qquad \forall g,t \tag{24}$$

$$\sum_{g} xgb_{gbt} = \sum_{l} xbl_{blt} + \sum_{f} xbf_{bft} \qquad \forall b,t \tag{25}$$

Equations (22 – (25) represent the flow balance constraints in each refinery, compressor station, city gate station and town bordering station, respectively.

$$xwr_{wrt} \leq M\lambda_{wr}, xwo_{wot} \leq M\lambda_{wo}, xry_{ryt} \leq M\lambda_{ry}, xay_{ayt} \leq M\lambda_{ay} \tag{26}$$

$$xro_{rot} \leq M\lambda_{ro}, xy\acute{y} \leq M\lambda_{y\acute{y}}, xyg_{ygt} \leq M\lambda_{yg}, xye_{yet} \leq M\lambda_{ye} \tag{27}$$

$$xyd_{ydt} \leq M\lambda_{yd}, xyp_{ypt} \leq M\lambda_{yp}, xys_{yst} \leq M\lambda_{ys}, xsy_{syt} \leq M\lambda_{sy} \tag{28}$$

$$xgb_{gbt} \leq M\lambda_{gb}, xgm_{gmt} \leq M\lambda_{gm}, xbl_{blt} \leq M\lambda_{bl}, xbf_{bft} \leq M\lambda_{bf} \tag{29}$$

Equations (26) – (29) show the constraints on presence/absence of a path in the model. Parameter λ represents the presence or absence of a certain path. If this parameter accepts a value of 1, the corresponding decision variable can take a value, otherwise the corresponding decision variable is zero**.** (M is a big number).

$$\lambda_{wr}Q_{wr}^{min} \leq xwr_{wrt} \leq \lambda_{wr}Q_{wr}^{max} \qquad \forall w,r \tag{30}$$

$$\lambda_{wo}Q_{wo}^{min} \leq xwo_{wot} \leq \lambda_{wo}Q_{wo}^{max} \qquad \forall w,o \tag{31}$$

$$\lambda_{ro}Q_{ro}^{min} \leq xro_{rot} \leq \lambda_{ro}Q_{ro}^{max} \qquad \forall r,o \tag{32}$$

$$\lambda_{ry}Q_{ry}^{min} \leq xry_{ryt} \leq \lambda_{ry}Q_{ry}^{max} \qquad \forall r,y \tag{33}$$

$$\lambda_{ay}Q_{ay}^{min} \leq xay_{ayt} \leq \lambda_{ay}Q_{ay}^{max} \qquad \forall a,y \tag{34}$$

$$\lambda_{y\acute{y}}Q_{y\acute{y}}^{min} \leq xy\acute{y}_{y\acute{y}t} \leq \lambda_{y\acute{y}}Q_{y\acute{y}}^{max} \qquad \forall y,\acute{y} \tag{35}$$
$$\lambda_{yg}Q_{yg}^{min} \leq xyg_{ygt} \leq \lambda_{yg}Q_{yg}^{max} \qquad \forall y,g \tag{36}$$
$$\lambda_{ye}Q_{ye}^{min} \leq xye_{yet} \leq \lambda_{ye}Q_{ye}^{max} \qquad \forall y,e \tag{37}$$
$$\lambda_{yd}Q_{yd}^{min} \leq xyd_{ydt} \leq \lambda_{yd}Q_{yd}^{max} \qquad \forall y,d \tag{38}$$
$$\lambda_{yp}Q_{yp}^{min} \leq xyp_{ypt} \leq \lambda_{yp}Q_{yp}^{max} \qquad \forall y,p \tag{39}$$
$$\lambda_{ys}Q_{ys}^{min} \leq xys_{yst} \leq \lambda_{ys}Q_{ys}^{max} \qquad \forall y,s \tag{40}$$
$$\lambda_{sy}Q_{sy}^{min} \leq xsy_{syt} \leq \lambda_{sy}Q_{sy}^{max} \qquad \forall s,y \tag{41}$$
$$\lambda_{gb}Q_{gb}^{min} \leq xgb_{gbt} \leq \lambda_{gb}Q_{gb}^{max} \qquad \forall g,b \tag{42}$$
$$\lambda_{gm}Q_{gm}^{min} \leq xgm_{gmt} \leq \lambda_{gm}Q_{gm}^{max} \qquad \forall g,m \tag{43}$$
$$\lambda_{bl}Q_{bl}^{min} \leq xbl_{blt} \leq \lambda_{bl}Q_{bl}^{max} \qquad \forall b,l \tag{44}$$
$$\lambda_{bf}Q_{bf}^{min} \leq xbf_{bft} \leq \lambda_{bf}Q_{bf}^{max} \qquad \forall b,f \tag{45}$$

Equations (30) – (45) represent the guarantee continuing net flow constraints. This set of constraint represents the range of possible physical flows that are limited to certain lower and upper bounds. These bounds are determined based on pipeline diameters, and the primal and secondary gas pressure in the related nodes

$$\boldsymbol{SLG_t} = \frac{\sum_w\sum_o \boldsymbol{xwo}+\sum_r\sum_o \boldsymbol{xro}+\sum_y\sum_e \boldsymbol{xye}+\sum_y\sum_d \boldsymbol{xyd}+\sum_y\sum_p \boldsymbol{xyp}+\sum_b\sum_l \boldsymbol{xbl}+\sum_b\sum_f \boldsymbol{xbf}+\sum_g\sum_m \boldsymbol{xgm}+\sum_w\sum_r \boldsymbol{xwr}\times(\boldsymbol{\alpha_1}+\boldsymbol{\alpha_2}+\boldsymbol{\alpha_3}+\boldsymbol{\alpha_4})}{\sum_o \boldsymbol{od_{ot}}+\sum_e \boldsymbol{ed_{et}}+\sum_d \boldsymbol{dd_{dt}}+\sum_p \boldsymbol{pd_{pt}}+\sum_l \boldsymbol{ld_{lt}}+\sum_f \boldsymbol{fd_{ft}}+\sum_m \boldsymbol{md_{mt}}+\sum_r \boldsymbol{eld_{elt}}} \quad \forall\, t \in T \tag{46}$$

$$SL \leq SLG_t \qquad \forall\, t \in T \tag{47}$$

Equation (46) represent the Service level gas constraint in period t that is defined for inventory or impacted gas line volume along supply chain and at consumption nodes, divided by the total demand. A new decision variable defined as a minimum target for the service level (SL), Equation (47), and the model then maximizes the minimum amount of the service level gas at any period t.

$$Xij_{ijt},\ SLG_t,\ SL,\ t, \geq 0 \tag{48}$$

Equation (48) represent that Xij_{ijt}, SLG_t, SL, and t are equal or greater than 0.

3-2- Problem Solving Approach

Multi-objective problems solving methods are classified into three categories based on decision-makers' preferences. These categories are the priori, interactive, and posteriori approaches [52]. In the priori approach, the decision-maker is rolled before the problem is resolved. While in the interactive approach, it usually converges to the best after several iterations. The main defects of the first and second categories are that the decision-maker does not have a general view about the trade-off before getting the Pareto optimal set. To avoid the mentioned defects, in the posteriori approach, such as the ε-constraint approach, at first, the set of Pareto optimal points are generated, then the decision-maker selects among them. In the ε-constraint approach, the objective function with the highest priority is optimized by adding the other objectives as unbinding constraints. Then the set of Pareto optimal points, including the weakly efficient solutions, are generated. To eliminate the weakly efficient solutions, Mavrotas and Florios developed a new issue of the ε-constraint algorithm called an augmented ε-constrained to generate Pareto optimal solutions without the weakly efficient solutions by adding the other objectives as binding constraints [53]. Therefore, the augmented ε -constraint algorithm avoids the generation of weakly Pareto optimal solutions and accelerates the whole process by avoiding redundant iterations. On the other hand, fuzzy-goal programming (FGP) approach has been a universal method to solving multi-objective supply chain problems. Several of usages have been investigated in a supply chain network design [6] and performance [54]. In this paper, the fuzzy goal-programming model consists of five goals formulated in a fuzzy manner. Equations (49)– (53) formulate the degree of satisfaction of each goal [6, 14, 55].

$$\text{Degree of satisfaction of goal 1} = \mu_1 = \frac{G_1 - \varepsilon_1}{AL_1 - \varepsilon_1} \quad (49)$$

$$\text{Degree of satisfaction of goal 2} = \mu_2 = \frac{\varepsilon_2 - G_2}{\varepsilon_2 - AL_2} \quad (50)$$

$$\text{Degree of satisfaction of goal 3} = \mu_3 = \frac{\varepsilon_3 - G_3}{\varepsilon_3 - AL_3} \quad (51)$$

$$\text{Degree of satisfaction of goal 4} = \mu_4 = \frac{\varepsilon_4 - G_4}{\varepsilon_4 - AL_4} \quad (52)$$

$$\text{Degree of satisfaction of goal 5} = \mu_5 = \frac{G_5 - \varepsilon_5}{AL_5 - \varepsilon_5} \quad (53)$$

Regarding the fuzzy goal-programming approach, the obtained values of the absolute priorities method for aspiration levels and the obtained values of the payoff results for the lower and upper tolerance limits for each aspiration level are presented in the Table 2. Where AL_1–AL_5 define the aspiration levels of the goals 1–5, respectively. ε_1 and ε_5 represent the lower tolerance limits for the total service level gas (AL_1) and total revenue of gas products (AL_5) situations, respectively. ε_2, ε_3 and ε_4 define the upper tolerance limits for the recovery (AL_2), environmental (AL_3), and economic (AL_4) costs situations, respectively. According to the definition of Tiwari et al., the objective function of the fuzzy goal programming model is as follows: [55].

$$\text{Maximize} f(\mu) = \sum_{i=1}^{5} W_i \mu_i \quad (54)$$

The fuzzy goal programming model is subject to: Constraints (6) – (53)

In the objective function of the obtained deterministic model that follows the Tiwari's method, it was aimed to maximize the total satisfaction levels of the goals, for which all the values of satisfaction membership degree were summed up. The point to be considered is the different importance of each of the goals for decision makers. Therefore, it is necessary to determine the weight of each goal by one of the common methods of determining weights by decision-makers [55]. Then each of these weights is multiplied by the degree of satisfaction of the corresponding goal; and finally, the results of each value are summed up, and the objective function will seek to maximize the obtained equation.

Table 2- Aspiration levels values and tolerance limits

AL1	1.083891	lower	1.02
AL2	94100.92	upper	270231.384
AL3	1787535	upper	1930970.048
AL4	345000000	upper	374224100
AL5	7900000000	lower	7888496000

4- Case study

Any process that takes place requires the use of a series of data and resources [56]. In this research, the multi-objective model has been solved using the fuzzy goal-programming algorithm. The fuzzy goal-programming is accorded and practiced in the GAMS 24.1.2−64 bit to solve the presented multi-objective model using the CPLEX solver. The specifications of the PC used to run the software are as follows: Intel Corei5 3.4 GHz processor with 4 GB of RAM. For verifying and validating the proposed model, a small-sized problem with real data has been solved. The natural gas supply chain of the problem includes forty-one gas wells, six oil wells, eight refineries, nine compressor stations, two storage tanks, ten city-gate stations, dispatching, twenty town bordering stations, two origin of importation, five exportation customers, two industrial customers, three power plant customers, twenty residential customers, three commercial customers and four small industrial customers [14, 15]. The model statistics and a small-size of the natural gas supply chain are shown in the Table 3 and Fig. 2, respectively.

Table 3- Model Statistics

Blocks of Equations	81	Single Equations	63,863
Blocks of Variables	21	Single Variables	20,532
Non Zero Elements	219,130		

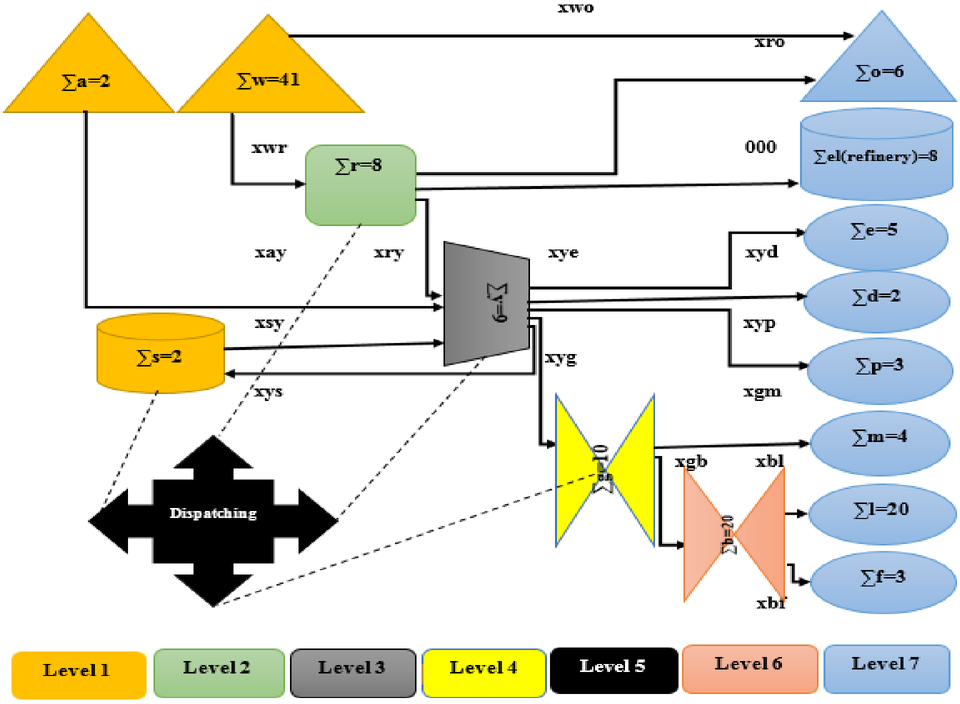

Fig. 2- A small-sized of the natural gas supply chain

5- Discussions

In this section, the obtained values and the mentioned real case study are analyzed. Table 4 epitomizes the results obtained by the optimization of the five goals, including, maximizing the service level (G_1:1.083891), minimizing the recovery (G_2:94906.147294), environmental (G_3:1809853.031645) and economic costs (G_4:3.45E+08), maximizing the total revenue (G_5:7.9E+09) and objective function (0.967738). Consequently, there is big trade-offs among the five goals. The chart of goals values of fuzzy goal programming method is shown in the Fig. 3.

Table 4- Goals values and objective function of fuzzy goal programming method

G_1	G_2	G_3	G_4	G_5	$f(\mu)$
1.083891	94906.147294	1809853.031645	3.45E+08	7.9E+09	0.967738

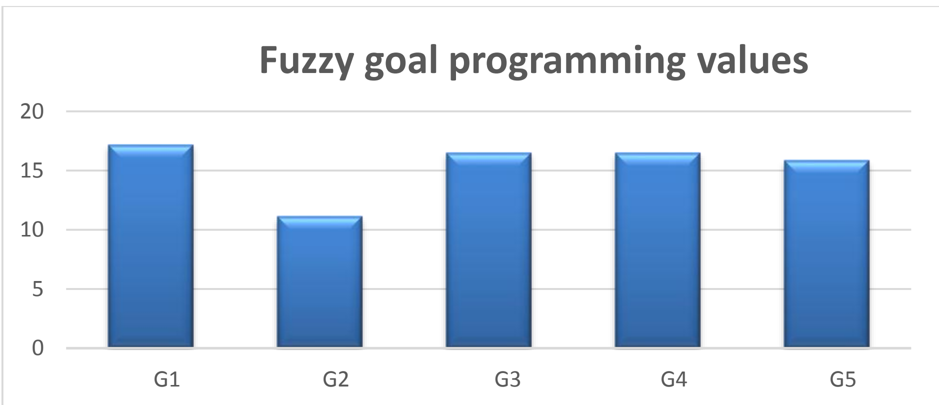

Fig. 3- The chart of goals values of fuzzy goal programming method

5-1- Sensitivity Analysis

Sensitivity analysis of various w, α and β values and the amount of the goals and objective function are shown in the Table 5, 6 and 7, respectively.

Table 5- Results of sensitivity analysis on parameters of w

∑_(Wi)	G1	G2	G3	G4	G5	f(μ)
0.2,0.2,0.2,0.2,0.2	1.083891	94910.690439	1809993.175	345000000	7900000000	0.967766
0.4,0.15,0.15,0.15,0.15	1.083891	94911.306249	1810012.171	345000000	7900000000	0.975804
0.6,0.1,0.1,0.1,0.1	1.083891	94912.881197	1810060.754	345000000	7900000000	0.983835
0.8,0.05,0.05,0.05,0.05	1.083891	96254.759921	1829394.332	345000000	7900000000	0.984797
0.15,0.4,0.15,0.15,0.15	1.083891	94910.828316	1809997.428	345000000	7900000000	0.974670
0.1,0.6,0.1,0.1,0.1	1.083676	94902.114825	1809728.641	345000000	7900000000	0.981461
0.05,0.8,0.05,0.05,0.05	1.082293	94834.954977	1807656.945	345000000	7900000000	0.988401
0.15,0.15,0.4,0.15,0.15	1.066824	94182.645599	1787535	345000000	7900000000	0.959860
0.1,0.1,0.6,0.1,0.1	1.066700	94182.645599	1787535	345000000	7900000000	0.973047
0.05,0.05,0.8,0.05,0.05	1.065333	94872.006882	1787535	345000000	7900000000	0.985258
0.15,0.15,0.15,0.4,0.15	1.083891	94911.306249	1810012.171	345000000	7900000000	0.975804
0.1,0.1,0.1,0.6,0.1	1.083891	94912.881197	1810060.754	345000000	7900000000	0.983835
0.05,0.05,0.05,0.8,0.05	1.083891	95002.758703	1823866.572	345000000	7900000000	0.987079
0.15,0.15,0.15,0.15,0.4	1.083891	94911.306249	1810012.171	345000000	7900000000	0.975804
0.1,0.1,0.1,0.1,0.6	1.083891	94912.881197	1810060.754	345000000	7900000000	0.983835
0.05,0.05,0.05,0.05,0.8	1.083891	95234.700207	1824546.788	345000000	7900000000	0.986776
0.05,0.05,0.1,0.4,0.4	1.062843	95963.659421	1787535	345000000	7900000000	0.983000
0.4,0.4,0.1,0.05,0.05	1.083891	94912.452035	1810047.516	345000000	7900000000	0.982462
0.3,0.3,0.2,0.1,0.1	1.083891	94910.581569	1809989.817	345000000	7900000000	0.967311
0.1,0.1,0.2,0.3,0.3	1.072692	94407.032505	1794456.717	345000000	7900000000	0.972647
0.25,0.25,0.2,0.15,0.15	1.083891	94906.147294	1809853.032	345000000	7900000000	0.967738

Table 6- Results of sensitivity analysis on parameters of Storage tanks

SC	G1	G2	G3	G4	G5	f(μ)
α=0.1	1.02	96810.987090	1790786.437	345262587	7888496000	0.59027
α=0.2	1.024239	95045.707263	1796359.491	345000000	7899298073	0.74379
α=0.3	1.02	95258.497123	1788703.207085	345001257	7900000000	0.746722
α=0.4	1.079124	94684.679495	1803021.360917	345000000	7900000000	0.958924
α=0.5	1.083891	94903.497632	1809771.296879	345000000	7900000000	0.967855
α=0.6	1.083891	94902.224497	1809732.024185	345000000	7900000000	0.967912
α=0.7	1.083891	94903.517390	1809771.906370	345000000	7900000000	0.967855
α=0.8	1.083891	94901.703462	1809715.951695	345000000	7900000000	0.967935
α=0.9	1.083891	94904.645252	1809806.697793	345000000	7900000000	0.967804
α=1	1.083891	94906.147294	1809853.031645	345000000	7900000000	0.967738

Table 7- Results of sensitivity analysis on parameters of demand volume of oil wells

Od	G1	G2	G3	G4	G5	f(μ)
β= 0.1	1.083891	95553.830942	1787535	345000000	7900000000	0.997937735
β= 0.4	1.083891	94944.532912	1787535	345000000	7900000000	0.998802574
β= 0.7	1.083891	94449.145523	1795755.788	345000000	7900000000	0.988042996
β= 1	1.083891	94906.147294	1809853.032	345000000	7900000000	0.967737702
β= 1.3	1.080120593	95471.793224	1819377.575	345085986.3	7900000000	0.938459561
β= 1.6	1.073410442	95874.612134	1824415.258	345166157.4	7900000000	0.904195716
β= 1.9	1.067772104	96786.797520	1833191.657	345376259.8	7900000000	0.867522768
β= 2.2	1.05603048	96668.045142	1833120.101	345337286.1	7900000000	0.822047175
β= 2.5	1.044139778	96668.045142	1833120.101	345337286.1	7900000000	0.775519881

β= 2.8	1.032339273	96668.045142	1833120.101	345337286.1	7900000000	0.729345516

The results of the analysis of the model sensitivity to the changes made in the parameters w, α and β show that the fuzzy goal programming model can provide a variety of optimal solutions. The proposed model demonstrates appropriate changes to the manipulation of the parameters and consequently one of the most substantial outputs of this model, i.e. maintaining the resilience and sustainability aspects of the supply chain, is adhered to. Changes in the parameter w representing the importance of the degree of satisfaction of the goals based on the preferences of the decision makers, lead to different degree of satisfaction in the objective function. Storage tanks are other strategic important constraints on the resilience and sustainability of the natural gas supply chain. i.e. applying the α parameters 0.1 and 1 of the storage tanks and, consequently, creating changes in the volume of storage capacity of the storage tanks, leading to increase of the service level from 1.02 to 1.083891 and increase of the objective function from 0.59027 to 0.967738, respectively.
Changes in the β parameter of the demand for gas from oil wells, lead to different amounts in the objective functions. i.e. by increasing the β parameter by 1.3, 1.6 and 1.9 times, decrease the service level and objective function, while increases the recovery, environmental and economic costs. Accordingly, the increase of demand for gas from oil wells, leads to the underutilization of facilities or the increase in the penalty per underutilized capacity. The economic costs are increased due to an increase in imported gas to overcome the shortage. Consequently, manipulating and making changes to the β parameter that relates to the demand for gas from oil wells or, in other words, the increase of gas injection into the oil wells, suggests that the increased demand increases the pressure inside oil wells and reservoirs and, as a result, increases oil recovery rates, with respect to the resilience and sustainability aspects of the natural gas supply chain. As the goals of the proposed model are fuzzy, changes in the parameters w, α and β make the values obtained by the goals to be between the aspiration levels and authorized low or high tolerances, and consequently one of the most important outputs of the model, i.e. maintaining the resilience and sustainability aspects of the supply chain, is adhered to.
Information, features, and conditions of the proposed model which, based on consulting with experts, are similar to the real model, can help decision makers make an optimal decision in terms of production, refinement, injection into oil reservoirs, storage, transmission and distribution of natural gas in warm and cold seasons of the year, and optimally allocate gas to each customer while taking into account the resilience and sustainability aspects of the supply chain.
Finally, the contributions of this research, compared to the previous researches, are as follows: 1. Consideration of the resilience aspect including the first and second fuzzy goals, and the sustainability aspect including the third, fourth and fifth fuzzy goals in the proposed model, and trade-offs among them and their optimization, 2. Application of Fuzzy goal programming approach and fuzzification of five goals of the proposed model, 3. A great compatibility of the proposed model and all its parameters with Iran's natural gas supply chain, 4. Considering the validity of the proposed model through the implementation and use of the actual parameters and the desired and optimal results of its outputs, 5. Considering the increase in the pressure of the oil wells and reservoirs through the injection of gas into them and, consequently, increasing their oil recovery while preserving the resilience and sustainability aspects of the natural gas supply chain.

6- Conclusions

The main purpose of this research was the mathematical modeling of the natural gas supply chain and its development with the optimized model approach of the fuzzy goal programming with conflicting goals by trade-offs among them. In this paper, based on the general structure of the Iranian gas industry and the relationship among its components, seven levels were introduced for the natural gas supply chain and a fuzzy goal programming model was developed to optimize the resilience and sustainability aspects at all its levels. Fuzzy goals of the proposed

model included the recovery, environmental and economic costs, as well as the service level and total revenue for the natural gas, and all four products derived from natural gas in multiple time periods (12 months) with the objective function of maximizing the total satisfaction degree of the goals. Therefore, the fuzzy goal programming model in this research with real data and parameters were resolved by Gams 23.1.2−64-bit software, using the CPLEX solver.
Sensitivity analysis on the key parameters, and their manipulation, made appropriate changes and provided various solutions. As the goals of the proposed model are fuzzy, changes in the key parameters, make the values obtained by the goals to be between the aspiration levels and authorized low or high tolerances, and consequently one of the most important outputs of the model, i.e. maintaining the resilience and sustainability aspects of the natural gas supply chain, and decision makers also have the optimal solutions, is adhered to.
For future studies, this model in the actual size of the supply chain nodes, can be solved through such other methods as Differential Evolutionary, Genetic Algorithm, Tabu Search, PSO and various heuristic and metaheuristic methods and comparing its results with the proposed model. In addition, another suggestion for future researches is considering some goals and constraints and adding them to the model.

7- Acknowledgments

Authors would like to express their gratitude to National Iranian Gas Company for its valuable cooperation.

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