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A techno-economic analysis of natural gas distribution network for an off-gas-grid site: a case study locality of Frane Ouargla, Algeria

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Abstract
Natural gas provides an immediate opportunity for leading an equitable energy transition by guaranteeing energy security and minimizing the risks linked to climate change. The objective of this study is to determine the technical and economic feasibility of a natural gas pipeline network design to supply natural gas for two off-gas-grid localities Frane and Elkoum in Ouargla City. The calculation of the distribution network is carried out using the APHYRE program. The results show that the network consists of 419 nodes, with a pressure of 2.33 bar. The total length of the network is 57 km, in which the highest percentage is attributed to a diameter of 40 mm (54 %) because it is the diameter that directly serves customers.
Keywords: Natural gas, Distribution network, APHYRE, Simulation, Algeria

1. Introduction

The carbon-neutralization of the global energy system will necessitate the deployment and scaling up of low-emission gases, in addition to the rising complexity of long and short-term gas supply security. Natural gas is a key energy for this transition; it plays a major role in electricity generation thanks to its flexibility and its ability to meet rapidly growing demand with the electrification of uses; it emits half as much greenhouse gas (GHG) as coal in electricity generation [IEA, 2024].

Natural gas, which is considered today as an alternative, clean, and low carbon footprint fuel, is the most suitable fuel for both domestic use for heating and cooking, power plants, industry (including petrochemicals and refining), or transport (CNG and LNG fuel) due to its interesting cost, its energy efficiency and its environmental qualities compared to those of conventional fuels [CEREFE, 2024].

Algeria has opted, since its independence, for the development of natural gas infrastructure, and access of the population to natural gas; this vector constitutes a priority that aims to improve the quality of life of the citizens on the one hand and the economic situation of the country on the other hand. Aware of this challenge, the sector has set the priority of developing all the axes guaranteeing the long-term coverage of the country's natural gas needs, in particular by the development of gas transport and distribution infrastructures [MEM,2019].

With a natural gas coverage rate at the national level that has currently reached 62%, ambitious and structured programs have been adopted by the public authorities and implemented making it possible to significantly improve gas penetration rates. The distribution network development plan includes the electrification and public gas distribution programs initiated by the State, the connections of the new customers as well as the maintenance and operating equipment, and the management and operation modernization projects. Thus, the development plan for the networks and infrastructures of the Algerian Electricity and Gas Distribution Company, over the period 2018-2028, plans to develop an electricity network of 106,563 km of lines, 51,694 stations, and 1,365,034 connections, and a Gas network of 54,509 km, with 2,322,184 connections [MEM, 2018].

In this context, the objective of our work is to study the technical and economic feasibility of a natural gas distribution network design of two localities in the Wilaya of Ouargla, namely; Frane and Elkoum. To meet the growing demand for energy from customers, improve their standard of living, and develop the Algerian gas network.

2. Natural gas infrastructure in Algeria

Algeria has proven hydrocarbon reserves, all products combined (crude oil, gas, condensate, and liquefied petroleum gas), estimated at more than 4,300 million tonnes of oil equivalent (MTOE), of which 55% is natural gas. Algeria is a major natural gas producer in Africa with an estimated 4,504 billion cubic meters (B.cu.m) of proven natural gas reserves at the beginning of 2023 among the largest worldwide. Dry natural gas production averaged about 98.77 B.cu.m between 2013 and 2023, while dry natural gas consumption averaged 46.09 B.cu.m over the same period. In 2019, natural gas production fell because of the impact of the COVID-19 pandemic on economic activity and thus lower crude oil consumption, however, it quickly rose again in 2021, reaching a record high of 101.1 B.cu.m (see Fig.1) [EIA, 2023]. After the extraction and production processes, natural gas is mainly exported or used domestically for power generation.

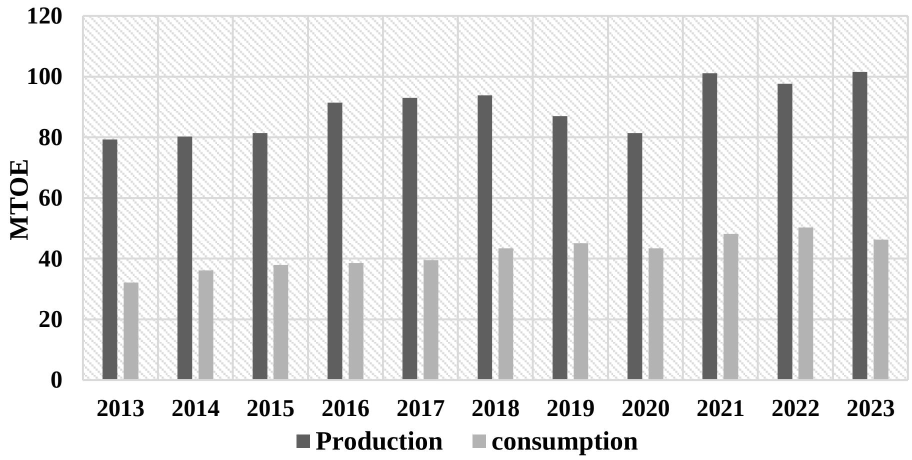

Figure 1: Natural gas production and consumption in Algeria [EIA, 2023].

The gas transmission network increased from 6,105 km in 2005 to 19,258 km in 2016 and will increase to 27,291 km in 2027, representing an average annual growth rate of 10.8% over the period 2005 - 2016 and 2.9% over the period 2017-2027. In 2021, the gas transmission network covers 20,705 km and has a total capacity of 404,342 Mtpa.

The pipeline transport network is subdivided into two complementary parts:

The Southern network starts from the fields and transports the effluents to the Liquid Hydrocarbon-Dispatching Center of Haoud El Hamra (LHDC) for crude oil and condensate and towards the National Gas Dispatch Center for natural gas and LPG located in Hassi R'Mel (NGDC) [SH,2022].

The northern network ensures the transport:

- Crude oil from CDHL to the refineries and ports of exports.
- Condensate from LHDC and Hassi R'Mel field to the refinery in Skikda and ports of exports.

- Natural gas from the NGDC to the domestic market, the gas pipelines dedicated to export, and the liquefaction complexes.
- Liquefied Petroleum Gas (LPG) from Hassi R'Mel to the separation Complexes.

Table 1: Hydrocarbon pipeline transport network [SH, 2021].

			Capacity (MTOE/y)		
Network	**Number of STC**	**Length (km)**	**actual**	**Reserved**	**Available**
Southern network	8	8,060	140,160	80,556	59,604
Northern network	14	12,645	264,182	148,911	115,271
Total	22	20,705	404,342	229,467	174,875

The network of transport by pipeline consists mainly of:

- 43 pipelines distributed in 22 systems of transport by pipelines.
- 85 pumping and compression stations installed along the network.
- 28 liquid hydrocarbon storage tanks with a usable capacity of 3.25 million TOE.
- Three petroleum ports in Arzew, Skikda, and Bejaia, with a loading capacity of 1.3 million tons.

Two international gas pipelines linking Algeria to Europe, with a transport capacity of more than 2.3 billion cm per year. These gas infrastructures are the gas pipeline Enrico Mattei (GEM), connecting Algeria to Italy via Tunisia, and the MEDGAZ, linking Algeria directly from Beni Saf to Spain [SH,2022].

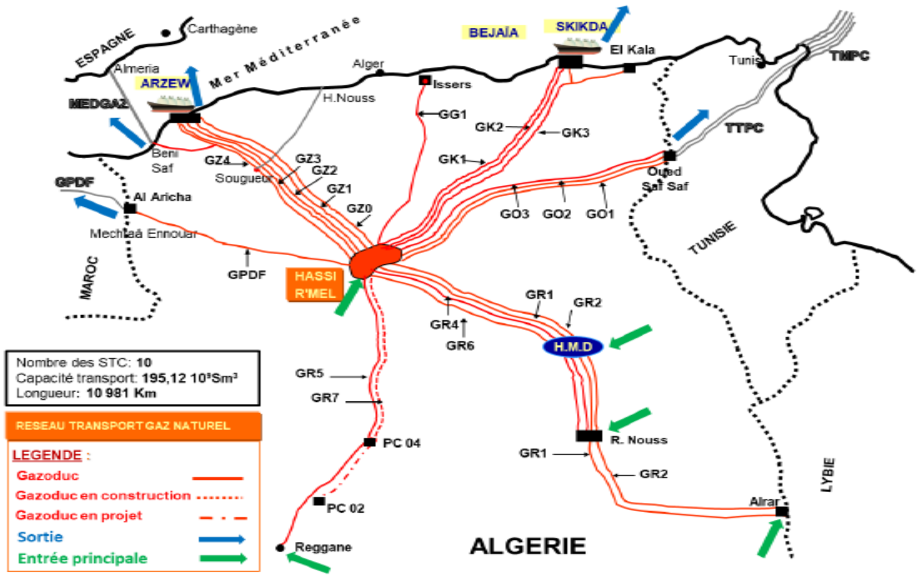

Figure 2: Natural gas distribution network [SH, 2018].

3. Presentation of the study area

Ouargla region is located at an altitude of 128 m, 190 km east of Ghardaïa, 388 km south of Biskra, and 160 km southwest of Touggourt. Capital of the desert, surrounded by five small oases: Sidi Khouiled, Chott, Adjadja, Rouissat, and Bamendil.

The climate of the Ouargla region is characterized by marked aridity and almost permanent dryness. The average annual temperature, measured over the period 2014-2024, is 24 °C. The average maxima and minima are 42 °C and 5 °C recorded, respectively, during July and January. The average annual thermal amplitude is therefore of the order of 39 °C. The average annual precipitation, over the same period, is 39.1 mm [WeatherS, 2024].

Ouargla region constitutes an economic center rich in gas and oil reserves, contained in the territory of Hassi Messaoud. With 2,887 km², the commune has a considerable surface area. Ouargla region has several subscribers to the natural gas distribution network of 65,769 customers, with a connection rate estimated at 93%, according to the energy and mines department. Several projects to connect to natural gas networks have been completed in the urban expansion areas of the wilaya of Ouargla, to improve the living environment of residents. Natural gas projects have been carried out over the last two years, targeting 55 sites in urban expansion areas of the municipalities of Ouargla, Rouissat, N'Goussa, Aïn Beida, and Sidi Khouiled, which have enabled the connection of 530 homes to this energy, for 55 million dinars [Elmoudjahid, 2024].

The locality Frane; in the commune of N'Goussa located northeast of the city of Ouargla with a total area of 14.52 km² and a current population of 9175 inhabitants [CPA, 2023].

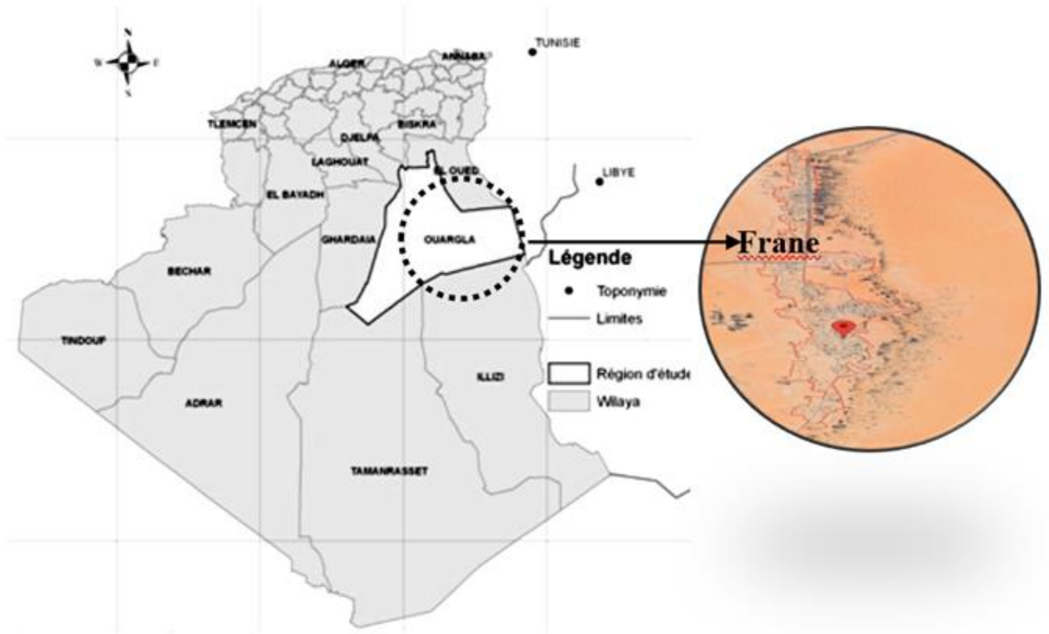

Figure 3: Geographical location of the locality Frane [Google Map, 2024].

4. Methodology

A pipeline gas distribution network study aims to find a network architecture capable of meeting energy needs on technical and economic levels. Technically, it is a question of designing a structure that is simple to operate and capable of satisfying, in the best conditions, the gas needs of existing consumers and those who will be supplied with gas in the future. Economically, it is a question of assessing the efficiency of the investments that will be made. This criterion is crucial in the choice of one of the technical solutions studied [GTDG4,2013].

The steps of a natural gas distribution network study for a given locality are in order:

- Market study (evolution of consumption);
- Analysis of the existing or projected network at different horizons (current state, short, medium, and long term),
- The search for a long-term structure,
- Economic study.

The architecture of natural gas distribution networks differs from one locality to another and is identified with the geography of the places. It depends on the location, the weight, and the axes of development.

4.1. Data collection

The data to be collected for a pipeline distribution network study is based on a certain number of data, which mainly concern:

- Cartography of places,
- Weather conditions,
- Existing structures,
- Current and future consumers and their needs.

The area to be supplied with natural gas must be precisely located and demarcated. It is therefore necessary to collect from the development bodies and/or the municipalities concerned all the information needed to do this: plans, types of buildings, number of dwellings, collective facilities, etc.

4.2. Calculation of specific consumption

The aim of this stage is the estimation and localization of annual, daily, and hourly consumption (in the short, medium, and long term) necessary for the design and development studies (reinforcement, restructuring, etc.) of natural gas distribution networks [GTDG3, 2013].

Consumption and emissions for an urban area must be examined under the following three aspects:

- Consumption and emissions for a year,
- Daily emissions,
- Hourly emissions.

The emissions of an operation will be the sum of consumption itself (domestic, commercial, and industrial customers) and losses (technical and commercial).

Consumption is linked to the size of the household (F1, F2, F3, etc.), to the concept of use, and the concept of occupation. We distinguish two types of consumption for domestic customers; Heating Consumption (HC) and Non-Heating Consumption (NHC).

4.2.1. Annual consumption

Annual Heating and Non-Heating Consumption is determined from the consumption bills of existing customers by usage following the equations (1&2):

$$NHC_A = \frac{QC_2+QC_3}{2} \times 4 \qquad (1)$$

NHC_A: Annual Non-Heating Consumption, which is equal to 4 times the lowest consumption of the four quarters recorded, Th/y

QC_i: Consumption recorded per quarter over a year $i \in [1-4]$

$$HC_A = TC_A - NHC_A \quad (2)$$

HC_A: Annual heating consumption, Th/y

TC_A: Total annual consumption

NHC_A: Annual Non-Heating Consumption

4.2.2. Daily consumption

Daily Non-Heating Consumption is determined from Annual Non-Heating Consumption by assigning them a number of days of use Nd. An investigation will determine the number of days of use. In the absence of data specific to a given operation, it is assumed that Nd is equal to 250 days for Non-Heating domestic uses, hence:

$$NHC_D = \frac{NHC_A}{N_d} \quad (3)$$

NHC_D: Daily Non-Heating Consumption, Th/d

N_d: Number of days

The Daily Heating Consumption is determined by the product between the heating gradient, and the difference between the threshold and risk temperatures.

$$HC_D = H_g\ (T_{th} - T_r) \quad (4)$$

HC_D: Daily Heating Consumption, Th/d

T_{th}: Threshold temperature, °C

T_r: Risk temperature, °C

The heating gradient H_g is equal to the ratio between the annual heating consumption and the annual number of degree-days.

$$H_g = \frac{HC_A}{N_{dd}} \tag{5}$$

H_g: Heating gradient, Th/degree-day

N_{dd}: Annual number of degree-days, degree-day/y

Hence the daily heating consumption:

$$HC_D = \frac{HC_A}{N_{dd}}\,(T_{th} - T_r) \tag{6}$$

4.2.3. Peak-Hour consumption

Depending on usage patterns, the number of hours per day is between 6 and 12 hours. An investigation will determine the number of hours per day.

$$PHoC_H = \frac{HC_D}{N_{HD}} \tag{7}$$

$PHoC_H$: Peak-Hour Consumption, Th/h

HC_D: Daily Peak Consumption, Th/j

N_{HD}: Number of hours of use per day, h/d

4.2.4. Hourly heating consumption

It is assumed that at a risk of 2%, heating devices operate in principle continuously (24 hours per day). In reality, it is observed that N_{HH} remains below this value. An investigation will determine the number of hours of heating use per day.

$$HC_H = \frac{HC_D}{N_{HH}} \tag{8}$$

HC_H: Hourly Heating Consumption, Th/h

N_{HH}: Number of hours of heating use per day, h/d

$$N_{HP} = \frac{TC_A}{HC_H \times PHoC_H} \tag{9}$$

N_{HP}: Number of hours of use of the peak,

4.3. Establishment of study plans

From the cartography and plans that have been collected, we establish skeleton plans of networks using the AutoCAD design and drafting software on which we highlight:

- The nodes with their numbering,
- The sections with their characteristics (length and diameter),
- The altitude in the case of low pressure for significant differences in level,
- The delimitation of the zones.

4.4. Formatting data for computer calculation

The data thus processed will serve as input to the APHYRE model for network calculation. The APHYRE model is a steady-state distribution network simulation model, it exists in three versions (200, 900, and 2000 nodes).

From the data characterizing the network and the consumptions put in the desired form, APHYRE calculates the pressures at the different nodes and the pressure losses on each section. Calculation of the pressure loss is carried out by the simplified RENOUARD formula [GTDG1,2013]:

This equation is given for low pressures (P<500 mmCE = 50 mbar):

$$P_1 - P_2 = 232 \times 10^6 \times S \times L \times \frac{Q^{1.82}}{D^{4.82}} \tag{10}$$

$P_1 - P_2$: Linear pressure loss, mmCE (mm water column)

For medium pressure, type B (P<4 bar relatives):

$$P_1{}^2 - P_2{}^2 = 48600 \times S \times L \times \frac{Q^{1.82}}{D^{4.82}} \tag{11}$$

$P_1{}^2 - P_2{}^2$: Quadratic pressure loss, absolute bars^2

S: Fictitious density of gas

L: Length of the pipe, km

D: Inner diameter of the pipe, mm

Q: Flow rate in the pipe, m^3/h (at 15°C and 1013 mbar)

$$S = d \times \left(\frac{\nu}{0.22}\right)^{0.18} \quad (12)$$

ν: Kinematic gas viscosity in cm²/s

d: Real gas density

The results of a network calculation are given in the form of pressures at all points in the network, flow rates, and pressure losses. Since these results are highly dependent on the data provided, they must be examined and interpreted carefully.

The following flowchart represents the different steps to follow for carrying out a study:

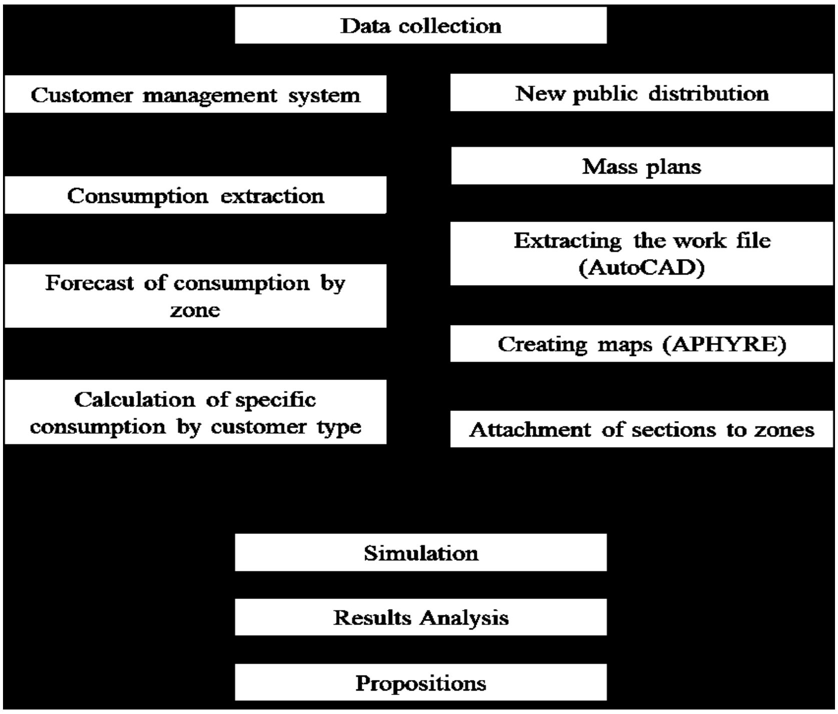

Figure 4: Flowchart of phases of a natural gas distribution network design.

5. Results and Discussion

5.1. Study data

To estimate the total consumption of the locality of Frane and Elkoum, we used data from the Communal Popular Assembly (CPA) of N'Goussa for the year 2023 [CPA, 2023].

Table 2: Study data [CPA, 2023].

			Frane	Elkoum
Sector	**Customer name**	**Customer type**	**Number /Area**	**Number/Area**
Tertiary sector	Education sector	Elementary school	1081 students	543 students
		Secondary College	670 students	/
		Programmed projects (High school)	500 students	/
	Mosques		3700 m²	1100 m²
	Health sector	Healthcare room	300 m²	300 m²
		Medical centre	300 m²	/
	Public facilities	Library	300 m²	/
		Road intervention	150 m²	/
Residential sector	Number of inhabitants 9175			
	Number of housing 1835			

5.2. Total consumption estimation

5.2.1. Residential sector

The purpose of establishing consumption forecasts is to define, within the framework of the dimensioning or analysis of a network, the location and value of needs at a given time. A series of sample assumptions determine the total consumption of domestic customers at different horizons:

- To facilitate the long-term multi-period modeling, the time horizon is divided into three five-year plans; (5, 10, and 20 years)
- The two localities Frane and Elkoum are characterized by a housing stock of different types (F1, F2, F3) and traditional houses. In our study, it's assumed that the entire stock is assimilated to F3-type housing,
- The specific consumption per customer of F3-type housing is 8.21 Th/h
- The number of housing is 1835
- The population growth rate, 2%/y
- Each housing unit holds 5 people,
- Equipment of accompaniment consume 390 Nm^3/h for each 2500 housing units
- The calorific value of the natural gas used is 9.75 Th/m^3.

Table 3: Summary of total residential sector consumption at different time horizons.

Time horizon	**Actual**	**Short**	**Medium**	**Long**
	2023	**2028**	**2033**	**2043**
Number of housing units	1835	2026	2236	2727
Population	9175	10130	11184	13634
Increase in the number of housing units	/	191	401	892
New housing consumption (Nm^3/h)	/	160.83	337.66	751.11
New equipment consumption (Nm^3/h)	/	29.8	62.55	139.15
Consumption of new housing (Nm^3/h)	/	190.63	400.21	890.26
Total consumption of housing (Nm^3/h)	**1545.16**	**1925.25**	**2134.83**	**2624.88**

5.2.2. Tertiary sector

The consumption of tertiary subscribers is determined based on their installed equipment and ratios obtained from the consumption history of similar subscribers of the control public distribution. The ratios used to estimate the consumption of tertiary subscribers are shown in the table below.

Table 4: Summary of current total tertiary sector consumption.

Designation	Heating consumption ratio (Th/h/student)	Number of students	Total consumption (Th/h)	Total consumption (Nm^3/h)
Elementary school	0.2	1624	324.8	33.31
Secondary school	0.25	1170	292.5	30
	($Th/h/m^2$)	**Area (m^2)**	**(Th/h)**	**(Nm^3/h)**
Health sector	0.26	1200	312	32
Public facilities	0.17	600	102	10.46
Mosques	0.17	4800	816	83.69
Total consumption (Nm^3/h)				189.48

Non-Heating Consumption is zero because the investigated establishments do not have school meals and boarding facilities. The current consumption of existing customers in the tertiary sector is equal to 189.48 Nm^3/h of which the largest consumption is that of mosques which represents 44.16%.

The total consumption (actual and projected over the time horizon of this study) of the two sectors of the localities of Frane and Elkoum is presented in the following table:

Table 5: Summary of total consumption.

Time horizon	Reference year	Short-term	Medium-term	Long-term
Total consumption (Nm^3/h)	1734.62	1925.25	2134.83	2624.88

5.3. Network development and coding

From the agglomeration mapping and the mass plan of the localities that were collected, we establish skeleton plans of networks using the Auto CAD program on which we highlight four stages:

1. The location of the starting station, which is the closest place to connect to the gas network,
2. Tracing on the plan the main pipelines namely: pipelines with a diameter of 200 mm from the gas regulator station to the last point of the locality via the main road, pipelines with a diameter of 125 mm (63, and 40 mm) via secondary roads,
3. Codification: the nodes with their numbering,
4. Measurements of the sections between two consecutive nodes with their characteristics (length and diameter), using an Excel sheet.

Figure 5: Second step: tracing on the plan the main pipelines.

5.4. Results of the Gas Network Calculation Program (APHYRE)

The network calculation is performed with a low-pressure regime. This distribution network simulation module in a steady flow regime uses the RENOUARD pressure loss calculation formula (eq.10). The results of the APHYRE program are:

- Pressure at each node,
- Flow rate (with direction) in each section,
- Pressure loss per unit length for each section,
- Indication of the sections with the highest pressure loss per unit length,
- Minimum pressure observed with identification of the node,
- Pipe lengths classified by diameter,
- Physical data entered,
- Number of meshed nodes, antennas, and total network,
- Ranking of the sections with the highest pressure losses.

It should be noted that the minimum pressure must not be less than 2 bar, to allow subscriber regulators to function correctly. The results obtained, after passing through APHYRE, are represented by the following results file:

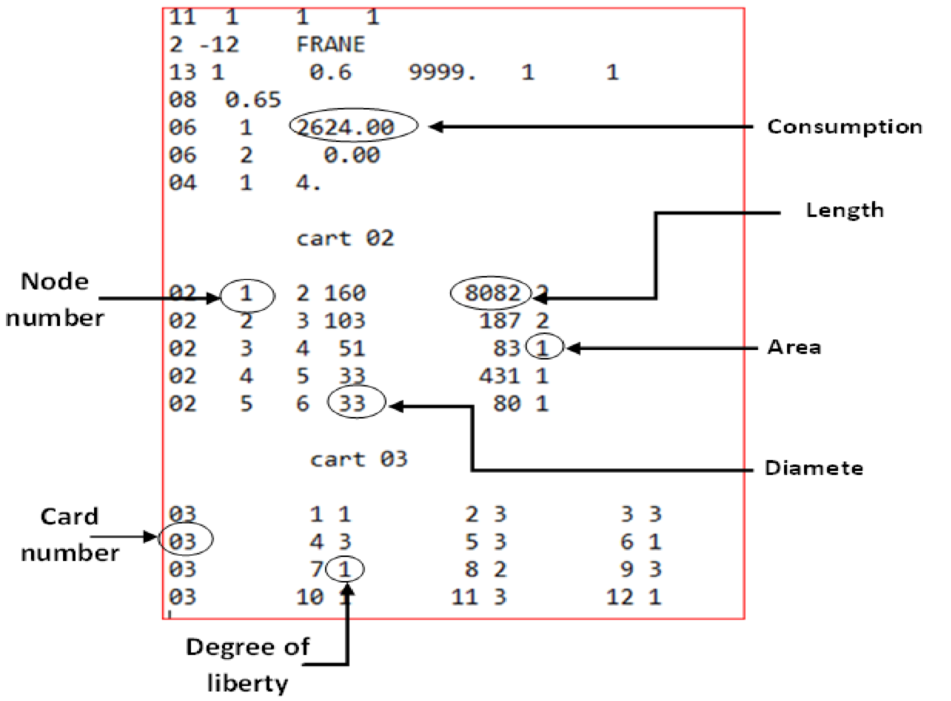

Figure 6: Example of result file.

As a result, we obtained 419 nods, the lowest recorded pressure equal to 2.33 bar and the high-pressure loss was equal to 14.021 bar². For the lengths corresponding to the diameters are summarized in the following table:

Table 6: Network characteristics.

Diameter (mm)	**40**	**63**	**125**	**200**
Length (m)	31152	8564	6091	11189
Percentage (%)	54.6	15	10.7	19.7

The total length of the network is 57 km, in which the highest percentage is attributed to a diameter of 40 mm because it is the diameter that directly serves customers.

5.5. Economic study of the project

To determine the economic profitability of the project, we use the results from APHYRE software, namely:

- The total lengths by diameter,
- The number of connections,

Unit prices are determined from statistics of projects carried out in the different areas of the national territory by the Algerian company Sonelgaz [Sonelgaz, 2023]. In Table (7), we illustrate the unit prices and the costs of the works by nature and by diameter as well as the total initial investment of the project.

Table 7: Unit prices by type and by diameter.

	Diameter (mm)				Connection	Station
	40	63	125	200		
Unit supply price (DA)	1,035	1,369	2,128	4,313	11,000	80,000,000
Unit price of implementation (DA)	1000	1000	2000.00	2000	10,000	2,000,000
Cost (MDA)	63.39	20.28	25.14	70.63	399	100

The total cost of the project is 678.46 Million DA. The gas connection to the subscribers represents the largest part of the total cost of the project approximately 58.04%, followed by the cost of purchasing and installing the distribution station (100 million Dinars, approximately 14.74% of the total investment).

The payback period is the amount of time taken to recover the cost of the initial investment. It is calculated by dividing the initial investment by the annual cash flow. To estimate the investment payback period, the calculation assumptions are [Sonelgaz, 2023]:

- 50% of customers will be integrated in the first year, 75% will be integrated in the 2nd year and 90% in the long term,
- The average price of thermal energy is 0.337 DA/Th.
- The average annual consumption per customer is 1500 Th/customer/year

Table 8: Payback period assumptions.

Integration rate (%)	Number of subscribers	Annual cash flow (MDA)	Average cash flow
50	918	4.64	8 MDA/year
75	1376	6.96	
90 (long-term)	2425	12.4	

By dividing the initial investment of 687.46 MDA by the average annual cash flow generated by the investment, the payback period is 85 years. The long payback period is justified because the average price of natural gas is low in Algeria, ten times lower than those abroad, and this is due to state subsidies, thus, the absence of strategic projects such as factories and large gas-consuming industries.

6. Conclusion

This study aims to study the development of a natural gas distribution network in two localities considered as gray areas in the Ouargla region. The total hourly consumption of the localities is equal to 1734.62 Nm^3/h for both residential and tertiary sectors, of which 89% of consumption is in the residential sector. By applying a population growth rate of 2% per year, the short, medium, and long-term consumptions are 1925.25, 2134.83, and 2624.88 Nm^3/h, respectively.

The network development was carried out using two programs AutoCAD and APHYRE. As a result, we obtained 419 nods, the lowest recorded pressure equal to 2.33 bar and the high-pressure loss was equal to 14.021 bar^2. The network's total length is 57 km, in which the highest percentage is attributed to a diameter of 40 mm because it is the diameter that directly serves customers.

To determine the economic profitability, we estimated the total cost of the project, which is equal to 678.46 million DA, of which the gas connection to the subscribers represents the largest part approximately 58.04%.

By dividing the initial investment of 687.46 MDA by the average annual cash flow generated by the investment of 8 MDA per year, the payback period is 85 years. The long payback period is justified because the average price of natural gas is low in Algeria, ten times lower than those abroad, and this is due to state subsidies.

On the other hand, the project has other socio-economic advantages such as:

- Settling of the population of Fran and Koum,
- Creation of direct employment by recruiting agents who will be used to monitor the network after commissioning,
- Indirect employment at the time of the implementation of the project (implementation company) and after,
- The comfort of the population like the population of Ouargla,
- The reduction of gray areas in Algeria.

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