The Network Strategy of a Gas Distribution Company

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Abstract:

For a gas distribution company the investment in the expansion of the network represent the opportunity of reaching more potential customers and eventually increase the sales. These long term investments will always be followed by an increase of the customers? What will happen when the attractiveness of gas decreases and customers do not connect themselves anymore?
This paper describes and analyzes the dynamics governing a gas distribution company and the effects of management's decisions about expanding or dismantling the network, taking in account different possible aspects that can be exogenously generated but can have an endogenous origin as well. Advantages and disadvantages of the possible strategies and their financial impact are discussed. The differences between a right or wrong decision is expressed in monetary terms.
The focus is on the classical use of gas, that means that each building is connected to the network and produces heat locally with a boiler.

Keywords: *System dynamics, gas network, long lived assets, energy, expansion strategy, attractiveness,…*

1. Introduction - Motivation

The success story of natural gas for building heating is related to its advantages, like less CO_2 emissions, an higher efficiency and major comfort in the use, that made it to the perfect alternative to heating oil and other oil products. But not only. The development of the distribution network, a capital intensive activity which has been mainly done by public (or partially public) companies, is a key factor to success. Investing in the development of the gas network was, until now, a way to reach even more buildings to potentially connect and increase the sales, still having a low risk about the return on investment.

An increased awareness about CO_2 emission and energy consumption on one side, and the deregulation process (unbundling of network from energy trade businesses) on the other side, represent the new challenges that gas distribution companies are facing. So for a traditional natural gas company there are two different strategies to design: the first related to the energy trade on its own or on other's networks, the second to the network development and maintenance.

The purpose of this paper is to tackle the second one, basing on a specific case, and identify the mechanism that drives the network development from the point of view of the companies but from the customer's one as well. Understanding and modeling of the current policies and the definition of a path towards a more efficient strategy (especially accordingly to the “new” situation described above) are the main goals of this paper.

Knowing that a gas network expansion requires not only ~~the initial~~ capital for the investment, but represents a source of future semi-fixed expenses in terms of maintenance, repairs and replacement as long customers are connected to it, basically the main question that we want to answer is “should a company keep expanding the network or not?”. Which policy should it adopt? With a systemic approach we can take in account all the influencing parameters and try to give an answer according to the hypothesis that the management of the company believes in.

Mastering this problem helps companies to develop a more efficient network strategy, avoiding to invest in a not-profitable network (that in the future will “get old” and generate excessive entertainment costs) or to miss an opportunity to make more business and/or serve an new part of the territory.

Eventually the companies can define policies and an optimal time plan for the different possible network future developments.
These can be:

- to <u>expand the network</u>, building additional pipes that allow to reach new potential customer,
- to <u>keep the existing network</u>, managing only the replacement of old pipes and connecting the customers that are already next to the pipes,
- to <u>dismantle of part of the network</u> that can be not profitable anymore, but reducing simultaneously the number of customers.

Due to the fact that most of the gas companies are “multi-utility” (they distribute electricity and water as well), it allows to have a more global vision and approach towards all these product, avoiding internal cannibalization. As for example electricity can be used as well to produce domestic heat (through an heat pump), a multi-utility company needs to have a clear strategy about its products in order to avoid inefficient and/or expensive distribution infrastructures for the same purpose (heating) over the same territory.

There are some challenges facing this problem. The first is the uncertainty given by of the external factors like politics, strategy of other concurrent products, price of gas, … These are not endogenously generated and the accuracy of the system’s outcome depends from the initial hypothesis about the external factors.
Another big challenge is to model the customer behavior in “connecting to” or “disconnecting from” gas network. There are many parameters that influence such decision and not all are easy to define or model. This process is nevertheless the most important because obviously the number of customers determines the sustainability of the investments.
Other difficulties that we can meet are the lack of complete information about the potential customers in the region where potentially expand the network, and the modeling the current decisions process of the company’s management, that can change over time.

All this work has to be done taking in account the existing network and activities that are generated by it.
In particular we have to keep the required level of safety (by a correct renewal of the old pipes, which consumes part of the total budget) and keep the minimal quality of the service (by sufficient capacity of the network, that at some point has to be reinforced).

An expansion strategy based only on the short term local profitability and the current customer request/pressure ignores for example that after a certain period (shorter that the lifecycle of the pipes) the customer could switch to another energy vector and that the pipes get old and will need maintenance or replacement. The fact that the cost (of capital and maintenance) can increase and the number of customers potentially decrease drives to an increase of unitary costs making the product less attractive.

A conservative strategy, focused on conserving the current assets value, could be a big mistake in order of missing an opportunity to connect further customers outside the already served territory.

In a dismantling strategy based on reducing the unprofitable part of the network, the negative impact on the image of the company and the product (even if it is increasing its performance) could unfortunately not be considered.

Ignoring the changes at legal or social level that happen now (in particular about climate change and pollution) that lead to a strong future reduction of consumption and a scarce attractiveness of natural gas, can be a major mistake in the estimation of future revenues.

2. The case of AIL (Aziende Industriali di Lugano)

The history of gas in the swiss-italian City of Lugano begins in 1864, when a private company producing gas from coke, the company Riedinger coming from the german city Augsburg, built the first production plant. At that time the main use for the gas produced was public lighting. In 1900, the City of Lugano bought the Company and AIL, the incumbent energy and water supplier in the southern part of Ticino (Sottoceneri), started its operations. The technique of producing gas changed in the mid Sixities, when instead of distilling coke, the gas was produced cracking light fuel. This technique was used until the end of the Eighties, when the City decided to take the risk and build a main pipeline connecting Lugano to the Italian natural gas network.

This decision can be defined as a turning point in the gas business and since then the network has been continuously expanded and the number of customers and the consumed volumes grew as well.
In the Nineties and the beginning of the last decade natural gas was considered as the best possible alternative to oil. The advantage of gas towards heating oil were and still are evident, but the increased sensitivity of the population and the politicians to renewable energy put natural gas in a "bad light" because, even if it is the best of the fossil energies, it is still a fossil one.

The expansion of the network happened in parallel with some smaller networks belonging to other Municipalities of the Sottoceneri region (Chiasso, Mendrisio and Stabio) connected to the transportation "backbone". These are "resellers" to which AIL sells gas wholesale but doesn't manage their network.
Another more recent reality present in Ticino (the only italian speaking Canton of Switzerland) is the company Metanord, that is expanding the gas network northern from Lugano, with the target of developing gas in the Sopraceneri region (Locarno, Bellinzona). This company is also connected to the main pipeline and the potentially served region they want to reach is quite big.

Current mental model and policies

The gas business at AIL has only known the growth (see the reference modes below). This happened through an intense network expansion and the favorable external conditions. Investments in the infrastructure were done without big worries for the future and the main idea was "*the more we expand, the better it is*". This means that, besides the obvious objective of increasing the density of customer on the already existing network, part of the strategy was to expand on new territory and acquire more potential customers.

The expectation that, as long there is enough capacity, the network expansion drives automatically to growth, is not considering all the unintended consequences over (very) long term: more network to renew or repair in the future, progressive reduction of the existing transportation capacity reserve, possibility that the customers disconnect from gas after a lifetime-cycle of their domestic plant. The current network expansion criteria are mainly based on local approach. With the assumption that soon or late a sufficient number the potential customers will connect to the gas network (like in the past), the company develops a local business plan in order to define whether or not expand the network in a region (can be a single road or a small town).

By this approach, and adding a role of "public service" that the company (partially) has, AIL has very rarely refused to connect some customer or to expand the network where demanded. The refuse of connection or expansion is considered a kind of taboo that is difficult to manage. The main idea is that the damages caused by a missed opportunity and a refused customer are bigger than the costs of entertaining a potentially unprofitable network over time.

Reference modes

The following graphs represent the "story" of the gas business at AIL, that allow to understand the current situation. In all the graphs it is possible to identify the turning point in the years 1988-1989, when the natural gas pipeline was built and the old town gas production was dismissed. Since then the company had a constant growth of the network, the consumers and the consumption.

The first graph (Figure 1) represents the evolution of the length of the network and the fractional yearly replacement and expansion rate. We can clearly identify the turning point. Before 1988 the main activity was the maintenance and the renewal of the network. There was no growth. After that, most of the resources were employed in the expansion and the acquisition of new customers.

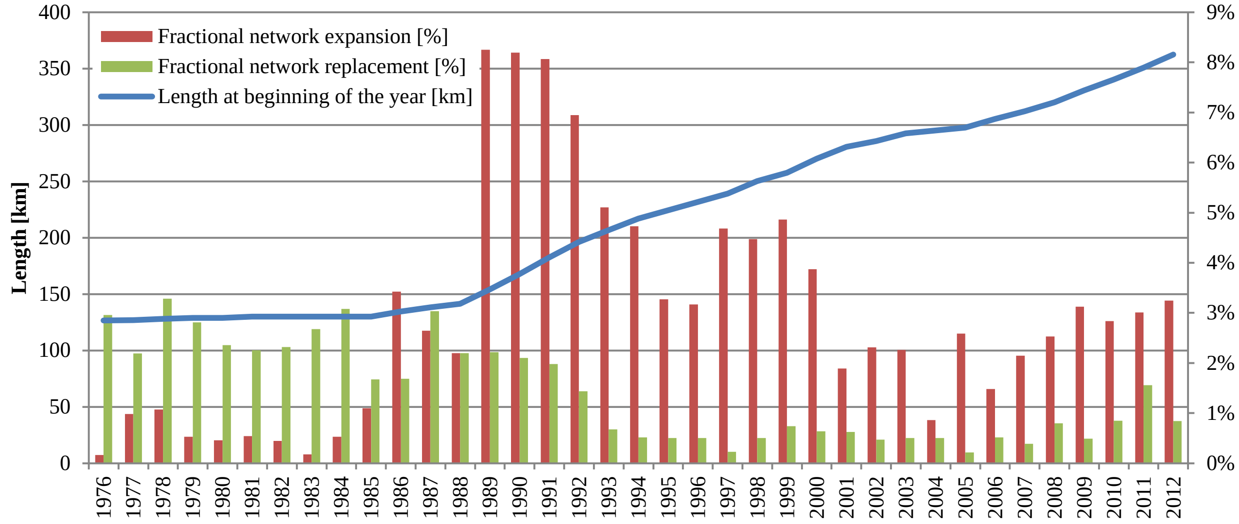


Figure 1: Evolution of the Gas Network over time

Figure 2 represents the number of house connections that we consider equal to the number of customers. The growth trend is clearly recognizable here too.

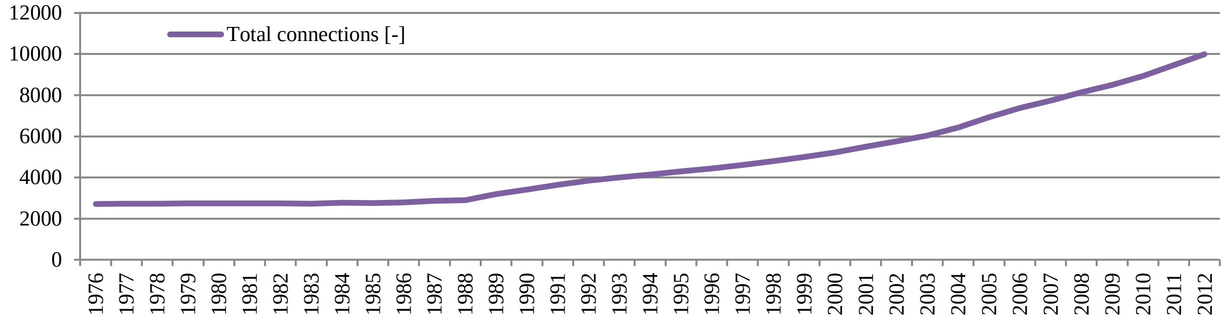


Figure 2: Evolution of the number of buildings connected to the Gas Network over time

The transportation capacity of the network backbone and the simulated required capacity at an external daily average temperature of -5°C are plotted in the following graph (Figure 3). We make a distinction between the main pipeline capacity (given by the size of the pipe, which is nowadays not constraining) and the pressure reducing stations capacity (called "available capacity"). We can see that the pressure reducing station have been reinforced in 2005 and are reinforced in 2012 too. Reinforcing means install more capable equipment (valves). The required capacity is split between capacity for our network customers and for our resellers.

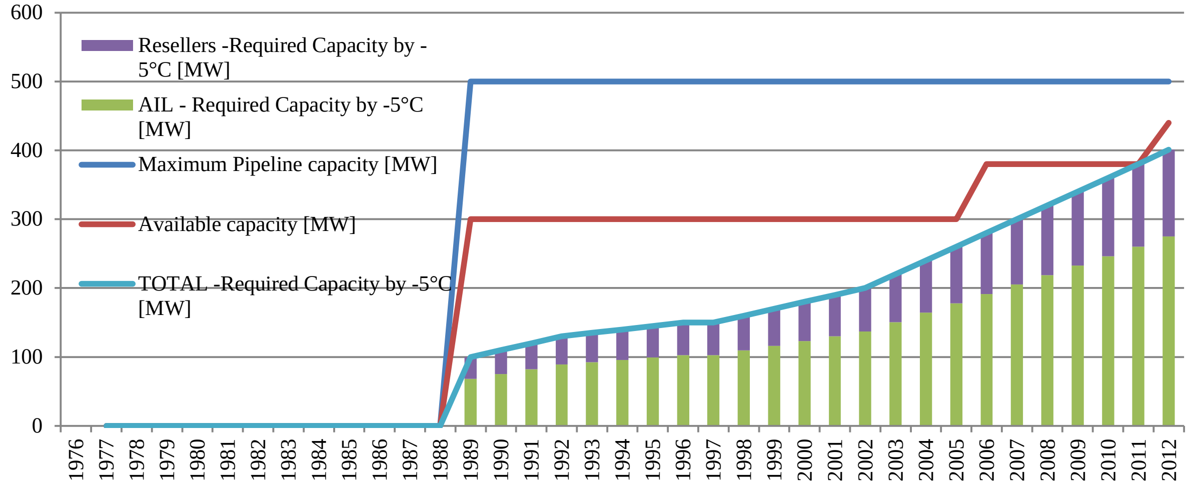


Figure 3: Available and required capacity at -5°C

The growth of the volumes of gas distributed every year is clearly represented in the Figure 4. Also here a distinction is done between the final network customers (AIL) and the resellers. The variations around the trend are to be primarily associated with "colder" or "warmer" winters.

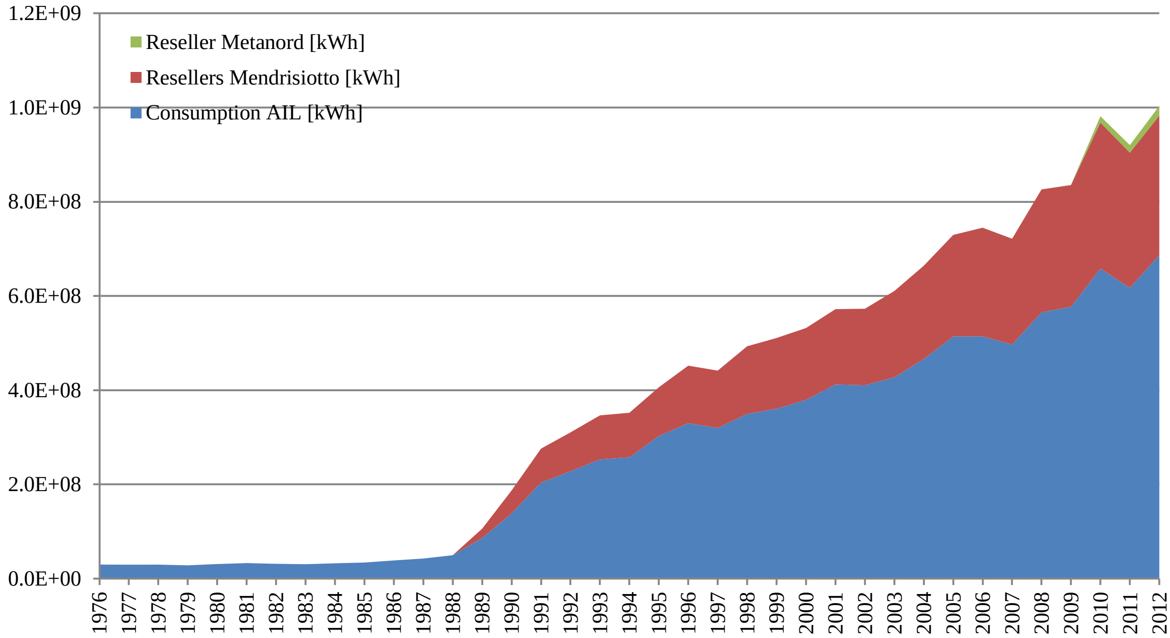


Figure 4: Evolution of the gas consumption over time

The most significant graph is eventually the following one (Figure 5),where the ratios between the above seen variables are calculated and plotted. These values can be helpful to define some starting values in the model. It is interesting to see that the "consumption density" (volume distributed per network length unit) is increasing even if the length has grown.

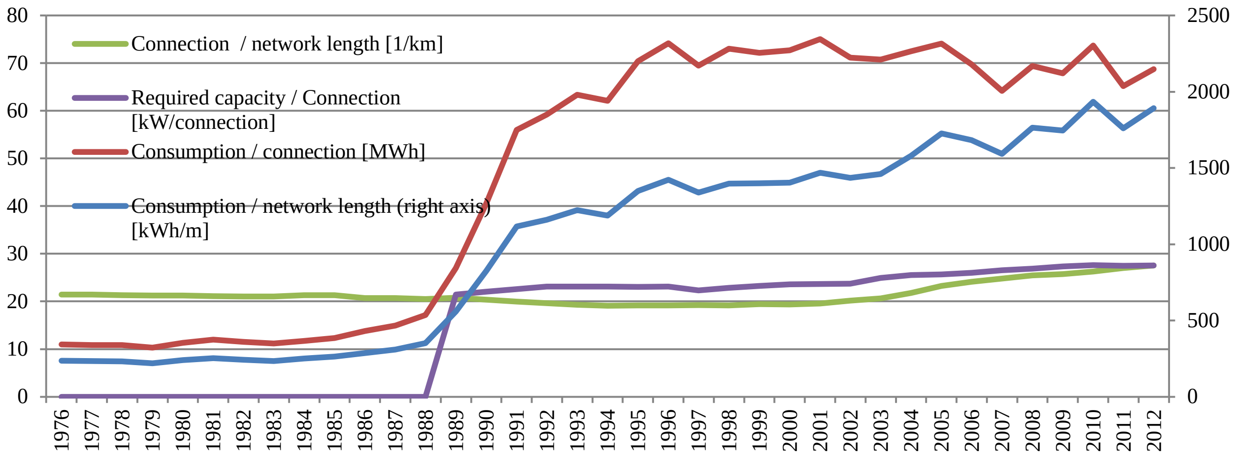


Figure 5: Evolution of ratios related to the Gas Network over time

3. Model description

Let's start mapping the process by the main Stocks and Flows (see Figure 6) and look at the feedbacks that characterize our system. We can identify two main stocks, the Potential Customers and the Customers. A potential customer represents a building/plant that could easily be connected to the gas network and use it, simply because the distribution network is available next to it.

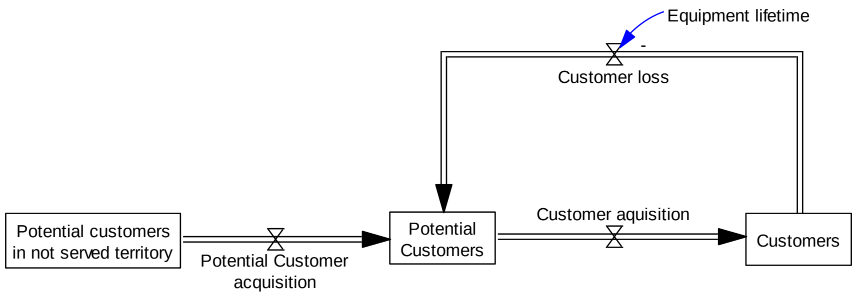


Figure 6: Main Stock and Flows in the Customers model

The expansion of the network provides new potential customers. This process called Potential Customers acquisition is only limited by the number of Potential customers in not served territory. Then a Potential Customer can become a Customer, that means that he takes a decision to use gas and (if not already connected) to connect its house/building to the network (Customer Acquisition). We do not consider for this project the time delay between the decision to use gas and the real beginning of consumption.

Once acquired, we admit that a customer stays in this "situation" for an average time of 20 years corresponding to an average lifetime of the consumer's equipment. After this period, the customer can be confirmed (or re-acquired) or lost. For simplicity we say that he becomes again a Potential customer (Customer loss). Once a customer is lost, there will be a (long) delay before he becomes again a potential customer. This is simply related to the switching costs from one system to the other and the lifetime of the alternative. Another way of losing Customers, in this case in a definitive way, is by dismantling the network.

The process of Customer (re-)acquisition depends essentially on the Attractiveness of gas, which is a variable that varies over time and depends basically on the Price for the customer, the Quality of the service and the Safety level, that depend from the age structure and the renewal activities, and eventually from other external factors, that we have defined as exogenous factors.

These are for example the alternatives to gas (heating oil, electrical heating pumps, wood pellets,…) and their properties. Some offer ecological advantages but higher prices, other the opposite. On top on this there are the political decisions that can “steer” the choices of the customers through legal restriction, taxes or subventions. These decisions can happen very quickly and change very strongly the direction that the system is following. An extremely low level of Attractiveness of gas can accelerate the Customer loss process.

The Price of gas depends negatively from the Total consumption and thus from the number of Customers. We admit an average consumption per customer which will progressively decrease, reproducing the effect of the increased efficiency of the equipment and the buildings (thermal insulation).
There are two reasons why an higher Total consumption of gas reduces the price: the first is that the fixed cost related to the network and the backbone capacity are split over a bigger amount of energy reducing the unitary cost, the second is that for the company higher volumes increase allows to obtain better prices from the big gas suppliers. These relationships generates our first reinforcing loop “Economies of scale” (R1) that can sustain the system independently from other decisions.

If the gas is very attractive, the company receives Pressure to expand the network. The response to a request to expansion becomes reality after a certain time delay (3 years on average) and eventually contributes to increase another important parameter which is the Network length. The longer the network is, the higher the number of Potential Customers becomes. We have so closed another reinforcing loop “Network expansion” (R2).

We have defined that the Customer acquisition is mainly determined by the Attractiveness of gas, but we can identify another factor that supports the increase of the number of new customers. This can be defined as a combination of positive word-of-mouth between customers and potential customers with the fact that there are many stakeholders that have stake in having a big number of gas customers. Especially installation, construction and maintenance companies or sellers of heating equipment supports and promote the acquisition process, together with the current “normal” marketing activities. “Stakeholders” (R3) is the loop that is closed relating these variables and is a reinforcing one.

Through their consumption and the instant Required Capacity (we admit an average required capacity per customer), the number of Customers impacts on the Capacity reserve, represented by the gap to the currently available Backbone capacity. The level of Capacity reserve affects directly the Quality of service, which stays high as long there is enough reserve, but falls dramatically to very low levels once the latter is reduced. We can only imagine what are the consequences of not being able to supply our customers in the coldest days of winter, when their need for heating is at the maximum level… As the Quality of service increases the Attractiveness of gas we have closed a first balancing feedback loop called “Quality of service” (B1) including a very strong non linearity. Notice that the in addition to the required capacity generated by our customers, there is an “external” capacity that is allocated to supply other gas distribution companies in Ticino that have an manage their own network.

The level of Capacity reserve indicates the new Desired capacity, whose gap to the current Backbone capacity generates Pressure to increase capacity which leads up to an higher Backbone Capacity after an important time delay (5 years), readjusting so the Capacity reserve level and closing another balancing loop called “Build capacity” (B2) operating at a slower pace and containing the second delay in our system after the “network expansion” one. Planning and constructing new infrastructures related to the backbone (pressure reducing stations or transport pipes) requires time and is strictly regulated and controlled by the Federal Inspectorate and/or the cantonal authority. For this reason it very important to forecast in which direction the system is moving.

The fact that the network is long has not only the advantage that there are more potential users of gas but means as well higher costs. The costs are generated by the invested capital, the depreciation of the assets, and the operating and maintenance costs, including repairs of failures. To the costs of the network we add the costs generated in a similar way by the backbone capacity and obtain the Cost of network and capacity. Of course this cost impacts positively (even if it is not really a positive thing…) the gas price, allowing to close two similar but independent balancing loops: the “Cost of network” (B3) and the “Cost of capacity” (B4) loop.

We have identified three reinforcing loops that can push the system to growth and four balancing loops that tend to stabilize the system. We have two main delays represented by the reaction to the pressure to build new capacity and expand network. All these loops and delays are related to the "physical" behavior of the system.

There is another dynamic effect given by the expectations of the company and the mental model of the management. If we have some excessive capacity reserve, we define a Desired network length, that we want to reach to "fill" this excess through the acquisition of new customers. This affects positively the Pressure to expand network seen before pushing to a length increase. To a given length corresponds a given Desired capacity that allows to have enough reserve for the future customers. If the Desired Capacity given by the current Capacity reserve (loop B2) is not enough, the Desired Capacity is "replaced" by the one generate by the future expectations. In this case we have the reinforcing loop "Exceeding capacity" (R4) not related to the current "physical" behavior of the system but from the expectation of managers that foresee only growth. It is a kind of floating goal mechanism that works only if other mechanism don't have already increased the goal. All the described loops are represented in Figure 7.

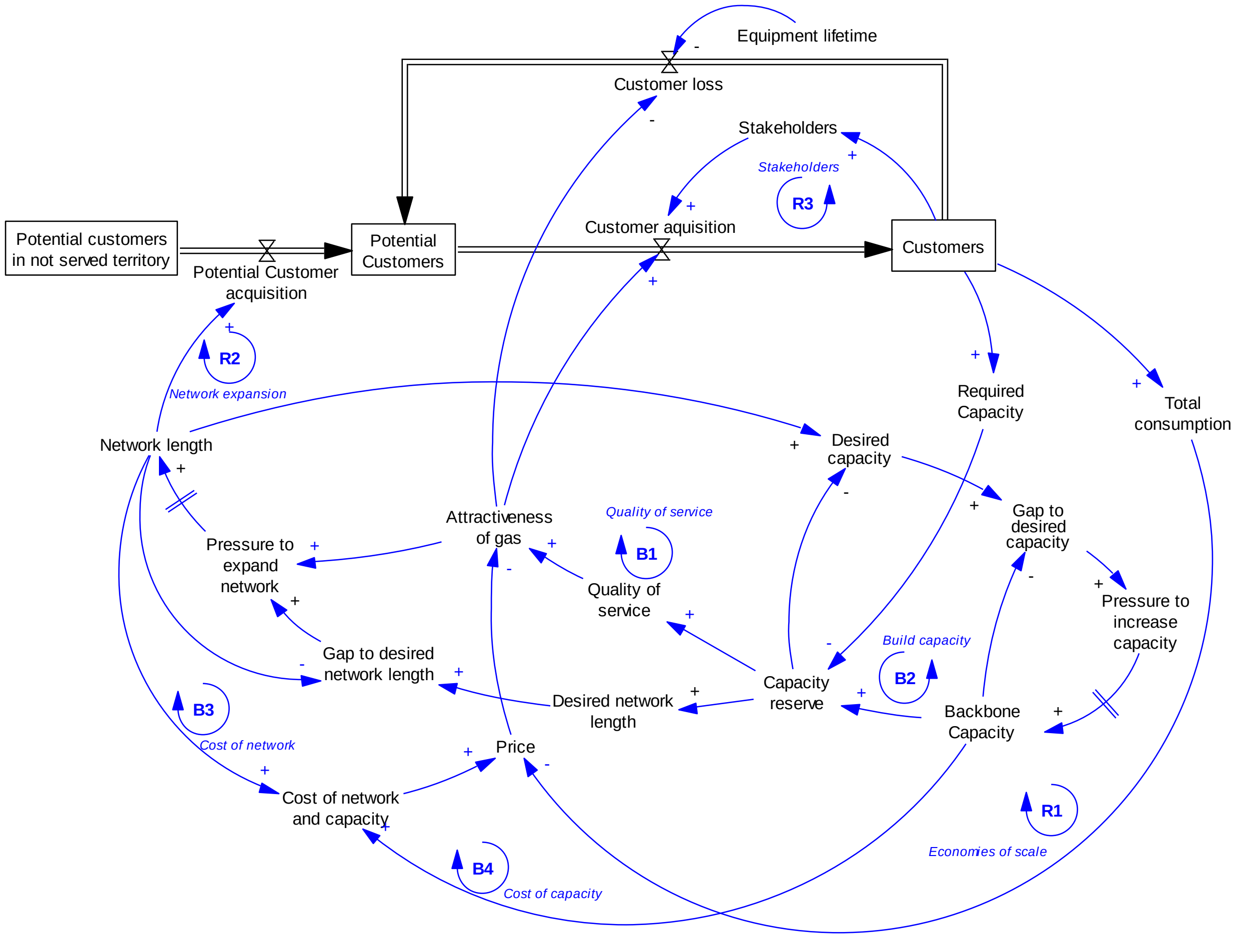


Figure 7: **Complete mapped system an identification of the loops.**

A last remark is about the "direction" of some variables: for instance we normally assume that the network length and the network capacity can only "grow" or "stay" but not be reduced. Dismantling part of the network or reduce unused capacity entails big costs, but is still possible. Some gas company of the German part of Switzerland there are already dismantling local networks that are not profitable anymore. For AIL this not the case, nevertheless the model allows this too.

5. Model formulation

The construction of the simulation model is done through the simulation software Vensim PLE, were all the relationships and the equations are defined.

5.1. Stocks and the flows: "Customers or Buildings"

On top of the three stocks seen above (Potential Customers in not served territory, Potential customers and Customers) we have added a new stock representing the Future Potential Customers. This is a buffer containing all the connectable building that are connectable but not "ready" to connect now (because of the switching cost and the sunk cost represented by a premature switch to another system), but will have to make a choice about their heating system in the future. This stock is fed not only through the network expansion, but also from the gas customers that decide to "leave" gas after having used it or the potential customers that we couldn't acquire.

So in our system we have the Potential Customers stock that represents only the currently (= "this year") acquirable customers and not all the connectable buildings. Their number is determined by the flow "Future to Potential", which is a first order system with an adjustment time corresponding to the lifetime of the alternative equipment. All the Potential Customers that are not acquired in the current year (the "missed" ones), get back to the Future Potential Customers. That means simply that they had the opportunity to be acquired, we didn't manage to acquire them and they choose an alternative.

The acquisition on new connectable buildings (or better new Future Potential Customers) is governed by the Network Expansion Rate times the "number of connectable buildings per network expansion length unit". This last factor is supposed not to be constant but to be linearly decreasing according to the residual length (the less residual length, the more we need to expand to have the same number of connectable buildings). This a simplification of the fact that in the in the regions surrounding the already built network the density of buildings is decreasing (small towns with lower density). Starting from a potential residual length of the network that we could build, we define the number of building that are connectable in this area, obtaining an average density.

This density is linearly distributed according to the residual length (keeping a minimum density value) using the following formulation:

Connectable Buildings per Expanded Network unit [buildings/km] =
Minimum Connectable Buildings per Expanded Network Unit
+2(Average Initial Number of Connectable Buildings per Residual Length - Minimum Connectable Buildings per Expanded Network Unit)/Initial Residual Length*Residual Length*

We have seen how we acquire Future potential Customers and how they become Potential customer for the current simulation year. But the most important flow is of course the "Customer Acquisition" one. The rate at which the potential become effective Customers is dominated by the Relative Attractiveness of Gas. We have a reference value for the Attractiveness of Gas to which corresponds a reference value for the Customer Acquisition Rate. The current acquisition rate is given by the current relative value of the attractiveness times the reference rate.

Once the customer is acquired, we consider that he is "captured" at least for all the lifetime of its gas equipment (20 year). We have modeled an aging chain where at the end of the equipment lifetime the customer can be either lost or reconfirmed. The percentage of lost (respectively reconfirmed) customers is mainly given by the Relative Attractiveness of Gas and a function called "Effect of Attractiveness of Gas on bad things" which gives a value between 0 and 1 giving more weight to low values of attractiveness and less weight on higher value. If the customer is loss, he goes directly to the Future Potential Customers stock. If instead he is confirmed, he starts again his path along the aging chain for another "round".

In the case that the company decides to dismantle part of the network, the consequence is that the (hopefully few) customers that were still connected have to be dismissed. This is another flow that reduces the Customer's stock and that is directly related to the network dismantling rate.

5.2. Stocks and the flows: “Network”

The constructed network is considered as a stock (unit in km), that is fed by the Network Expansion Rate, which uses up a “Residual Length” stock, whose initial amount can be defined and represents the potential of expansion.
The Network Length is in reality an aging chain where the pipes are classed by age. This has two reasons. The first is that beside the expansion of the network there is the need to replace the oldest pipes. The pipes to be replaced have to be identified, especially if the age distribution is not homogeneous. The second reason is that the number of failures per length unit (leakage of gas due to defect pipes) depends (not linearly) on their age.

There are many formulations of the failure rate for the pipes (water or gas). Accordingly to our statistical data, we can use the following equation:

*Failure Rate = 0.1 * EXP(0.05 * (age -30)) [failure/(year*km)]*

The number of failures has an impact of the safety image of gas and on the maintenance costs, so eventually on the Attractiveness of Gas. The Network Expansion Rate is theoretically a free choice of the company, but there are two “internal” forces that impacts on the desire of expansion. The first is still the Relative Attractiveness of Gas, that using the inverse of the above seen “Effect of Attractiveness of Gas on bad things” function, pushes the company to have a wider network. This formulation represents the fact that if the gas is attractive, we have continuously request of connection from buildings outside the served territory. The company reacts to this request expanding the network (after a local check of the financial sustainability).

The second reasons why the company should expand the network is the fact that there is an exceeding capacity, and in order to exploit this capacity more new customers are required so a solution can be to expand the network. To define the desired additional length, we use the current Adimensional Network Customer Density and not the residual one, replicating on purpose a wrong management decision.

Adimensional Network Customer Density = Customers / (Customers + Potential Customers + Future Potential Customers)

The Network Expansion Rate is of course limited on one side by the maximum residual length, and on the other side by a maximum construction capacity of the company, which is not infinite. The Indicated Network Renewal Rate, the amount of pipes to be replaced in one year, is determined using different possible policies: renew all the pipes older than 40 years (age based renewal) or keep a desired Safety level (renewal depending on the number of failures).In any case only pipes above 35 year can be replaced, but starting from the oldest ones.

The Network dismantling can happen independently from the network expansion. Some policies can be defined in order to define “when” and “how much” to dismantle (basically based on the current trend of the density of customer or of consumption).

5.3 Stocks and the flows: “Backbone Capacity”

A Stock & Flow structure is used to model the Backbone Capacity, which is the part of the whole backbone that is “artificially” allocated to serve the transportation capacity requirements of the network customers (and not of the resellers). The Backbone Capacity is increased by the Capacity Increase Rate, which is determined by the gap between the current and the Desired Capacity. The Required Capacity is directly related to the number of customers through an Average Capacity per Customer. The Capacity Reserve is defined as follows:

Capacity reserve = (Backbone Capacity – Required Capacity) / Backbone Capacity [-]

The company determines a Desired Capacity Reserve (0,2 for instance) that gives a certain margin over time and covers the risk of a very cold day (remember that we have our capacity designed for an external daily temperature for -5°C). The Desired Capacity Reserve determines the Desired Capacity.

Desired Capacity = Required Capacity / (1-Desired Capacity Reserve) [MW]

5.4. Attractiveness of gas and related parameters

We have seen that one of the most important parameter of our system is the Relative Attractiveness of Gas which is the ratio between the current attractiveness AG and a reference attractiveness AG*. We define that the impact on the relative attractiveness is a multiplicative combination on many effects.

AG / AG = Effect of Price on AG * Effect of Quality of Service on AG * Effect of Safety Level on AG * Effect of Exogenous Factors on AG.*

Each “effect” is formulated through a log-linear model

$$\text{Effect of } X \text{ on } Y = (X/X^*)^a$$

where X* is the reference value for the parameter X corresponding to the reference value of Y (in our case AG*) and “a” is the elasticity of Y with respect to the change of the normalized input (X/X*).

Table 1 defines the elasticities, that allow us to give more or less importance to each variable. In reality these values should be defined analyzing the real behavior of the (potential) customers. For the purpose of this work we admit some given values. It is always possible to test different values and see their impact. We describe as well which Reference value is set up.

Effect	***Reference value***	***Elasticity***
Effect of Price on AG	*Average (heat) price of all the possible solutions*	*-0.5*
Effect of Quality of Service on AG	*1*	*0.2*
Effect of Safety Level on AG	*1*	*0.2*
Effect of Exogenous Factors on AG	*0.5*	*0.8*

Table 1: Reference values and elasticity in the Gas Attractiveness model

We allocate to the Exogenous Factors the most important weight, followed by the Price and eventually the Safety and Quality level.

Heat Prices

The Price of gas is the sum of the Transportation price (the network-use fee) and the Energy price of the gas. The Energy price of gas (Market price) is assumed exogenous, but the Transportation price depends on the Total transportation costs divided by the Total consumption. We will see later how the transportation costs are determined.

To be comparable with the alternative solutions considered in this model (heating oil or electricity heating pump) we have to convert the price of the “raw” energy into the price of the heat produced by this energy. This is done considering the different techniques, the different amount of initial investment for the equipment and the different efficiency level of each solution. Eventually we have three “heat prices” (HP) that we can compare and that we use to define the “Effect of the Price on AG”.

$$\text{Effect of Price on AG} = (\text{Heat price gas} / \text{Average heat prices})^{-0.5}$$

The Average heat price used as reference cannot be higher than the one and a half times the minimum of the three prices.

Quality of Service

The Quality of Service is directly related to the current Capacity Reserve through a Table function. With a Capacity reserve below -0,2 we have a Quality of service equal to 0 and above +0,2 the Quality of Service is 1. Between -0.2 and +0.2 the Quality of service is linearly defined. The "meaning" of this function is that even if we have a Capacity reserve below zero, we still have some Quality of Service, because first of all the Capacity is defined for -5°C (and thus the probability that it happens is quite low and customers will not remark the scarce capacity) and secondarily because some customers have the possibility to switch to another fuel (typically heating oil) and will not suffer of the lack of capacity.

$$\textit{Effect of Quality of Service on AG} = (\textit{Quality of Service} / 1)^{0.2}$$

Safety Level

The Perceived Safety Level (PSL) is a Function of the Ratio between an Acceptable Failure Rate (AFR) and the Current Failure Rate (CFR).

$$PSL = f(ACR/CFR)$$

where PSL=0 if ACR/CFR=0, grows linearly until 1 when ACR/CFR=1 and stays at 1 above.

Eventually the effect on the Attractiveness (in other words, how much an excessive number of failures can undermine the perception of a safe product and thus discourage the choice of gas) is the following.

$$\textit{Effect of PSL on AG} = (PSL / 1)^{0.2}$$

Exogenous Factors

The Exogenous Factors are, as we have seen the "heaviest" parameter on the gas attractiveness. But are also the most difficult to model in a simply way. We start defining a reference value, that we choose arbitrary at the level of 0,5. We will the use a Table function where the output is a positive value depending on the time (keeping in mind that 0,5 is the reference value). The idea behind that is to have the possibility to model in a simple way all the external factors (like legal constraint, political decisions, …) that can happen over the time. Especially in the scenario analysis, this table function can be different for each scenario, depending if the "external world" will foster or inhibit the gas distribution and allowing different time patterns.

$$\textit{Effect of Exogenous Factors on AG} = (\textit{Exogenous Factors} / 0.5)^{0.8}$$

Differently from the Quality of Service and the Safety Level, the value of Exogenous Factor can be above the reference value having a positive effect and not only a negative impact.

Our starting hypothesis is that this value will have a "bad" trend, only decreasing. This has to be understood in the sense that natural gas distributed through the capillary network for individual traditional use in the buildings (traditional heating) will be supported "by the laws" only as a good substitute of heating oil. As the main focus of this project is on analyzing the question related only to the capillary distribution and not the use of gas "in general" (like electricity production or combined heat and power plants connected to district heating networks) we consider that this will be supported only for few time (until some all oil plant are replaced).

5.5. Financials

In the model an entire view is dedicated to the financial aspects. These are important on one side because they give an internal feedback to the system (through the Transportation price), on the other side because they allow to define one on the key variables which is the profitability.

The model calculates the Yearly total investment using unitary investment costs.

Total Investment = Investment in Network + Investment in Capacity [CHF/year]
*Investment in Capacity = Unitary Capacity Cost * Capacity Increase Rate [CHF/year]*
*Investment in Network = Unitary Construction Cost * Total Construction [CHF/year]*
Total Construction = Network Expansion Rate + Effective Network Renewal Rate [km/year]

The Total yearly investment is a flow that "feeds" the Asset Value. The Asset Value is decreased by the Depreciation, which is defined by the initial value and the lifetime (linear depreciation). An Extraordinary Depreciation can be added in case of premature dismantling of the network (based on the residual value).

We have a (very) simplified Balance Sheet and now we need to have some more information about the operations costs in order to have all the data needed for the calculation of the Network tariffs (=Calculated Transportation Cost/Total consumption) accordingly to the regulation.

The Operational & Maintenance costs (O&M) are composed by a fixed part (like the basis personnel, the IT infrastructure, the emergency service, the reserve material,...), a part related to the network length (with an inspection cost directly proportional to the length to be inspected) ad a part related to the number of failures.

The regulator allows to ascribe on the "Calculated Transportation Cost" the "Cost of financing", the "Depreciation" and the "O&M costs".

We have defined the two last values (Depreciation and O&M costs). The Cost of financing is calculated applying a "regulatory" WACC on the Asset Value. This WACC represents the "allowed" return on assets (in fact it is a ROA, but has to be shown as a WACC…) considering a reference debt-to-equity ratio, the cost of the liabilities and the expected return on equity (with respect to the risk premium associated to the gas network activities).

The difference between the real WACC of the company and the "regulatory" WACC generates a profit. Assuming that all the other cost are "real" (Depreciation and O&M), this is the only profit from the gas network.

Other profits can be done on the energy trade. Even if we want to focus on the network "business" (that should be unbundled form the energy trade) the model allows to add to the profits a margin on the sold energy (represented by a fix unitary margin of 1 CHF/MWh multiplied by the total consumption).

A simplified Cash Flow can be as well calculated in order to identify potential problems of liquidity.
Calculated Transportation Cost = Depreciation + Calculated Cost of Financing + O&M cost
Net Profit = Calculated Cost of Financing - Real Cost of Financing = Asset Value(WACCregulated – WACCreal)*
Cash Flow = Net Profit + Depreciation - Total Investment

Notice that with this system the higher the Asset Value is, the more the company earns. The reality it is not like this and there are some limitation. In particular it is supposed that there will always be a sufficient number of consumers and a relative consumption to divide the Calculated Cost of Transportation and obtain an "acceptable" Network tariff.
To be more precise and capture what would happen if many customers would be lost and all the network cost are allocated on the few remaining customers, we define a Maximum Network Tariff, corresponding to the limit value. If the Calculated Tariff is above this value, the difference is born by the company and can first erode the margins and then drive to big financial losses.

In case of Network dismantling some additional cost are introduced. These corresponds to the fact that the (few) customers connected to a part of network that will be dismantled will receive some money from the company accordingly to the age of their heating plant.

6. Model Analysis

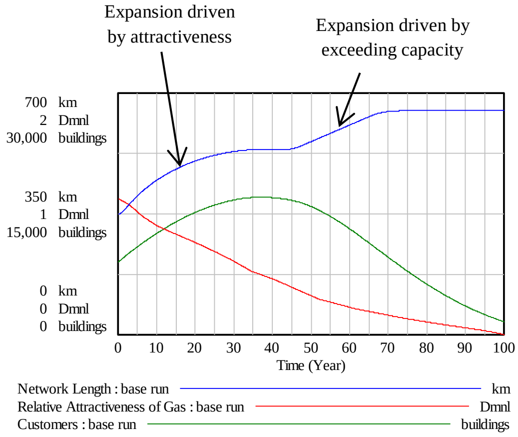
The basic functions of the model have been tested during its construction. Particular attention has been devoted to avoid “impossible” situations, like negative stock levels, or infinite rates. To let the model run we have defined some initial conditions and parameters that correspond to the current company’s situation and policies. These are realistic and based on the experience, but not scientifically proven.
The simulation time is over 100 years starting from now.

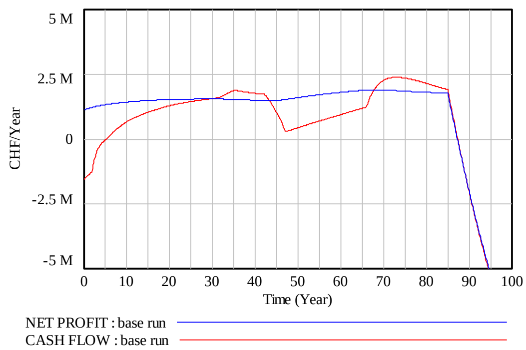
Beside the analysis of the different loop dominances, in order to evaluate the different options we use as ultimate parameter the Net Present Value, calculated at time zero over the whole simulation time, using as discount rate the real WACC of the company (and not the regulatory one).

<u>Base run</u>
For the base run the main conditions are:

Policy/ Parameter / Variable	Status	Remarks
Network Expansion driven by gas attractiveness	allowed	
Network Expansion driven by exceeding capacity	allowed	
Network Renewal policy	allowed	based on the age
Network Dismantling	not allowed	based on the adimensional customer density
Transportation Capacity increase	allowed	
Exogenous factors	activated	
Maximum Network tariff	activated	at 100 CHF/MWh
Revenues from energy trade	not considered	1 CHF/MWh

The evolution of the main parameters is represented on Figure x.





For the base run the evolution of the system is dominated at the beginning and until year 30 by the gas attractiveness, which on one side allows to acquire even more customers, on the other side pushes the company to expand the network. During this period the cash flow can be negative due to the expansion investments.
The progressive decrease of the gas attractiveness, in this case determined by the exogenous factor (that we assume will have this trend), is at the origin of the stop of the network expansion around year 30 (the feedback loop R2 stops to be effective. Nevertheless it is still sufficient to keep increasing the number of customers (new and reconfirmed) at least until year 40.
At that time the number of customers begins to decrease, setting free the up-to-then built capacity. This activates the other network expansion policy, driven by the exceeding capacity.
If that can happen in reality it is not given for grant. What is sure is that this decision in quite insane, because it increases the network cost while the customers and the total consumption decrease.

Eventually it accelerates the third phenomenon: the increase of the unitary network costs (generating a further reduction of the attractiveness) that reaches the maximum allowed value at year 85. Beyond that time the company bears the losses (up to 8 million CHF per year) and is designated to bankruptcy.

The NPV calculated at time zero is nevertheless positive and equals around 17 million CHF (the future huge losses are very far away in the future).

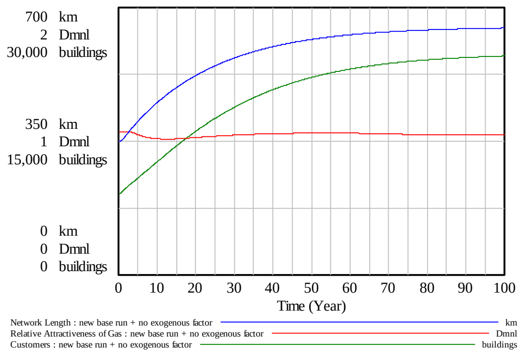
Network expansion driven by exceeding capacity

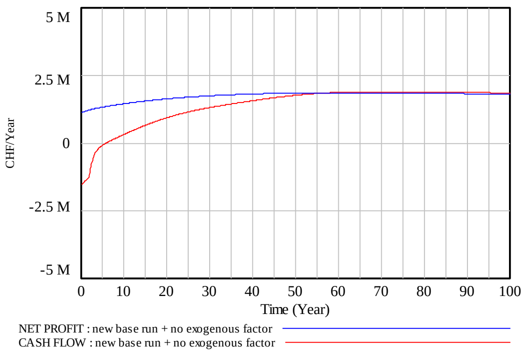
We have seen that the exceeding capacity driving to expand the network (looking for new customers) has a perverse effect. This policy is definitely disabled in the model (→ “new base run”).
In any case this decision has an impact only on the second part of the simulation period (after 45 years). Before, due to the growth, there is never enough exceeding capacity.
Avoiding to expand the network when customers are leaving makes the situation a little bit better (NPV around 19 million CHF) but the behavior in the first phase remains the same.

Effect of the exogenous factor

We have seen that the exogenous factor (that is progressively more unfavorable to the gas attractiveness) has a determining role in the model. If we remove this component (setting the elasticity to zero) the endogenous relationships assume more importance and the internal dynamics of the system is more clear.

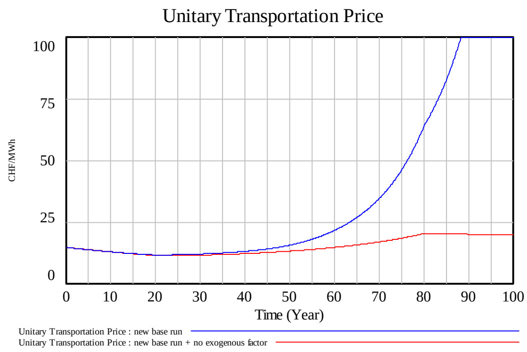
With the other parameters unchanged and without this negative external component, the system grows progressively to its maximum, with the network expanded over all the “expandable” territory and the customers that are acquired and successively reconfirmed.





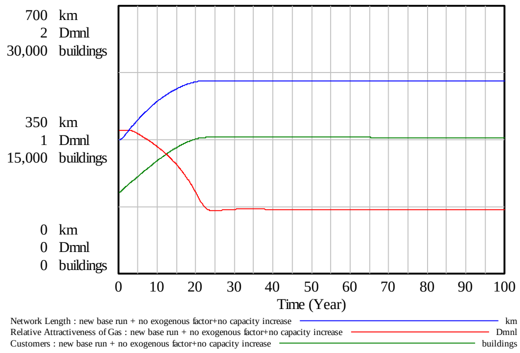
Because of the more intensive investments in expanding the network, the NPV (16 million CHF) is not better than the base case, when the exogenous factor is taken in account.

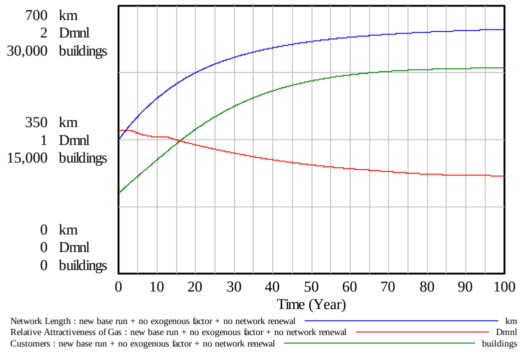
Due to the progressive reduction of the consumption-per-building foreseen in the future (starting from year 20 and stopping in year 80), the network tariff (in CHF/kWh) at the end will be higher than at the beginning. Even if the customer density grows continuously, the consumption density decreases, generating an increase of the unitary network tariff. In the following figure the evolution of the unitary network fee are represented for the situation without exogenous factor (red line) and with the exogenous factor (blue line), For the latter, we clearly see the effect of the customer loss and the consumption reduction on the network tariff. After year 87 the maximum allowed tariff is reached and then the loss begins.



With the external factor disabled we can look at the effects of some other parameters or policies: what happens if we do not adapt the transportation capacity to the customers growth or what are the consequences of a scarce network renewal rate ?

If the transportation capacity of the backbone is not consequently adapted to the needs, the quality of service decreases and eventually impacts on the attractiveness of gas, stopping the growth after year 23 (left graph). If the company decides to not renew the old pipes anymore (right graph) the effect of the increased number of failures on the attractiveness is less important but still visible.





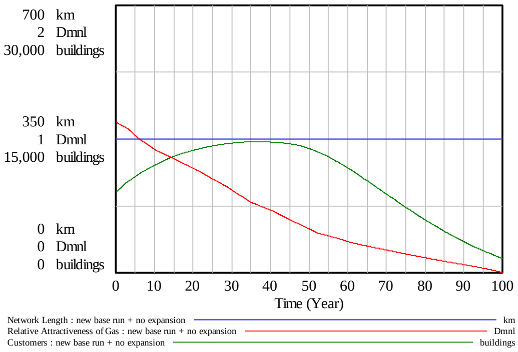
Expand, not expand or dismantle the network?

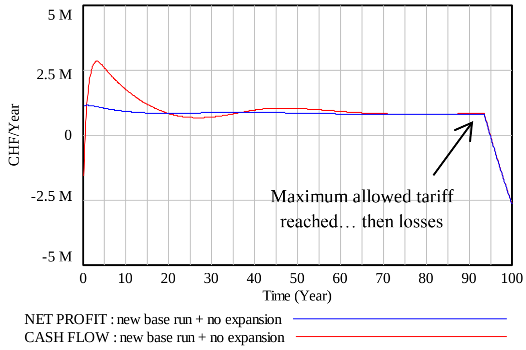
The different behaviors of the system seen up to now are mainly based on the fact that the attractiveness of gas increases the pressure to expand the network. In the model the expansion is driven by this pressure, reproducing the behavior of the company known until now.

We can now decide to try new decisions that the management could adopt. These are to refuse to answer to the pressure to expand or at some time start with the network dismantling.

In the first run we simply switch off the expansion possibility. That means that independently from any external pressure the network length will stay constant at the initial level. The backbone capacity instead will be progressively adapted to the needs.

We can notice that the number of customers still can grow but not so much like with the network expansion. The financial result is generally better. Nevertheless, if the admit a maximal value for the network fee, there will be a point when the calculated price will be above the maximum value and generate losses. This happens later in comparison with the (new) base run. Avoiding expansion investments the cash flow is positive and the NPV equals 32 million CHF (in the base run the NPV is 19 million CHF). This is a first indicator that expanding the network is not always a good decision.

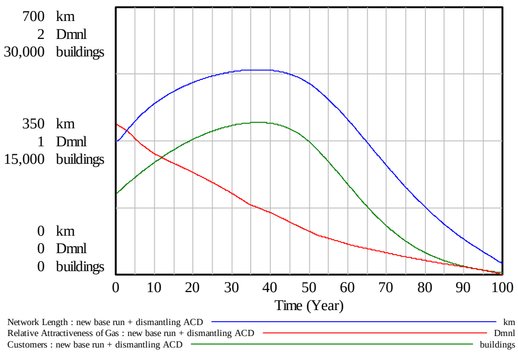


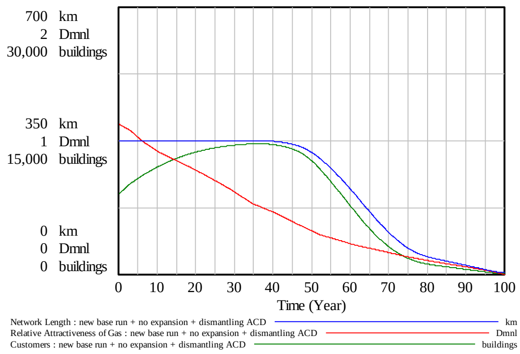


We can now test what happens if we would decide at some time to start with the network dismantling. In the model this decision is driven by the slope of the adimensional customer density (the ratio between the number of customers and the potential customers). When we get aware that this ratio cannot be increased anymore and begins to be decreasing, we decide to reduce the network length.

We can test this behavior one time after that the system has grown (like in the base run) and another time with the expansion switched off.

In the first case (left graph) the network length grows until year 40, then the dismantling process begins. The NPV reaches 16 million CHF. If we avoid to invest to increase the network before dismantling it (right graph) the NPV is higher (around 28 million CHF), even if less customers are reached.





<u>Adding the revenues from energy trade</u>

Until now the focus has been put only on the network system. For an incumbent gas distribution company, even in a context where the market in totally open, part of the revenues still come from the energy trade. From the previous results, the best choice from the "network" point of view seems to be to not expand the network end (if possible) avoid to dismantle it.

Let's see what happens if we add the revenues generated by the energy, supposed in our model with a value of 1 CHF/MWh.

In the new base run the NPV reaches 40 million CHF (22 more come from the energy) and with the network expansion switched off it reaches 52 million CHF.

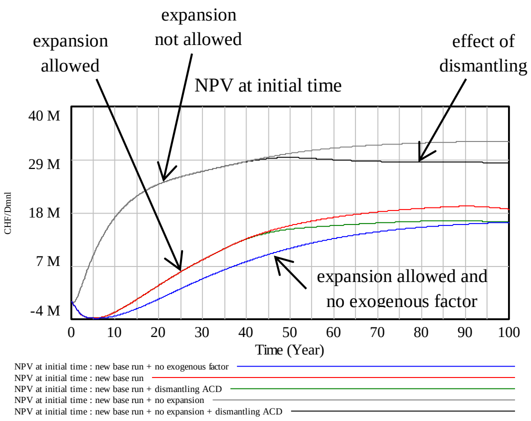
The adopting the dismantling policy seen before the NPV equals 36 million CHF in the “normal” expansion situation and 47 million CHF with the expansion switched off.

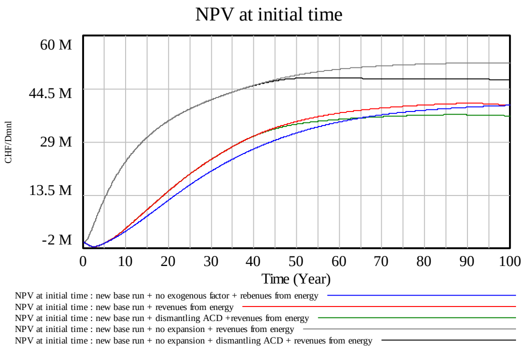
<u>Resuming the results</u>

We can represent the outcome of the runs focusing in the Net Present Value, that represents eventually the goodness of the decision taken. The NPV is calculated non only over the whole simulation period, up to each simulation step. This can give a better understanding of the evolution of the profitability over time.

We have two main choices to make: the first is about expanding the network or not (resting to the pressure given by the attractiveness), the second is about dismantling the network if at some time it is convenient.

We combine these different choices and evaluate them using two values, the first is the NPV generated only by the network business (left graph), the second is the NPV taking in account the revenues from the energy trade as well (right graph). The results are compared with the run where the exogenous adverse factors are switched off and the system grows to the maximum of the length driven by the even increasing attractiveness of gas (blue lines).





What is to remark is that the higher cash flow generated in the first years if we decide to stop immediately the expansion investments, determines the definitely higher NPV (15 to 20 million CH more) than if we keep expanding. The future higher revenues (determined by the higher asset value and from higher consumption) are not enough to compensate this big cash saving at the beginning.

The dismantling does not influences so much the NPV at initial time but will be important in the future. A correct dismantling strategy, related to the current evolution of the number of customers connected to the network will avoid or at less minimize the effect of the negative feedback loop “less customer – higher unitary prices – less attractiveness –less customer”. As the infrastructure has to be kept working even if only one customer is connected, it has to be the smallest one in order to have the lowest cost (remember that we have defined a maximum unitary cost, above which the cost are born by the company).
On the other side dismantling the network means reducing the asset value and thus the regulatory allowed revenues. If these cost are born only by the company and are not added to the network fee, the company will face a critical period. An optimization process is then required.

In order to minimize even more the effect of the final phases of the lifetime of the network, a possible solution could be to create a “dismantling fund” that is created and financed by part of the network fees and acknowledged by the authority. This would dampen the final phase and create a more sustainable situation for the distribution company.

The following table resume the main outcomes of the different simulation, assuming that the dismantling process will be driven by the customer density.

Network Expansion driven by gas attractiveness	**Revenues from energy trade**	NPV at initial time (after 30 years)	NPV at initial time (after 50 years)	NPV at initial time (after 100 years)	Maximum Network Length	Maximum Number of Customers	Maximum Total Consumption
		[CHF]	[CHF]	[CHF]	[km]	[buildings]	[MWh/year]
no	**no**	26'591'196	29'437'216	28'230'294	350	14'672	961'975
yes	**no**	8'291'523	14'623'450	16'056'451	536	17'066	1'072'888
no	**yes**	41'251'236	47'510'256	47'059'624	350	14'672	961'975
yes	**yes**	23'857'676	34'151'124	36'569'284	536	17'066	1'072'888

7. Conclusions

We used a "new" approach in understanding the network expansion and the mechanisms that reside behind, and this can have an impact influencing and changing the management's point of view. The long term approach, considering even the "end of life" of the system, allows to better take decision about the expansion strategy. Remember that this work is about the expansion of the capillary network that allows to reach every single building for individual heating, and no other uses.

Even if it could seem attractive and profitable to expand the network and increase the asset value (regulatory ROA), it isn't like that. The results of the simulation runs show that from the company's point of view it seems recommendable to not expand the network anymore and "milk it" as a cash cow, connecting the potential customers that are on the existing network (densifying). The difference at financial level (NPV) can be high.

This is obviously correct only under the external conditions that we adopted in the model (even more negative exogenous factor and unitary consumption pre building decreasing).

About the dismantling strategy ("when?" and "how much?") an optimization process is required. On one side we want to avoid a not-dense-enough network, on the other side reducing the network length means reducing the asset value and thus the allowed revenues. The right solution depends as well from what will be allowed by the regulation and if the dismantling of parts of the network can be put on charge of the network tariffs.

The system can be optimized on other parameters as well, one over all the network renewal strategy. In this case the danger is to be attracted to reduce too much the network security to increase the profitability.

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