Cost-benefit evaluation of investment in natural gas distribution

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Abstract: Investment in the distribution of natural gas must be assessed by combining a technical analysis of the investment and an assessment of the social costs and benefits, to evaluate the impact of the project on social welfare in monetary terms. This paper describes how such an analysis can be conducted, by developing a methodology for the evaluation of investment in the distribution of natural gas. Once the net social benefit (NSB) of the investment has been evaluated, it is also important to assess the degree of reliability of such an estimate. This assessment can be conducted through two types of tests: sensitivity analysis and risk analysis. The critical variables are identified in sensitivity analysis as those that have a significant impact on the predicted outcome when they change. To address any uncertainties in the critical variables, a risk analysis quantifies the probability that the NSB is less than that estimated when using modal values for the critical variables. This type of analysis, combined with a technical evaluation, can be effectively used to assess the social consequences of an investment.

Keywords: Risk analysis, Natural gas, Net Social Benefit, Industrial plant.

1. Introduction

Cost-benefit analysis (CBA) is an analytical tool used to estimate the advantages or disadvantages generated by a project involving an investment, assessing its costs and benefits as a measure of the impact on social well-being, i.e., on the community. (Mishan, 1974; Nuti, 1987).

This analysis is required when public funding is involved. The lender can use it to ensure the investment brings not only private but also net social benefit (NSB), estimated as the difference between the social benefits and costs of the project (Tomo et al., 2011).

The social benefits include both the consumer's and the producer's benefit surplus. The former is the consumer's willingness to pay to use the service, which decreases with the increase in the quantity used and is typically represented by a demand curve with a negative slope. The surplus of the consumer is obtained by the sum of the willingness to pay (the integral of the demand curve) minus the market price of the goods corresponding to each quantity demanded.

The surplus of the producer is obtained from the difference between the market price and the production costs (market price for the corresponding quantity minus the integral of the corresponding cost curve).

The NSB is this difference corrected for any externality (Feldstein, 1964), i.e. effects not internalized in the prices of the goods.

The EU regulation 347/2013 establishes the guidelines for applying CBA to gas infrastructure projects, requiring the assessment of the social and economic sustainability of the gas network development plans. According to EU regulation, Italian law recalls CBA guidelines to support the tenders and grant the 177 planned local gas distribution service licenses.

This paper proposes a CBA applied to the natural gas distribution field, modelled according to the Italian regulation. A focus on the risk assessment shows that a two-step sensitivity analysis, combined with the probabilistic risk analysis, allow to identify the critical variables impacting the project NSB and managing their variability quantitatively.

The paper is structured as follows. In section 2 the CBA analytical framework is described. In section 3 the risk assessment steps are described. In section 4 the application of the CBA method to the natural gas sector is reviewed, while in section 5 the CBA model applied to natural gas distribution is detailed. Section 6 describes the risk assessment methodology applied. Finally, results and discussion are drawn in section 7 and the conclusions in section 8.

2. CBA analytical framework

The analytical framework of the CBA includes the following concepts:

- Opportunity cost. The lost gain deriving from the inability to exploit the second-best between mutually exclusive options. If inputs, outputs and external effects of an investment project are evaluated in terms of opportunity cost, the economic return represents an adequate measure of the project's contribution to the social well-being.
- Long-term perspective. The investment time horizon is set between 10 and 30 years.
- Calculation of performance indicators in monetary terms. The CBA is based on pre-established project objectives and assigns a monetary value to all the positive and negative effects on the social well-being.
- Microeconomic approach. Indirect effects (e.g. on secondary markets) and wider effects (e.g. regional growth) are excluded from the CBA.
- Incremental approach. The CBA compares the scenario involving the realization of the project with a scenario in which the project is not realized. In the absence of a pre-existing infrastructure, the alternative scenario is the one without any intervention. If the project aims at improving existing infrastructures, the alternative scenario includes the interventions necessary to maintain the service at an ordinary level of operability.

The CBA includes seven steps (Figure 1):

1. Description of the context.
2. Definition of the objectives.
3. Identification of the project.
4. Technical feasibility and environmental sustainability.
5. Financial analysis.
6. Economic analysis.
7. Risk assessment.

The NSB is computed in step 6.

3. Risk assessment

Article 101 of Regulation EU n. 1303/2013 (Information necessary for the approval of a large project) requires a risk assessment accounting for the uncertainty in investment projects.

The risk assessment involves the following steps:

- Sensitivity analysis.
- Qualitative risk analysis.
- Probabilistic risk analysis.

Sensitivity analysis makes it possible to identify the critical variables of the project, those whose changes have the greatest impact on the performance. The analysis is conducted by modifying the values associated with each individual variable and evaluating the effect of this change on the NSB. The variables subjected to verification must be independent and as much as possible disaggregated.

The sensitivity analysis also calculates threshold values, i.e. the values that the analysed variable should assume for the NSB to become zero or fall below the minimum level of acceptability. The use of threshold values in the sensitivity analysis makes it possible to judge the risk of the project and the opportunity to undertake risk prevention actions.

The qualitative risk analysis includes the following elements:

- A list of adverse events to which the project is exposed.
- A risk matrix for each adverse event indicating:
    - the possible causes of onset;
    - the connection with the sensitivity analysis;
    - the negative effects generated;
    - the probability levels of occurrence
    - the severity of the impact;
    - the overall level of risk.
- An interpretation of the risk matrix that allows the assessment of the risk levels associated with the whole project;
- A description of the mitigation and prevention measures of the main risks.

A probabilistic risk analysis is required if the exposure to residual risk is still significant. This type of analysis attributes a probability distribution function to each critical variable identified in the sensitivity analysis. The distribution is built around the best estimate and used to calculate the expected values of the NSB. The probability distribution for each variable can be obtained from different sources, including experimental data, distributions of similar cases reported in the literature, and through expert consultations. To calculate the expected value of the NSB it is possible to use the Monte Carlo methods.

A neutral attitude towards risks is recommended, as the public sector can in general manage the risks associated with many projects. In some cases, the designer can detach from neutrality and prefer a higher or lower risk than the expected rate of return. These choices must be clearly justified.

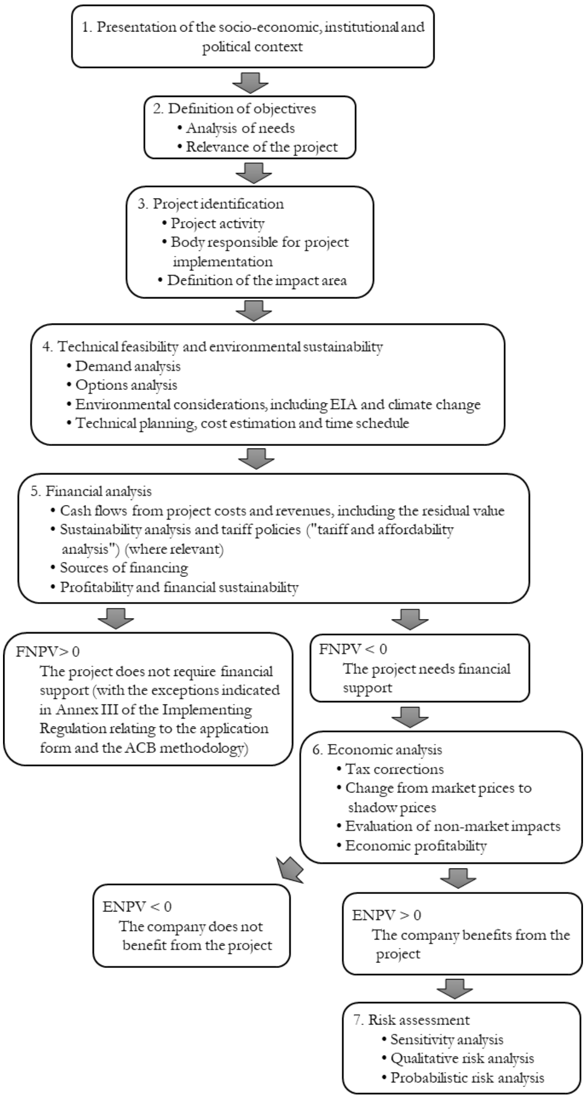

Figure 1: Project evaluation steps (from the EU guide, 2014).

4. CBA in the natural gas sector

CBA is one of the decision support methods employed in the upstream gas sector (Shafiee et al., 2019). On the other hand, a growing interest in socio-economic impacts of gas exploration, extraction, and transportation is outlined by the scientific literature (Buse, 2019).

In Europe, natural gas represents around a quarter of the European Union's overall energy consumption: about 26% is used in the power generation sector and around 23% in industry. Most of the rest is used in the residential and tertiary sectors.

Natural gas is considered playing a strategic role in the transition pathway to a sustainable energy production, since it can substitute the more polluting coal in the power generation, allowing to replace oil-fired generators with more efficient gas-fired ones (Dickel, 2018), also providing flexible back up to renewable energy sources.

Since natural gas infrastructures represent strategic European assets, in 2013 the European Union introduced the CBA method to evaluate and select gas related "projects of common interest", representing a novelty for the European gas industry and underlining the need for evaluating and maximise the NSB of a gas-related investment project (Keyaerts and Glachant, 2014).

In our study, we applied the CBA model to local gas-related project, considering the Italian regulation.

In Italy, the natural gas is the main source of primary energy to produce electricity, being the thermoelectric sector the main consumer of natural gas immediately after the residential. In 2017, local distribution networks (residential and services sectors) account for about 40.5% of total national gas consumption (ARERA, 2018). The Italian law regulating the distribution of gas (DM 226/11) assigns to local authorities the task of managing public tenders for granting the gas distribution services concessions. Considering the law procedural guidelines, a cost-benefit analysis model was developed using the methodology derived from the regulations (EU, 2014).

5. CBA model in the natural gas distribution

The used model (Gullì, 2016) is structured in different project categories. The overall formula includes all the formulas related to a single project, that is, projects that only include one output. From this, it is possible to reconstruct the different combinations of investments.

In the case of individual projects, the model considers the following categories awarded by the Italian tender procedure:

1. Extension of the network for user acquisition (both new and existing).
2. Projects to improve supply security (continuity of service).
3. Projects to improve service quality.
4. Projects to increase reliability (network renewal and safety from accident risk, remote control, odorization, cathodic protection, etc.).

A brief description of the categories is reported below.

5.1 Network extension

This category includes the extension of the network for the acquisition of new users and to replace other energy carriers.

5.1.1 Extension of the network for the acquisition of new users

This type of project requires new users to be connected, with an increase in the number of redelivery points.

As these are new users, the benefits should be estimated by measuring the total increase in consumers. If the construction of new settlements takes place regardless of the type of energy supply the net benefits of the extension must be evaluated differently, it must be compared to the best possible alternative energy supply. In such a case it is not necessary to estimate the entire surplus of consumers but only the possible loss of well-being, due to the transition from natural gas to the alternative form of supply. If there is a loss, appropriately discounted over time, it constitutes the NSB of the investment in the extension of the natural gas distribution network.

It should also be noted that the project output is given by the final service (e.g. the use of heat for heating purposes). Therefore, the total investment to be considered includes both the expenses for the transformation plants owned by the users (e.g. the heating boilers), and the expenses for the purchase of the energy carrier (the "raw material" and the "sale "), alongside those for its carriage. The user investment in general has a different useful life than the one in distribution, thus the investment should be split into two parts: supplier side and consumer side.

For the purposes of quantitative assessments, the district heating was chosen as an alternative to natural gas. The Italian legislation requires it as a comparison, therefore it is implicitly considered to be the best alternative to the gas sector (at least in the context of northern Italy, where it is justified by the demand for heat). Thus, it is assumed that the cost of the district heating is well represented by the price charged by the companies, which is generally equal to the price of gas (the alternative source), including taxes.

5.1.2 Extension of the network to replace other energy carriers (pre-existing users)

In this type of intervention, the network (in its broadest sense) is extended to established settlements. The NSB of the investment must therefore be considered as the NSB of the existing supply. Here, no reference to the best possible alternative should be made, as it is neutralized in the comparison of natural gas with the future supply (both should in fact be compared with the best alternative). The expression for the NBS is therefore almost identical to the one obtained for the previous type of projects where the existing solution should be applied.

5.2 Project to improve the security of supply (continuity of the service)

The continuity of the service is a classic external benefit, there is no market value for this service and any improvement has non-excludable characteristics. No consumer, regardless of his willingness to pay, can be excluded from the benefits of the project. Consequently, the benefits in this respect should be estimated in the same way as for other externalities, as these project surely produces an advantage for consumers. The methods to estimate these external advantages vary from the typical contingent valuation to engineering methods, based on the costs of backup technologies.

5.3 Project to improve service quality (regardless of the continuity of the service)

This is the most uncertain type of project from a CBA perspective, as the benefits are definable and can be estimated, although with difficulty.

The improvement in the quality of the service (having excluded the continuity of the supply) is essentially linked to the pressure the natural gas is made available to users. The optimal operating conditions require that this pressure must be within a well-defined range of values. If outside this range, an investment in the network is desirable, and by optimizing fluid dynamic conditions within the optimality range can be achieved.

In terms of a cost-benefit analysis, since the consumers do not perceive this inefficiency, it is difficult to evaluate this type of investment and any contingent valuation (of the type mentioned above) can be unreliable. The only solution here is to rely on engineering assessments.

As part of these assessments, the most important aspect is the impact of supply pressure on the efficiency of boilers using natural gas. If this pressure is not within a certain range, the efficiency of the boiler suffers, and consequently there is a higher cost for heating and greater externalities, particularly of an environmental nature. Thus, the benefits of the interventions on quality of service can be estimated considering the positive impact that these interventions have on the performance of the plants. Specifically, reference will be made to heating systems, in terms of the efficiency improvements that can be achieved by replacing old boilers with those that are more efficient boilers or by increasing the efficiency of the current boiler.

An intervention generally involves an increase in pressure for a certain number of users but also a decrease in pressure for others. The decrease in the quality of the service for the latter is computed in the external costs. In addition, fluid dynamics models cannot calculate the increase and decrease of the pressure for each intervention, only for the entire plant. Consequently, we calculate the increase and decrease in the quality of the service for the entire plant and divide the corresponding values into individual interventions, based on their investment quotas.

5.4 Project to improve supply reliability (remote control, odorization, cathodic protection)

This type of project aims to increase the reliability of the grid regarding exceptional events that can affect human health (and possibly deaths). This type of project includes measures to put the system in higher safety conditions to even protect against the risk of "catastrophic" natural events (earthquakes, floods, etc.). It also provides for the renewal and modernization of the infrastructure in terms of security. This category also includes odorization, remote control and cathodic protection interventions. The output of the project is therefore substantially constituted by the reduction of the risk of damage from a major accident.

The information required for this evaluation is as follows:

- The reduction of the risk of accidents.
- The average number of deaths and the damage to health that these accidents involve.
- The value of human health and life.
- The costs of restoring the supply network and the infrastructure involved.

6. Risk assessment methodology

The last step of CBA consists of analysing the evaluation reliability. The manuals recommend performing two types of checks: a sensitivity analysis and a probabilistic risk analysis.

The first step in the sensitivity analysis identifies the critical variables, i.e., those that have the greatest impact on the estimated result. A variable is considered critical if a variation in its absolute value is smaller than or equal to 1%, and that generates a corresponding absolute variation of more than 1% in the NSB. The second step in the sensitivity analysis identifies the value for each variable leading to an NSB equal to 0. Each variable is changed in the interval (0, +∞) while keeping the others fixed. A Golden-section search probes different values for the variable and thus for the NSB, restricting the search space after each iteration.

A probabilistic risk analysis is also undertaken, a probabilistic evaluation of the impact of the joint variation of critical variables over the NSB. The output is the cumulative probability that the NSB is less than each value it can achieve. This analysis is performed using Monte Carlo methods and by attributing an independent probability distribution to each critical variable.

In our scenario we consider the overlapping uncertainty on two variables: the investment cost and the social discount rate. A truncated normal distribution (only positive values) with a mean of 7451.00 € and a standard deviation of 224.00 € is considered for the investment cost, while the discount rate is assigned a truncated normal distribution with a mean of 4.00% and a standard deviation of 0.02%. The analysis generates 1000 investments and discount rates, it computes the NSB for each couple and orders the NSBs in an increasing fashion. For each NSB, the number of NSBs lower or equal to it is computed and divided by 1000+1, this estimates the probability that the NSB is lower or equal to the value of the NSB analysed.

The sample case is of the first type; it involves the acquisition of new users.

7. Results and discussion

The first column of Table 1 reports results of the first step of the sensitivity analysis. It contains for each variable the relative percentage difference between the original NBS value and the NSB after a 1% change. The second column reports results for the second step of the sensitivity analysis. It contains the relative percentage differences between the original variables values and their values generating an NSB equal to 0.

Table 1: Results of the sensitivity analysis.

Variable	NSB relative difference [%]	Variable relative difference [%]
Investment [€]	4.49%	122.26%
Discount rate [%]	1.76%	186.04%
Customer externalities coefficient [%]	-1.87%	46.63%
Natural gas shadow price [€/kWh]	7.96%	112.56%
Heat pump energy shadow price [€/kWh]	-9.83%	89.83%
Inflation rate [%]	-2.29%	47.04%

The first step of the sensitivity analysis identifies 6 of the 43 variables as critical. The second step indicates that sizable variations in the variables are required to equal the NSB to 0. This second finding could spark a re-evaluation of the first analysis results, since the variables might be locally critical but still able to generate positive values of the NSB for an ample range of variation.

The probabilistic risk analysis results are reported in Figure 2.

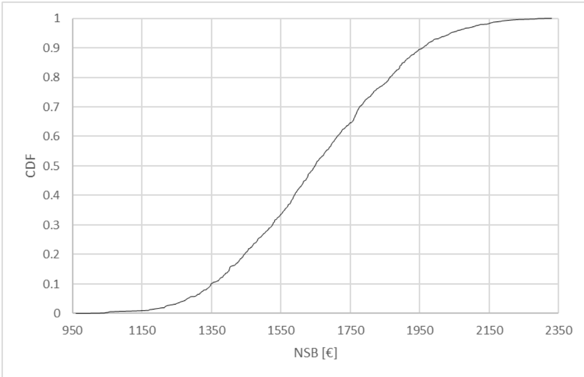

Figure 2: Risk analysis results.

The probabilistic risk analysis confirms the conclusions obtained in the second step of the sensitivity analysis, while the variability around the expected value is sizeable the probability of achieving negative NBS is close to zero.

Both Table 1 and Figure 2 show that sensitivity and probabilistic risk analysis can jointly capture significant aspects of the project, evaluating the most important variables and managing their variability quantitatively.

It is also to be noticed that the probabilistic risk analysis results are affected by the variables selected for testing. In the current scenario only the investment cost and the discount rate are analysed, if other variables among the critical ones are introduced the results might change. This introduces a trade-off as, for each new variable, estimations must be made over its distribution shape and parameters. If such estimations are unreliable the analysis could be misleading.

8. Conclusions

In this paper the methodology for developing cost-benefit analysis is illustrated and used to estimate the advantages or disadvantages generated by a project involving an investment. Obtaining a project social costs and benefits is important, in particular when a project aims at accessing public funding.

The importance of a risk and a sensitivity analysis is also illustrated: in this context the two-stage sensitivity analysis is both coherent with the probabilistic risk analysis and useful to identify critical variable from a total NSB standpoint.

The proposed tool is adaptable to different types of projects and is of fundamental importance when participating in public tenders.

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