Análise económico-financeira associada à corrosão num gasoduto

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July 2021

Abstract - Most of the materials on our planet are in constant interaction with the environment. These interactions can cause changes or damage to those materials. A well-known interaction between material and environment, especially for inorganic materials, is corrosion. Although there are international measures that regulate the practices that can be applied to prevent corrosion – which would allow an estimated savings of between 15% and 35% of the global cost associated with corrosion – they are not always applied by the companies.

The focus of this study was a project to build a gas pipeline, based on the gas pipelines of REN, a leading Portuguese company in the electricity, natural gas and telecommunications sectors. The main objective was to assess the costs and benefits associated with the prevention and maintenance of corrosion, considering its future use and conservation. Through the literature review on several methods to assess the feasibility of projects, the cost-benefit analysis methodology was selected to create the evaluation model for this project. This decision was based on the possibility of accounting and evaluating all the factors involved (tangible and intangible).

It was concluded with this study that the construction of this type of infrastructure must consider the various types of costs associated with the maintenance and prevention of corrosion in gas pipelines, contributing to open a new study in the energy industry, namely in the distribution of natural gas because it allows to combine the costs inherent to occurrences (tangible costs) with the associated intangible costs.

Thus, this study is important to understand how maintenance work can be intensified in the future to prevent infrastructure corrosion.

Keywords: Corrosion; Natural Gas; Maintenance Prevention; Pipelines; REN.

1 - Introduction

An important interaction between the material and the environment, especially for inorganic materials, is corrosion (Snow, 2003).

In addition to being a current theme, corrosion has also become historical and global, as throughout the evolution of our species. After so many years, corrosion continues to be an obstacle in various activities and accompanies us in our day to day, causing material damage and can also jeopardize our safety.

Portugal is mostly bounded by a vast coastline, which makes the sea have a strong influence on the Portuguese economy. There is a strategic investment in this type of economy, as it extends to various sectors that are decisive for economic growth and its sustainability. Corrosion is strongly accelerated by the sea, being the main cause of infrastructure maintenance costs requiring greater robustness in terms of material and infrastructure protection, and the implementation of management and corrosion combat strategies (Nd and Ran, 2016).

In Portugal, the maintenance and prevention of corrosion are themes little explored in the literature, so this dissertation comes with the purpose of carrying out an economic and financial study to help Redes Energéticas Nacionais [REN], the company responsible for the main infrastructures of transport of electricity and natural gas, in making strategic decisions to combat corrosion. REN will benefit from this study as it has a large extension of gas pipelines and there are plans for this to increase. Thus, this study will allow us to assess whether the current focus on prevention and corrosion is adequate so that we can move forward with the planned increase in extension.

2 – Pipelines and Corrosion

Pipelines are one of the safest ways to transport natural gas. Despite being very reliable, there is always concern on the part of the sector with their safety and integrity, since an accident in a gas pipeline can have consequences at an economic, social and company image level (Cabral, 2007).

Corrosion is one of the main processes causing failures in equipment and piping on natural gas production and transport platforms. These failures, in addition to harming the image of the distribution companies, cause losses related to operational continuity and are associated with high maintenance costs. Corrosion is also associated with risks to the health of workers and serious environmental problems (Lemos et al., 2016).

In the face of all the failures and series of failures in gas pipelines, new regulations and practices for controlling and preventing corrosion have been implemented. According to Portuguese Decree Law No. 140/2006 of July 26, sections of overhead or surface-installed gas pipelines must be externally protected against atmospheric agents and any mechanical actions, by painting, metallization, mechanical guarding or any other suitable process. Underground or submerged steel pipe sections must be protected by a suitable protective coating (passive protection) and must be provided with a cathodic protection system (active protection).

All infrastructure and equipment are profoundly impacted when affected by corrosion and its effects. This impact is mainly manifested in the maintenance, repairs and replacement of the affected materials, and it limits the availability, performance and conditions of the materials, also affecting the infrastructure installations (Thompson et al., 2005).

In 2002, NACE International and FHWA presented a study entitled "Corrosion costs and preventive strategies in the United States", based on an analysis from 1999 to 2001. This study proved that the estimated direct costs of corrosion in the United States of America [USA] were around 276 billion dollars, which translated into approximately 3.1% of their Gross Domestic Product [GDP].

The costs associated with corrosion in pipelines are incorporated in the infrastructure sector. From the total value attributed to this sector, corrosion, specifically in gas pipelines, has a total cost of 6.4 billion euros, which corresponds to around 32% of the total spent in the infrastructure sector and around 5% of the total cost of corrosion. These figures were extrapolated to the total US economy (7.89 billion euros), accounting for an annual cost of corrosion of around 247.6 billion euros (counting tangible and intangible assumptions costs).

Regarding the Portuguese case, the participation of the natural gas sector in the creation of wealth in the Portuguese economy is measured through the weight of the Gross Value Added [GVA] of the sector, in the national GVA, which is the same as saying in the GDP evaluated at current prices. Since 1999, the variation in values has been significant, so that the average annual growth rate is 11%. However, considering the active population in Portugal and those employed in the natural gas sector, the level of wealth generated per unit of work in this sector is almost ten times higher than that of the economy (ERSE, 2017).

Portugal has all the conditions to boost this sector and establish itself as an international reference. However, there are several economic and engineering obstacles that require a planned strategy. One of the main causes of high infrastructure maintenance costs is corrosion, understood as material degradation due to the aggressive action of the environment. In several sectors of the European Union [EU], predominantly industrial, the global costs induced by corrosion represent about 3.5% of GDP, which is a very painful value for the economy (Nd and Ran, 2016). In Portugal, the scenario remains and the fight against corrosion is too costly.

The implementation of strategies and measures for the prevention, protection and management of corrosion can lead to a reduction of around 30% in the costs inherent to the degradation of infrastructure, products and equipment. Thus, considering the value of GDP in Portugal in 2016, this means savings of around 1.400 million euros that can be reinvested in new infrastructure, thereby strengthening national economic competitiveness (Rodrigues and Rocha, 2016).

In REN's case, as macroeconomic conditions become more favorable in Portugal, the company will benefit mainly from the positive impact that an improvement in the credit rating and yield (return on an investment in shares) of Portuguese Republic bonds can have in REN's financing income and costs. The increase in internal energy consumption and the increase in economic activity may stimulate the growth of REN's Gross Annual Income [RAB] and, consequently, of its income (REN, 2016).

3 – Methodology

This study used the Cost-Benefit Analysis [CBA] methodology. CBA has been intensively developed over the last 50 years, it relates to the notion of human preference and to the concept of well-being. According to Ward (1991), a CBA aims to assess the net economic impact of an investment project, and it can be used in various situations. This type of analysis introduces the evaluation of decisions that have a direct impact on society, allowing the feasibility of projects to be considered and their impacts assessed, based on the comparison of costs and benefits over a given time horizon (Mishan, 1994). CBA is an important quantitative analytical tool for estimating the economic benefits of projects, but also for considering the efficient allocation of resources.

The level of analysis used must consider the impact that the project has on society. All impacts must be assessed, whether they are financial, economic, social or environmental. The purpose of a CBA is to identify and assign a monetary value to all possible impacts, to determine the costs and benefits of a project. It is also essential to define different assumptions and estimates since these elements may have a direct or indirect relationship with the project, as well as having a tangible or intangible characterization (Williams, 2008).

Subsequently, this analysis groups the results, that is, the net benefits. According to the European Commission's guidance on methodology for carrying out cost-benefit analyzes (2003), costs and benefits should be assessed on an incremental basis, considering the difference between the project scenario and an alternative scenario without the project. The costs and benefits can be born and occur at different levels, so a decision needs to be made as to which ones are important to consider.

The impact of the project must be evaluated against previously defined objectives. Thus, a project should be evaluated against microeconomic indicators, and the CBA can assess its consistency with specific macroeconomic objectives and their importance to them. When estimating the potential impacts of a project, the existence of a certain level of uncertainty is verified. Thus, uncertainty must be properly considered and addressed in the CBA (Weiss, 1998).

The use of this methodology has several advantages, and this method has as its main advantage the possibility of supporting decision-making based on exhaustive analysis and comparison of solutions, considering multiple assumptions and alternative scenarios (Williams, 2008). On the other hand, the usefulness of this analysis is reflected in the ability to integrate the different impacts on social well-being and allow the decision maker to obtain detailed knowledge regarding the costs and benefits, resulting from their identification and valuation, promoting a decision sustained and properly considered. Additionally, from an economic point of view, the aggregation of financial indicators makes it possible to carry out an evaluation of the project, as well as to analyze the broad social, economic and environmental effects (Vörös, 2018). The CBA is a formal process for evaluating the performance of each project through the analysis of the net monetary benefits of its impacts (Jones, Moura and Domingos, 2014).

However, the CBA has some limitations in its application, given that there is a degree of subjectivity in the interpretation of its results associated with the analyzes carried out to support decision-making, which does not confer total objectivity on the tool. On the other hand, some assumptions that do not correspond to the reality in the long term are considered, neglecting some considerations (especially environmental) and these assessments are extremely sensitive to the values used in different assumptions, which may change the results.

Even so, the difficulty in assigning a monetary valuation to all elements of the project is one of the existing difficulties, given that its exclusion from the results can end in an inaccurate assessment (Jones et al., 2014).

To complete the analysis, this study uses a Sensitivity Analysis [AS]. The object of the AS is the selection of critical variables of the CBA model, that is, those whose variations in relation to the value used as the best estimate have a more pronounced effect on the financial and economic parameters.

The criteria used in choosing the critical variables may differ depending on the specifics of the project considered and must be rigorously evaluated. All the variables used to calculate all the parameters of the economic and financial analysis must be identified, grouping them into categories. Afterwards, the identification of possible interdependencies between variables that could lead to distortions in results or double accounting must be carried out. Variables should also be evaluated over time. Critical variables can be related to fictitious prices of costs and benefits or to market price conversion coefficients. Furthermore, the value of time and the assessment of externalities must also be considered.

4 – Descriptive Analysis

Regarding REN, considering the values in the 2018 Report & Accounts, the group proceeded with the investment project for the construction of a gas pipeline, which registered one of the main initiatives to ensure the specific needs of this business sector. In this sense, and considering the objectives defined, it is essential to identify and determine the costs associated with the corrosion of a gas pipeline, throughout its useful life, as well as regarding the preventive maintenance of the necessary infrastructure, in a way to ensure compliant and standardized operation.

On the other hand, it is necessary to carry out a cost-benefit analysis of the costs associated with the construction project of a gas pipeline, to assess and mitigate possible impacts on the distribution network and its users due to irregularities in the performance of the infrastructures.

As such, in the context of the REN group's strategy, the need arose to move forward with an investment project for the construction of a gas pipeline. After a meeting with Engineer Carlos Sousa (personal communication, April 30, 2019), it was possible to gather the total extension for REN pipelines (1.375 kilometers) and the total cost for this extension (1.2 billion euros).

Considering the mentioned investment, it is essential to unequivocally identify the projects that were analyzed. Therefore, and considering the initial investment data identified for the construction of a gas pipeline, it is necessary to frame the approach of this dissertation in two distinct dimensions. As such, for the study of the REN case, projects A and B were identified as the target of financial feasibility analysis according to the CBA method defined above.

To carry out this study, the initial investment base for the total length of the pipeline (1.375 km) was considered but for the object of analysis, only the evaluation of a segment with a length of 1.000 km was evaluated.

Through this definition of projects, it is intended to list all tangible and intangible variables, as well as to identify and detail all parameters associated with costs and benefits of each of these projects, considering the direct and indirect socioeconomic effects. Subsequently, through the CBA, it is possible to carry out a thoughtful and reasoned assessment of the economic impact of investment projects and analyze their feasibility, considering the respective financial, economic, social and environmental impacts, by comparing the cost and benefit in the medium and long term. In this way, it will be possible to correlate the set of variables under analysis, draw conclusions and identify risks and limitations of each of the projects.

4.1. Project A

This project corresponds to the approach that only considers the initial investment in the construction of the new segment, neglecting activities related to preventive maintenance and monitoring of corrosion indicators in these infrastructures.

Considering the 10th Report of the European Gas Pipeline Incident Data Group (period 1970 - 2016) of EGIG (2018), the study of the extension of gas pipelines over time, the number of accidents reported on those years and their environmental associated damage costs by Belvederesi, Thompson and Komers (2018) and the total cost of corrosion for USA by NACE International (2016), it was possible to gather all the costs for project.

The set of tangible benefits associated with the inexistence of periodic infrastructure maintenance activities, this project is exposed to several risks such as failures, incidents or disruptions, and the useful life period becomes reduced, which may impact the costs of production and/or provision of services.

As such, the tangible benefits related to the project that does not consider equipment maintenance consider the set of annual operating costs related to maintenance activities.

In the case of the intangible benefits associated with the project related to the lack of periodic maintenance of infrastructure, the occurrence of possible failures or disruptions can lead to leaks and high costs of repair, replacement or fines related to environmental impacts. Therefore, the intangible benefits associated with this project only reflect the inexistence of fixed annual costs, as well as the annual costs not incurred, if an incident due to corrosion in REN's supply network does not occur. It is considered that the initial investment does not reduce the probability of the occurrence of a corrosion incident, increasing the exposure of the equipment. As such, in the case of inexistence of interruptions or failures in the supply service, the benefit lies in the set of economic impacts on the various existing consumer segments and if there is no occurrence due to corrosion, it has no impact in the market position of the distributor.

Taking in account all the previous studies and considerations, the project A operational costs and benefits (€ / 1.000 kms) are presented in the Table 1:

Table 1 – *Operational costs and benefit analysis for project A.*

Category	Costs	Benefits
Social	1.666,67€	23.000,04€
Property	432.803,67€	5.972.690,13€
Environment	234.413,27€	3.234.903,13€
Economic	1.439.083,00€	19.859.345,40€
Operational	0,00€	7.212.712,73€
Total	**2.107.966,61€**	**36.690.387,03€**

4.2. Project B

This project corresponds to the approach that includes the entire set of operating costs associated with the prevention of corrosion in the construction of the gas pipeline segment and the monitoring of corrosion indicators.

The following table (Table 2) sets out the set of operating costs, costs of tangible assets and intangible assets, respectively.

The values presented in table represent annual prevention and monitoring costs about the set of operating costs to be considered in the REN gas pipeline investment project.

Table 2 - *REN's operational costs.*

Type	Tools, procedures and concerns	Cost (k€/1.000 km)
Operacional	Inline inspections [ILI]	55
	Coating condition inspections	36
	Anticorrosive treatment of surface stations	73
	Characterization and repair of defects	29
	PIMS (Catodic protection)	10
	SCADA (Catodic protection)	Residual
	Salaries and formations	*Own staff*
	Non-destructive testing [NDTs]	103
	Excavations	
	Repair of a section	
	Full replacement of a section	
Tangible	Eddy current protections	52,71
	Cathodic protection	
	High density polyethylene	
	Specialized interior painting	
Intangible	Environmental problems	Not defined
	Service interruptions / failures	
	Loss of reliability	
	Image	

Considering the set of tangible benefits associated with the maintenance of infrastructure, the periodic monitoring of equipment allows to reduce the risk of failures, incidents or disruptions, through the extension of the useful life period and, consequently, the reduction of production costs. In the case of gas pipelines, these infrastructures are assumed to be effective investments, so it is essential that there is a thorough control of their quality.

The operating costs and tangible costs referred to above make it possible to maintain the pipeline and, if necessary, intervene without the need to interrupt the flow. Also, it is essential to notice the importance of corrosion protection which can reduce repair costs due to corrosive damage. Sometimes, depending on the observed and characterized defect, certain sections must be repaired or completely replaced (Soares, 2009).

In this way, the tangible benefits obtained by the implementation of a project that considers the periodic maintenance of infrastructures relate to the reduction in the probability of an incident occurring due to corrosion in REN's supply network. Considering that the project includes in the initial investment the set of cathodic protections, against eddy currents and specialized painting of infrastructures, it can be considered that the benefit is based on the unique need to use specific protections. As such, the assumption that the entity is willing to make an initial investment is considered, which drastically reduces the probability of occurrence of a corrosion incident.

The occurrence of possible failures or ruptures can lead to leaks and high costs of repair, replacement or fines related to environmental impacts. By preventing injuries and damage from corroded equipment, companies can avoid legal and environmental liabilities. The results of these inspections allow the development of coating repair programs, also evaluating the state of the cathodic protection system and the level of corrosion of the pipes (Ribeiro, 2003). On the other hand, reliability, understood as the ability to provide the service as promised, is a dimension that can be related to the issue of image. Image is considered an instrument of competitiveness in organizations. Once a bad impression is made, it will be difficult to reverse this thought. If the past image of a product or service exactly matches reality, the satisfied customer/consumer will try to assess other aspects of the quality of the product or service. Otherwise, it will lose reliability (Martins and Laugeni, 2005).

Taking in account all the previous studies and considerations, specially from the REN's costs report, the project B operational costs and benefits (€ / 1.000 kms) are presented in the Table 3:

Table 3 – *Operational costs and benefit analysis for project B.*

Category	Costs	Benefits
Social	0,00€	10.333,35€
Property	0,00€	2.683.382,75€
Environment	0,00€	1.453.362,27€
Economic	0,00€	8.922.314,60€
Operational	306.000,00€	965.418,92€
Total	**306.000,00€**	**14.034.811,9€**

5 – Results

After identifying the objects of study, it is necessary to carry out a cost-benefit analysis of the previously defined investment proposals. In this subchapter, the main objective is to analyze the economic activity inherent to each of the projects presented based on the comparison of costs and benefits, respectively. As such, through the CBA it is possible to assess the impact of different projects by comparing microeconomic indicators, allowing both to carry out a weighted assessment of the net benefits of each project, as well as to consider the macroeconomic impacts related to the investment project in the medium/long term. Thus, it is intended to analyze the decision-making based on the economic evaluation and on the performance indicators of the projects, considering the mentioned projects.

The CBA of this study intends to carry out an economic evaluation of projects A and B, which correspond to the investment in a segment of a 1.000 km long gas pipeline, neglecting preventive maintenance activities and monitoring of corrosion indicators (project A), or otherwise side assuming the operating costs related to preventive maintenance activities and monitoring of corrosion indicators in these infrastructures (project B).

To proceed with this analysis, it is important to highlight some aspects relating to the case under study, which implies a total investment of 1.200.000.000€ for a total extension of 1.375 km in length referring to the pipeline to be installed.

Considering the objective of this dissertation, the following analysis intends to support the decision making of the investment project, based on the analysis of costs and benefits, and for this analysis an evaluation period of 20 years was considered and a rate of inflation of 1.8%, from REN's 2018 Report & Accounts. To analyze the investment, the financial indicator CBA and the total cost of the project were considered, considering the set of costs previously described associated with the segment under analysis.

5.1. Analysis of Project A

According to the analysis carried out, it is possible to consider that the implementation of investment project A presents an initial investment of €872,674,560.00 in the installation of infrastructure. To carry out the assessment of the financial feasibility of this project, its cost was calculated, considering the following data:

- Life of pipeline: 50 years (Williams Transco Central Penn Line South, nd.);
- Devaluation assumption rate: 2,0%;
- Corrosion accident cost: 2.107.966,61€;
- Repair cost: 103.000,00€;
- Probability of occurrence (annual) of an accident due to internal corrosion: 31%.

As mentioned above, in the analysis of project A, it considers the initial investment of the project, however it is exposed to the possibility of incidents arising from the corrosion of infrastructure, since the protection or maintenance against corrosion in the segment in analyze. In this sense, the probability of occurrence of an incident per 1,000 kilometers of extension is 31%, so an annual repair value of the segment under analysis was considered referring to the repair cost product by the probability of occurrence of an annual incident. As such, and assuming the mentioned assumptions, the following results were obtained:

- **Total cost of project A =** 1.231.793.258,14€.
- **CBA (with updated values) of project A =** -880.357.911,77€.

5.2. Analysis of Project B

According to the analysis carried out, it is possible to consider that the implementation of investment project B, presents an initial investment of €872,727,272.73 in the installation of infrastructure. To carry out the assessment of the financial feasibility of this project, its cost was calculated, considering the following data:

- Lifetime of the gas pipeline: 125 years;
- Devaluation assumption rate: 0,8%;
- Operational maintenance cost: 306.000,00€;
- Probability of non-occurrence (annual) of an accident due to internal corrosion: 69%.

In this project, and according to information collected from REN, the lack of a history of major occurrences in REN's gas pipelines allows considering a zero cost for repairing the gas pipelines. As such, and assuming the mentioned assumptions, the following results were obtained:

- **Total cost of project B =** 1.017.599.510,70€.
- **CBA (with updated values) of project B =** -876.691.676,77€.

5.3. Discussion

After identifying the projects and based on the cost analysis associated with each one, it is possible to conclude that, for the purposes of decision support, project B presents numerous benefits from a financial, economic, environmental and service quality point of view.

The benefits of choosing this project relate, in a first phase, to security issues in the supply infrastructure network, which, in turn, significantly reduces the likelihood of interruptions in the supply of public utility services. The guarantee that all the quality parameters of the supply network are safeguarded is another added value of this choice.

Choosing this project makes it possible to invest heavily in the frequent monitoring of maintenance indicators, through the implementation of prevention strategies for infrastructure. Monitoring and prevention are the key factors to be able to mitigate the impacts associated with the phenomenon of corrosion, as well as to increase the useful life of a gas pipeline, which reduces its amortization rate.

The focus on maintenance and prevention significantly reduces the likelihood of incidents that could cause environmental damage. The environmental concern is increasingly in evidence in society, prioritizing the approach of people to nature, so avoiding environmental damage caused by corrosion means that the company's efforts in this area are recognized by stakeholders. It is possible to conclude that there is a reduction in total net costs compared to project A.

To carry out the analysis, a perpetuity of the investment was considered, which, according to Jones et al. (2014), do not consider the effective value of an asset over time, attributing a constant economic value, without any time limit. In this sense, for project analysis, the perpetuity of the project elements after a period of 5 years was assumed.

Finally, the Cost-Benefit Ratio [CBR] was calculated, which is used to make a comparison between the monetary value of the benefits and the monetary value of the costs. We can see reflected the economic indicators calculated for each of the projects analyzed in Table 4:

Table 4 - *Obtained economic indicators of each project.*

KPI	Project A	Project B
Benefit	36.690.387,03€	14.023.878,5€
Cost	1.231.793.258,14€	1.017.599.510,70€
CBA	-880.357.911,77€	-876.691.676,77€
CBR	0,0298	0,0138
Residual Value	523.604.736 €	733.090.909,09 €

According to the results presented, it is possible to verify that in both projects the CBA presents negative results, that is, in any of the projects its execution does not present economic viability. This factor is also verified through the RCB, since in any of the projects, the ratio between the sum of benefits and the sum of costs, during the period of analysis, presents a value of less than 1. However, these values are expected since the monetary benefits associated with the transport and sale of natural gas business were not considered.

For the project analysis, the values related to the monetary flows were not considered, since the project does not analyze the IRR variation, not considering the annual returns arising from the implementation of the investment project in any of the years, being a factor that causes an impact on project costs, and, consequently, on their unfeasibility.

6 –Prospecting values

6.1. Number of annual incidents variation

During the analysis of the investment projects associated with the case study, one of the factors with a high degree of uncertainty is related to the annual variability associated with the number of occurrences resulting from the corrosion of gas pipelines. This factor is considered as a variable that presents a high degree of uncertainty given that, despite the decreasing trend in recent years, it presents the possibility of changing previously assumed assumptions that may occur in a given period of time. For the sensitivity analysis, the number of incidents was varied by 50% based on the average value of incidents considering the period of analysis (1970-2016), to verify the impact of project indicators on the if there is an average number of annual incidents according to the variation attributed in this sensitivity analysis. We can see reflected the obtained values in Table 5 and Table 6.

Table 5 - *Project A sensitivity analysis according to the number of incidents.*

Incidents	CBA	Total Cost	Benefits
44	-884.273.942,68€	1.236.914.942,38€	29.641.469,70€
29	-880.357.911,17€	1.231.793.258,14€	36.690.387,03€
15	-876.615.375,91€	1.226.898.483,96€	49.976.502,20€
0	-872.674.560,00€	1.221.744.384,00€	58.028.117,90€

Table 6 - *Project B sensitivity analysis according to the number of incidents.*

Incidents	CBA	Total Cost	Benefits
44	-877.278.363,43€	1.018.299.488,51€	21.172.438,4€
29	-877.079.465,39€	1.018.062.182,60€	14.023.878,5€
15	-876.890.574,77€	1.017.836.816,61€	7.193.200,05€
0	-876.691.676,77€	1.017.599.510,70€	0,00€

The variation of this parameter has an impact on project indicators that reflect the need for repair and replacement of a segment, as well as environmental costs in project B.

However, the history presented by the company indicates that the impact produced by incidents is not relevant when addressing issues such as causing interruptions, failures, damage to the image or property of users, so only environmental aspects (derived from small spills) should be considered. In this way, it is possible to verify that the 50% increase in the number of annual incidents causes an absolute increase in both the CBA and the total cost of project A compared to project B, being insufficient to present the feasibility of the project A.

If there is a 50% reduction in the number of annual incidents, the CBA value in project A is slightly lower than in project B. However, the cost associated with all projects for the period analysis is superior. Additionally, in the period between 1970 and 2016, only in 4 non-consecutive years there were records of less than 15 annual incidents across the entire length of gas pipelines, which allows us to conclude that this scenario, although possible, is highly optimistic.

In case there is no annual incident related to corrosion, the total cost of project A has a higher cost than project B. Additionally, the scenario of inexistence of any incident due to corrosion along the entire length of the gas pipelines presents extreme optimism, and it is not considered plausible to assess the feasibility of the projects in view of this scenario.

Thus, considering both indicators, the necessary conditions are not considered to be in place to verify the feasibility of project A, in this scenario.

6.2. Pipeline extension variation

This analysis was intended to assess the impact associated with the CBA and total costs of both projects, in the case of a variation of 500 km in 500 km in that segment, until the probability of an incident happening is greater than 1. We can see reflected the obtained values in Table 7 and Table 8.

Table 7 - *Project A sensitivity analysis according to the pipeline extension.*

Kms	CBA	Total Cost	Benefits
500	-440.037.257,68€	615.708.062,66€	18.345.193,52€
1.000	-880.357.911,17€	1.231.793.258,14€	36.690.387,03€
1.500	-1.320.960.307,85€	1.848.248.577,06€	55.035.580,5€
2.000	-1.761.770.090,89€	2.464.976.772,26€	73.380.774,06€
2.500	-2.202.812.045,90€	3.082.010.259,47€	91.725967,5€
3.000	-2.644.086.172,88€	3.699.349.038,67€	110.071.161,09€
3.500	-3.085.563.966,12€	4.316.955.801,65€	128.416.354,00€

Table 8 - *Project B sensitivity analysis according to the pipeline extension.*

Kms	CBA	Total Cost	Benefits
500	-440.037.257,68€	615.708.062,66€	18.345.193,52€
1.000	-880.357.911,17€	1.231.793.258,14€	36.690.387,03€
1.500	-1.320.960.307,85€	1.848.248.577,06€	55.035.580,5€
2.000	-1.761.770.090,89€	2.464.976.772,26€	73.380.774,06€
2.500	-2.202.812.045,90€	3.082.010.259,47€	91.725967,5€
3.000	-2.644.086.172,88€	3.699.349.038,67€	110.071.161,09€
3.500	-3.085.563.966,12€	4.316.955.801,65€	128.416.354,00€

Based on the values obtained, it is possible to verify that, as in the analysis of investment projects, the variation in the extension of the segment under study presents a negative CBA in any of the cases. However, in the analysis for each of the projects, it is possible to verify that in the case of project A, the increase in the length of the pipeline under analysis causes a proportional increase in the probability of an incident occurring, and the associated impacts are proportionally manifested through of the set of property, people, economic and environmental costs. In turn, the increase in the probability of the event plus the costs of repair or replacement of the segment, proportional to the weighting of costs referred to by REN (103.000€/1.000km), causes a negative increase in the value of the CBA and the total costs associated with the project A.

In the case of project B, the fact of varying the length of the gas pipeline under analysis, to assess the variability of economic viability indicators, proportionally increases the set of annuities related to preventive measures and operating costs associated with the investment project in said pipeline. In this analysis, when considering the fact of increasing the length of the gas pipeline, the investment project assumes the entire set of annual costs that allow for adequate protection of the infrastructures, preventing corrosion phenomena, as well as their frequent monitoring.

Thus, it is possible to conclude that in the case of the investment project related to the 500 km gas pipeline, the CBA difference between project A and project B registers a total of €1.691.419,29, while the difference between the costs total project registers a total of 106.908.307,31€. On the other hand, in the case of the investment project relating to the gas pipeline with a length of 3.500 km, the difference between the CBA of the projects registers a total of 17.143.097,42€ while the difference between the total costs of the projects registers a total of 755.357.514,20€.

Through this sensitivity analysis, it is possible to conclude that, as verified in the feasibility analysis of each of the projects, the alternative that does not consider the annual investment in infrastructure operational maintenance costs (project A) does not have any economic viability. In this sense, the development of this analysis allows, in a robust way, to conclude that the results obtained correspond to reality, since the fact of investing in annual maintenance costs allows to mitigate the susceptibility to corrosion phenomena. Thus, it is plausible to conclude that project B allows safeguarding interests, as it prevents interruptions in supply while mitigating environmental, economic and heritage impacts.

Since the parameters studied in the sensitivity analysis have a great influence on the analyzed model, project A is considered unfeasible, according to the results of the sensitivity analysis, and the scenarios that demonstrate better results are also highly unlikely. As such, project A would only show encouraging results in case the average number of incidents in the European pipeline network is nil during the analysis period, as well as in case the investment project presents a very short pipeline extension. However, both situations are optimistic scenarios, since the probability of non-existence of incidents arising from corrosive phenomena throughout the European network is very low, as well as in the case of the extension of the gas pipelines under analysis, since the feasibility only refers to a very short extension of gas pipelines, which, from REN's point of view, may not present an investment alternative.

7 – Conclusions

REN presented an investment project for the construction of a gas pipeline that registered one of the main initiatives to guarantee the specific needs of this business sector. In view of this initiative by REN, it was necessary to identify and determine the costs associated with the corrosion of a gas pipeline, throughout its lifetime. To guarantee the normal functioning of this infrastructure, it was also essential to measure and analyze the costs related to the preventive maintenance of the infrastructures. In this project, there was also a need to assess and mitigate possible impacts on the distribution network and its users and, for this purpose, a cost-benefit analysis was carried out in relation to the costs associated with the construction of a gas pipeline.

This study presented two distinct projects. Project A, which consisted in the construction of a gas pipeline based on an approach that neglected preventive maintenance practices for infrastructure. On the contrary, project B consisted in the construction of a gas pipeline considering the various types of costs associated with the maintenance and prevention of corrosion in REN's pipelines.

For project A, it was calculated that the set of costs of an occurrence has a total value of €653.469,65, given the probability of occurrence of 31% compared to the average of identified accidents, based on the set of assumptions made. that the largest associated cost of an accident is relative to economic costs.

For project B, after conducting an analysis with Engineer Carlos Sousa from REN, it was possible to determine the annual costs associated with the company's periodic maintenance practices.

Regarding the cost-benefit analysis, project B was chosen because it presented the most benefits at various levels (financial, economic, environmental and service quality). Some key points for this decision are highlighted: frequent monitoring of maintenance indicators, implementation of infrastructure prevention strategies, increase in the useful life of the gas pipeline and consequent reduction in the amortization rate, reduction in the probability of occurrences that cause environmental damage, mitigation of impacts associated with the phenomenon of corrosion and, finally, the reduction of total net costs compared to project A, because after the economic analysis, it was possible to conclude that the choice of project B, allows a reduction of 220.568.895,62€ compared to project A.

As for the limitations of this project, the main difficulty was related to the calculation of costs associated with impacts caused by corrosion. There is little information about the tangible costs associated with corrosion prevention and even less about the intangible costs. Faced with this complication, the conclusions of this project resulted from the assumptions made, which were also difficult to assume.

Also limiting this study was, for reasons of information security, the difficulty in obtaining data by the entity. The data provided were important, however reduced due to the needs of the problem in question.

As a suggestion for future research, it would be necessary to understand how maintenance work can be intensified more effectively and efficiently to prevent infrastructure corrosion, given that its impacts are astronomical if there is an occurrence.

Finally, it should be noted that the objective of this dissertation was achieved despite all the difficulties and limitations involved.

8 – References

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