Extended Abstract

Feasibility of capturing and converting industrial CO_2 in synthetic methane using Power-to-Gas

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1. Introduction

With the recent changes in the Earth's climate, especially the high level of CO_2 emissions (Jarraud & Steiner, 2014), it has become more necessary than ever to discover and develop processes to tackle this issue. One way to do so is by substituting natural gas with biomethane, which is already a reality, since 17% of all gas consumed by the road transport sector in Europe is composed with it (NGVA Europe, 2020). One other alternative is to produce synthetic methane by using a technology that has brought much research attention in the last few years: Power-to-Gas, namely through carbon capture. This synthetic methane also has the same applications as natural gas: for heating, industry and as a fuel for transportation (European Commission, 2016).

Therefore, the performed dissertation can be divided in two main sections: the first one, to provide a theoretical basis in order to discuss the feasibility of a possible implementation of Power-to-Gas in Portugal, by performing an economic-financial assessment; the second one, to present a specific case study regarding a Power-to-Gas implementation, with the main goals being the determination of all the technical flows related to the project, as well as performing an economic and financial analysis to assess its feasibility. Lastly, a sensitivity analysis on key variables which could affect the project was performed.

2. Power-to-Gas & case study presentation

Regarded as a long-term, large capacity energy storage solution, commercialized power-to-gas (PtG) technology has drawn much research attention in recent years (Liu et al., 2017). In PtG, as shown in figure 16, the hydrogen is acquired from an electrolysis plant, which uses excess electrical energy to split water into hydrogen and oxygen. After that, the hydrogen and captured CO_2 (that would be normally released to atmosphere) are fed into a methanation reactor. Finally, the gas Is sent to the gas distribution grid and is ready to be used. A diagram of this process is shown in figure 1 below.

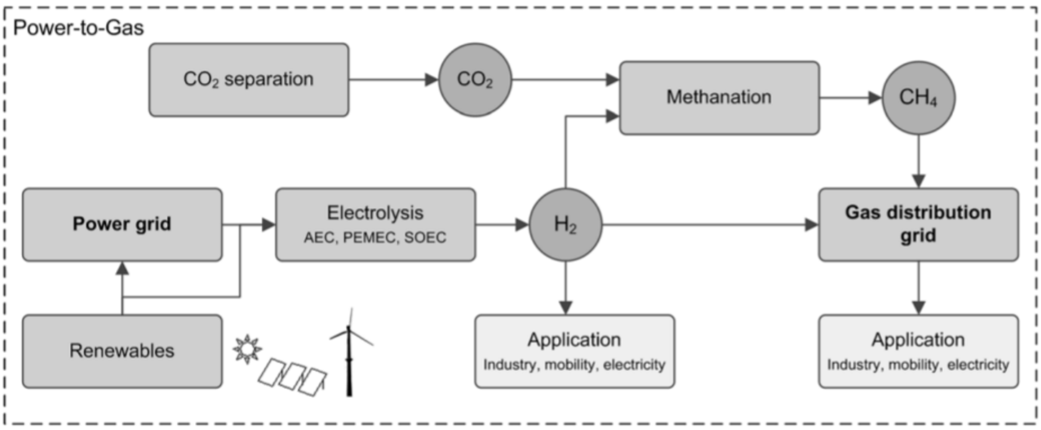

Figure 1 - Main process steps in a power-to-gas system. (Source: Reiter, 2016*)*

In the specific analysed case study, the implementation was based on the installation of photovoltaic panels and an electrolyser with 5 and 2.5 MW power, respectively. In order to determine the technical flows of the project, the energy produced by the photovoltaic panels was determined, followed by all the flows produced regarding electrolysis and methanation, based the stoichiometry of the reactions.

For the economic and financial analysis, the CAPEX was projected to be of 11.2 M€ and the OPEX was estimated to be 3% of this value, 0.336 M€. Depreciation was defined to be of 12.5% and the rate of return for this project was of 4%. Solely for the financial analysis, a 70% reimbursement of CAPEX was considered, becoming of 3.36 M€, and a 10-year loan with a 2 grace year period and with a yearly interest tax rate of 1.7% was contemplated. The tax was of 23%. Production was set to start only in year 3 of the project.

To evaluate a project, Blank & Tarquin (2017) defined several criteria that can be used to measure worth when evaluating a project. The most important ones for this study are present worth (PW), future worth (FW) and annual worth (AW) analysis. The LCC analysis mostly uses the AW method, especially when only one alternative is studied. However, if there are expected revenues or other benefits, the PW analysis is the recommended one. In addition to the mentioned metrics, rate of return (ROR) and payback time analysis may be used together with the previous ones, to provide a more complete analysis.

LCC analysis has been used to evaluate different types of projects throughout the years, and projects related with renewable energy are no different, which is why and LCC analysis is going to be analysed in this specific case study. The measures of worth which are hereafter going to be presented were also presented by Owens (2002) for the United States Agency International Development (USAID) regarding “Economic & Financial Evaluation of Renewable Energy Projects”. These metrics were used, for example, by Jun et al. (2011) regarding “Gas Power Generation Projects Considering Carbon Emission Reduction” or Espinoza & Rojo (2015), concerning a case study evaluation of a solar project. In terms of actual PtG projects in Portugal, there are no references which can be used, since there is no project of this kind in the country.

3. Results

3.1. Technical implementation and Revenues

Regarding its technical implementation, this project can be split in four main areas:

- The production of solar renewable electricity, resulting in the production of 10.18 GWh/year of electricity. Of those, 76% can be used for the production of green hydrogen, whereas the remaining 24% are to be utilized for the factory’s self-consumption.

- The production of green hydrogen through water electrolysis. With the produced electricity, the expectation for the production of H_2 is of about 154.96 tons, which corresponds to a necessity of around 1395.81 tons of water and a production of 1239.67 tons of O_2.

- The capture of 852.47 tons of CO_2, which is the annual amount of CO_2 captured from the steam boilers in this industrial unit.

- The production of 310.69 tons of synthetic methane and 697.90 tons of water, as well as 882.40 MWh/year of heat.

As expected, since all the project is based on the electricity dependency, months with more radiation correspond to periods of higher production, which occurs in Spring and Summer. Generally, around 2/3 of the production occurs in the months between March and September. These production flows allowed for the estimation of annual revenues for this project, with the creation of 2 base alternatives:

- The use of the produced CH_4 for this industrial unit's process, which includes 3 different sources of revenue: steam to be used in the process (30% of total revenues), saved money from certificates which no longer have to be paid (5% of total revenues) and the selling of electricity which was produced but not used for electrolysis (65% of total revenues). This income is estimated to be of ~0.470 M€/year.

- The use of CH_4 as a fuel for mobility, namely in NGV vehicles. In this case, there are now 5 different sources of income: steam to be used in the process (4% of total revenues), certificates which no longer have to be paid (4% of total revenues), electricity which was not used in electrolysis being sold (54% of total revenues), the synthetic CH_4 being sold as fuel for vehicles (34% of total revenues) and the tax which does not have to be paid (4% of total revenues). This income is estimated to be of ~0.568 M€/year.

3.2. Economic and financial analysis

Regarding the economic analysis. the cumulative cashflows for base alternatives 1 and 2 are presented in figures 2 and 3, respectively.

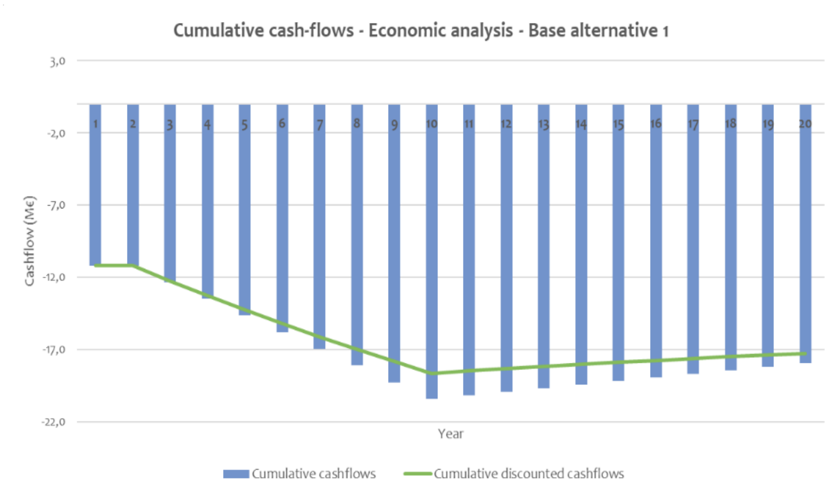

Figure 2 – Cumulative cash-flows – Economic analysis – Base alternative 1

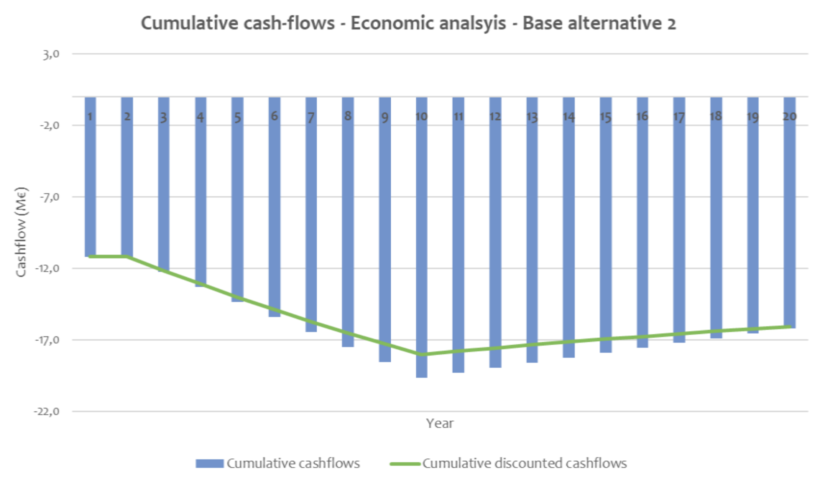

Figure 3 - Cumulative cash-flows – Economic analysis – Base alternative 2

The results for a 20-year economic analysis are presented in table 1 and show that the PW/NPV of this project is < 0 for both alternatives, which means this project is not feasible from an economic perspective for a 20-year period.

Table 1 - 20-year economic feasibility analysis - base alternatives

Parameter	Alternative 1		Alternative 2	
	Value	Unit	Value	Unit
PW/NPV @4%	-17.27	M€	-16.01	M€

For the financial analysis. the cumulative cashflows for base alternatives 1 and 2 are presented in figures 4 and 5, respectively.

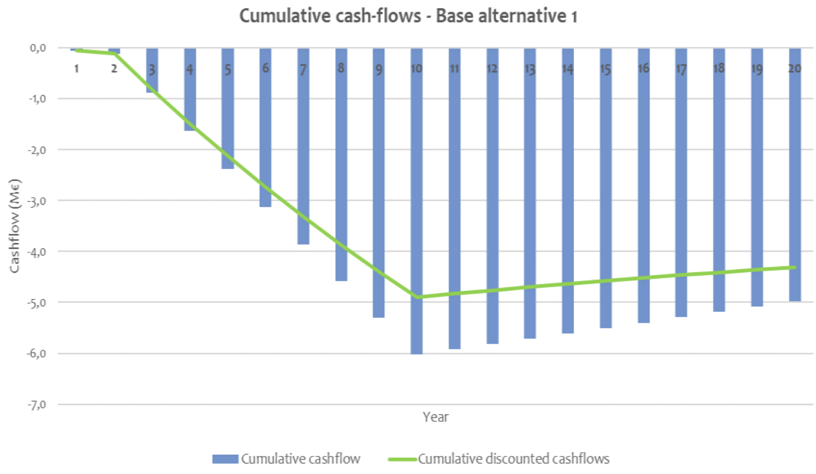

Figure 4 - Cumulative cash-flows – Financial analysis – Base alternative 1

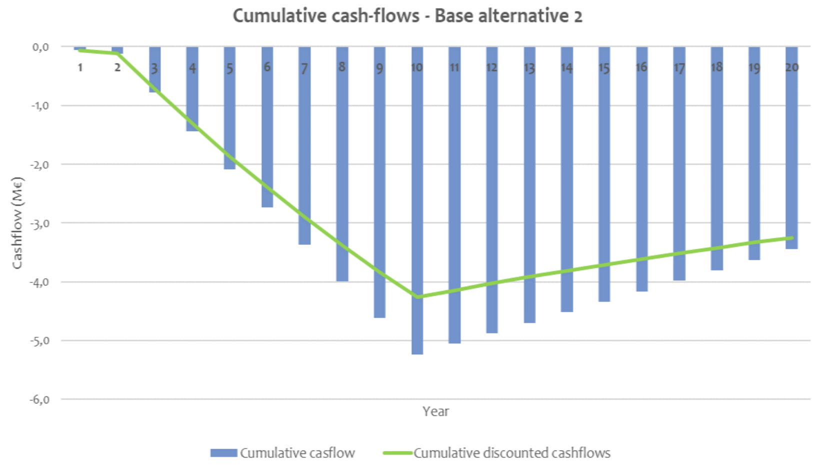

Figure 5 – Cumulative cash-flows – Financial analysis – Base alternative 2

The financial indicators for both base alternatives are shown in table 2. As it is possible to observe, the resulting PW/NPV of the project is negative for both alternatives, meaning that the project is not feasible in any of the base alternatives.

Table 2 - 20-year financial feasibility analysis - base alternatives

Parameter	Alternative 1		Alternative 2	
	Value	Unit	Value	Unit
PW/NPV @4%	-4.309	M€	-3.248	M€

3.3. Sensitivity analysis

The next step was to perform a sensitivity analysis. In order to do so, 4 main variables were defined to be varied: price of CO_2 emissions, synthetic methane selling price, electricity price and CAPEX. This analysis was executed in 3 different dimensions:

- KPIs research – in this first case, each one of the variables was varied individually, in order to determine its impact on the feasibility results. All the variables were subject to variations, with results showing that this project is never feasible economical and financially in both alternatives, by varying 1 single variable.
- Best case alternatives – In this alternative, all the variables were varied to the value that would most benefit the results, within the ranged presented for KPI research. Once again, results showed that even when assuming the best possible values for all variables within the defined ranges, this project does not become feasible.
- Later start & lower CAPEX – This alternative was analysed in order to provide an overview on what would happen if the project is set to start 5 years later, but with a CAPEX (and consequently OPEX) reduction of 35%, due to the evolution of technologies, which are expected to result in a price decrease in the next years. In this alternative, the results remained the same, i.e., determining a non-feasibility for this project.

It is possible to observe from the performed analysis that this project is never feasible in any of the described alternatives, mainly due to the high CAPEX involved to install all the necessary equipment, which generates low annual revenues, especially because of the fact that there are currently no incentives to turn this synthetic methane into a more profitable product. This, along with the current low price for CO_2 emissions, explains the fact that even though production of electricity is not the main goal of this project, it has, by far, the highest impact on total revenues.

In order to search for a solution that can turn this project feasible, it was considered that CAPEX, electricity price and methane selling price would not be changing from the base alternatives. On the other hand, CO_2 annual growth could be subject to change and a feed-in tariff could be created, in order to value synthetic methane's production. Results showed that in most cases, this feed-in tariff has to be valued between 60 and 70 €/MWh in order for the project to be profitable. The breakeven points found for this tariff for specific increase on the price of CO_2 emission were the following: 72.10 €/MWh with no CO_2 tax annual increase; 68.44 €/MWh with a 5% increase; 64.97 €/MWh with an 8% increase; 61.88 €/MWh with a 10% increase.

Besides CO_2 annual increase, CAPEX is also an extremely important variable on this project's feasibility. Therefore, considering a 5% annual increase on CO2 emission tax, it was also possible to estimate the necessary values for feed-in tariffs. In this case, if: a 10% decrease in CAPEX the feed-in tariffs need to be valued between 45 and 50 €/MWh. However, if a 15% reduction occurs, this feed-in tariff would need to be between 35 and 40 €/MWh. If CAPEX can be decreased in at least 20%, feed-in tariffs below 30 €/MWh would also turn the project into a feasible one.

At the time being, there are currently no funding schemes and benefits apart from certain aid regarding initial investment for the production of renewable gases or carbon capture. However, and as expected, PtG projects can only become feasible through government policies which can allow for these renewable gases to be competitive with fossil fuels. One way to do so is through the creation of feed-in tariffs and the increase of CO_2 emission tax. However, and even though these possibilities were not presented for this specific case study, tax incentives and green certificates with monetary value can also help in the development of production of synthetic methane through PtG.

4. Conclusions

Several conclusions can be drawn regarding the implementation of the Power-to-Gas technology throughout this dissertation. The first and more obvious one is the fact that this technology is clearly far from being competitive when comparing to what already exists in today's world: fossil natural gas. Results showed that the production of synthetic methane requires an extremely high CAPEX, but the annual revenues generated by that production are extremely low in comparison.

The second conclusion achieved from the analysis conducted is the fact that there are 3 key points which are essential when discussing the feasibility of PtG:

- the first one being cost of technologies, which is currently extremely high, and can only realistically decrease with a global support for R&D into its development;
- secondly, the cost of CO_2 emissions, which is extremely important in order to punish the current production of fossil fuels, needs to keep its tendency of grow in the following decades;
- thirdly, the production of synthetic methane must be valued when comparing to the current fossil fuels price, since it contributes for the decarbonisation of society, namely industry and transportation, if used as a fuel for mobility. This last point could be achieved with tax exemptions and the creation of feed-in tariffs or green-certificates with monetary value.

As the worlds progresses, so does Energy: prior to the industrial revolution, energy sources were extremely scarce: for heat, sun, wood and straw; for transportation, horses and wind; for work, animals. Industrial revolution allowed mankind to start using coal and, shortly after, petroleum and natural gas, followed by nuclear and renewable energies in the 20^{th} century.

In recent years, the production of electricity using renewable sources (solar, wind, hydro, tidal, geothermal and biomass) has suffered significant advances. In addition to these, the production of renewable gases, namely green hydrogen, biomethane and synthetic methane can contribute decisively for a successful energy transition to a decarbonised society.

Regarding renewable gases, in which synthetic methane, which was the focus of this dissertation, is included, its production is highly dependent on Governmental support and a global cooperation into the development of more efficient and cheap technologies. However, one thing is certain: this is the path for a more sustainable future and to leave a better world for current and future generations.

5. References

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