Chemical **L**ooping G**a**sification fo**r** Sustain**a**ble Production of Biofuels

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1. Introduction

The present report discusses the economic risk of investing in a Chemical Looping Gasification, CLG, plant to produce biofuel from biomass feedstock (i.e. pelletised forest residues and wheat straw). The technical characteristics of the plant under analysis are described in deliverable reports D1.3, D1.4, D1.5 and D1.6 [1]. The aim is to determine the likelihood of loss on the investment, helping investors to understand the economic feasibility of the plant, the main factors affecting it and possible mitigation strategies. To carry out the economic risk assessment for the full process chain, the software @Risk 8 [2] was used, which is based on the Monte Carlo simulation [3].

The main types of economic risks within the present assessment are identified as follows:

- Risk on the project capital cost estimating
- Risk on Net Present Value and Internal Rate of Return coming from uncertainties in:
  - ✓ Supply cost for feedstock
  - ✓ Fisher Tropsch products selling price (i.e. naphtha, biodiesel and wax)
  - ✓ Oxygen carrier cost
  - ✓ Purchasing electricity price
  - ✓ Carbon tax/credits price

2. Risk on the Project Capital Cost Estimating

When the base cost of each component for a project is estimated, there is always uncertainty as to the accurate content of all items in the estimate. These uncertainties are risks to project execution. To cover the uncertainty inherent in cost and time, a contingency reserve is necessary to be added to the original cost estimate, guaranteeing that the budget is not exceeded at the end of the project. It is worth noting that the contingency reserve calculated excludes some items, such as project scope changes, extraordinary events, currency effects and profit.

For the estimation of the capital contingency, a range and distribution are set for each cost component. The individual ranges and distributions are then combined to give the overall range and distribution for the project. Monte Carlo simulation adds together the costs for each of the sections to get the total project cost. The procedure is repeated many times (50,000 for the present analysis) and in each iteration, new individual costs are allocated in accordance with the specified range and distribution for that section. When all the iterations are complete, the total costs from each iteration are plotted on a histogram to show the probability that the capital cost meets the expected value.

Deliverable D7.2 [4] sets the most likely cost of each component for the CLARA Biomass To Liquid, BTL, plant. For the Monte Carlo simulation, we assumed that the cost of each component varies according to a predefined distribution. The more common distributions used are the Triangular and the Pert distribution. The literature suggests that the use of Triangular distribution is generally more conservative since the probability of extreme events is higher [5]. Figure 1 shows the triangular distribution compared to the Pert distribution for one of the items considered in the contingency analysis. The Triangular distribution tends to have tails that are fatter than the Pert. However, it is worth noting that the impact on the result coming from choosing either the Triangular or the Pert distribution is limited if we consider a high number of risk factors, as in the present case. Values vary between a low value, the most likely value (value defined by D7.2) and a high value. It is assumed that there is a zero-risk probability of the cost being lower than the lowest cost value or higher than the highest value, and it is assumed that the maximum probability is at the most likely value.

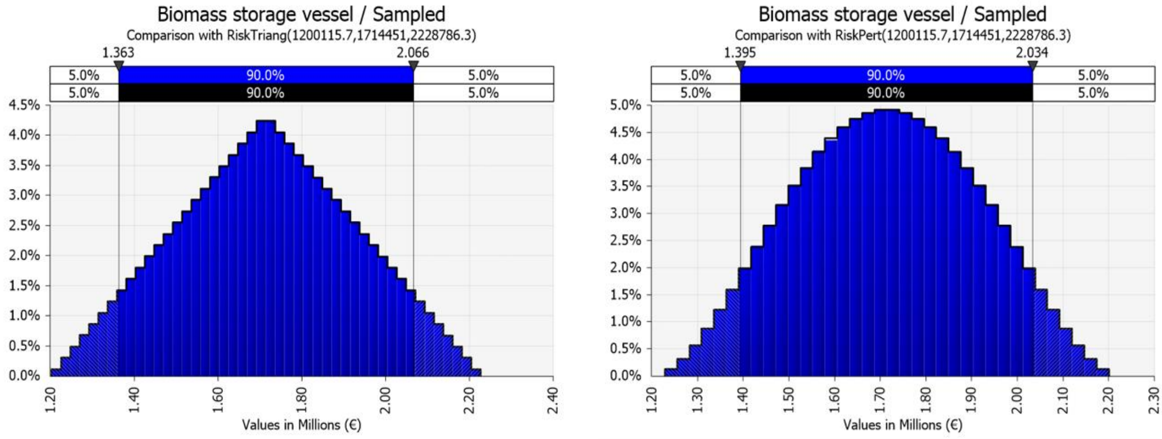

Figure 1. Comparison between Triangular and Pert distribution for one of components of the BTL plant

To define the extreme values for the Triangular distribution, we used a different percentage variation of the most likely value (derived from D7.2), based on the maturity, characteristics of the specific component and on the operating risk discussed by D6.1 [6]. We defined a variation between 80% and 180% of the most likely value, for the riskiest and novel components (e.g. fuel reactor, air reactor, gas cleaning and compression), a variation between 70% and 150% for the components that are carrying a mild operating technical risk (e.g. biomass handling components, COS Hydrolysis and amine scrubber and stripper) while, for the more common components without critical technical operating risk, we assumed a range between 70% to 130%.

As previously mentioned, a value of 50,000 simulations has been set for assessing the result. Figure 2 shows that there is a probability of 98% in overrunning the set budget, that is of 193 M€.

Figure 2 also shows the cumulative distribution. To have a 95% probability of not overrunning the budget, a reserve (contingency budget) of 26 million euros is needed, which represents 14% of the budget. For the calculation of the NPV and IRR, therefore, a contingency of 15% has been considered.

Figure 3 shows the influence of different components on the risk of capital estimating (without the CCS option). The fuel reactor and the air reactor, have together an influence of about 50%, being the two key components of the gasification unit with the highest cost and highest risks.

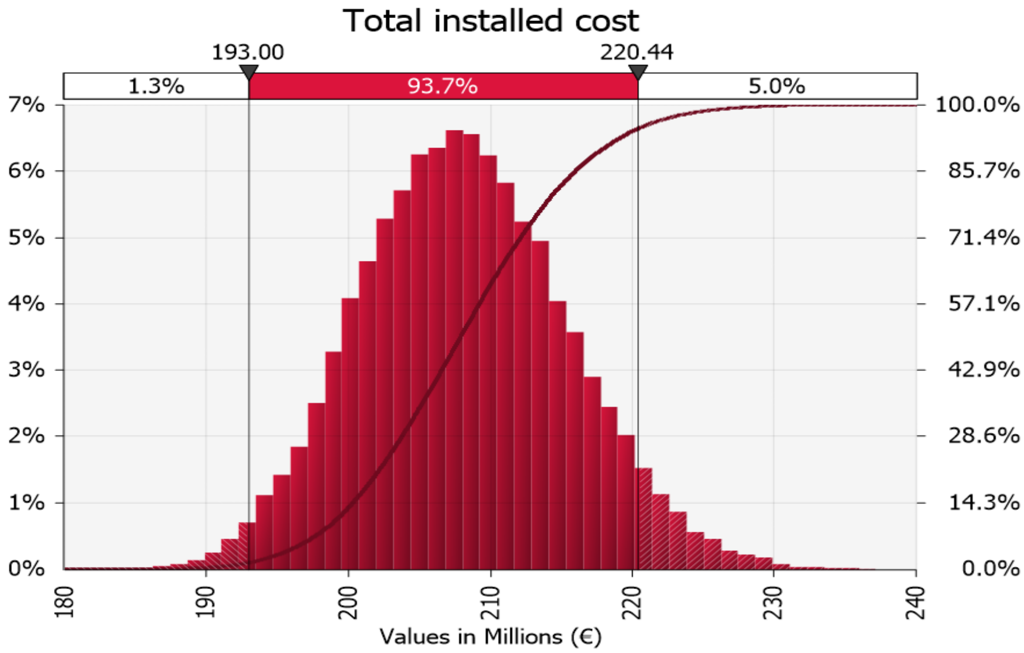

Figure 2. Risk on the total installed cost estimation

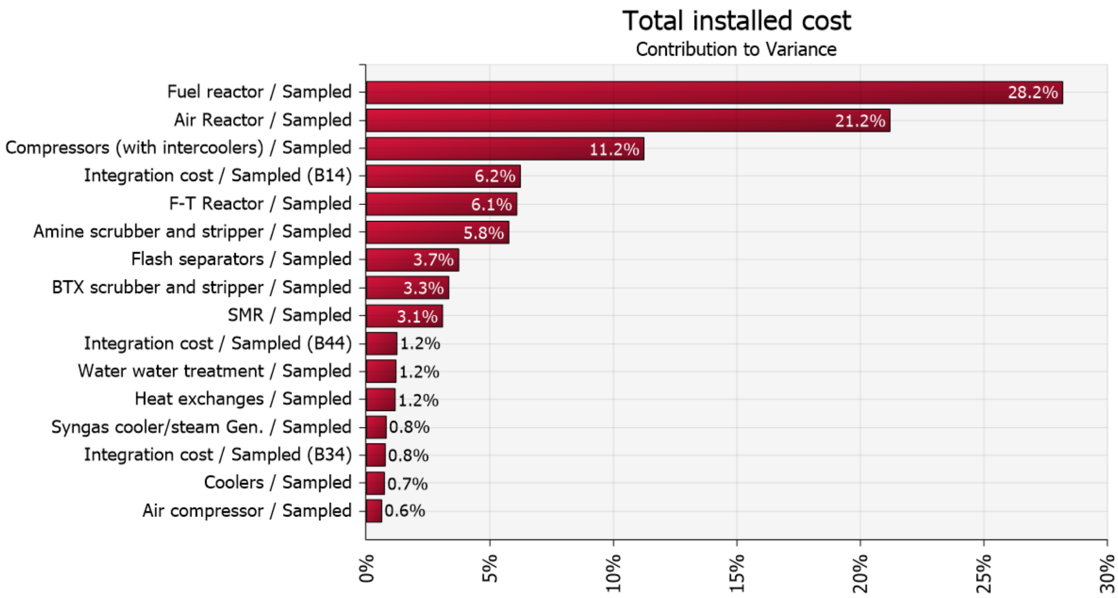

Figure 3. Main variations on the capital cost estimation

In the following analysis, we will also consider the additional cost coming from adding a capture and energy storage system, i.e., CCS, to the CLARA BTL plant. Therefore, a contingency analysis has been done for the specific case. The cost of the capture and storage system has been assumed to be 10M€ and to vary between 70% and 150% to define the extreme values of the Triangular distribution. The result with the CCS option is shown in Figure 4.

There is a probability of 99% in overrunning the set budget, which is 203 M€. As for the previous case, the fuel reactor and the air reactor are responsible for 45% of the variation of the total installation cost estimation. Figure 4 also shows the cumulative distribution. To have a 95% probability of not overrunning the budget, a reserve (contingency budget) of 29 million euros is needed, which represents 14% of the budget. For the calculation of the NPV and IRR, as in the previous case, a contingency of 15% has been considered.

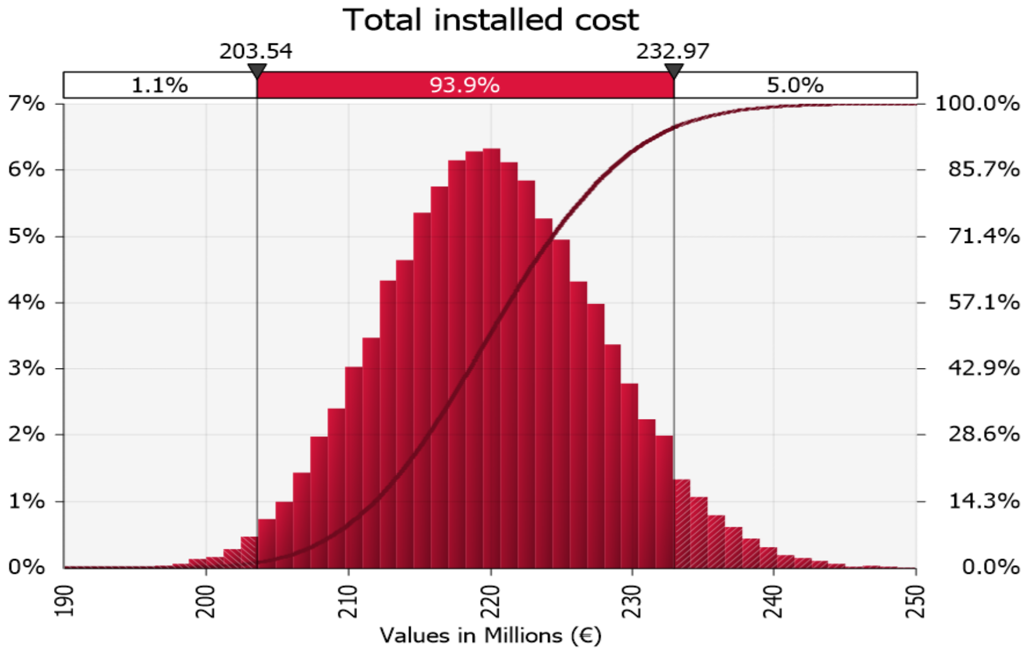

Figure 4 Risk on the total installed cost estimation

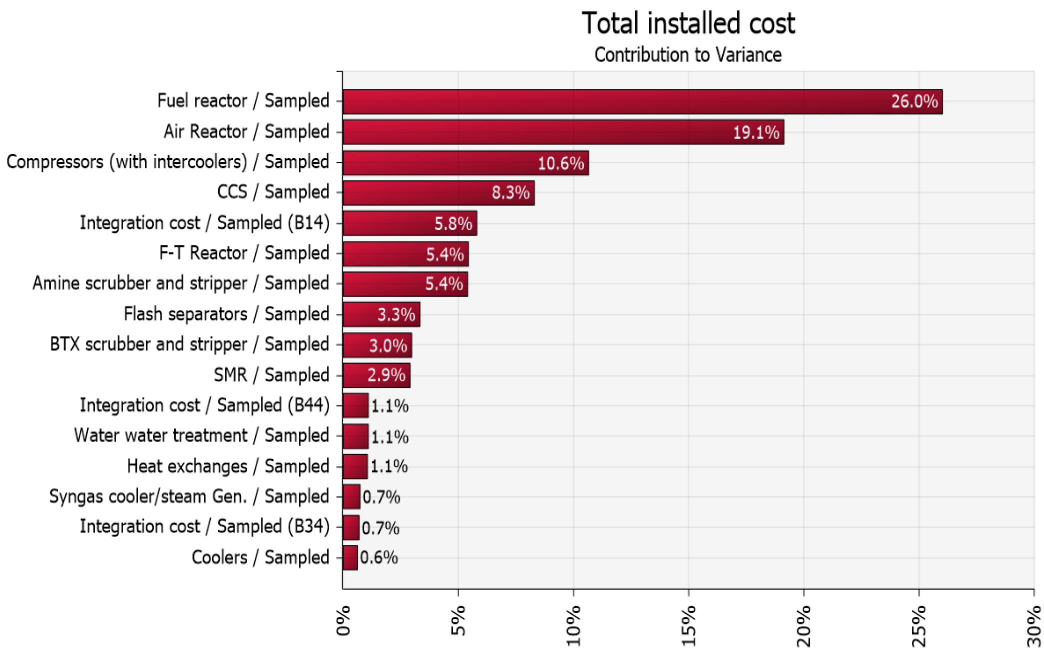

Figure 5. Main variations on the capital cost estimation

3. Risk on the Net Present Value and Internal Rate of Return

The following risks have been considered:

- ✓ supply cost for feedstocks
- ✓ FT products selling price (i.e. naphtha, biodiesel and wax)

- ✓ oxygen carrier cost
- ✓ purchasing electricity price
- ✓ carbon tax/credit

As discussed in D7.3, the BTL plant is eligible for carbon credits only considering adding a carbon and capture storage system to the plant, with an increase of 10 M€ in the capital cost, and a reserve budget of 29 M€.

Therefore, three different cases will be analysed:

- *Case 1.* The system is **without CCS**. We assume that the CO_2 biogenic emission is not all subject to the carbon tax levy, as it is currently widely accepted [7] but only the indirect CO_2 coming from using electricity is subject to the carbon tax levy.
- *Case 2.* The system is equipped **with a CCS** system and carbon credits can be sold.
- Case 3. The system is equipped **with a CCS** system and can sell the excess heat to a nearby site in addition to the carbon credits.

Deliverable 7.3 discussed an additional case when the CO_2 biogenic emission is all subjected to a carbon tax levy. However, being this scenario extremely unfavourable for the investment, it was not considered in the risk assessment.

Table 1 shows the range of variation of the different uncertainties considered. A triangular distribution has been considered for the assessed parameters, for a more conservative estimation.

For the supply cost of the feedstock, D7.1 suggests a variation between 64.7 €/tonnes and 86.6 €/tonnes for the wheat straw and 88.5 €/tonnes and 130.6 €/tonnes for the pelletised forest residues, which is about plus minus the 16% of the central value. Considering the future forecasted reduction in biomass availability [8] and the recent volatility of the waste price (SRF variation), a variation of plus minus 30% of the central value defined by D7.1 has been considered [9].

Naphtha prices are highly correlated with crude oil. In order to understand the price variation, we looked at the commodity market, over the counter and contract for difference for naphtha, which has been available online for the last 5-10 years, and some historical data from the previous years for the EU [10]. We have assumed a maximum price of 1203 €/tonnes, and a minimum price of 680 €/tonnes, considering that the price in the EU is, in general, higher than the price in the Asian markets. Furthermore, recently, the naphtha price in the EU has seen an important increase due to the geopolitical situation with Russia, where 50% of the naphtha comes from.

For paraffin wax, we looked at the price trend in the EU, US and Asian markets (chemanalyst n.d.), and we identified a range of variation between 714€/tonnes and 2,500 €/tonnes [11][12].

For the biodiesel, considering the data shown in *(the IEA report, 2021)* and the 2022 market price a price range between 689 €/tonnes to 2600 €/tonnes was selected [13, 14]. The oxygen carrier (ilmenite) cost has been assumed to vary between 100 €/tonnes to 400 €/tonnes, based both on the historical trend from 2011 to 2020 and the more recent values [15].

Regarding electricity prices, the assessment of electricity price variation over the lifespan of the project (2020-2045) is particularly challenging, as suggested by (Gabrielli et. al.) [16]. The reasons are the difficulty in analysing the variation in an extensive time horizon for a commodity that has a very small-time resolution, and the impacts of events that have not been observed in the past but may deeply influence the future cost of electricity, especially now that the energy system is moving towards a net zero emission energy system. (Gabrielli et. al.*)* proposed a new methodology, providing, for a timeframe from 2020 to 2035, a variation of the electricity price considering different scenarios of existing and baseline policies [16].

The stochastic analysis shows a variation between 40 €/MWh and 140€/MWh for the timeframe. The UK Department of Business, Energy, and Industrial Strategy (BEISS) published an updated about energy and emissions projections in 2020 [17]. In the report, in the high price scenario, the maximum value of the electricity price for industry in the analysed interval between 2001 and 2040 is 13.5p/kWh, which is translated into a maximum price of 148€/MWh. We have therefore considered a variation in the electricity price between 40€/MWh and 150€/MWh for the project lifespan (Table 2).

For the carbon tax, a variation between 30 €/tonnes and 120 €/tonnes has been assumed, which are the benchmarks identified in the Effective Carbon Rates 2021 report, which measures the carbon prices for CO_2 emissions in 44 OECD and G20 countries [18]. A similar variation has been attributed to carbon credits. It is worth noting that EU markets have already shown peak prices of 98 €/tonnes of CO_2 [19].

Table 1. Definition of the range of variation of the different uncertainties considered

Prices	Low	Most likely	High
Supply cost for wheat straw [€/tonnes]	65	77	100
Supply cost for forest residues [€/tonnes]	89	110	143
Naphtha price [€/tonnes]	681	700	1200
Wax price [€/tonnes]	700	1800	2500
Biodiesel price [€/tonnes]	688	1500	2600
Oxygen carrier cost [€/tonnes]	100	300	400
Purchasing electricity price [€/MWh]	40	80	150
CO_2 carbon tax [€/tonnes]	30	50	120
CO_2 carbon credits [€/tonnes]	30	50	120

3.1 CASE 1. BTL plant without CCS

Case 1 considers that there is no possibility of selling the carbon credits since no CCS has been considered for the plant. A carbon tax is paid for the indirect CO_2 emissions linked to the electricity used.

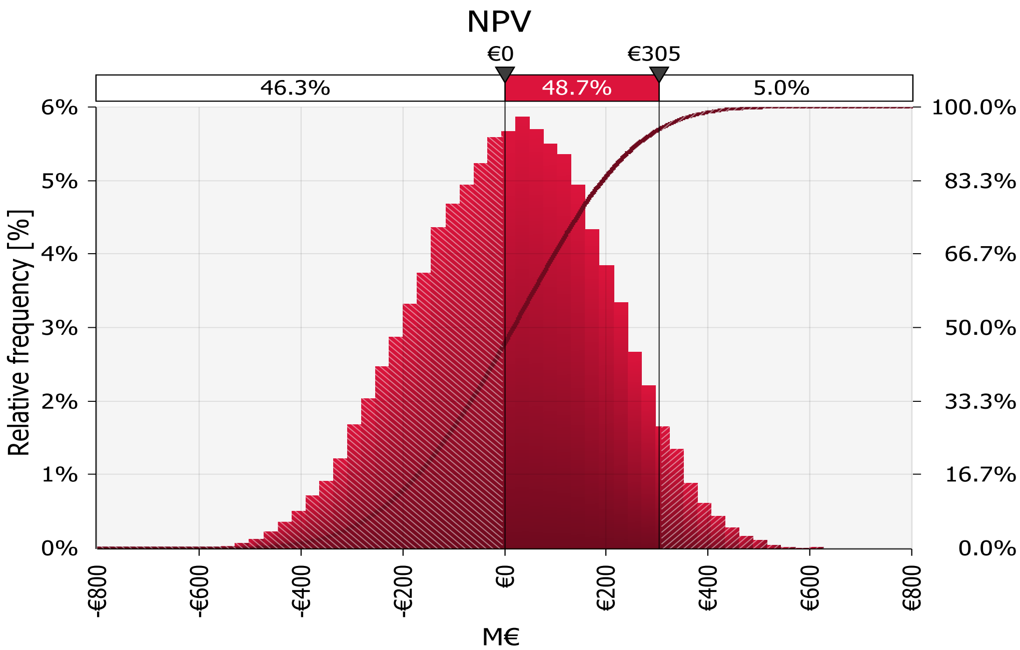

Figure 7. Distribution of the estimated NPV for PFR CASE 1 (BTL without CCS)

For PFR, the probability of having a negative NPV is 46.3% (Fig.7), with a probability of 41.8% having an IRR below 6% (Fig.8), being 6% the discount rate considered for the investment. In this case, the main factors affecting the NPV are the prices of wax and biodiesel price, having an influence of 91%. The variation of the feedstock price has a lower influence, of about 5%. Minimal is the influence of the variation in electricity price, Ilmenite, and the carbon tax.

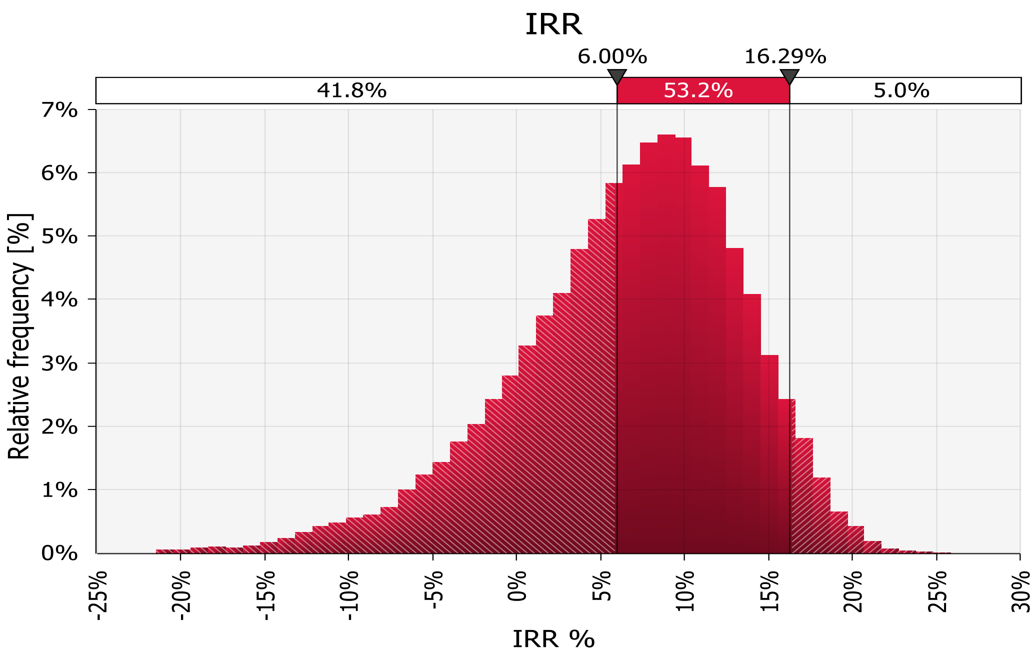

Figure 8. Distribution of the estimated IRR for PFR CASE 1 (BTL without CCS)

For wheat straw, for Case 1, we found a similar result; there is a 45.2% probability of having a negative NPV (Fig.9), and variations in wax and biodiesel price are the main parameters (92.5%) affecting the NPV. There is a probability of 42.1% having an IRR lower than 6% (Fig.10), which is the discount rate used in the estimation of the investment. The small differences are mainly due to a lower feedstock cost, but a slightly lower production of wax and biodiesel.

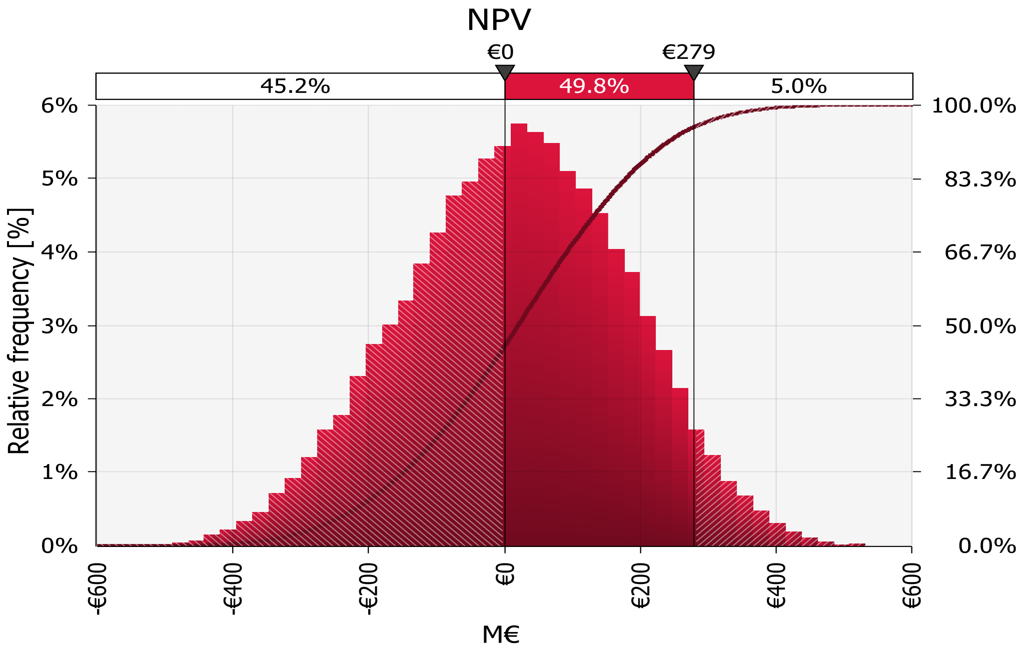

Figure 9. Distribution of the estimated NPV for WS Case 1 (BTL without CCS)

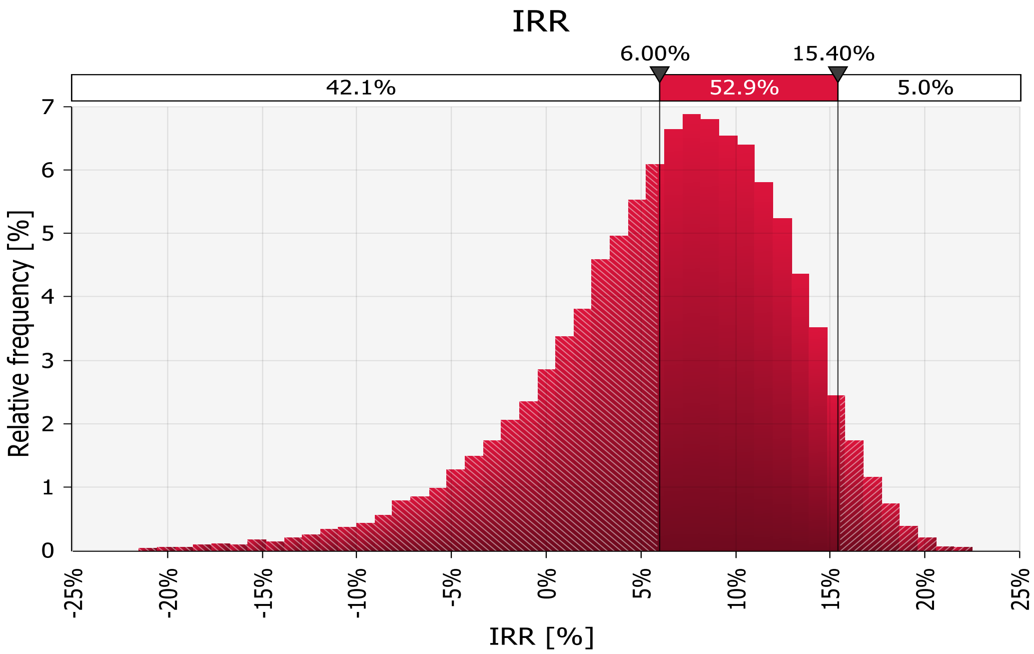

Figure 10. Distribution of the estimated IRR for WS Case 1 (BTL without CCS)

3.2 CASE 2. BTL plant with CCS

Case 2 considers adding a CCS system to the CLARA BTL plant. As a result, an additional 10 million have been considered for the investment with a 15% contingency. In this case, the CO_2 captured, minus the one coming from the electricity used can be sold to the grid, as explained in Deliverable 7.3 [20].

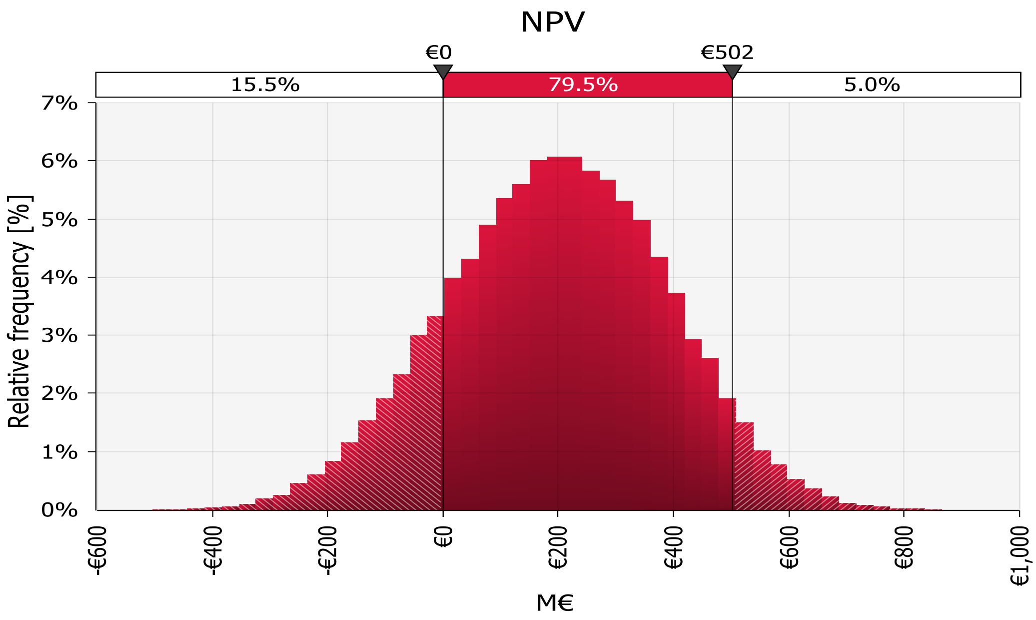

Figure 11. Distribution of the estimated NPV for PFR CASE 2 (BTL with CCS)

For the forest residue, for Case 2, the revenues coming from selling the carbon credits, reduce the risk of a negative NPV to 15.5% (Figure 11) and the risk of having an IRR below 6% to 15% (Fig. 12). Wax and biodiesel price are still the two main parameters affecting the NPV (85%), followed by the value of the carbon credits (7%).

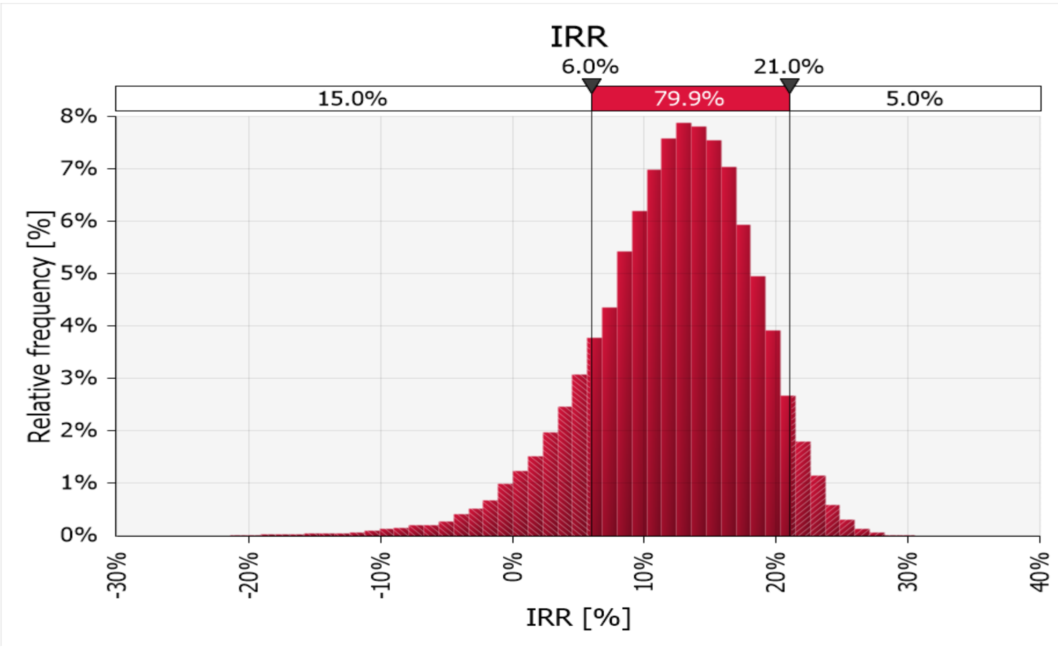

Figure 12. Distribution of the estimated IRR for PFR CASE 2 (BTL with CCS)

Similar results can be observed for Case 2 with wheat straw, with a risk of 12.9% of having a negative NPV (Fig.13) and a 12.8% of having an IRR below 6% (Fig.14). The two parameters affecting the NPV are the wax price and the biodiesel cost (83.5%), followed by the feedstock price (9.6%).

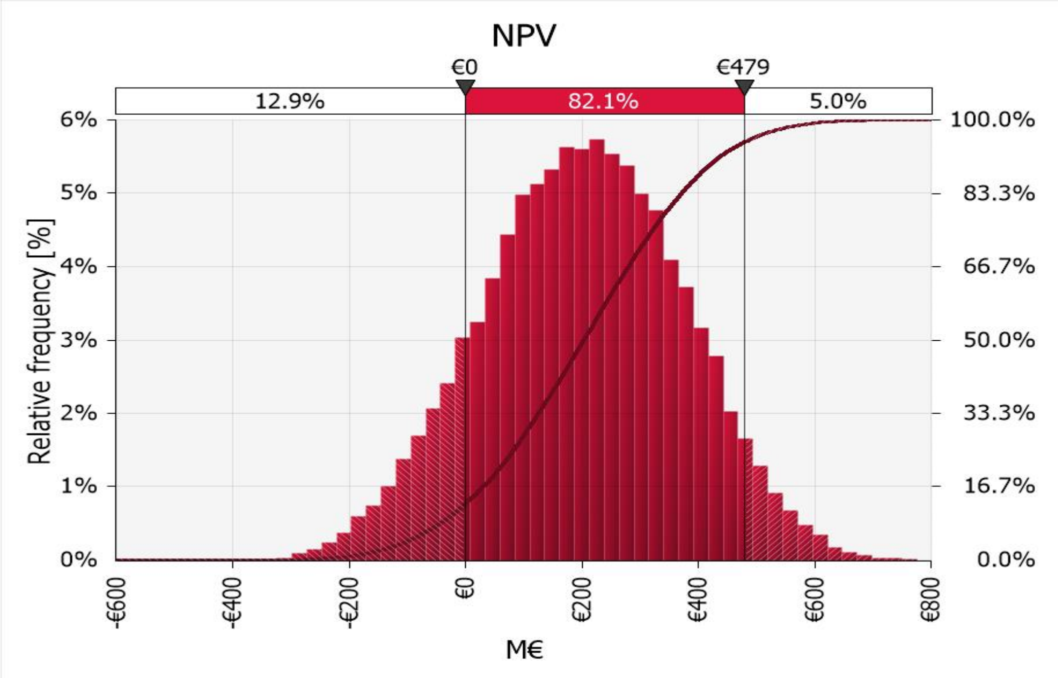

Figure 13. Distribution of the estimated NPV for WS CASE 2 (BTL with CCS)

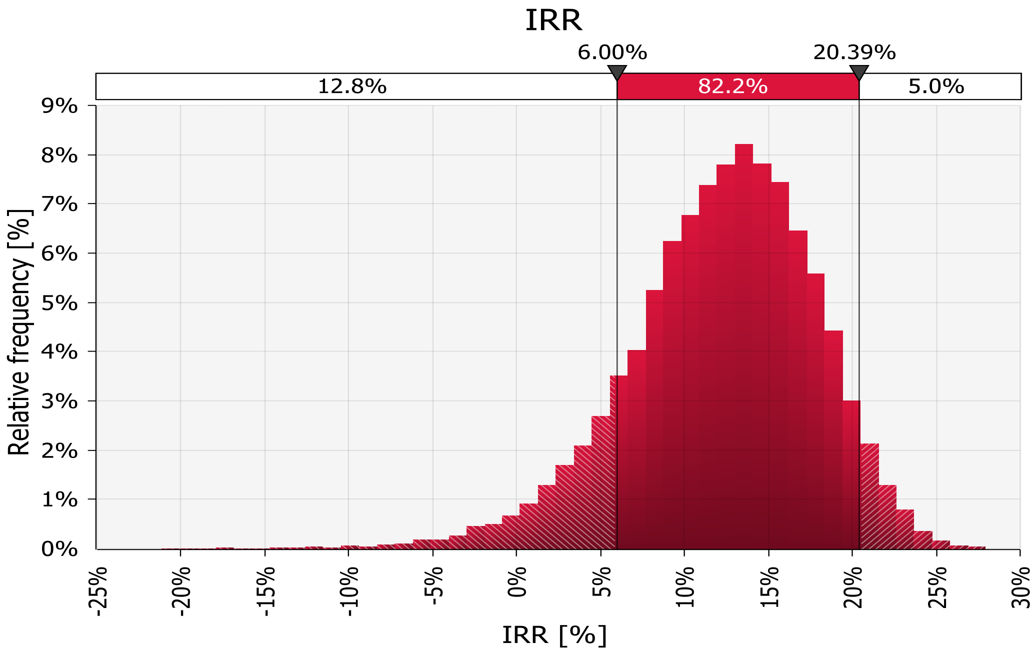

Figure 14. Distribution of the estimated IRR for WS CASE 2 (BTL with CCS)

3.3 CASE 3. BTL with CCS and the possibility of selling the excess heat

For Case 3, we have assumed, in line with Deliverable 7.3, to have a CCS system and to have the possibility to sell the excess heat of 61 GJ to a nearby end user.

For the forest residue, for Case 3, the risk of having a negative NPV further reduces to 7.3% (Fig.15) with a risk of having an IRR lower than 6% being 7.3% (Fig.16). Key parameters affecting the NPV and the wax and biodiesel price (87.7%), followed by the carbon credits (8.4%).

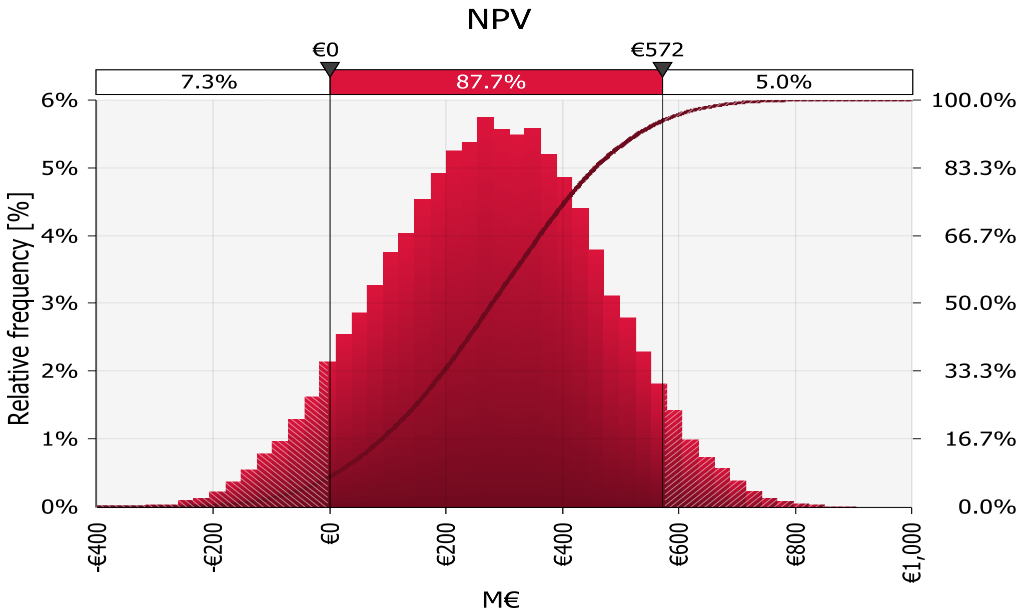

Figure 15. Distribution of the estimated NPV for PFR CASE 3 (including CCS and heat selling)

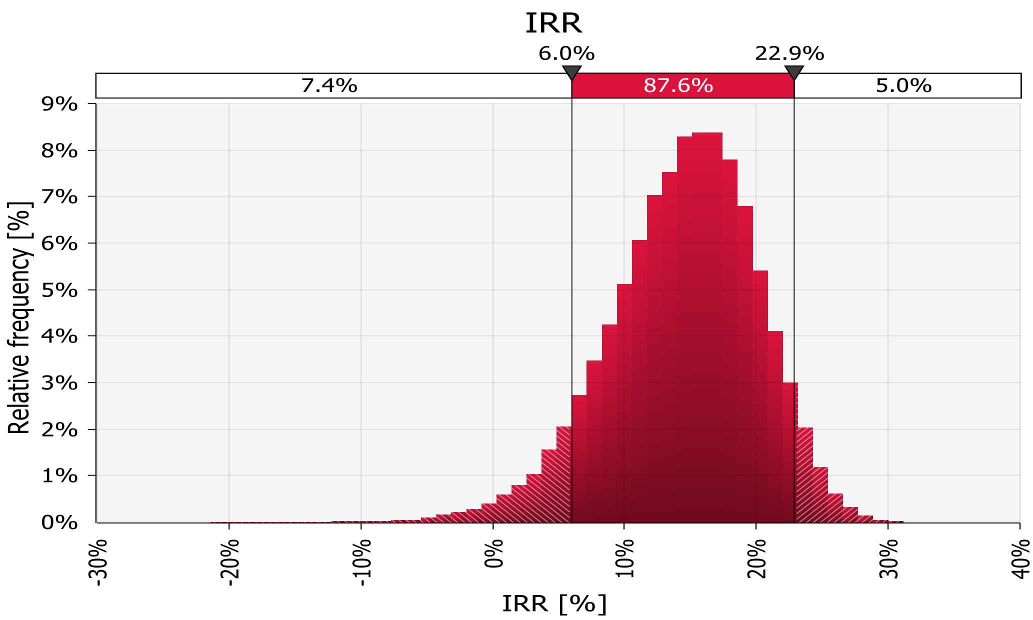

Figure 16. Distribution of the estimated IRR for PFR CASE 3 (including CCS and heat selling)

Again, we found similar results for Case 3 wheat straw. The risk of having a negative NPV is 7% (Fig.17), with the risk of having an IRR lower than 6% being 6.9% (Fig.18). Key parameters affecting the NPV and the wax and biodiesel price (83.4%), followed by the carbon credits (9.2%).

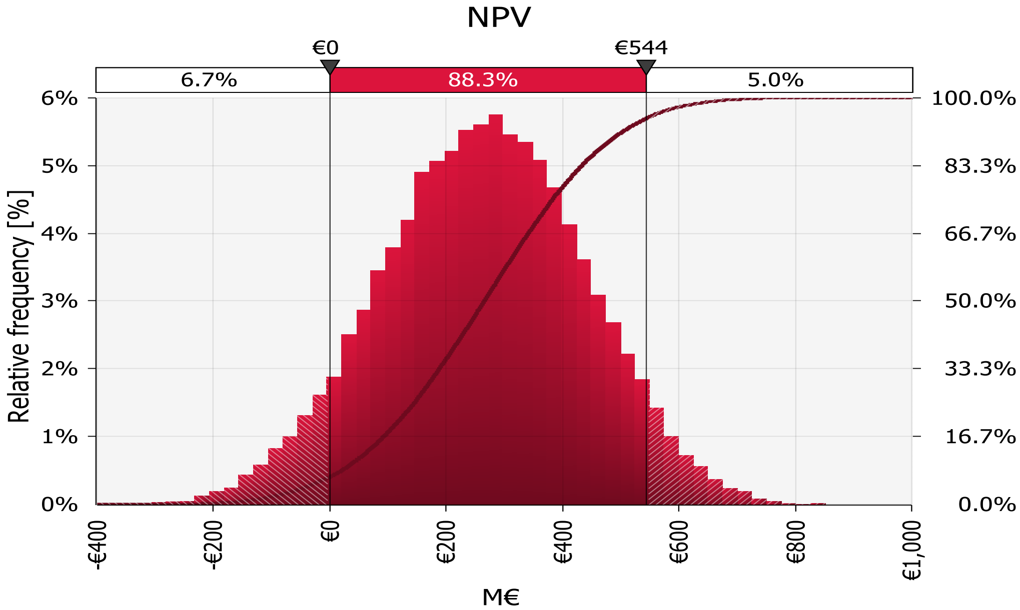

Figure 17. Distribution of the estimated NPV for WS CASE 3 (including CCS and heat selling)

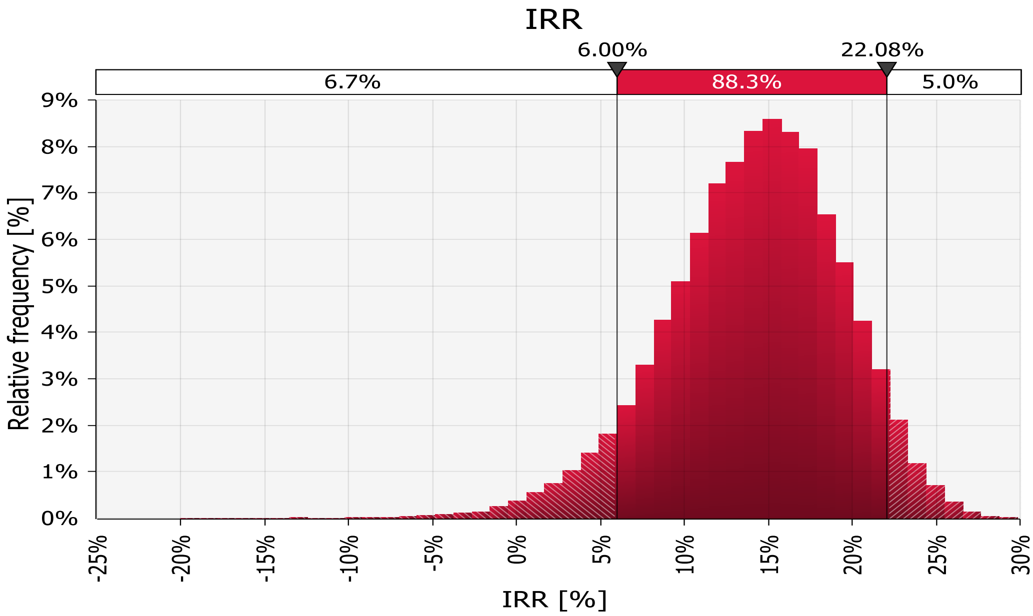

Figure 18. Distribution of the estimated IRR for WS CASE 3 (including CCS and heat selling)

4. Conclusions

The present report has discussed the economic risk of investing in a Chemical Looping Gasification, CLG, plant to produce biofuel from biomass feedstock (i.e. pelletised forest residues and wheat straw). Results show that to have a 95% probability of not overrunning the budget estimated by D7.2 for the BTL plant, a reserve (contingency budget) of 26 M€ is needed, which represents the 14% of the budget.

Regarding the risk on the NPV and IRR, for both the PFR and the WS, the results found that without the use of CCS, which allows for selling carbon credits, there is a high risk of having a negative NPV or an IRR below the discount rate, making the investment not feasible.

As possible mitigation strategies for the specific case, investors should look at long-term bilateral contracts to fix the price of wax and biodiesel, which are responsible for more than 90% of the variation of the NPV and to identify a strategy for utilizing the carbon captured that is ready to be used.

Thanks to the CCS for PFR, the risk of having a negative budget reduces from 45% to 16% and for WS from 42% to 12%, making the investment attractive.

The best solution would be, however, to ensure that in addition to the CCS system, the heat produced by the plant could be used. Extra revenues coming from selling the heat produced, in fact, could further reduce the risk of having a negative NPV for the PFR and WS case to 7.5% and 7%, respectively. Again, long-term contracts to fix the wax and biodiesel selling price can hedge the investors from any losses during the lifespan of the plant and from any reduction in the carbon credits price. It is also worth noting that the analysis has considered a variation in the feedstock price of a maximum 30%.

Results also show that differences between the two feedstocks are limited, with slightly better results obtained for WS. Wax price and the biodiesel price are the two key factors affecting the results.

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