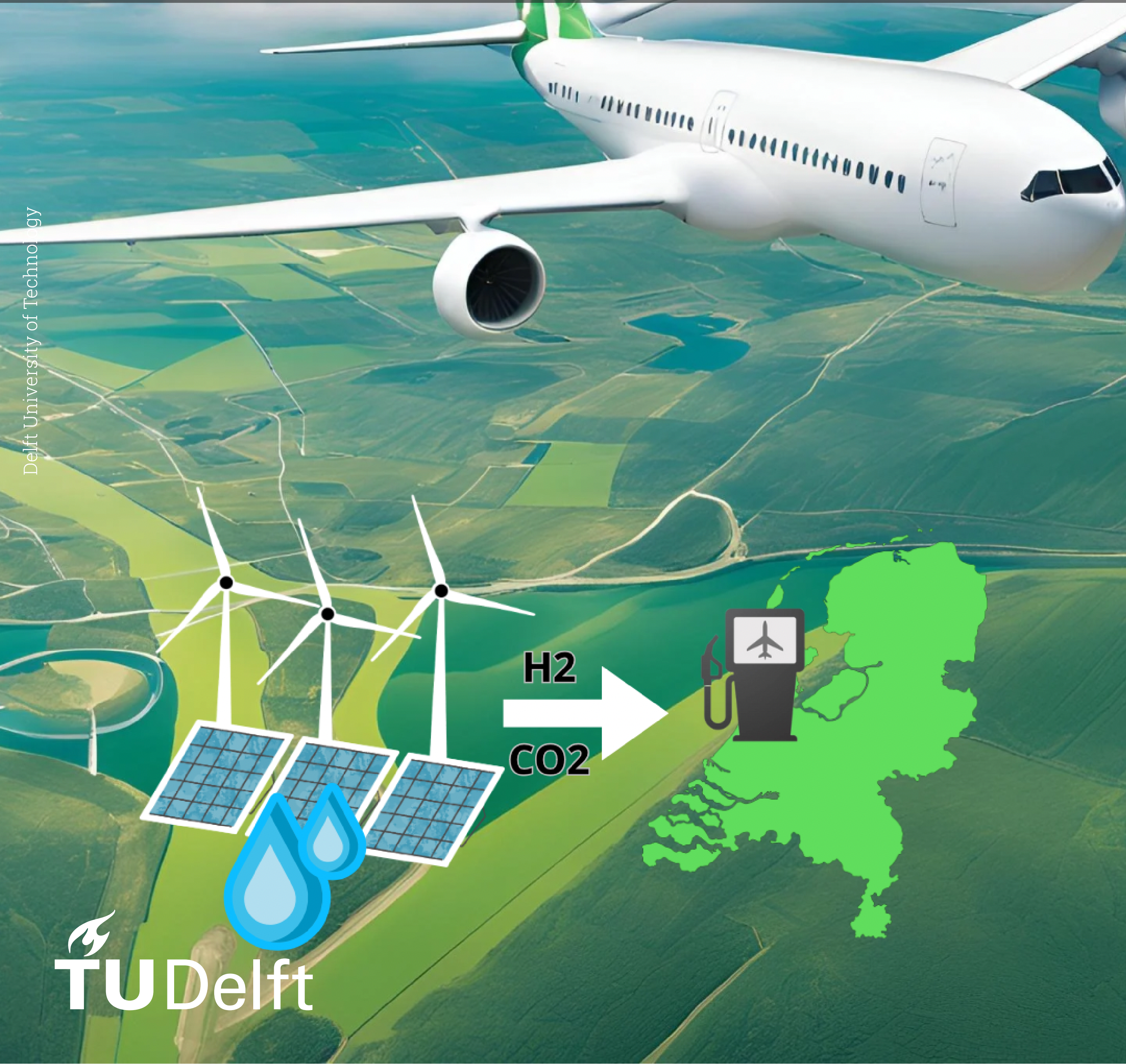
From Regulation to Revenue:

How Policy Unlocks the Economic Potential of Dutch e-Jet Fuel Plants

Master Thesis by

Lisa Hop

Delft University of Technology



TU Delft

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Preface

This document marks the end of my academic career at TU Delft. The idea for this thesis began during another course during my masters, where I first came into contact with Sustainable Aviation Fuel. Having studied Aerospace Engineering for my bachelors, this topic allowed me to combine my passions for aviation and sustainability. The aviation industry being one of the more polluting ones within the transportation sector, it had always remained an internal dilemma of mine on how to combine the two. Through the course, analysing the barriers to technology adoption, it quickly became apparent the main ones were high costs and low availability. At a later stage, I was introduced to the Real Options valuation method by my first supervisor during his course Financing Technology Ventures. Afterwards, while being his teaching assistant, I started gaining even more insight in financial valuation. Together we started exploring the idea for this thesis.

The purpose of this paper is to develop a method that improves the financial outlook for sustainable aviation e-kerosene, in the Netherlands specifically. So far, only few work has been dedicated to financial viability of PtL e-kerosene, while the topic is very relevant. The lack of information created some challenge in developing the methodology, however, also presented opportunity to add value to the body of knowledge. The method applied in this paper builds on these previous works by adding project managerial flexibility and both internal and external risk in the Dutch context specifically to the valuation. This is relevant, considering the technologies novelty and dependability on other factors. Next to this, the application of policy scenarios provides additional insight to what it required for profitable investment in a large scale PtL plant in the Netherlands. Adjusting parameters in the model as result of financial and market incentives shows to what level the project value improves and, in turn, which types of incentives would be most effective.

After introducing the topic and presenting the research questions and objective, the body of this paper is structured in the following manner. Chapter 2 first provides additional context into the technological aspects of PtL e-fuel, next to current European regulation, external risk, planned projects in Europe, previous techno-economic work on SAF and real option valuation. The methodology on forming the decision tree model is provided in detail in Chapter 3. All steps required to compose the final model are provided here, next to variations made to it through the policy scenarios. Chapter 4 shows the results after valuation of all the scenarios and indicates which combination of incentives is most effective. Chapter 5 discusses the contribution and implication of the results in a broader context, next to the limitations within this study and recommendations for future work. It discusses the different strategies available for policy incentives and highlights the trade-off policy makers and other stakeholders have to make to enable energy transition in the aviation industry within the required time-frame. The paper is concluded in Chapter 6, where the research question is addressed and the key take-aways of this paper are highlighted.

I want to thank both my supervisors for guiding me through this last period of my studies. I have very much enjoyed writing this under your supervision. I thank you for your support and flexibility to help enable combining my studies with my softball career. Your encouragement and guidance has meant a lot during stressful times. It has motivated me to finish this work to the best of my abilities and create something meaningful.
I want to thank my Dutch National team coaches for allowing me flexibility in my training schedule to finish this work. Thank you for allowing time to maintain a dual career, knowing that a career in sports will end one day. Thank you for showing interest in what I do off the field, allowing me to be more than my sport.
Lastly, but certainly not least, a big thank you to my parents, my partner and those close to me. Thank you for supporting me to choose my own path and encouraging me to keep walking it. You all have made this possible for me.

Closing off, during my time within this Master program I have enjoyed learning about different fields through working with people from different engineering backgrounds. Broadening my horizon inspired me to look beyond what I know, be curious and continue to learn. One take-away that remained relevant for all fields is the complexity of technological transitions. How values for distinct stakeholders can differ, how a solution can seem obvious at first, but more complex from different perspectives. A valuable insight for other parts in life as well. To this and all other insights, memories and friends I dedicate this work. I am thankful and proud for the path I have walked so far, excited for what lies ahead of it and curious what hidden side tracks will present it selves in the future!

Lisa Hop
September 9th, 2024.

Executive Summary

The European Union has implemented Sustainable Aviation Fuel (SAF) blend mandates in its member states, starting for bio-SAF in 2025 and for synthetic SAF (e-SAF) in 2030. Various e-kerosene plant projects have taken off in the last years in Europe. However, due to the high investment costs and dependency on feedstock availability, no plant has reached final investment decision yet. In the Netherlands, two full scale e-kerosene plants have been announced to be build in the next decade. This paper estimates the net present value of one of these in the current market conditions of the Dutch aviation fuel market. For this, a real option tree model is created to represent the current risks, investment costs and market state in the Dutch geographical context. In addition, the impact of various policy measures are added to the model to create different policy scenarios. The objective of this paper is to find which policy scenario's yields a positive net present value for the analyzed PtL plant in the Netherlands.

The real option decision tree was composed in various steps. The model is based on an e-jet fuel plant based in the Netherlands with annual jet-fuel production capacity of 50,000 tonnes. The e-fuel mix contains 75% jet fuel, 12.5% diesel and 12.5% naphtha. This plant sources green hydrogen and CO2 externally, therefore does not require investment in direct air capture systems or an electrolyzer. First, the project stages and options were defined as in other energy projects. The length of each is approximated based on the status and expected deployment of current PtL e-kerosene plants. Next, the project investment and value was determined following the findings of previous works. The CAPEX was split up over the investment stages determined previously, and adjusted for inflation. Likewise, the OPEX found in various literature sources was inflation adjusted and averaged. The selling price is modeled to decrease at the same rate as the projected electrolyzer costs because of technology maturity. Market conditions were based on both fuel demand projections in the Netherlands and the European blend mandates for synthetic fuels until 2050. From this, two market condition scenarios were modeled. These were based on whether the modeled plant or its smaller competitor reaches market first. This makes a difference, as the fuel demand in the first years of operation is limited because of lower blend-mandates. Next, the abandon options were modeled by determining the salvage value. The salvage value was defined as the current replacement costs minus the depreciation. For this, the depreciation rates for each investment during both testing and operation were determined. After finding the values, the probability distribution for the options in the different project stages were determined. This was done using the probability ranges as defined in the classical risk matrix. The current and forecasted status of most prominent project and market risks were described, where after the risks were allocated to a probability range. The main value of each was used in the probability distribution. Lastly, the different policy incentives and scenarios were defined.

Results indicate that the blend-mandates imposed by the European Union are insufficient for an large scale e-kerosene plant to yield a positive NPV in the market landscape within the Netherlands. Optimizing market conditions for these plants increases the NPV, however, not sufficiently. Instead, the risks of green hydrogen, grid electricity availability and the high CAPEX investment costs early in the project significantly impact the NPV, resulting in an unfeasible business case. Therefore, measures to reduce CAPEX and ensure feedstock supply will be most beneficial to increase the project value. Scenario's imposing combinations of certain policy incentives resulted in a positive NPV, hence, financial viability. Those with the most effect combined CAPEX lowering with either optimizing market conditions or increasing cash flow through a tax cut. In addition, a scenario was modeled that included a waiting period before the construction phase to increase the probability of hydrogen and green grid electricity availability. As the markets of each are projected to grow annually, there is a trade-off between risk reduction during construction and increased cost of capital and asset depreciation by waiting. It was found that a waiting period of 3 years before starting the construction phase resulted in the highest NPV.

This study found that more is required than currently incentivized by the European Union for PtL

projects to become operational and successful long-term within the Netherlands. The focus of the Dutch and European policy makers needs to shift towards lowering capital expenditures for PtL plant construction and reducing feedstock supply risk in the following years. Only then can the first two full scale plant in the Netherlands continue to the next phases of their projects and eventually cover the market demand of the first years following 2030. The real option tree model composed in this study combined with the policy scenario's contribute to the economic analysis performed on PtL e-fuel plants. The decision tree model incorporates managerial flexibility and both project and external risk within the valuation within the Dutch context specifically. As the presence of both risk and options significantly affects the project NPV, this method adds to results found in previous techno-economic analysis works. The model provides an adjustable framework for policy makers, to test under what market conditions and within which policy scenarios investing in these plants would be profitable. The challenge lies in finding the right combination of incentives that allows the financial viability within the right time frame, while avoiding to put the entire financial burden on one group of stakeholders. Large scale deployment of (e-)SAF is the best pathway to meet European climate goals for aviation in 2030 and beyond. A trade-off needs to be made between sustainability and economic prosperity to enable this. Achieving this balance will be necessary to ensure the both environmental and economic objectives are met, enabling a sustainable and prosperous future for the Dutch aviation industry.

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1 Introduction

In response to the global climate crisis, the European Union aims to reduce emissions as a result of transport by 90% by 2050 (ReFuelEU, 2021). Emissions caused by the transportation sector account for approximately one-fifth of global total emissions (Ritchie, 2020). Of all transportation emissions, the aviation sector contributed 11.6% in 2018. Although this is not the majority share, global demand for aviation is expected to double by 2040 (IATA, 2023). Therefore, it is essential for the aviation sector to find novel ways to limit fossil emissions to reach the 2050 reduction goal. Although other transportation industries have successfully integrated technologies powered by sustainable energy sources, the aviation industry has made smaller steps in the energy transition. Several promising innovative technologies are currently in the pipeline, including electric, hydrogen, or hybrid aircraft. However, these technologies are not compatible with existing aircraft or infrastructure and still need much development to become commercially viable. To implement these alternatives, airlines are required to purchase entire new aircraft and abandon existing ones to fully transition to sustainable technology. This poses a substantial hurdle for the energy transition in aviation.

For this reason, an intermediate solution is to invest in the development of Sustainable Aviation Fuel (SAF). These fuel types can be used as propulsion source in existing aircraft together with fossil jet-fuel. With approved blend-in limits being up to 50%, the SAF currently on the market have the potential to reduce emissions by 80% (Kousoulidou & Lonza, 2016). Despite the higher blend in limits, SAF accounted for only 0.05% of the total jet fuel consumption in Europe in 2019 (ReFuelEU, 2021). The problem with SAF is that its pricing can currently not compete with conventional fossil jet kerosene. When it comes to SAF adoption, airlines are the most influential stakeholder, as they hold the power to purchase and therefore control the technology demand (Singh et al., 2023).

It leaves one to wonder why the adoption rate is as slow, while the demand and need for sustainable aviation is high and the technology that allows it exists. A reason for the high fuel price is the alternatives' newness and the limited availability. Sustainable aviation fuel can typically be divided in two categories: Bio- and Synthetic Jet Fuel. Currently, only Hydroprocessed Esters and Fatty Acids fuel (HEFA), a type of bio-jet fuel, is commercially available. HEFA, however, relies on bio feedstock as input, which requires vast amounts of land and water to produce Batteiger et al. (2022). One of the less resource intensive pathways is Power-to-Liquid production, creating a type of synthetic kerosene. The PtL production pathways combine green hydrogen and CO2 to produce fuel. This production method currently has a TRL of 6-9 and has more potential to upscale and be used commercially then other production pathways (Batteiger et al., 2022). However, the projected production price and required capital to upscale are some of the main obstacles for this technology to do so. Because of the substantial capital requirement for development, high levels of uncertainty and risk and the very established position of fossil kerosene in the aviation sector, investors seem to remain hesitant to commit their funds.

Various research has already been dedicated to improve the economic outlook of SAF. Rojas-Michaga et al. (2023) perform a techno-economic and life-cycle assessment to analyse the minimum selling price of PtL based on the cost of production. Batteiger et al. (2022) provide insight in PtL performance in terms of market-readiness, environmental benefits, production price and scalability. It also provides a SWOT model and suggests requirements for scale up and large-Scale deployment.

Wang et al. (2021) perform a quantitative policy analysis for other bio-jet fuel pathways, where they assess the impact of various sustainability policies on the Net Present Value (NPV) of a production facility to find what MSP would yield a positive NPV. These studies provide valuable insight in the economic position of the technology. However, their methods do not address the existing market uncertainty, technological risk of an emerging technology and the effect of the relevant policy incentives and macro-economic factors on the potential return of PtL e-fuel. Therefore, they do not paint a complete picture on whether the investment in a PtL production plant will yield a positive return or not.

This study will build on findings from previous studies, but value a PtL plant as an R&D project with managerial flexibility in the form of real options . The objective is to find what the NPV of a full scale PtL plant would be when including these options with project and market risk. In addition, this paper will explore which potential policy incentives will influence this return the most. Different policy scenarios will include a combination of grants, tax reduction and optimized market conditions. These matters will be addressed in the course of this study by answering the following research question:

Which potential policy incentive scenario will yield a positive net present value for a Power-to-Liquid (PtL) fuel plant with 50,000 tonnes annual jet-fuel capacity in the Netherlands?

In order to answer the question above, it is divided into various sub-questions.

1. What are the current regulations around e-fuels in the Netherlands?
2. In order for a PtL plant to become market ready, what are the different investment phases required and what is their corresponding probability of success?
3. What is the required project investment and how can the enterprise value be estimated?
4. What are the different options available throughout the project?
5. Which possible policy incentive scenario results in the highest NPV?

This study will aim to provide more insight into the possibility of PtL to achieve market competitiveness. Findings from the study could be valuable to companies or individuals seeking to invest in PtL development. Information on the effects of different policy incentives on the return of the investment will also be valuable to policy makers. The study seeks contribute to the body of knowledge in the field of sustainable aviation and the overall transition to renewable energy in the aviation sector.

This paper is structured as follows. chapter 2 includes relevant background on the current development of PtL fuel, European and Dutch legislation around (e-)SAF, project risks and planned plants in Europe. More attention is paid to current work around techno-economic analysis of SAF and their findings. Here, Sub-question 1 is addressed. Lastly, this section includes background on real option valuation, along with its application in various energy projects. After this, the real option decision tree model is composed in chapter 3. This section addresses sub-questions 2, 3 and 4. chapter 4 shows how different policy scenarios are applied to the decision tree model. This section will answer sub-question 5 by finding the resulting project NPV of each scenario. chapter 5 discusses the implications of the results, the contribution of the study, its limitations, and recommendations for future work. Finally, the main research question is answered in chapter 6 along with the main takeaways of this paper.

2 Background

This section includes relevant background on the current development of PtL fuel, European and Dutch legislation around (e-)SAF, project risks and planned plants in Europe. Current works performing techno-economic analysis of SAF and their findings are discussed. Finally, background on real option valuation is included, along with its application in various energy projects.

2.1. What is PtL e-kerosene?

To understand what is required for PtL e-kerosene to enter the market, it is essential to understand the production process and its different components. The biggest difference between PtL e-SAF and other bio-SAF is that PtL production does not rely on biofeedstock to produce fuel. Rather, it uses hydrogen (H2) and carbon dioxide (CO2) as input. There are different methods for obtaining these, but European legislation has set several criteria for these to meet emission requirements. Using hydrogen and CO2, the feedstock can be converted to electronic fuels in two ways: through Fischer-Tropsch (FT) synthesis and upgrading, or through Methanol (MeOH) synthesis and conversion (Batteiger et al., 2022). Currently, only the production of e-kerosene via the FT path is currently certified for blending up to 50% with conventional fossil jet-fuel(ASTM, 2022). Production via MeOH has not yet been approved. A simplified version of the entire FT process is shown in Figure 1

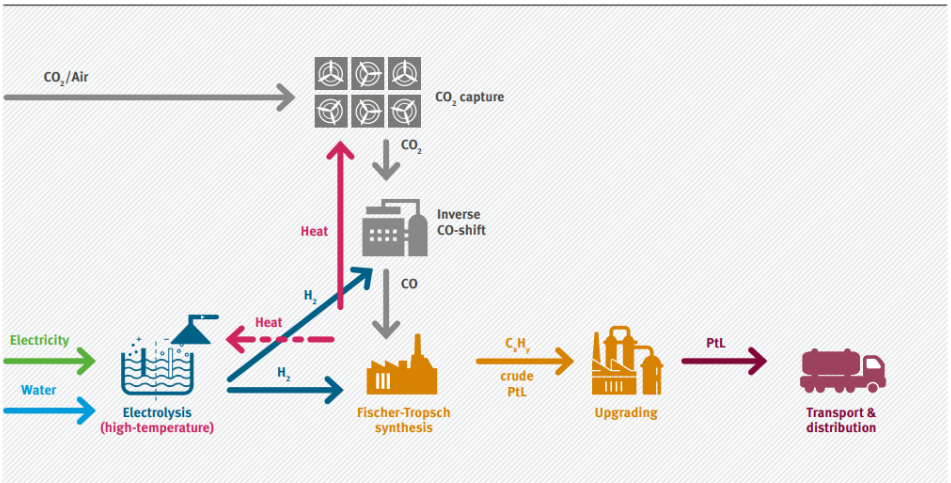


Figure 1: PtL production process via the Fischer-Tropsch pathway. This process includes an electrolyzer and direct air capture unit. From Batteiger et al. (2022)

The output of via the FT-process yields synthetic jet fuel, diesel and naphtha (Rojas-Michaga et al., 2023). The conversion and upgrading can be shifted to yield more than 50% share e-kerosene (Batteiger et al., 2022). Moreover, TransportEnvironment (2024) state this share can be up to 75%.

Rojas-Michaga et al. (2023) found that the PtL system with the Fischer-Tropsch process has the Global Warming Potential (GWP) of 21.43 gCO2/MJ, which is significantly lower than that of traditional kerosene. Moreover, the system's GWP is highly dependent on the GWP of the supplied electricity. Therefore, using green electricity for feedstock and fuel production is essential for the fuel to meet the standards defined in ReFuelEU. The water footprint of the system is higher than that of traditional fossil jet fuel, however, much lower than other bio-SAF methods (Rojas-Michaga et al., 2023). This is mainly because bio-SAF pathways rely on bio-feedstock to produce fuel. In the case of HEFA fuel, the most commonly used SAF, the required feedstock includes rapeseed, soybean and other bio-oil. Since waste oil has a limited supply, as vast area's of agricultural land are required to grow soybean and rapeseed. In turn, HEFA methods require over 150x more water than PtL with a FT process (Batteiger et al., 2022).

2.2. Regulations

As for the policy side of SAF, several initiatives have been proposed to speed up both bio- and e-SAF adoption at European scale. The ReFuelEU Aviation initiative, part of the Fit for 55 package, was presented by the European Commission in 2021 as their plan to reduce CO2 emissions by 55% by 2030 compared to the level in 1990 (CouncilOfTheEU, 2023). Based on this initiative, the European Council has adopted a new regulation to enhance industry SAF adoption (CouncilOfTheEU, 2023). Its main provisions require aviation fuel suppliers to supply a minimum share of 2% bio-SAF to European Airlines and Airports as of 2025, and a minimum share of 0.7% synthetic fuels (e-SAF) as of 2030. The mandated minimum share will gradually increase to 70% and 35% respectively in 2050, as shown in Figure 2. The ReFuelEU study estimated that the renewable electricity generation in the EU needs to increase with 0.4% and 5.5% by 2030 and 2050 respectively to meet the blend mandates (EASA, 2022).

For the period of 1 January 2025 until 31 December 2034, the minimum SAF shares will be taken over the average supply to all airports in the European Union Berg (2023). This will help current fuel suppliers in this market transition, as they have the flexibility to supply a higher share of SAF to different airports. Some locations will be easier to supply due to distance from the location of SAF production, or suitable transportation infrastructure. In addition, countries are adopting higher SAF blend mandates than required. Within the Dutch Agreement on Sustainable Aviation, Dutch airports have set the blending mandate at 14% in 2030. In addition, Schiphol (2022) set an aspirational goal of having 30% SAF blend in 2030. Therefore, fuel suppliers supplying different airports with different needs will benefit from this transition period (Berg, 2023).

Year			Volume shares (% of aviation fuel to EU airports)	
			SAF	Synthetic aviation fuel
2025			2%	-
2030	1st Jan 2030 – 31st Dec 2031		6%	Avg 1.2% (min. 0.7%)
	1st Jan 2032 – 31st Dec 2034	1st Jan 2032 – 31st Dec 2033		Avg 2.0% (min 1.2%)
		1st Jan 2034 – 31st Dec 2034		2.0%
2035			20%	5%
2040			34%	10%
2045			42%	15%
2050			70%	35%

Figure 2: Blend mandates in the European Union for SAF and Synthetic Aviation Fuel (PtL) (Berg, 2023)

In turn, sufficient the electrolyzer capacity is required to create green hydrogen. For the e-fuel to meet sustainability standards, the EU created criteria around the feedstock. TransportEnvironment (2024) summarizes these criteria: The hydrogen used for e-fuel production needs to be generated through electrolysis powered by renewable/nuclear electricity. The electrolysis must also happen within the same or nearby bidding-zone as the electricity source. Bidding-zones are in most cases defined as a countries national borders (ACER, n.d.). The CO2 supply can be sourced from biogenic carbon, industrial emissions or through direct air capture. For the industrial emissions as carbon source, the legislation approves fossil CO2 from power stations as carbon source until 2036 and from other fossil sources until 2041. Next to requirements for the feedstock, the fuel production must also be powered with renewable electricity.

Fuel suppliers and aircraft operators not fulfilling the mandates are required under ReFuelEU to pay at least twice the difference between that years average conventional fuel price and that of SAF. Here, this fine only applies to the amount of fuel shares not meeting the required SAF fuel blend (TransportEnvironment, 2024). Income from the fines are designated to fund emerging SAF projects (Berg, 2023). For airlines to avoid risking these fines to be passed on to them, the have to option to engage directly with SAF fuel suppliers instead to ensure they meet the fuel blend mandates.

2.3. Risks

Even though the incentives from ReFuelEU have established long-term predictable demand within each European member state by reducing investment risks in e-kerosene, project developers still face various challenges. Types of external risk include the limited availability of green hydrogen, renewable electricity, approved carbon sources, and market demand due to the high price of fuel (TransportEnvironment, 2024). These risks are addressed in the following.

2.3.1. Hydrogen supply

There are different types of hydrogen, differentiated by the colours blue, gray and green Centraal (n.d.). Gray hydrogen is the type that is used mostly in industry because it is currently the cheapest method. For this type of production, natural gas and electricity are converted to hydrogen while releasing CO2. This CO2 is considered pollution as it is added to the carbon cycle. To counteract this, some production facilities collect the emitted CO2 and store or recycle it. As CO2 would in this case not end up in the atmosphere, the hydrogen produced with this method is considered blue hydrogen. Because the electricity used for blue hydrogen is typically not produced sustainably, the hydrogen produced via this method cannot be considered as sustainable and therefore a suitable supply source for sustainable e-kerosene production. The only type of hydrogen suitable for this is green hydrogen. For green hydrogen production, electricity divides water into hydrogen and oxygen by electrolysis. With this process, an advantage is that CO2 is not an end product of electrolysis. The only requirement for the process to be sustainable is that renewable electricity is used for conversion.

As for European legislation, the production site must also adhere to geographical correlation for it to be considered green hydrogen. This means that the hydrogen production site must be within sufficient approximation of the location the renewable electricity is retrieved from (TransportEnvironment, 2024). This poses a problem for countries with limited access to renewable electricity. Especially in the early stages of the hydrogen economy, it will be likely that hydrogen will have to be imported from regions with an abundance of renewable energy.

2.3.2. Biogenic CO2 availability and Carbon Capture & Storage

As with hydrogen, the CO2 supply should also be sustainable. There are different ways to obtain the required CO2 for the production of e-kerosene. According to TransportEnvironment (2024), plants are mostly considering using an external biogenic carbon source for their CO2 supply. Biogenic carbon sources are typically larger industrial plants that capture and supply their CO2 emissions from biomass combustion processes (CaptureMap, n.d.). *Capture Map* provides an overview of the different locations of such biogenic carbon sources. Different industrial plants to be considered for this are ethanol plants, biomass power plants, waste to energy plants, cement plants, pulp & paper production and alcohol & sugar production. The reason why this method is considered sustainable is that the carbon obtained from this type of source had already been part of the carbon cycle in the form of biomass. Therefore, with biomaterial combustion, no new CO2 is added to the cycle.

Another alternative for the CO2 supply is to obtain it by direct air capture (DAC). With DAC, CO2 is captured directly from the air and separated. The technology for this is relatively new and still has a low TRL. Therefore, according to TransportEnvironment (2024), most projects are turning to biogenic carbon sources instead of investing in the development of DAC technology. The reason for this is the related costs for the development, as well as the lack of policy incentives to stimulate it. Interesting enough, most papers with techno-economic analysis are evaluating PtL systems with Direct Air Capture for CO2 supply. Perhaps the results from these are relevant at a later stage; however, for now project developers express the availability of biogenic carbon sources to be a limitation to the possible amount of e-kerosene plants (TransportEnvironment, 2024).

2.3.3. Market demand

Market demand is essential in the early stages due to the high investment costs of development and construction Batteiger et al. (2022). Because of the high anticipated prices for e-kerosene, it is likely that the demand for e-kerosene will entirely depend on the European blend legislation. However, as mentioned before, Dutch airports, several airlines and other stakeholders have agreed to set the bio-SAF blending mandate at 14% in 2030 within the Dutch Agreement on Sustainable Aviation DuurzameLuchtvaart (2020). In addition to this, Schiphol (2022) set the ambitious goal of having a 30% SAF blend in 2030. Some airlines started individual fuel blend standards. KLM (2024) started blending bio-SAF in 2022 at 0. 5% for every departure flight from Schiphol Airport. This year, their standards increased to 1% per flight. They, like other airlines, also give passengers the option of including more SAF for a higher ticket price. Since some airlines have introduced higher bio-SAF blend standards than required, they might do the same for e-SAF. Therefore, there is a chance that the actual fuel demand might turn out to be higher than that as a result of the required e-kerosene blend.

2.4. Planned Projects in Europe

To meet the PtL demand, various PtL demonstration plant projects have been announced over the last years. In North America, Airbus is partnering with the SAF+ Consortium to develop the first large-scale PtL production site in North America (Airbus, 2021). In Europe, more projects have emerged and some have started operations. PtL demonstration plants have been announced in Iceland, Finland, Germany, Spain, and Norway (ICAO, 2019), (Hauptmeier, 2021). The first European PtL demonstration plant from Norsk E-Fuel has been built in Norway and has started operations in 2023 (Surgenor, 2020). Ineratec announced that operations for the largest e-fuel plant currently in Germany will start in 2024, producing 2500 tons of e-fuels per year (Ineratec, 2023). Both are demonstration plants. Several large-scale plant projects are currently in the pipelines. (TransportEnvironment, 2024) identified 45 European e-kerosene projects in 2023, of which 25 are large-scale and 20 are pilot-scale. Larger-scale projects produce an annual capacity of 26,000 to 164,000 tonnes, whereas demonstration projects generally produce between 1,500 and 7,500. Of these 45 projects, three are in a further development stage and seek to reach their final investment decision by the end of this year (TransportEnvironment, 2024). One of these is a partnership between Norsk E-Fuel and Norwegian airlines, which plan to build the first full-scale PtL plant by 2026, capable of producing 100 million liters of fuel annually (Surgenor, 2020), (Harrington, 2023). The 45 combined projects could produce 1.7Mt by 2030, which is well above the blend mandate target of 0.6Mt for 1.2% (TransportEnvironment, 2024). However, it is uncertain what the success rate of these projects will be, as none have reached a final investment decision yet. In addition, success is highly dependent on the development and availability of green hydrogen, biogenic CO2, and local sustainable electricity. As described in , these factors might hinder plant development and project timeline.

In the Netherlands, there are currently two large-scale e-kerosene plant projects. The larger of the two plans to produce 50,000 tonnes of e-kerosene annually (TransportEnvironment, 2024). Their competitor announced to produce on a smaller scale with 26,000 tonnes of e-kerosene annually (Ineratec, 2023). Both have announced their commissioning to begin in 2027. However, as mentioned before, neither has reached the final investment decision yet. At this moment, the larger plant seems to be ahead of its competitor, as they are in a further stage of the project (TransportEnvironment, 2024). However, more factors will influence who gets to the market first and will cover the first part of the fuel demand. More about this in subsection 3.4.4.

2.5. Techno-economic Analysis of SAF in Literature

Different papers have used various methods to valuate SAF production plants. Wang et al. (2021) use a discounted cash flow rate of return analysis to determine the NPV of production facilities of several bio-SAF pathways based in the United States. They make various financial assumptions in their model. Like others, they assume the production facility is "nth of its kind", rather than a first of its kind, therefore neglecting any technological or market risk. They use a positively skewed beta-pert distribution to account for uncertainty in the fixed capital investment. After determining the NPV and Minimum Selling Price (MSP) for a baseline scenario, they show how various types of policy impact the MSP of the different bio-jet fuel pathways. The policies they evaluated included feedstock subsidies, capital grants, output-based incentives, and policies that reduce project risk. The results visualize the effect of each policy measure on the NPV and the MSP per SAF production method. The findings of the paper included the median policy costs to make an SAF production plant economically viable in the United States. In addition to this, they found that a combination of policies, rather than a singular one, results in economic viability.

Rojas-Michaga et al. (2023) evaluate the technical, economic, and environmental performance of a PtL plant including a DAC system and alkaline electrolyzer based in the United Kingdom. The entire PtL system is modeled, whereafter in the ecomic analysis the the Capital Expenditures (CAPEX), Operating Expenses (OPEX) and MSP are estimated. Also here the analysed plant is assumed to be the nth of its kind, neglecting the higher technical risk and market risk of pioneering plants. The MSP is determined with a discounted cash flow analysis using parameters found in literature. They divide the FCI over three periods of 12 months instead of one period. This creates a more accurate estimation of the NPV, as the three investment moments are discounted over different periods. To account for sensitively and uncertainty of these parameters, such as CO2 cost and Hydrogen cost, they include low, nominal and high values for each parameter in their calculations. Sensitivity analysis applied on these parameters using Monte Carlo simulation to visualize the impact of each parameter in the MSP. Their analysis found the highest sensitivity for variations in the price of hydrogen production (therefore electricity price) and CO2. In addition, they found that the e-kerosene price would always remain higher than the gate price of fossil jet-fuel. This implies that economic policy incentives are required for successful market operations.

Dietrich et al. (2018) analyzed and compared the economic performance of three fuel production processes: Power-to-Liquid, Biomass-to-Liquid (BtL) and Power-and-Biomass-to-Liquid (PBtL). For this, the entire system of each method was mapped, followed by a techno-economic performance for an assumed capacity of 11 Mg/h. This is representative of a full scale plant producing 30,000-55,000 tonnes annually, depending on the amount of operational hours. They found the lowest capital investment costs out of the three for PtL, amounting to 660M EUR. The analysis was done for a Fischer-Tropsch process including an alkaline electrolyzer and DAC in the system, increasing the capital investment costs. Out of the total, 55% is due to electrolyzer investment costs. PtL production yielded the highest net production costs out of the three, being 3.76 € per kg fuel produced at the time of writing. Out of the NPC, 67% is contributed by the power required for electrolysis. The net production costs could be similar for a plant obtaining hydrogen and CO2 externally, depending on the market price of each resource. The economic findings fluctuate however, as they are highly dependent on the price of the required raw materials. The findings for the NPC were compared to other findings by Tremel et al. (2015), Becker et al. (2012) and Schmidt et al. (2016). Sensitivity analysis was only performed for PBtL production in this paper, showing the largest effect of the investment costs of the electrolyzer on the NPC of PBtL.

Batteiger et al. (2022) also analyze the technical and economic aspects of both Fischer-Tropsch and Methanol PtL production processes. Fuel costs are determined for three different regions around Europe: Central Europe with Germany as proxy, Southern Europe with Spain as proxy and MENA with Morocco as proxy. As the price of fuel is highy depended on the price of green electricity, the findings may differ for each region. The production capacity of the analyzed plant was scaled to be 1000 kt of liquid hydrocarbons per year. Of which, 50-75% of the fuel mix composition can consist of e-jet fuel (Batteiger et al., 2022), (TransportEnvironment, 2024). The analyzed system also creates green hydrogen and captures CO2 internally through electrolysis and DAC. The results projected a jet-fuel cost of 2000 EUR/t for a plant in the region of Central Europe. Of this, 53% is due to electricity supply, mainly due to electrolysis.

The techno-economic analysis works mentioned above serve as a good starting point to assess the investment value of a PtL project, but do not incorporate external risk and managerial flexibility that come with the development stages of an emerging technology. An interesting observation is that most scheduled plant projects use a carbon point source to obtain CO2, while the works above include a DAC system in their analysis (TransportEnvironment, 2024). In addition, some plants choose to obtain green hydrogen externally rather than investing in an electrolyzer system themselves. As mentioned above, several demonstration PtL plants are starting operations, but the fuel is not being produced on a larger scale yet. Hence, there are still some hurdles to pass for PtL to reach a higher TRL and enter the market, with associated investment stages and technological risk. Previous works do not address these risks and uncertainties in their valuation methods. Hence, this is where a gap in this research field lies. In addition, the impact of policy on the NPV of a PtL plant has not been analyzed, nor for a plant situated in the European Union. This paper will aim to address both these aspects, by modeling the findings from previous works together with the different project stages and decision gates into a real option decision tree. The risk of each stage varies, as different aspects affect its chance of success, which affects the project value. With the current situation in the Netherlands modelled in the base case scenario, the effect of various policy measures on the project NPV will be investigated. These will separately be incorporated in the model to find which variables in the model are most influential, and which policy measures would improve the NPV the most.

2.6. Real Option Valuation

A way to incorporate risk and flexibility in valuation is with the application of the Real Options theory. This method allows to evaluate investment projects by providing options at decision points. This provides a more realistic estimation of the project value, as different scenarios with high uncertainty can be included in the valuation and irreversible investment can be delayed to later stages (Fernandes et al., 2011). A real option is "the right, not obligation to take an action at a predetermined cost for a predetermined period of time" Schneider et al. (n.d.). The theory has been widely used over the years to value various high-risk renewable energy projects. Fernandes et al. (2011) present various works that apply the real options method to investments made in renewable energy projects dating back to 2002. Real options are also applied for policy evaluation, to evaluate how different measures affect the project value. More recent applications of real option theory on energy projects includes the work of Mombello et al. (2023) Heidari & Heravi (2024) or Loncar et al. (2017). These works and other applications use different pricing methods to value options and estimate uncertainty, including binomial lattice, Monte Carlo simulation, partial differential equations and the least squares Monte Carlo. Schneider et al. (n.d.) illustrates the general project valuation procedure as shown below in Figure 3.

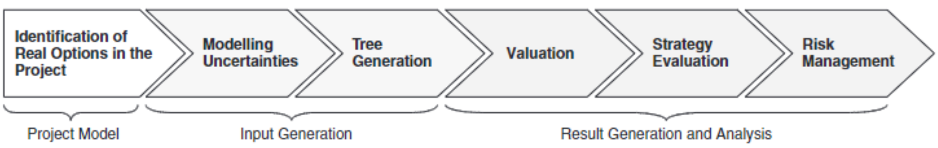


Figure 3: Steps of estimating project value using Real option decision trees. From Schneider et al. (n.d.)

Metrick & Yasuda (2021) provide thorough explanation on application of Real Option theory using a more simplified approach to value R&D projects in the form of a real option decision tree. Defining a real option problem into a decision tree model is typically done in two parts, by first spotting the available options within the scenario, followed by valuing the options. The available options, or decisions, are illustrated with square decision nodes within the option tree. The probability of different outcomes is represented by the circle formed risk nodes. In the context of R &D projects, risk nodes typically illustrate market risk or technical risk, but can also be used to show the probability distribution of external circumstances on the outcome. Option types can be divided into 'call' and 'put' options. Call options include the option to Delay, Expand or Extend (Metrick & Yasuda, 2021). Put options include the option to Abandon and to Shrink. These different option types can be applied within a decision tree model to increase the complexity and mimic the real life situation. After the tree is generated, the project value can be estimated by discounting the resulting project value of all options over the project time, incorporating the risk of each option.

This methodology will be used in the following chapters to model the currently scenario of starting a PtL plant project in the Netherlands. An advantage of this method is that the decision tree can be modeled to different levels of complexity, depending on what is fitting to the situation. The more challenging part of using this methodology is the definition of risk and probability of success within the model. The success of different project stages and market adoption of dependent on several main factors. The decision tree method assumes these probability distributions are inherently known. Since this is a novel technology without statistical information on probability distributions, these need to be estimated from various sources in literature. Other papers include a sensitivity analysis to their methodology as well. The application of the Monte Carlo Analysis, for example, gives insight into the sensitivity of the findings to varying factors. The variable ranges used for the analysis in Rojas-Michaga et al. (2023) were based on previous analysis or statistical information. Applying a sensitivity analysis to the decision tree model is more challenging because of the limited availability of information. Therefore, it remains the question how accurate a sensitivity analysis would be if the variable ranges are estimations. However, it can be insightful to change the variables in a hypothetical scenario. For example, by varying the CAPEX in the different phases or the probability estimations, one can find how these factors relate to the project NPV. Hence, after the base case model is completed, comparative statics will be applied to find which change in variable affects the NPV the most. A more detailed description of the real option decision tree application will follow in the next chapter.

3 Decision Tree Methodology

This section will describe the methodology of composing the real option decision tree used for analysis in the rest of the paper. Due to limitations of this study, all information used in the model originates from literature and online articles, rather than expert interviews or real time financial data. The option tree will be created for a PtL plant project based on the current projects in the Netherlands. As mentioned previously, two larger scale plant projects have been announced. The plant modeled in this paper will be based on the larger plant with 50,000 annual e-fuel production capacity. The presence of the competitor will be incorporated to estimate market conditions. Here, the cases in which the competitor reaches market before the the modeled plant and vise versa are modeled in two scenario's to estimate the market conditions. Different elements required to compose the decision tree are discussed in this chapter. Once completed, the policy scenarios are composed and explained in the final section.

3.1. Project Stages

To create the decision tree for a PtL plant, the different project stages and the decision points need to be defined.
To get an accurate estimation on the project stage length, the time data sources of various plant projects in Europe are used. One plant in the Netherlands announced their intention to start the project in September 2021 (SkyNRG, 2024). They have stated their intention to produce at full capacity by 2027 (TransportEnvironment, 2024). This indicates that the expected duration of the entire project is 6 years. However, in a report of TransportEnvironment (2024), published in 2024, states that this project has not reached the Final Investment Decision stage yet. This report analyzed all announced PtL plants in Europe and the status amongst them. They state only three major industrial plants are planning to reach the Final Investment decision by the end of 2024, and start production in 2026/2027. Therefore, they anticipate the stage between the financing and commissioning to take up to 3 years.

As for the stages of the project, TransportEnvironment (2024) indicate that these for major energy projects typically consist of a feasibility study, pre-engineering, Front-End Engineering Design (FEED), Final Investment Decision, engineering design, detailed engineering and procurement, construction, commissioning, startup of operations. Here, during the feasibility study the viability of the project is assessed and whether the project is worth pursuing. In the FEED, the project's technical requirements are defined next to the rough investment cost. The Final Investment Decision is the critical decision point where project sponsors evaluate all relevant information. For the decision tree, this point will be a critical decision point on whether or not to continue with the project.

How the industry defines the stages of energy projects is globally the same, however, the level of detail differs. WattCrop (2022) define four main stages: pre-development, development, construction and project management & maintenance. Bradshaw (2024) lists Conceptual Design, Front End Engineering Design, Detailed Design and Fabrication. Mbasa (2023) goes into more detail and define 10 stages for a project. EEFIG (2017) assess the project life cycle from the perspective of both the investor and the project developer. For the project developer, the development phase consist of the concept design, basic design and detailed design. In the final phase of the development phase, the decision to invest/lend is made from the investor perspective. Then, the developer proceeds with the Implementation phase, which includes the stages Installation and Commissioning. Lastly, the final phase includes the Operation stage. Loncar et al. (2017) translates the project stages into a real option decision tree model. Here, the stages 'Initiate', 'Evaluate' and 'Design' make up the first real option phase. The stages 'Execute' and 'Operate' make up the second phase. The Final Investment Decision is between the two phases.

As the Final Investment is the most critical decision point for both project developers and investors, this will be defined as the separation point between the first two phases for our model. Phase 1 is defined as the 'Design Phase', Phase 2 as the 'Construction Phase' and Phase 3 as the 'Operational Phase'. Similar to EEFIG (2017), the first phase will include the design stages of the project. The Construction Phase includes detailed installation design, procurement, construction and commissioning. After Phase 2, project developers make the final decision on whether to enter the market in Phase 3 or exit.

Figure 1 shows the decision tree up until now. As mentioned before, the final phase between commissioning and the Final Investment decision is anticipated to take around 3 years. The first phase starts in 2021, which is when the intention to start the project was announced. Even though the anticipated start of operations was in 2027, like the Norwegian plants, no PtL plants in Europe have reached the Final Investment Decision at the moment of writing (TransportEnvironment, 2024). The first blend mandates in the European Union for e-kerosene will be introduced in 2030. To be ready for operations at that time, the modeled plant needs to reach Final Investment decision by 2027. Therefore, in the decision tree model, the duration of Phases 1 and 2 are defined to be 6 and 3 years respectively. Similar to Rojas-Michaga et al. (2023), the plant life is defined to be 20 years. Therefore, the operational Phase 3 will take place from 2030 until 2050.

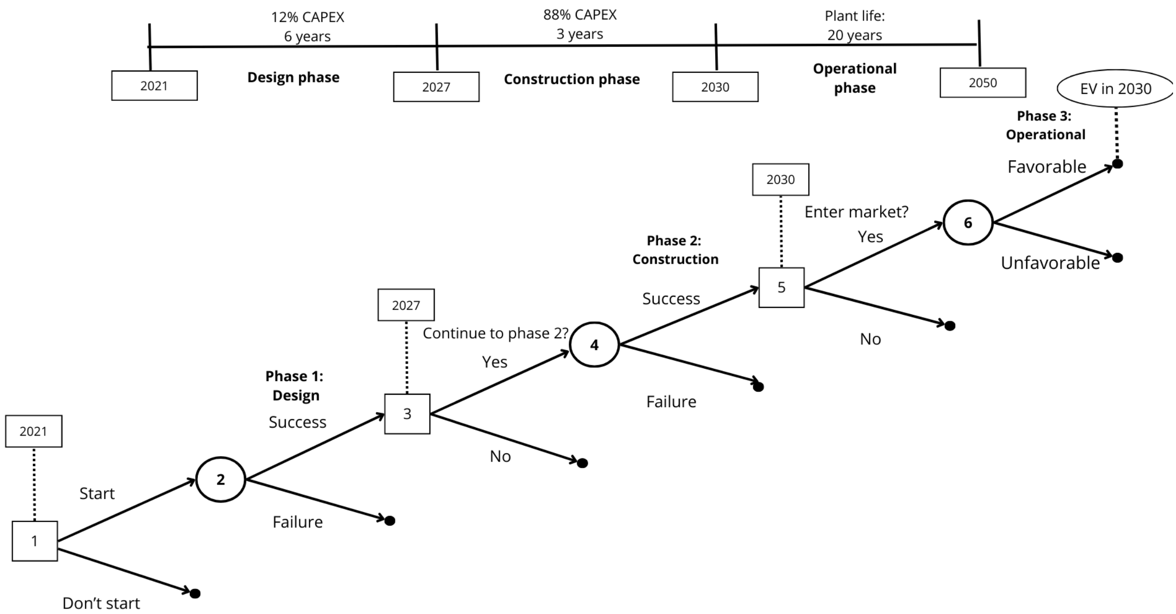


Figure 1: Decision tree for the modeled PtL plant. Project phases plus duration

3.2. Project Investment and Value

Next, the project expenses need to be determined. Previous articles performing a techno-economic analysis of PtL-plants find the Capital Expenditures (CAPEX) and Operational Expenses (OPEX) of the plant. (Dietrich et al., 2018) report the Total Capital Investment (TCI) to be 660M EUR. Of this amount, 55% consists of electrolyzer costs. Since the PtL-plant analyzed in this model obtains green hydrogen externally, the TCI lowers to 297M EUR in 2018.

These investment costs are made at the start of Phase 1 and Phase 2. (Dietrich et al., 2018) do not report at which period of the project these costs are made, nor how they are distributed over the different project phases. Therefore, this distribution will be defined similar to the Real Option model of (Milovanovic, 2013). Here, the "Initiate", "Evaluate" and "Design" phases contribute 1%, 3% and 8% respectively. In the PtL plant model, all three phases combined represent Phase 1: Design stage. Added up, Phase 1 costs 12% of the entire CAPEX, amounting to 35.6M EUR in 2018. Here, we assume the duration of the "Initiate", "Evaluate" and "Design" stages are equal at 2 years each. "Execute" and "Operate/Commission" represent 86% and 2% of the CAPEX. Therefore, Phase 2: Construction stage consists of 88% of the CAPEX, which amounts to 261.4 M EUR in 2018. As the majority of capital is invested in Phase 2, the final investment decision occurs between the two at Node 3.

As the CAPEX from Dietrich et al. (2018) was calculated in 2018, it needs to be corrected for inflation. Table 3.1 shows the inflation rates in the Netherlands (OECD.org, n.d.) of the past 10 years. To get a more accurate estimate of inflation after 2025, the average rate over the past 10 years is used. In the Netherlands, this was 2.90%.

2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	(average)2030
0.2%	0.1%	1.3%	1.6%	2.7%	1.1%	2.8%	11.6%	4.4%	3.7%	2.4%	2.9%

Table 3.1: Inflation rates in the Netherlands. From (OECD.org, n.d.)

Project Stage	**Investment year**	**CAPEX in 2018 (M EUR)**	**CAPEX in investment year(M EUR)**
Initiate	2021	2.97	3.133
Evaluate	2023	8.91	10.78
Design	2025	23.76	31.13
Execute/Construction	2027	261.36	360.83

Table 3.2: CAPEX investments Corrected for Inflation

In terms of net production costs or OPEX, Batteiger et al. (2022) report 1,700 EUR/t, or 1,70 EUR/kg. Dietrich et al. (2018) find net production costs of 3.76 EUR/kg. Other work mentioned in their article find the NPC to be 2.35, 6.68 and 2.67 EUR/kg respectively, shown in Table 3.3. Rojas-Michaga et al. (2023) conclude that 73% of the Minimum Selling Price (MSP) would cover the operating expenses. They find the MSP to be 5.16 Pounds/kg, or 6.03 EUR/kg. Therefore, the OPEX yields 4.40 EUR/kg.

To estimate the OPEX and MSP in 2030, these also need to be corrected for inflation. As shown in Table 3.3, the OPEX prices are first corrected to the inflation rate of each year until 2025. For the years up to 2030, the average rate is used. Following the correction of the different values found in literature, this model will use the average value of 4.234 EUR/kg for the operating expenses. Following the contribution of 73% OPEX in MSP found in Rojas-Michaga et al. (2023), the selling price in the first year of operations will be 5.799 EUR/kg PtL.

Article	**OPEX/NPC (EUR/kg)**	**in 2025**	**in 2030 (2.9% annual inflation)**
Batteiger et al. (2022)	1.70	1.88	2.17
Dietrich et al. (2018)	3.76	4.96	5.72
Tremel et al. (2015)	2.35	3.20	3.69
Becker et al. (2012)	2.67	3.63	4.19
Rojas-Michaga et al. (2023)	4.40	4.67	5.39
		Average	**4.234**

Table 3.3: Operational Expenses for PtL production via Fischer–Tropsch process found in literature

Since both the OPEX and MSP are for a large part depended on the price of green hydrogen, and in turn, green electricity, they are likely to follow the same price development as that of green hydrogen. To forecast this price development, the International Council of Clean Transportation presents three scenarios in price development (pessimistic, central and optimistic) (Navarrete & Zhou, 2024). In their central scenario, they estimate alkaline electrolyzer costs to decline from $1,163/kW in 2020 to $634/kW in 2050. Assuming this development will decay linearly, the annual percentage decrease is calculated as shown below:

$$\begin{aligned} Growthrate &= \frac{Newprice - Oldprice}{Oldprice} \frac{1}{t_{newprice} - t_{oldprice}} \\ &= \frac{\$634 - \$1,163}{\$1,163} \frac{1}{2050 - 2020} \\ &= -1.516\% \end{aligned} \tag{3.1}$$

As found in the above equation, the green electricity price is likely to decrease on average with 1.52% a year. Assuming green hydrogen, and in turn PtL e-kerosene, will follow the same price development, the e-kerosene prices are modeled to develop over the years as shown in Table 3.4.

Year	2030	2031	2032	2033	2034	2035	...	2049
PtL e-kerosene SP (EUR/t)	5,799	5,711	5,625	5,540	5,456	5,373	...	4,338

Table 3.4: PtL e-kerosene Selling Price development over the plant lifetime

As described in chapter 2, the produced e-fuel mix can be shifted to yield about 75% e-kerosene. The other 25% of the mix consist of diesel and naphtha. It is assumed that these by products can be sold at conventional fuel price of the operating year. At the time of writing, the European selling price for naphtha is 608.59 EUR/t, which is around 0.609 EUR/kg. In the Netherlands, the diesel price is 1,5512/L. With 0.832kg/L, that is around 1.291 EUR/kg(Fulltank, 2024). It is assumed both products have equal fractions in the remaining fuel blend. Correcting for the inflation rates in Table 3.1, the selling prices of both products at the start of operations is shown in Table 3.5. In each year of operation, the selling price of Diesel and Naphtha will be increased with 2.9% according to the average inflation found in Table 3.1.

E-fuel	Percentage in e-fuel mix	Price in 2024 (EUR/kg)	Price in 2030(EUR/kg)
e-Diesel	12.5%	1.291	1.525
e-Naphtha	12.5%	0.609	0.718
e-Jet Fuel	75%	-	5.799

Table 3.5: Selling prices of each e-fuel product in 2030

3.2.1. Market Conditions

Figure 2 from Berg (2023) shows the blend mandates installed in the European Union following the ReFuelEU initiative. It shows the different blend mandates for Synthetic Aviation Fuel up until 2050, which applies to PtL fuel. For the case of the sub-optimal conditions, the minimum values of 0.7% and 1.2% are considered for 2031 and 2032. Since the expected selling price for e-kerosene is vastly higher than that of fossil jet fuel, it is assumed that the demand will not exceed the annual blend mandates.

Next, the forecasted fuel demand in the Netherlands needs to be considered. Davydenko & Hilbers (2024) model the Dutch fuel demand until 2050 in three different scenario's based on current policy measures, as shown in Figure 2. The model is based the findings of the Climate and Energy Outlook (KEV) 2022, who estimate an annual flight demand growth of 2%. They also estimate trends for slower and faster growth to be -0.5% and +0.6% compared to the middle growth trend, based on external uncertainty factors, including "population growth, economic growth, cost trends and propensity to fly". These trend projections are shown in Figure 2.

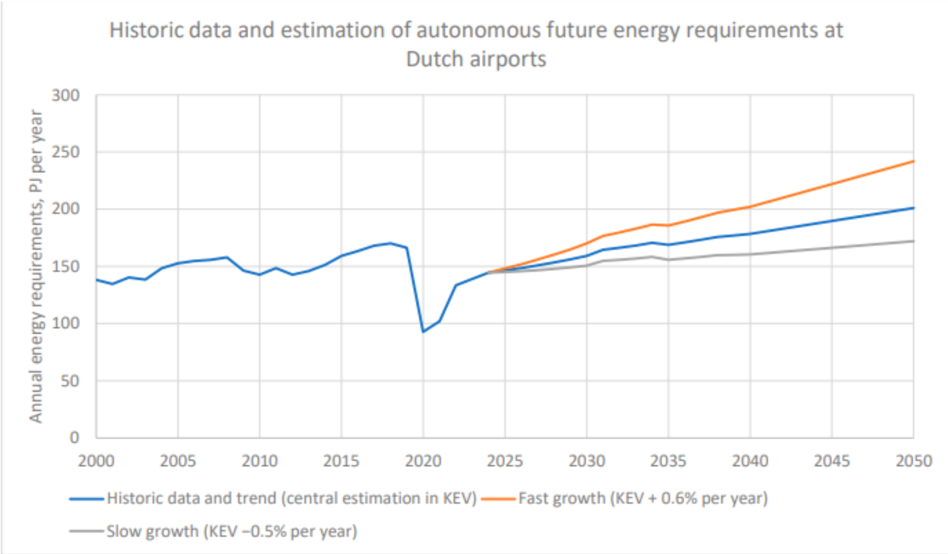


Figure 2: Jet fuel demand forecast in the Netherlands (Davydenko & Hilbers, 2024).

Using the conversion from PJ to tonnes as displayed in Table 3.6, the entire Dutch aviation fuel demand projection is converted to tonnes in Table 3.7. To determine the demand for PtL fuel from this, the blend mandates per year are included in Table 3.8. These blend mandates of ReFUelEU only apply to intra-EU flights, which make up about 65% of the entire energy requirement (Davydenko & Hilbers, 2024). The demand for e-kerosene in each year per growth projection is shown in Table 3.8.

Jet fuel characteristics		Source
1250	L/ton	"Sustainable fuel conversions" (2024)
0.8	kg/L	"Sustainable fuel conversions" (2024)
159	L/barrel	"Sustainable fuel conversions" (2024)
67,100	barrels/day in 2022	"Netherlands: Jet fuel consumption" (2024)
=3,115,319	tonnes/year in 2022	
130	PJ/year in 2022	Davydenko & Hilbers (2024)
=23,964	tonnes/PJ	
150	PJ/year in 2030	
=3,594,599	tonnes/year in 2030	

Table 3.6: Conversion from PJ to tonnes a year for Jet Fuel

Jet Fuel projections	2030	2050	Annual growth
Slow growth	150 PJ/year =3,594,599 tonnes/year	170 PJ/year 4,073,878 tonnes/year	1 PJ/year 23,964 tonnes/year
Middle growth	150 PJ/year =3,594,599 tonnes/year	200 PJ/year 4,792,798 tonnes/year	4.5 PJ/year 59,910 tonnes/year
Fast growth	150 PJ/year =3,594,599 tonnes/year	240 PJ/year 5,751,358 tonnes/year	2.5 PJ/year 107,838 tonnes/year

Table 3.7: Dutch Jet fuel projections converted from PJ to tonnes a year (Davydenko & Hilbers, 2024)

	2030	2031	2032	2033	2034	2035
Blend mandate	0.7%	0.7%	1.2%	1.2%	2.0%	5.0%
Slow growth	3,594,599	3,618,563	3,642,527	3,666,491	3,690,455	3,714,419
PtL demand	16,355	16,464	28,412	28,599	47,976	120,719
Middle growth	3,594,599	3,654,509	3,714,419	3,774,329	3,834,239	3,894,149
PtL demand	16,355	16,628	28,972	29,440	49,845	126,560
Fast growth	3,594,599	3,702,437	3,810,275	3,918,112	4,025,950	4,133,788
PtL demand	16,355	16,846	29,720	30,561	52,337	134,348
Continued						
	2040	2045	2050			
Blend mandate	10.0%	15.0%	35.0%			
Slow growth	3,834,239	3,954,058	4,073,878			
PtL demand	249,226	385,521	926,807			
Middle growth	4,193,698	4,493,248	4,792,798			
PtL demand	272,590	438,092	1,090,362			
Fast growth	4,672,978	5,212,168	5,751,358			
PtL demand	303,744	508,186	1,308,434			

Table 3.8: E-kerosene demand per year, for slow, middle and fast fuel demand growth projections.

To estimate the current market conditions in the Netherlands, in this model there is one competitor in the Netherlands for the supply of e-kerosene. This plant has a smaller production capacity, producing 26,000 tonnes annually. The competing plant is assumed to expect the same commissioning date, but two years behind in development opposed to the modeled plant, being in the pre-feasibility stage within the design stage at the time of writing.

With this in mind, two scenarios will be modeled in the real option decision tree. Assuming that both plants are in the same stage now, the worst-case possibility would be that the competitor reaches commissioning earlier than the modeled plant. This would mean that the competitor first establishes supply contracts, covering the first 26,000 tonnes annually of the demand, as shown in Table 3.9. As seen here, if the modeled plant enters the operational stage in 2030, no revenue would be generated in the first years of operations. Only in its fifth operational year would the plant be able to supply to full capacity. The better scenario is shown in Table 3.10. Here, the modeled plant would be first to establish supply contracts and therefore cover the first 50,000 tonnes of annual demand. Also in this scenario, the fifth operational year is the first year the plant can sell up to full capacity. However, a larger part of the revenue is earned in the previous years of operation.

	2030	2031	2032	2033	2034	2035
Slow growth	-838 0%	-670 0%	17,710 5%	17,998 5%	47,809 44%	159,721 100%
Middle growth	-838 **0%**	-418 **0%**	18573 **6%**	19292 **7%**	50685 **48%**	168707 **100%**
Fast growth	-838 0%	-83 0%	19,723 7%	21,017 9%	54,519 53%	180,689 100%

Table 3.9: Unfavorable market conditions: Demand for the modeled plant if the competitor first establishes supply contracts

	2030	2031	2032	2033	2034
Slow growth	25,162 33%	25,330 33%	43,710 57%	43,998 57%	73,809 100%
Middle growth	25,162 **33%**	25,582 **33%**	44,573 **58%**	45,292 **59%**	76,685 **100%**
Fast growth	25,162 33%	25,917 34%	45,723 59%	47,017 61%	80,519 100%

Table 3.10: Favorable market conditions: Demand if the modeled plant establishes supply contracts first

As shown in both tables above, there are no great differences for the percentage supply between the 3 different growth projections. For all operational years, the "Middle growth" row shows the average values of the 3 growth projections. Since Davydenko & Hilbers (2024) do not specify whether one projection has a higher tendency to occur, it is assumed that all have the same probability. Therefore, the decision tree model can be simplified as shown in Figure 3. Here, only the mid-growth projection is used to find the PtL plant valuation for both market scenarios.

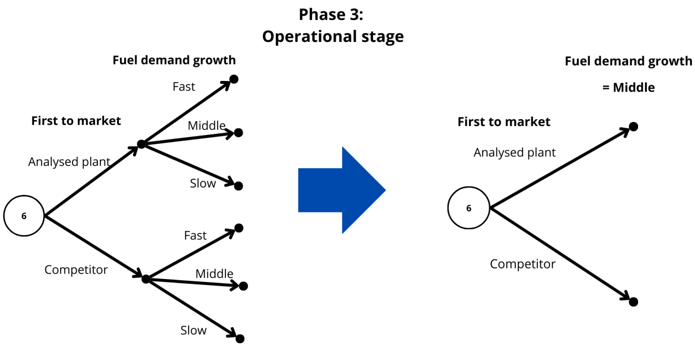


Figure 3: Phase 3 - Decision tree

3.2.2. Enterprise Value

The values at the end of the model represent the expected valuation of the plant after market introduction in both favorable and unfavorable market conditions, also known as the enterprise value (EV). The enterprise value is estimated by adding each discounted annual cash flow throughout the life of the plant. Equation 2 below is used to find each annual free cash flow (FCF). Here, FCF is the cash flow, EBIT is earnings before interest and taxes and Δ Net Working Capital is any change in net working capital. The depreciation is added back to the EBIT, as it is a non cash charge. In 2023, the tax rate applied to SAF producers in the Netherlands was 10%, according to the annual report of SAF producers Neste Oil (Neste, n.d.). The tax rate in this calculation is assumed to be constant throughout the life of the plant.

$$FCF = (EBIT(1 - TaxRate)) + Depreciation - CapitalExpenditures - \Delta NetWorkingCapital \quad (3.2)$$

Finally, the enterprise value in 2030 is determined by discounting all future free cash flows to the time of market entry in 2030 using the Weighted Average Cost of Capital (WACC). The WACC represents the average rate a company is required to pay to finance the project, which is commonly used as the discount rate to find the project valuation (Investopedia, 2024). Rojas-Michaga et al. (2023) use a discount rates of 10% as the nominal value in their techno-economic assessment, and take 8% and 12% as optimistic and pessimistic values in their uncertainty analysis. Gargalo et al. (2016) use a similar value of 10% for the discount rate for the DCF rate of return to assess early stage designs for glycerol valorization in bio-refinery concepts. They based their value on the interest rate representing the minimum rate of return the company is would to accept for a new investment (Gargalo et al., 2016). Since the projects in both papers are early technological stage refineries, the risk levels can be assumed to be similar. Therefore, the discount rates used in the papers before can be used as the WACC here. The enterprise value is found by using the equation below.

$$EV = \Sigma_i \frac{FCF_i}{(1 + WACC)^y} \quad (3.3)$$

Here, EV is the enterprise value, i is the operational year and y is the amount of years since market entry. The equity value is found by deducting the net debt from the equity value, as shown in Equation 3. Since most European e-kerosene projects are joined ventures formed by larger corporations, it is assumed that the project is entirely internally financed with no external debt. Hence, the Equity Value here is equal to the Enterprise Value.

$$EquityValue = EV - NetDebt \tag{3.4}$$

The DCF calculations for the different market conditions resulting from all findings of the above subsections are included in Appendix A. As shown here, the EV in 2030 found with favorable market conditions is 349.9 M EUR. The EV with unfavorable market conditions is 262.2 M EUR. Integrating these in the decision tree model together with the values found in the previous leaves us with the following model for the base case scenario:

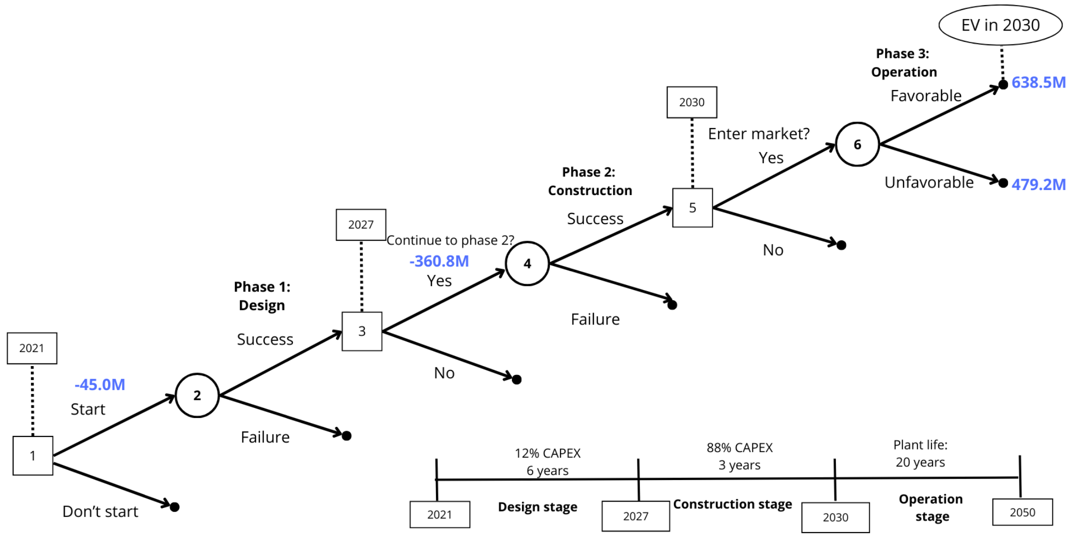


Figure 4: Updated decision tree model. Now also including the investments per project phase and the estimated valuation for both market states at start of operations.

3.3. Abandon Option

At every decision node in the tree model, there is an option to abandon. A project developer may choose to take this option whenever the present value of the project at the time is less than the project salvage value.

Determining an asset salvage value depends on a number of factors and is done in different ways. Loncar et al. (2017) designed the abandon option to sell assets for 85% of the CAPEX value spend at that time. "FasterCapital" (2024) describes different factors influence the salvage value. It depends on the state of the asset, annual depreciation, market trends, asset type, technological obsolescence and more.

During the first two project phases, the purchased equipment will only be used for testing and not for full capacity fuel production yet. Therefore, the amount of depreciation during the first two project phases will be less than during the operational life. The plant life is 20 years with linear depreciation during the operational lifetime, similar to used in Rojas-Michaga et al. (2023).

The PtL production involves emerging and novel technology. Next to this, the need for e-kerosene will remain for the upcoming decades because of the imposed European blend mandates. Therefore, the risk of technological obsolescence in this field is rather small. In the case where the plant cannot be repurposed to create e-kerosene for aviation, the fuel blend can be adjusted to create higher concentration of diesel and naphtha. Hence, the plant can be repurposed for supplying e-fuel for other forms of transportation requiring these fuel types. In addition, the Fischer-Tropsch system within can also be used to create desired fossil fuel blends. The modeled plant does not include DAC and electrolyzer units, but obtains hydrogen and CO2 externally. The hydrogen and CO2 do not need to have green origins for the plant to create fuel. Therefore, fossil fuel providers can also re-purpose the PtL plant equipment to produce fossil fuels. As for this reasoning, it is assumed that the demand for all purchased parts of the system will remain for the lifetime of the plant.

"FasterCapital" (2024) illustrate different methods for calculating the salvage value. The method used within this model is based on the "Replacement Cost Approach". Here, the salvage value is based on the asset replacement costs minus the depreciation, as shown below.

$$Salvagevalue = Replacementcost - Depreciation \tag{3.5}$$

Since the assets are purchased at different times within the first two phases, and the amount of usage differs from the operational phase, some adjustments to the equation method will be made to determine the salvage value. Following the investment values determined in Table 3.2, the average annual depreciation is shown in Figure 5.

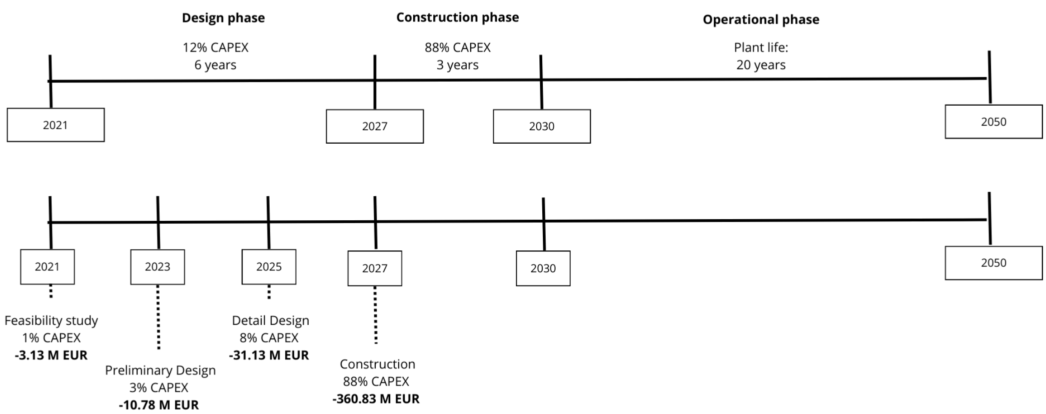


Figure 5: Timeline of investment per project phase. Based of Loncar et al. (2017)

Amount of Investment (EUR)	Depreciation period	Annual depreciation(EUR)
3,133,082	29	-108,037
10,783,266	27	-399,380
31,131,375	25	-1,245,255
360,833,062	23	-15,688,394

Table 3.11: Average annual depreciation per CAPEX investment

It is assumed that the investments will depreciate throughout the duration of the project. Regarding the amount of usage, it is assumed that the usage during the testing in the first two phases 10% compared to full capacity usage. Therefore, the depreciation per investment is divided accordingly:

$$TestingDepreciation = 10\% * AnnualDepreciation * TestingYears \tag{3.6}$$

The total operational depreciation in this case depends on the amount of usage. As seen in Table 3.10 and Table 3.9, the demand for PtL in the first operational years is lower than 100%. Therefore, the amount of usage in those years will also be lower. This leads to the following equation for the Operational Depreciation.

$$Depr_{FullCapacity} = (AnnualDepr * Operationalyears + 90\% * (AnnualDepr * Testingyears)) * \%AnnualDemand \quad (3.7)$$

Applying the equations above to the investments in the different stages, the values for depreciation per investment type are shown in Table 3.12. The depreciation values per project year for different market conditions are included in the Appendix.

Avg annual depr (EUR)	Testing years	Linear depr in testing	10% Capacity depr (EUR)	Operational years	Linear depr in operation (EUR)
-108,037	9	-972,336	-97,234	20	-2,160,746
-399,380	7	-2,795,662	-279,566	20	-7,987,604
-1,245,255	5	-6,226,275	-622,628	20	-24,905,100
-15,688,394	3	-47,065,182	-4,706,518	20	-313,767,880
Continued					
Full Capacity depr (EUR)	Total Asset depr (EUR)				
-3,035,848	-3,133,082				
-10,503,700	-10,783,266				
-30,508,748	-31,131,375				
-356,126,544	-360,833,06				
Total Depreciation (EUR)	**-405,880,786**				

Table 3.12: Calculation of depreciation for testing and full capacity production operational period.

Following the previous calculations, the salvage values at different times of the project has been determined in Figure 2. The resulting values are shown below in Equation 3.5. In the case of project failure, it is assumed that the assets become less valuable due to technical or market circumstances. Here, similar to Loncar et al. (2017), the assets are salvaged for 85% of the present value. Including these values leads to the following decision tree shown in Figure 6.

Node #	Year	Salvage value (EUR)
Node 1	2021	0
Node 2	2027 (failure)	37,887,983
Node 3	2027	44,574,098
Node 4	2030 (failure)	340,148,614
Node 5	2030	400,174,840

Table 3.13: Salvage value at different decision tree Nodes

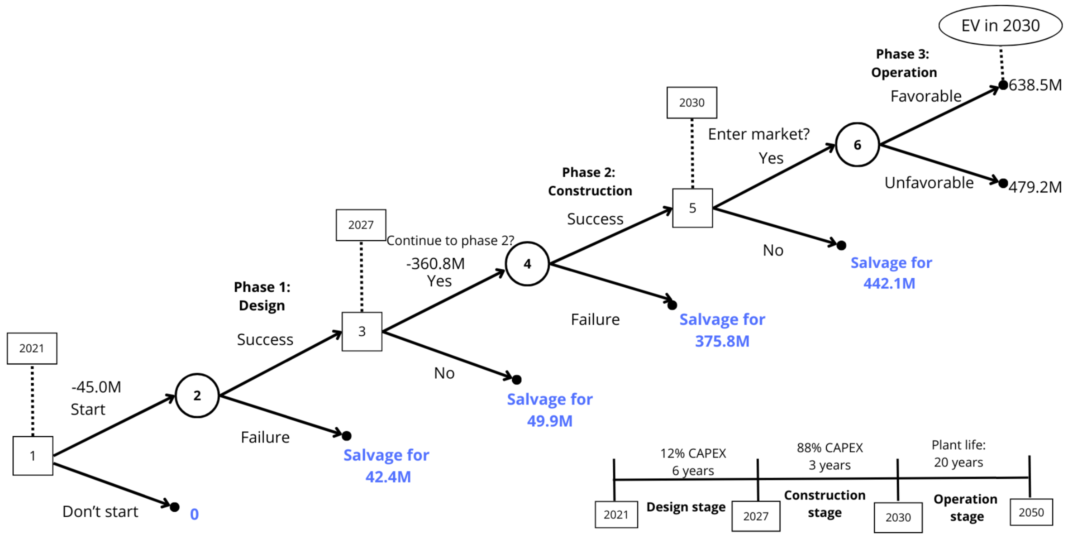


Figure 6: Updated decision tree model. Now also including the salvage values for the abandon options at every node.

3.4. Probability Distributions

The final step in completing the real option decision tree model is finding the probability of success during the different project phases. As mentioned in the previous chapter, external risk within different stages can be modeled within the real option decision tree. The higher the risk in different stages, the lower the NPV becomes. Therefore, the factors affecting the risk in different stages need to be adequately evaluated to determine the NPV correctly.

An assumption of using real option tree analysis is that the probability distribution are known (De Reyck et al., 2008). The probability distribution is usually based on subjective expert opinion or historical data from comparable projects. Since the technology of the analyzed project is emerging, no historical data on technological success or market risk is publicly available. In addition, the success of the PtL plant is largely dependent on other external factors, which are very uncertain in themselves. With the means available during the time of this thesis, the probability will be determined with subjective estimation instead. Here, the current and future estimated states of each risk factor are described and evaluated. Then, the risk will be valued within a probability range similar to that of a classical risk matrix, as shown in Table 3.14 (Ni et al., 2010). The probability value will then be estimated as the mean value within this range.

Description	Remote	Unlikely	Likely	Highly likely	Near certainty
Probability range	0.00-0.10	0.10-0.40	0.40-0.60	0.60-0.90	0.90-1.00

Table 3.14: Probability categories from the classical risk matrix (Ni et al., 2010)

The factors determining the probability of success differ per phase. For the Design Phase, the main aspect that influences probability is only the technological risk. In the Operational Phase, only the market risk influences the outcome. That is, whether the modeled plant reaches the market first and captures the main share of the market, or its competitor. However, the Construction Phase depends not only on technological risk, but also on external factors. During this phase, project developers need to establish supply contracts to obtain the green hydrogen and CO2 required for production. In addition, access to the electricity grid is required for operation. The high congestion on the grid in the Netherlands poses a hurdle for new companies, as electricity providers are denying access to the grid to maintain service quality (AGconnect, 2024). The relevant factors in each of these phases are described in more detail and evaluated according to the risk matrix in the following sections.

3.4.1. Green hydrogen availability

One of the key determinants of success for a PtL plant in the Netherlands is the future availability of green hydrogen, preferably within reasonable approximation. The availability of H2 for an e-kerosene plant depends mainly on two aspects: the estimated supply and the estimated level of demand and competition.

A study performed by the European Hydrogen Observatory in 2023 also investigated the demand per industry per European country for 2022. They distinguish demand for conventional hydrogen from green hydrogen. Where emerging hydrogen applications in the Netherlands only accounted for a small fraction of the entire conventional hydrogen demand, it was responsible for the vast majority of demand for green hydrogen in 2022 (EHO, 2023).
In terms of demand for green hydrogen, GasUnie reported that supply and demand in 2019 are 1.5M tonnes (or 175PJ) in the Netherlands, which consists entirely of gray hydrogen (GasUnie, 2019). They forecast the demand to grow using three scenarios, with low, medium, and high growth, shown in Figure 7. Here, the difference between the low and high demand scenarios is about 1,750 ktonnes/year in 2030. The sectors with the largest growth in demand are mobility, energy, and electricity. They also report that in a scenario where the demand is higher than in the middle scenario, importing hydrogen could be an option to meet the additional demand. This scenario would most likely only occur after 2030. The Dutch government also stated that international cooperation is required for the transition, due to the large predicted demand (*Waterstof*, n.d.).

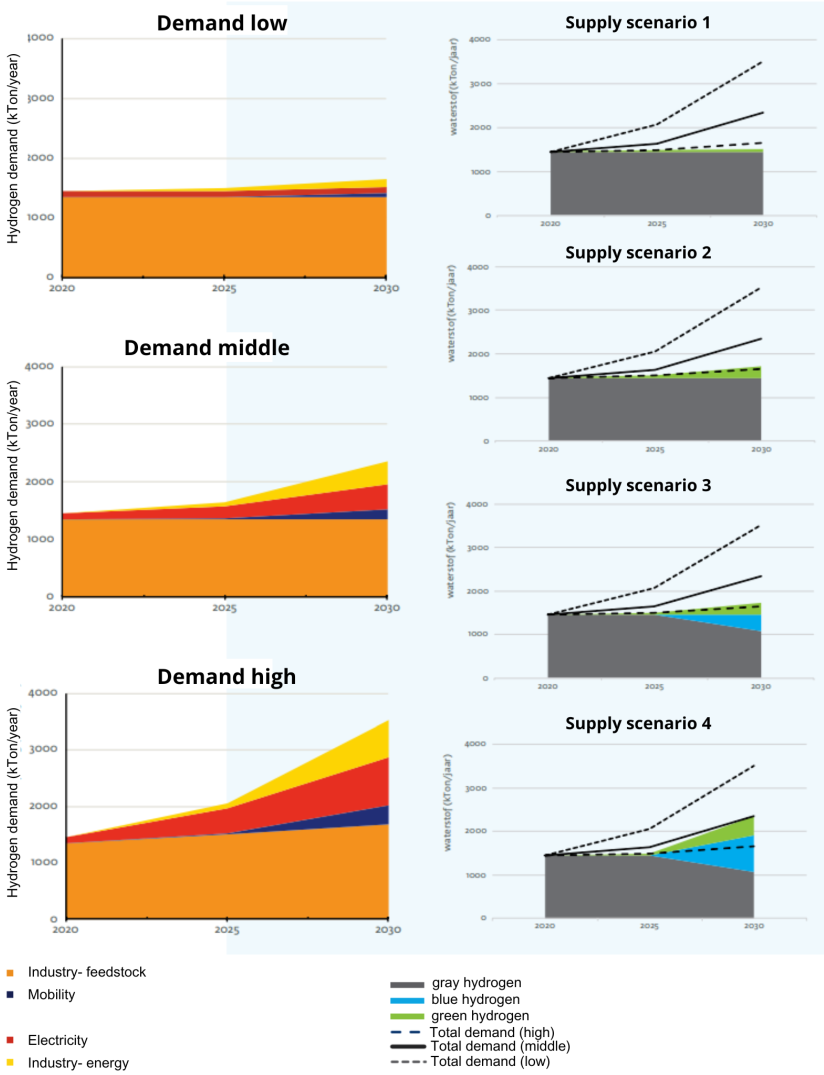


Figure 7: Hydrogen Supply & Demand Scenarios. Translated from GasUnie (2019)

For a e-kerosene plant producing 50.000 ton SAF annually, around 25.000 tonnes of green hydrogen would be required. Figure 7 shows the demand per sector. Comparing both the supply and demand projections, the orange sector in the demand graphs takes up the majority of the current gray hydrogen production. In all supply scenario's on right, the green hydrogen production only takes off after 2025. The supply graphs show that as of 2025 the gray hydrogen supply would either remain the same (scenario 1 & 2), or partially be replaced by blue hydrogen (scenario 3 & 4). As the demand Industry - feedstock will approximately stay the same in all demand scenario's, the graphs imply that this sector will only use gray and blue hydrogen. Since PtL production needs to be performed with green hydrogen to meet the sustainability standards, their only competitors will be those in the mobility, electricity and others in the Industry-energy sectors. In the 'Demand Middle' scenario, these sectors require about 600 kTon/year of green hydrogen in 2027 and about 1000 kTon/year in 2030. Therefore, according to these projections, the middle-demand will surpass the supply in all scenario's except in Supply scenario 4. Here, the green and blue hydrogen supply will meet the demand in 2028-2030.

According to an overview provided in 2022 by TKI Nieuw Gas, project leaders of Dutch green hydrogen initiatives are optimistic of achieving these supply numbers (NWP, n.d.). An updated hydrogen map, provided by MissieH2 and TKI Nieuw Gas, provides an up-to-date dashboard with their forecasted annual hydrogen production in the Netherlands (MissieH2, n.d.). As of the time of this report, they estimate the green hydrogen supply to be 33.5 ktonnes in 2026, 851ktonnes in 2028 and 1.555 ktonnes in 2030. The available capacity trend is shown here in Figure 8. Since this forecast is up to date, it provides a more accurate look at the supply and demand development.

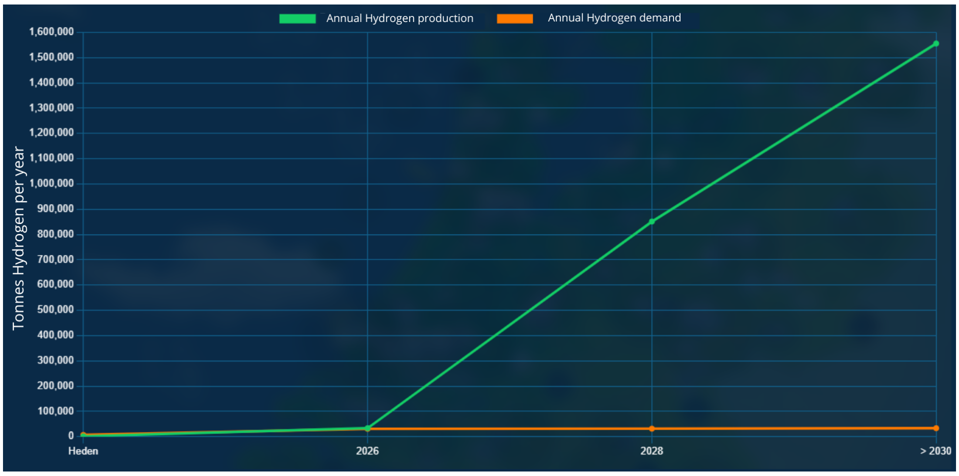


Figure 8: Green Hydrogen capacity forecast as of 2024: 33.5 ktonnes in 2026, 849ktonnes in 2028 and 1.554 ktonnes in 2030. Translated from (MissieH2, n.d.)

The green hydrogen demand projection is remaining low, similar to the "Demand low" scenario from Figure 7. It seems therefore unlikely that the demand will follow the "Demand high" scenario. However, it is likely that the demand will increase whenever more green hydrogen plants reach operation. The demand in 2030 for the "middle" scenario is around 280 PJ a year (GasUnie, 2019). This is equal to around 2,330ktonnes of hydrogen, of which 830ktonnes is green & blue hydrogen. If the demand will develop similar to the "middle" demand scenario and the supply develops according to shown in Figure 8.

Year	Demand (kTonnes)	Supply (kTonnes)
2025	250	33.0
2026	366	33.5
2027	482	408.8
2028	598	851
2029	714	1203
2030	830	1555

Table 3.15: Green hydrogen supply & demand according to Demand Middle (GasUnie, 2019) and supply (MissieH2, n.d.)

Figure 9 shows the current and expected status of all green hydrogen projects in the Netherlands. Even though the forecasted operational plants is increasing, it remains uncertain how many planned hydrogen projects will actually become operational. As of now, about 70% of the announced projects are not in the operational stage yet. About 48% still need to receive the final investment decision and about 25% is still in the concept phase.

Figure 9: Current and expected status of all green hydrogen projects in the Netherlands. Translated from (MissieH2, n.d.)

Despite this uncertainty, the number of announced hydrogen projects is still growing each year. The director of TKI Nieuw Gas states that even of only 10% of the announced projects makes it to market, that the supply would be sufficient to achieve the climate goal (SLUIJTERS, 2022). However, others suggest the current progress is insufficient to reach the climate goal. An study on behalf of the Ministry of Economic Affairs and Climate Policy states that based on their research the predicted electrolysis capacity only reaches 1.3 GW in 2030, therefore not reaching the 4GW target (Moerenhout et al., 2023). Their model suggests an increase in renewable hydrogen production around 2035-2040 instead.

Because of the relatively high level of expected demand of green hydrogen, and the mixed opinions on the potential availability of it, the overall availability of hydrogen probability in the beginning of the construction phase would fall in the "likely" category with a probability range of 60%-90%. As the Construction phase starts in 2027, the projected demand surpasses the projected supply, as seen in Table 3.15. Since the demand will be partly covered, the probably is estimated at the mean value of the range at 75%. Thereafter, in 2028, the supply surpasses the demand. However, since it is uncertain what part of the green hydrogen projects will reach the operational stage, the probability of green hydrogen availability will increase gradually to 100% in 2030.

3.4.2. Biogenic CO2 availability

The other key determinant is the consistent supply of CO2 for production. As described above, the CO2 source of the analyzed e-kerosene plant will be biogenic waste CO2, available from various types of sources. (CaptureMap, n.d.) shows the locations of these different sources in Europe and North America. As seen here, there are locations of all defined source types in the Netherlands.

Some national governments are considering carbon capture and storage (CCS) to meet the 2030 European emission goals. This technique includes capturing mostly industrial carbon emissions, transporting them via pipelines and storing them in a location underground. CCS projects mostly consider empty natural gas fields as a suitable place to store larger amounts of CO2. Essentially, as this CO2 does not end up in the atmosphere, industrial processes using fossil fuels are considered to be net-zero in CO2 emissions. CCS is considered mostly as a temporary, but necessary solution to limit the amount of CO2 emissions, as the industrial transition to sustainable energy takes longer than can be afforded (MilieuCentraal, n.d.). Potential competition for e-kerosene plants, however, is Bio-CCS. Here, biogenic carbon emissions are being captured and stored underground. Reason why this might be attractive for national governments to implement, is because this process removes CO2 from the carbon cycle.

As of 2026, the first major CCS projects in the Netherlands are planned to be operational (Porthos, n.d.). The Dutch government recently approved this first CCS project, in which fossil CO2 will be captured from industries in the Port of Rotterdam in an empty gas field under the North Sea (NOS, n.d.). This project is only concentrated to industrial plants in the Port of Rotterdam. Porthos will be executing this project. Their website states they work together with four potential customers and currently do not have sufficient capacity for additional customers. This suggests that for at least the first period after their deployment, no additional customers with fossil emissions will be making use of the CCS, let alone biogenic CO2. Another factor for limited availability for additional CCS locations in the Netherlands is the public acceptance. Another CCS was disapproved for this reason, as the gas field location was planned under an urban location in Barendrecht. Another potential option is to use the gas field in Groningen for CCS. If Porthos is successful with their first project, it is likely they will expand there.

As far as current information suggest, there are no plans in the Netherlands, nor in Europe, to perform CCS with biogenic captured CO2. Most likely because of the current abundance of industrial fossil CO2, and the limited capacity of the current CCS project. Therefore, the overall level of risk of potential competition for biogenic CO2 seems very low. Potentially the probability will increase in the next decades, but this would be a factor in the later stage of the PtL plants operational life. It is assumed that once supply contracts are established, consistent supply will remain over the entire lifetime of the plant. Therefore, the probability for biogenic CO2 availability is estimated to be "very likely", with a probability range of 90-100%.

3.4.3. Grid Capacity

Another main concern regarding the energy transition in general is the electricity grid capacity and the share of renewable electricity it supplies. ReFuelEU states that the production of synthetic jet fuels must be done with green electricity (Berg, 2023). The majority of the electricity required in the production of PtL fuel is used for the production of hydrogen through electrolysis (Batteiger et al., 2022),(Dietrich et al., 2018). Since the plant analyzed in this paper obtains hydrogen externally, a smaller percentage of green electricity is required for the remaining part.

The supply of renewable electricity in the Netherlands has grown rapidly in the past decade, as has the demand for renewable energy (StatisticsNetherlands, 2024). In 2023 the amount of renewable electricity production in the Netherlands had grown with 21% as compared to the prior year, contributing to 48% of electricity of the total amount of production (StatisticsNetherlands, 2024). The grid capacity has suffered because of the large supply and demand for renewable electricity, especially during peak production hours. To realize the electrification of the fossil industry, the capacity of the grid must grow accordingly, which takes time and significant investment (AGconnect, 2024). As a consequence, companies wanting to request access to the energy grid are facing more difficulties. The Dutch government has recognized this as a problem for the energy transition and came with a plan for accelerated expansion of the grid (TweedeKamer, 2024). NetbeheerNederland (2024) shows a map of the grid consumption in the Netherlands. The map shows that in the Port of Amsterdam, the projected locations for two e-kerosene plants to be built in the next decade, no electricity transport capacity is available at this moment. Therefore, there will be significant difficulty in obtaining the required permits for an energy plant in a crowded industrial environment as such.

On the one hand, this presents a problem for e-kerosene developers aiming to start operations. However, this presents an opportunity to grow the hydrogen economy and electrolysis capacity. At peak solar and wind hours, there is an abundance of electricity supply that the grid cannot accept. If energy producers do not have sufficient battery capacity to store electricity, it will essentially go to waste. Due to this problem, the first electrolyzer in the Netherlands was built as a result (GroenLeven, 2022). The Dutch government also sees investing in batteries and electrolyzers as a part of the solution to alleviate the electricity grid (TweedeKamer, 2024). Therefore, increasing the green hydrogen supply capacity is one of the requirements to relieve grid congestion. Following this, the probability of sufficient grid capacity in the Netherlands at the time of construction is similar to that of the hydrogen availability; they are interdependent. Therefore, the probability of sufficient grid capacity will be in the same probability range: 60-90%. In the decision tree model, the mean value of this range of 75% will be used.

3.4.4. Technical and Market Risk

In chapter 2 the PtL process system is described along with the maturity level. The total TRL level in the system is in the range of 6-9 in 2022 (Batteiger et al., 2022). Without an electrolyzer and direct air capture, most key process components are in TRL 9. Only the rWGS reactor necessary for the production of PtL via the Fischer-Tropsch pathway remains at TRL 6 (Markowitsch et al., 2023). This implies that there is low technical risk during the first two phases of the project. Therefore, the technical risk in Phase 1 is estimated to be higher than in Phase 2 due to technological maturity. Therefore, the probability of success in terms of technological risk in Phase 1 is estimated to fall into the 'likely' range, with a mean value of 75%. The success probability in phase 2 is estimated to fall in the "most likely" range, with a mean value of 95%.

The probability of market success in Phase 3 is based on the likelihood that the modeled plant reaches the market first and captures the main share of the market. As stated before, the competing plant in the model is in the pre-feasibility stage in 2024. Translated into the decision tree phases, the modeled plant is about two years ahead of its competitor. Both plants have to deal with the same external risks. Therefore, it seems unlikely that the competitor will catch up. However, the competing plant is planning to produce at a smaller annual capacity of 26,000 tonnes. Therefore, it might be somewhat easier for the smaller plant to establish hydrogen and CO2 supply contracts in times of shortage. In addition, a smaller plant puts less pressure on the electricity grid.

Overall, the likelihood that the competitor reaches market first still seems somewhat small. Therefore, the probability the modeled plant will reach market first will fall into the range of 60-90%. For the base case model, the mean value of this range of 75% will be used.

3.4.5. Probability determination

Following the probability estimations done in the previous sections, the main values of each probability range are used to find the probabilities for success and failure in Phase 2. This is shown in the following equations.

$$\begin{aligned} P_{success}(Phase2) &= P_{H2} * P_{CO2} * P_{Grid} * P_{Tech} \\ &= 75\% * 95\% * 75\% * 95\% \\ P_{success}(Phase2) &= 50.8\% \end{aligned} \tag{3.8}$$

$$\begin{aligned} P_{Failure}(Phase2) &= 100\% - P(Success) \\ &= 100\% - 51\% = 49.2\% \end{aligned} \tag{3.9}$$

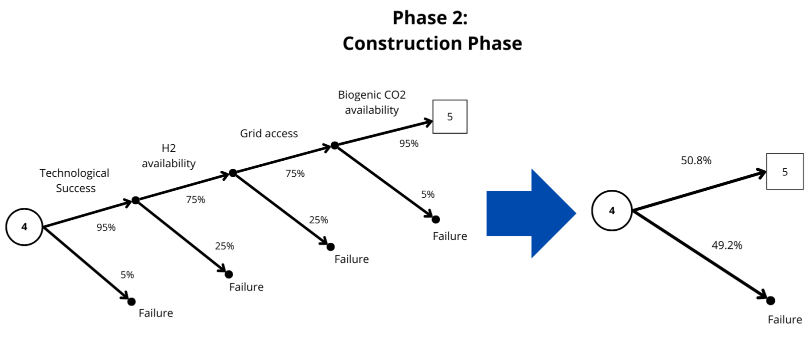


Figure 10: Probability distribution of Phase 2 expanded.

Along with the other probability values, the final decision tree model for the base case can be drawn as shown in Figure 11

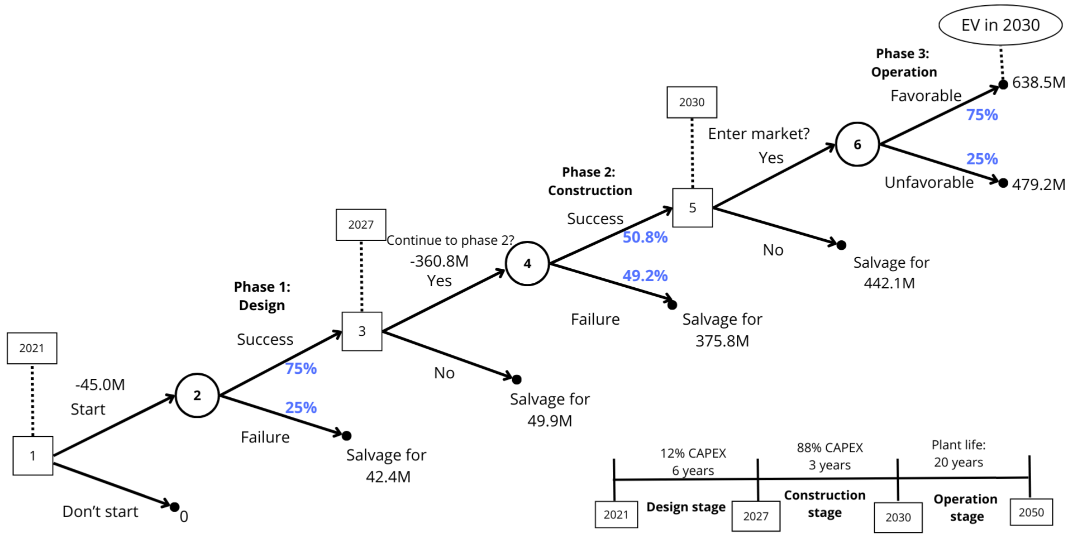


Figure 11: Final decision tree model for the base case. Now also the probability distributions for each project phase.

3.5. Policy Scenarios

Now the base case decision tree model is finalized, the effect of policy incentives on the NPV can be investigated within different scenarios. The base case will be defined as Scenario 1. The policy incentives will be analyzed individually or in combination with others, as shown in Table 3.16. An explanation of each incentive is given in Table 3.17. The incentives are used alone and in combination with others to find which has the most effect on the project NPV.

Scenario	Description
Scenario 1	No extra policies
Scenario 2	Market risk = 0%
Scenario 3	Market risk = 0% + Tax cut
Scenario 4	Average EIF grant
Scenario 5	Tax cut + average EIF grant
Scenario 6.1	Market risk = 0% + average EIF grant
Scenario 6.2	Market risk = 0% + average EIF grant + wait period Node 3

Table 3.16: Option Tree Policy Scenarios

Policy Incentive	Explanation
Market risk = 0%	Policy makers ensure that the modeled plant can supply 100% of their max capacity for the entire life of the plant. This increases enterprise value and eliminates risk in Phase 3.
Average EIF grant	An average sized EIF grant (for projects in similar sectors) is awarded at the start of the project, reducing the project CAPEX.
Tax cut	The plant is exempt from paying taxes on their earnings. This increases the EV in both Market conditions.

Table 3.17: Explanation policy incentives

To find a representative EIF grant size to use in Scenarios 4 to 6, recent grants are compared in Table 3.18.

As shown here, for grants awarded by the European Innovation Fund (EIF) in 2023 and 2024 for projects with a similar sector, the average grant size is 57.1M EUR.

Acronym	Country	Technology	Sector	Start-date	Grant (EUR M)
Columbus	Belgium	e-methane	Refineries	01/01/2024	68.6
eM-Rhone	France	e-methanol	Chemicals	01/01/2024	115.2
FirstBio2Shipping	Netherlands	Bio-LNG	Biofuels and bio-refineries	1/1/2022	4.3
SOL	Netherlands	Sugar Oil	Biofuels and bio-refineries	01/06/2023	4
BIOZIN	Norway	Biofuels	Biofuels and bio-refineries	01/01/2023	75
E-fuel pilot	Norway	e-fuels	Refineries	01/01/2024	40
Triskelion	Spain	Green Methanol	Refineries	01/01/2024	48.8
W4W	Spain	?	Biofuels and bio-refineries	01/01/2022	2.5
BioOstrand	Sweden	Biofuels	Biofuels and bio-refineries	01/01/2024	166.6
HySkies	Sweden	e-fuels	Refineries	01/01/2024	80.2
BioOstrand	Norway	e-fuel	Refineries	01/07/2023	40
Nordic Electrofuel	Norway	e-fuel	Refineries	01/07/2023	40
				Average grant size	57.1

Table 3.18: Comparable EIF grants awarded in 2023 and 2024 (EuropeanCommission, n.d.)

To find the influence of the external risks in Phase 2 on the NPV, Scenario 6 is divided into two sub-scenarios. Here, Scenario 6.2 includes a waiting period before deciding to continue to Phase 2. The construction phase is expected to start in 2027 and take 3 years. The estimated probability of availability during phase 2 was 75%. The waiting period is interesting to analyze because, as mentioned in subsection 3.4.1, the expected green hydrogen availability in the Netherlands will increase at a higher rate from 2026 to 2030. Here, 2028 is the first year where the expected green hydrogen supply exceeds the demand. However, this largely depends on the amount of hydrogen projects actually making it to the operational stage. Therefore, the probability is modeled to linearly increase to 100% in 2030. As the grid access probability was defined to follow that of the hydrogen availability, this probability will follow the same trend. The resulting probabilities for Phase 2 per year are shown below in Table 3.19. As the success probability increases, there will be a trade-off between this probability and the cost of capital. This, because the cost of capital increases with a longer waiting period.

Start Phase 2	t Wait(years)	H2 certainty in year x	Success phase 2	Failure phase 2
2027	0	75%	50.8%	49.2%
2028	1	83.33%	62.7%	37.3%
2029	2	91.67%	75.8%	24.2%
2030	3	100%	90.3%	9.8%
2031	4	100 %	90.3%	9.8%
...	...	...	...	...

Table 3.19: Success probability Phase 2 over the years

4 Results

This section includes the results of the real option valuation for the 7 policy scenarios defined in section 3.5. The model obtained in Figure 11 for the base case is adapted based on the influence of the scenario-specific incentives. The resulting trees with the NPV calculations are shown and discussed in the following. The present value for the decision nodes will be discussed in reversed order, as the real option calculation happens to finish to start.

4.1. Scenario 1

The results for Scenario 1 are summarized in Figure 1 and Table 4.1. As seen in the table, the present value at t=9 years is 598.7M EUR, higher than the salvage value. Therefore, the decision at node 5 would be to enter the market. However, within Phase 2, the relatively low probability of success and high CAPEX costs significantly lower the present value when discounting to t=6 years. As a result, the value is lower than the salvage value, which results in a recommendation to abandon at node 3. Therefore, the present value at t=6 years changes to that of the salvage value: 49.9 M EUR. After discounting this to t=0 years, a resulting NPV of -6.20 M EUR is obtained. Because this is a negative value, the recommendation for this base-case scenario would be not to start the project.

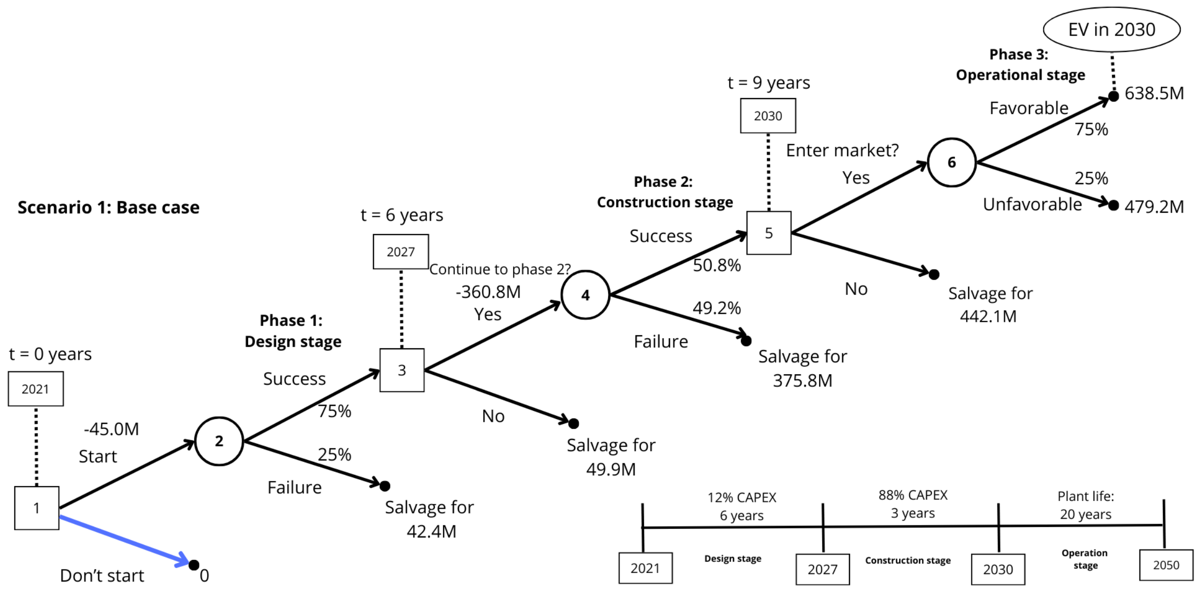


Figure 1: Scenario 1 - decision tree result

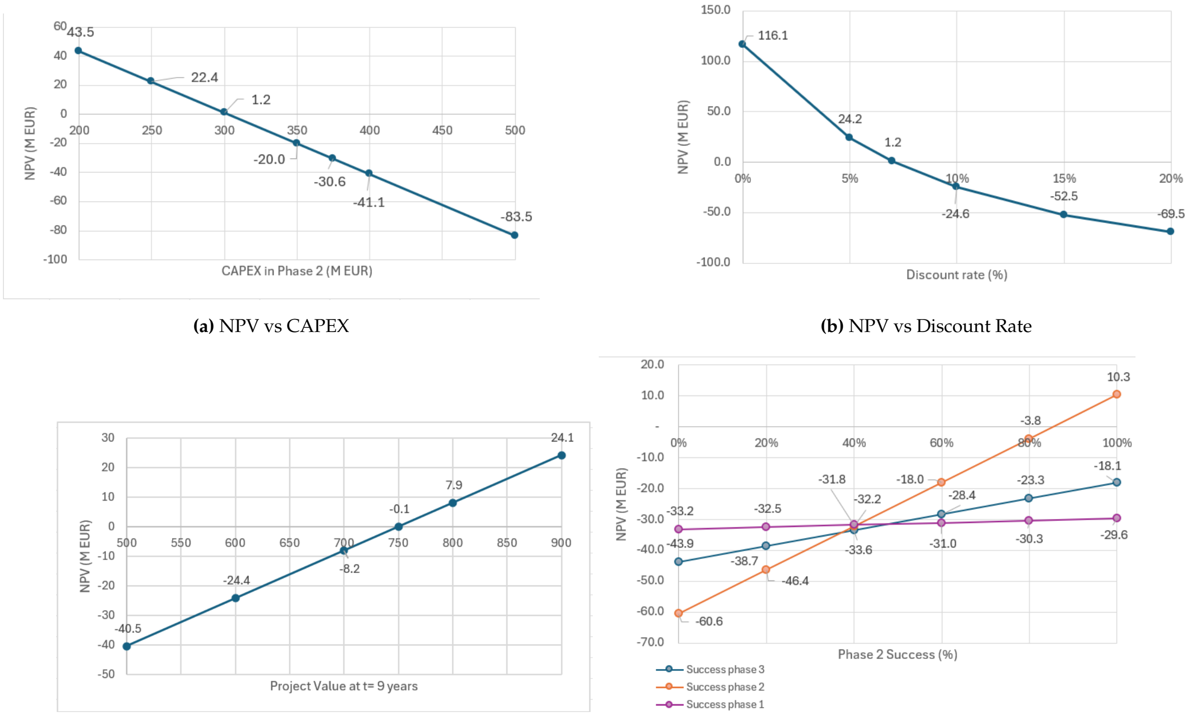
Table 4.1: Real option calculation for Scenario 1

Scenario 1	**Base case - no policies**				
WACC	10%				
Node 6	End Phase 3	2050			
	Market conditions Phase 3	Favorable	75%	Unfavorable	25%
	EV		638.51 M EUR		479.21 M EUR
	value at t=9	598.68 M EUR			
Node 5	Start Phase 3	2030			
	time since start	9 years			
Proceed?	**Value if YES**	**598.7 M EUR**	Value if NO	442.12 M EUR	
Node 4	Probability success Phase 2	Success	50.8%	Failure	49.2%
	value at t=9		598.68 M EUR		375.80 M EUR
Node 3	Duration Phase 2	3 years			
	Costs Phase 2	-360.83 M EUR			
Proceed?	Value if YES	6.52M EUR	**Value if NO**	**49.89 M EUR**	
Node 2	Probability success Phase 1	Success	75%	Failure	25%
	value at t=6		49.89 M EUR		42.41 M EUR
Node 1	Duration stages in Phase 1	2 years	2 years	2 years	
	Costs Phase 1 1	-3.13 M EUR	-10.8M EUR	-31.3 M EUR	
Start?	Value if YES	-6.20M EUR	**Value if NO**	**0 M EUR**	
NPV at t=0	**-6.20 M EUR**				
	Don't Start				

To see which individual policy incentives would influence the NPV the most, the NPV is plotted with relation to various parameters below. Knowing which impact the NPV the most, gives an indication on which (combination of) incentives to invest in. As seen in the figure below, the NPV decreases linearly with increasing CAPEX in Phase 2. This happens at a rate of -0.42 M EUR NPV/M EUR CAPEX. It shows that the NPV will be positive when the CAPEX in Phase 2 is somewhat less than 350M EUR. Figure 2c shows that also the discount rate as great impact on the NPV. For a discount rate of less than 7%, the NPV will be greater than zero. If the project value at t=9 years increases, the NPV will as well. This happens at a linear rate of about 0.16 M EUR NPV/M EUR PV. Therefore, a million euro change in the Phase 2 CAPEX has a greater impact on the NPV than an equal change in the project value at the start of operations. Because of this, it is expected that obtaining a grant in Phase 2 would have a greater impact on the project NPV than measures to optimizing market turnover in the operational Phase 3.

Figure 2d shows the impact on the NPV of varying success probabilities of the 3 different phases. As seen in the figure, the NPV increases linearly for all 3 success probabilities, however, with different slopes. The orange line, representing the success probability of Phase 2, has the highest slope and therefore the most impact on the NPV. The success of Phase 1 varies the NPV the least. This shows that measures reducing the risk in Phase 2 would be more effective for increasing the NPV than measures increasing market success in Phase 3 or reducing technical risk in Phase 1.

Figure 2: Comparative Statics for base case without policy incentives.



(a) NPV vs CAPEX

(b) NPV vs Discount Rate

(c) NPV vs Project Value at t=9 years

(d) NPV vs % Success of the Project Phases

4.2. Scenario 2

The results for Scenario 2 are summarized in Figure 3 and Table 4.2. This scenario is similar to the first; however, here the effect of policy measures that optimize the market conditions in the operational stage is evaluated. This model assumes that the plant can supply 100% of its maximum capacity a year. Policies that would enable this could either be a higher mix mandate in 2030-2033 and/or a monopoly right, where the plant would be entitled to the first 50,000 tonnes of e-kerosene of the total demand. These measures result in an increase in the anticipated value of the enterprise in 2030 and a rise in market success to 100%.

As seen in Table 4.2, the present value at t=9 years in this scenario has increased to 669.9 M EUR, which is higher than in the base scenario. Therefore, like in Scenario 1, the decision at Node 5 would be to enter the market. After discounting to t=6 years, however, the present value remains lower than the salvage value at that point. Because of this, the decision at Node 3 would be to abandon the project and sell the assets. Therefore, the new present value at t= 6 years is equal to the salvage value. Discounting this to t=0 again results in a NPV of -6.2 M EUR and a recommendation not to start the project at Node 1.

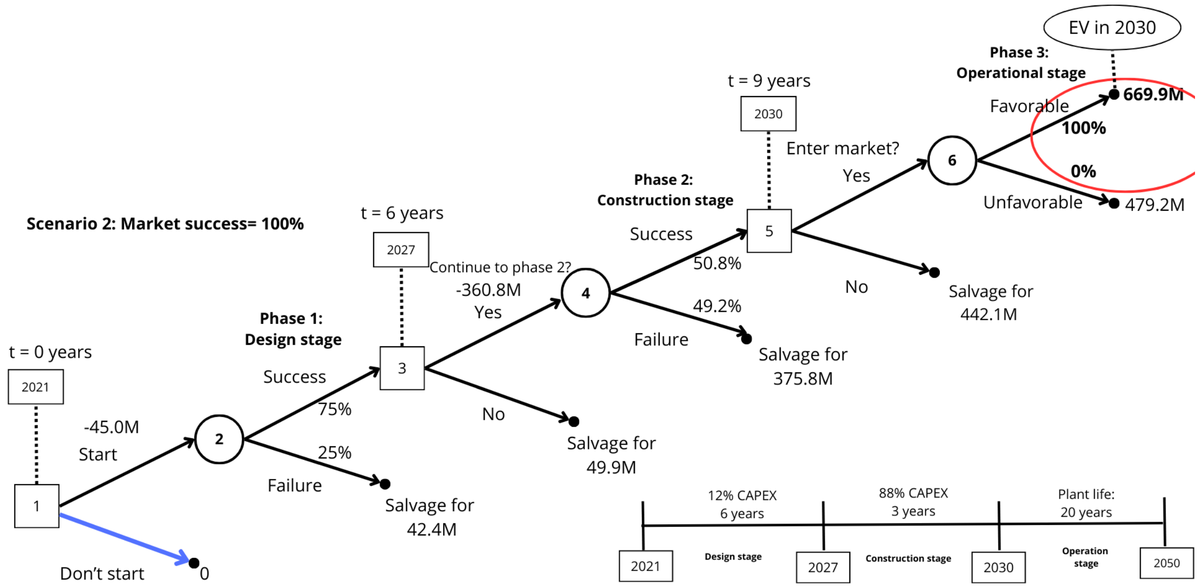


Figure 3: Scenario 2 - decision tree result

Table 4.2: Real option calculation for Scenario 2

Scenario 2	**Market Success -> 100%**				
WACC	10%				
Node 6	End Phase 3	2050			
	Market conditions Phase 3	Favorable	100%	Unfavorable	0%
	EV		669.93 M EUR		479.21 M EUR
	value at t=9	669.93 M EUR			
Node 5	Start Phase 3	2030			
	time since start	9 years			
Proceed?	**Value if YES**	**669.93 M EUR**	Value if NO	375.80 M EUR	
Node 4	Probability success Phase 2	Success	50.8%	Failure	49.2%
	value at t=9		669.9 M EUR		375.80 M EUR
Node 3	Duration Phase 2	3 years			
	Costs Phase 2	-360.83 M EUR			
Proceed?	Value if YES	33.69 M EUR	**Value if NO**	**49.89 M EUR**	
Node 2	Probability success Phase 1	Success	75%	Failure	25%
	value at t=6		49.89 M EUR		42.41 M EUR
Node 1	Duration stages in Phase 1	2 years	2 years	2 years	
	Costs Phase 1 1	-3.13 M EUR	-10.8M EUR	-31.3 M EUR	
Start?	Value if YES	-6.20M EUR	**Value if NO**	**0 M EUR**	
NPV at t=0	**-6.20 M EUR**				
	Don't Start				

4.3. Scenario 3

The results for Scenario 3 are summarized in Figure 4 and Table 4.3. This scenario adds to Scenario 2, where in addition to optimal market conditions, a tax cut for PtL fuel sales is also included to increase accumulated cash flow over 20 years of operation. Discounting all tax cash flows over the plant lifetime for the optimal market conditional, as shown in section A.4, to 2030 results in an cumulative value of around 53.6 M EUR. Here, the tax rate is 10% tax rate, as in the standard scenario. Discounting all cash flows to the start of operations results in an enterprise value of 723.5 M EUR with optimal market conditions. As market certainty is 100% in this scenario, this is also the present value at t = 9 years. Therefore, unlike before, the present value is high enough to recommend the decision maker to proceed to Phase 2 at Node 3. However, when discounting to t = 0 years, the technical risk and CAPEX costs in phase 1 are still too high to result in a positive NPV. Therefore, for Scenario 3 the advice is not to start the project at Node 1.

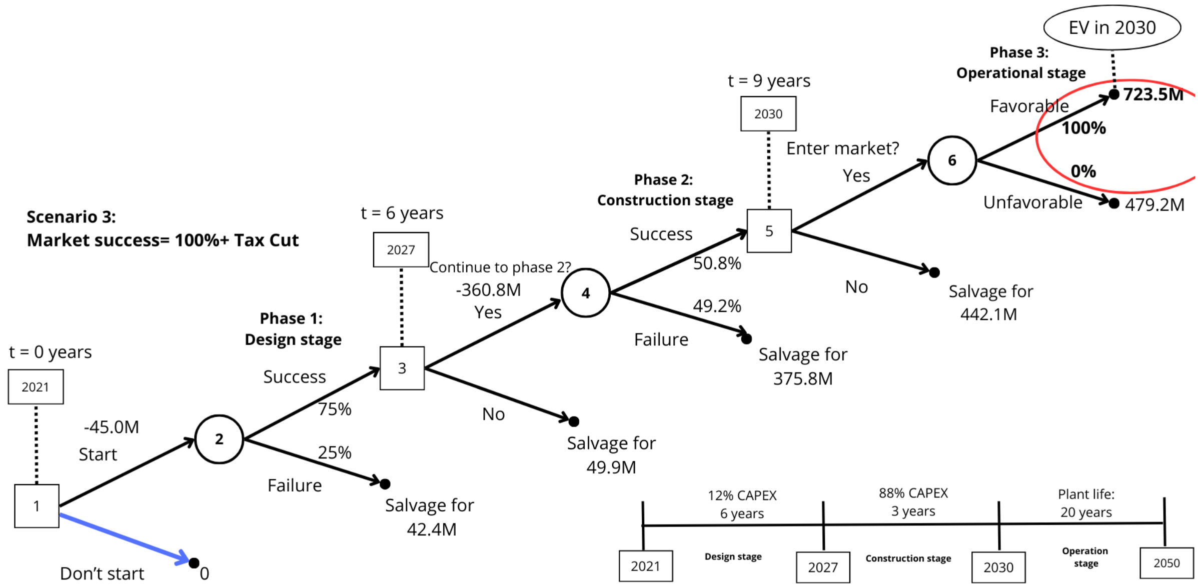


Figure 4: Scenario 3 - decision tree result

Table 4.3: Real option calculation for Scenario 3

Scenario 3 WACC Taxes	**Market Success -> 100% + Tax Cut** 10% 0%				
Node 6	End Phase 3 Market conditions Phase 3 EV	2050 Favorable	100% 723.55 M EUR	Unfavorable	0% 322.99 M EUR
	value at t=9	723.55 M EUR			
Node 5	Start Phase 3 time since start	2030 9 years			
Proceed?	**Value if YES**	**723.55 M EUR**	Value if NO	442.12 M EUR	
Node 4	Probability success Phase 2 value at t=9	Success	50.8% 723.55 M EUR	Failure	49.2% 375.80 M EUR
Node 3	Duration Phase 2 Costs Phase 2	3 years -360.83 M EUR			
Proceed?	**Value if YES**	**54.14 M EUR**	Value if NO	49.89 M EUR	
Node 2	Probability success Phase 1 value at t=6	Success	75% 54.14 M EUR	Failure	25% 42.41 M EUR
Node 1 Start?	Duration stages in Phase 1 Costs Phase 1 1 Value if YES	2 years -3.13 M EUR -4.40M EUR	2 years -10.8M EUR **Value if NO**	2 years -31.3 M EUR **0 M EUR**	
NPV at t=0	**-4.40M EUR** ***Don't Start***				

4.4. Scenario 4

Scenario 4 shows the effect of obtaining an average sized EIF grant of 57.1 EUR. This grant would be awarded at the start of Phase 2, whenever the design phase has been successfully finalized. The grant reduces the CAPEX costs in that stage from 360.8 to 303.7 million EUR. As seen above in the comparative analysis for scenario 1, lowering the CAPEX has a relatively large effect on the NPV. Figure 5 and Table 4.4 and show the resulting decision tree and the NPV calculations. Like in the base scenario, the decision at Node 5 is to enter the market. Although here the present value is lower at t= 9 years compared to the previous two scenarios, the present value at t= 6 years is significantly higher. Since the value is higher than the salvage value, the decision at node 3 would be to start phase 2. When discounting the project value to t = 0 years, the technical risk and CAPEX costs in Phase 1 result in a slight negative NPV of -0.4 M EUR. Therefore, the recommendation remains not to start the project at decision Node 1 when the grant size is 57.1M. However, as previously seen in Figure 2a, a slightly lower CAPEX in Phase 2, around 300M, results in a positive NPV. Therefore, the grant size only has to increase slightly for the recommendation to change at Node 1.

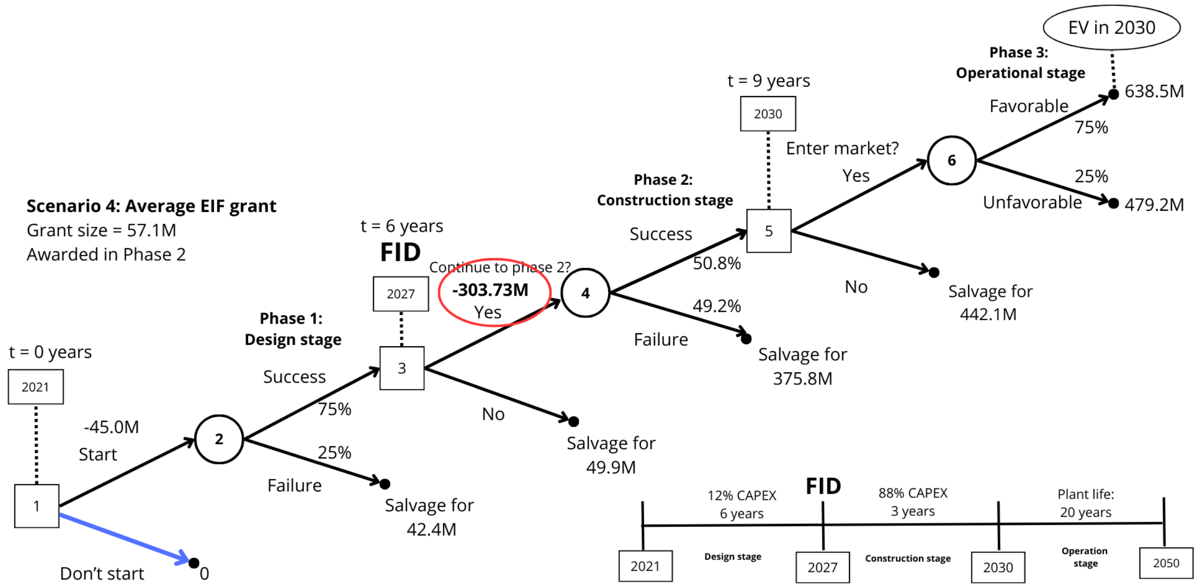


Figure 5: Scenario 4 - decision tree result

Table 4.4: Real option calculation for Scenario 4

Scenario 4 WACC EIF Grant at Phase 2	**EIF Grant** 10% 57.1 M EUR				
Node 6	End Phase 3 Market conditions Phase 3 EV	2050 Favorable	 75% 638.51 M EUR	 Unfavorable	 25% 479.21 M EUR
	value at t=9	598.68 M EUR			
Node 5	Start Phase 3 time since start	2030 9 years			
Proceed?	**Value if YES**	**598.68 M EUR**	Value if NO	442.12 M EUR	
Node 4	Probability success Phase 2 value at t=9	Success	50.8% 598.68 M EUR	Failure	49.2% 375.80 M EUR
Node 3	Duration Phase 2 Costs Phase 2	3 years -303.73 M EUR			
Proceed?	**Value if YES**	**63.62 M EUR**	Value if NO	49.89 M EUR	
Node 2	Probability success Phase 1 value at t=6	Success	75% 63.62 M EUR	Failure	25% 42.41 M EUR
Node 1 Start?	Duration stages in Phase 1 Costs Phase 1 1 Value if YES	2 years -3.13 M EUR -0.39M EUR	2 years -10.8M EUR **Value if NO**	2 years -31.3 M EUR **0 M EUR**	
NPV at t=0	**-0.39M EUR** ***Don't Start***				

4.5. Scenario 5

Scenario 5 illustrates the situation when policy makers do not want to influence the market dynamics in Phase 3 more than currently done. Instead, a tax cut applies for the sales of PtL fuel within the expected market conditions, along with an EIF grant awarded of 57.1M EUR at the start of Phase 2. Unlike in Scenario 3, where policy incentives allow the plant to run at full capacity throughout its lifetime, here the tax cut is applied with the expected market conditions. Table 4.5 shows that the amount of tax savings is slightly lower than found in Scenario 3.

The results of applying the tax cut and awarding the grant in Phase 2 are summarized in Figure 6 and Table 4.6. As seen here, the tax cut will increase the value of the company in favorable and unfavorable market conditions as compared to the base case scenario. The grant decreases the CAPEX costs in Phase 2.

Table 4.5: Discounted tax revenue in 2030 for expected market conditions

	Favorable market	Unfavorable market
10% tax	692.93	519.96
Disc tax revenue	54.43	40.75
Market expectancy	75%	25%
Resulting discounted tax revenue in 2030	51.01	

The increased EV for both market conditions result in a higher present value at t = 9 years compared to the base scenario. Therefore, the decision at Node 5 would again be to enter the market. Discounting to t= 6, while including the success probability and costs of Phase 2, the present value would be 83.1 M EUR at the start of the Phase. This is about twice the size of the salvage value at that time. Therefore, the decision at Node 3 would be to continue to Phase 2. After discounting to t=0 years, while including the costs per stage and the project risk in Phase 1, the resulting NPV equals 7.85 M EUR. As the NPV is positive, the recommendation to the decision maker at Node 1 in this scenario would be to start the project.

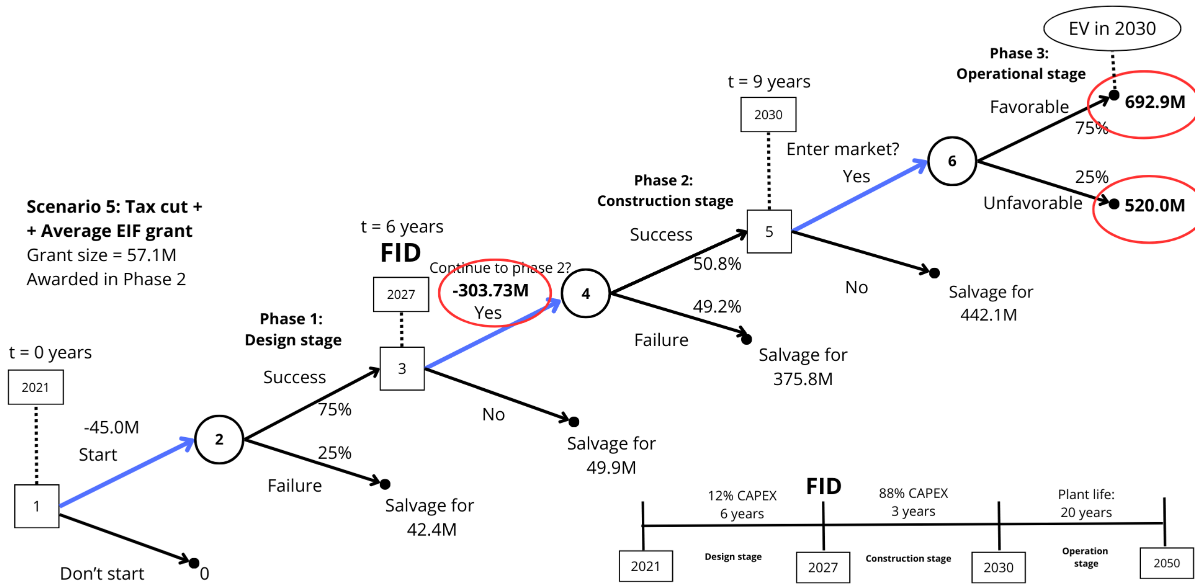


Figure 6: Scenario 5 - decision tree result

Table 4.6: Real option calculation for Scenario 5

Scenario 5	**Tax Cut + EIF Grant**				
WACC	10%				
Taxes	0%				
EIF Grant at Phase 2	57.1 M EUR				
Node 6	End Phase 3	2050			
	Market conditions Phase 3	Favorable	75%	Unfavorable	25%
	EV		692.93 M EUR		518.96 M EUR
	value at t=9	649.69 M EUR			
Node 5	Start Phase 3	2030			
	time since start	9 years			
Proceed?	**Value if YES**	**649.69 M EUR**	Value if NO	442.12 M EUR	
Node 4	Probability success Phase 2	Success	50.8%	Failure	49.2%
	value at t=9		649.69 M EUR		375.80 M EUR
Node 3	Duration Phase 2	3 years			
	Costs Phase 2	-303.73 M EUR			
Proceed?	**Value if YES**	**83.1 M EUR**	Value if NO	49.9 M EUR	
Node 2	Probability success Phase 1	Success	75%	Failure	25%
	value at t=6		83.1 M EUR		42.41 M EUR
Node 1	Duration stages in Phase 1	2 years	2 years	2 years	
	Costs Phase 1 1	-3.13 M EUR	-10.8M EUR	-31.3 M EUR	
Start?	**Value if YES**	**7.85 M EUR**	Value if NO	0 M EUR	
NPV at t=0	**7.85 M EUR**				
	Start				

4.6. Scenario 6.1

Scenario 6.1 combines the effect of optimal market conditions through policy incentives and the inclusion of an average sized EIF grant, as circled in red in Figure 6. Like in the previous scenario, the grant reduces the CAPEX in Phase 2 to 303.7 M EUR. In Phase 3, optimal market conditions are reflected in the market success of 100% with an increase in the enterprise value of 669.9M EUR. The market conditions in Phase 3 result in the present value at t = 9 years of 669.9 M EUR, which is high enough to decide to enter the market at node 5. Subtracting the CAPEX in Phase 2 and applying the success probability, discounting this value to t = 6 years results in a present value of 90.8 M EUR. This is significantly higher than the salvage value at that point. Therefore, the decision at node 3 would be to start Phase 2. Discounting to t = 0, while including CAPEX and success probability, the resulting NPV is 11.1 M EUR. As the NPV is positive, the recommendation to the decision maker at node 1 in this scenario would be to start the project.

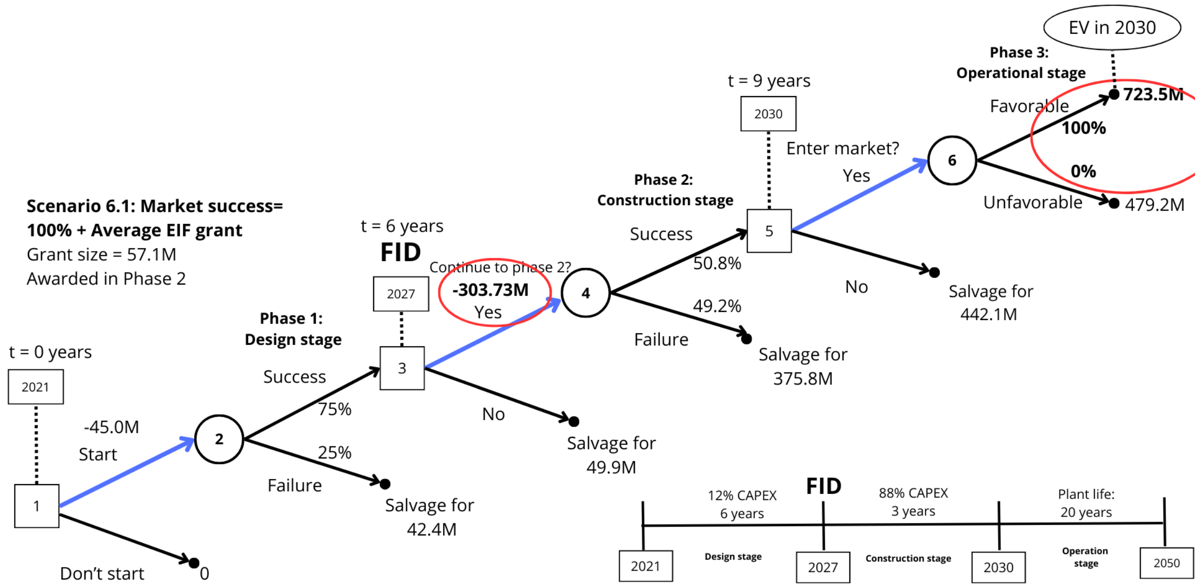


Figure 7: Scenario 6.1 - decision tree result

Table 4.7: Real option calculation for Scenario 6.1

Scenario 6.1 WACC EIF Grant at Phase 2	**Market Success -> 100% + EIF Grant** 10% 57.1 M EUR				
Node 6	End Phase 3 Market conditions Phase 3 EV	2050 Favorable	 100% 669.93 M EUR	 Unfavorable	 0% 479.21 M EUR
	value at t=9	669.93 M EUR			
Node 5	Start Phase 3 time since start	2030 9 years			
Proceed?	**Value if YES**	**669.93 M EUR**	Value if NO	442.12 M EUR	
Node 4	Probability success Phase 2 value at t=9	Success	50.8% 669.93 M EUR	Failure	49.2% 375.80 M EUR
Node 3	Duration Phase 2 Costs Phase 2	3 years -303.73 M EUR			
Proceed?	**Value if YES**	**90.79 M EUR**	Value if NO	49.89 M EUR	
Node 2	Probability success Phase 1 value at t=6	Success	75% 90.79 M EUR	Failure	25% 42.41 M EUR
Node 1 Start?	Duration stages in Phase 1 Costs Phase 1 1 **Value if YES**	2 years -3.13 M EUR **11.12M EUR**	2 years -10.8M EUR Value if NO	2 years -31.3 M EUR 0 M EUR	
NPV at t=0	**11.12M EUR** ***Start***				

4.7. Scenario 6.2

As seen in all previous scenario's, the value of the PtL plant drastically decreases during the Construction Phase 2. This could be due to high project investment costs but also because of the high risk. Scenario 6.2 describes the situation where the hydrogen availability and the grid congestion risk are reduced in the event of waiting. As discussed in previous sections, the amount of green hydrogen expected from electrolysis is substantially higher in the Netherlands as of 2030. The increased hydrogen production will alleviate grid congestion as renewable energy produced in access will instead be used for hydrogen production. In combination with the higher share of renewable energy within the grid, the success probability of grid access will also increase with time. Since the PtL plant stimulates the green hydrogen market, obtaining contracts for green hydrogen supply and grid connection are assumed to go hand in hand. Therefore, the success probabilities for Phase 2 increase by waiting, as previously determined in Table 3.19. However, more factors come into play when initiating a waiting period. The project value will have to be discounted over more years, which decreases the value the longer the waiting period. In addition, assets will also depreciate for a longer period, which also decreases the value of the project over time. However, the inflation rate has a positive impact on the asset value. As the salvage value was defined by the replacement costs of the assets minus the depreciation, inflation increases the replacement costs of the assets. Using the success probabilities previously determined per year for Phase 2, the resulting NPV values per number of waiting years are shown in Table 4.8. Figure 8 shows the NPV plotted versus the number of waiting years before starting Phase 2.

Year	t Wait (years)	H2 certainty	Success	Value @ Node 2 (M EUR)	NPV (M EUR)
2027	0	75%	50.8%	90.8	11.1
2028	1	83.33%	62.7%	100.8	15.3
2029	2	91.67%	75.8%	108.8	18.7
2030	3	100%	90.3%	114.9	21.3
2031	4	100 %	90.3%	98.4	14.3
2032	5	100%	90.3%	83.7	8.1
2033	6	100%	90.3%	70.8	2.7
2034	7	100%	90.3	59.4	-2.2
2035	8	100%	90.3%	49.4	-6.4

Table 4.8: NPV calculations per amount of waiting time for Scenario 6.2

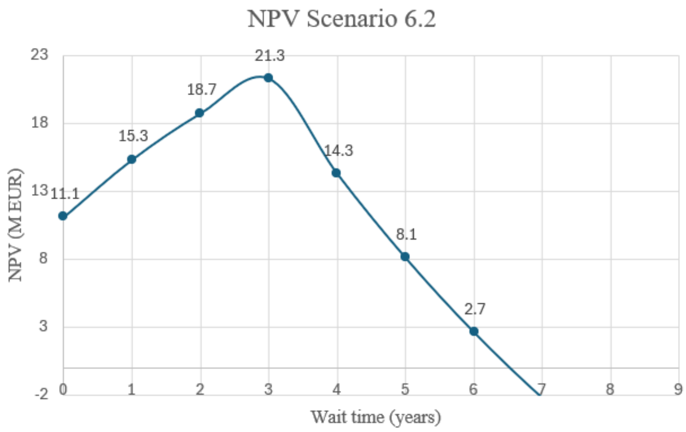


Figure 8: NPV versus waiting time at Node 3 for Scenario 6.2. Trade-off between higher success probability in Phase 2 and increased cost of capital and depreciation

Figure 8 shows that for waiting time 0-3 years, the NPV increases linearly. According to the figures above, the optimum waiting period resulting in the highest NPV is 3 years. Thereafter, the NPV decreases at a steep rate because of the cost of capital and the asset depreciation.

The waiting period of 3 years, the optimal market conditions and the EIF grant are modeled in the decision tree shown in Figure 9. The NPV calculation for this scenario is shown in detail in Table 4.9. As seen here, like in Scenario 6.1, the optimal market conditions the market success in Phase 3 and the enterprise value. Therefore, like in any other scenario, the decision at Node 5 would be to enter the market. The waiting period of 3 years resulted in a success probability in Phase 2 of 90.3%. The CAPEX costs in Phase 2 are decreased because of the EIF grant, but increased because of inflation. Together, discounting to t=6 years yields a value of 114.9 M EUR. This is higher than the salvage value at that time. Therefore, the recommendation is to wait 3 years before starting Phase 2. In turn, the project value can be discounted to t= 0 years, which results in a NPV of 21.3 M EUR. Because of this, the recommendation at Node 1 would be to start the project in this scenario.

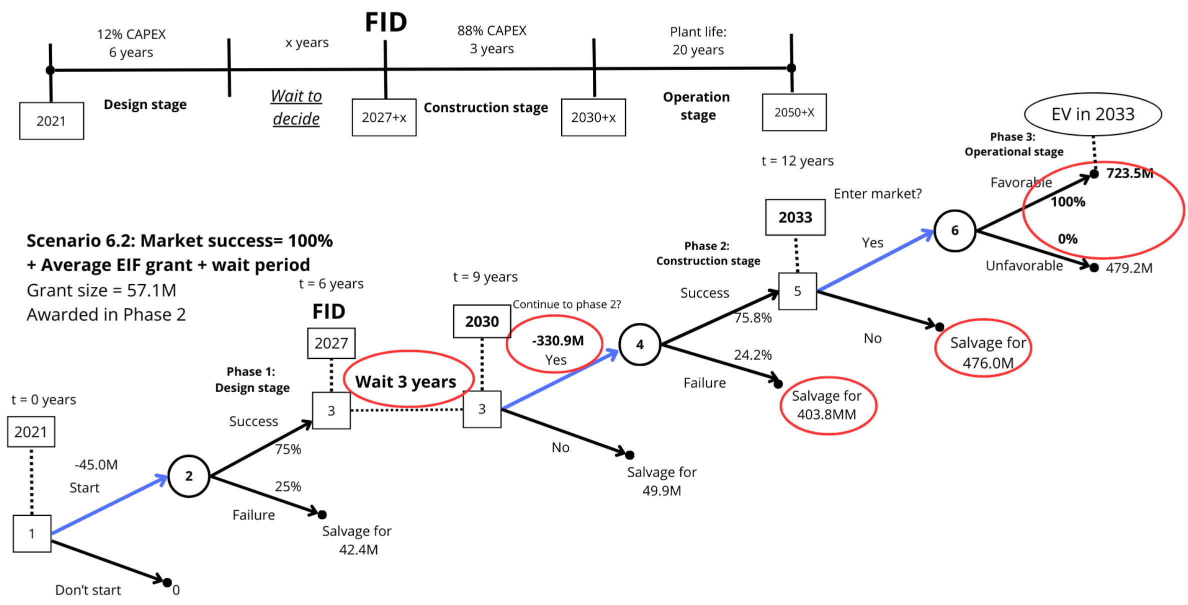


Figure 9: Scenario 6.2 - decision tree result

Table 4.9: Real option calculation for Scenario 6.2

Scenario 6.2 WACC EIF Grant at Phase 2	**Market Success = 100% + EIF Grant + Wait period @ Node 3** 10% 57.1 M EUR				
Node 6	End Phase 3 Market conditions Phase 3 EV	2050 Favorable	 100% 669.93 M EUR	 Unfavorable	 0% 479.21 M EUR
	value at t=9	669.93 M EUR			
Node 5	Start Phase 3 time since start	2030 9 years			
Proceed?	**Value if YES**	**669.93 M EUR**	Value if NO	403.75 M EUR	
Node 4	Probability success Phase 2 value at t=9	Success	90.3% 669.9 M EUR	Failure	9.8% 403.75 M EUR
Node 3 Start Phase 2?	Duration Phase 2 Costs Phase 2 **Value if YES**	3 years -330.93 M EUR **152.9 M EUR**	 Value if NO	 49.9 M EUR	
Wait to decide	3 years				
Proceed?	**Value if YES**	**114.87 M EUR**	Value if NO	37.5 M EUR	
Node 2	Probability success Phase 1 value at t=6	Success	75% 114.87 M EUR	Failure	25% 42.41 M EUR
Node 1 Start?	Duration stages in Phase 1 Costs Phase 1 1 **Value if YES**	2 years -3.13 M EUR **21.31M EUR**	2 years -10.8M EUR Value if NO	2 years -31.3 M EUR 0 M EUR	
NPV at t=0	**21.31 M EUR** ***Start***				

4.8. Interpretation of Results

Seven different scenarios for the PtL plant model were evaluated to find the net present value of each using the analysis of the real option tree. Table 4.10 shows these different scenarios along with the NPV at the start of the project t=0.

Scenario	Description	NPV in 2030 (M EUR)	in 2027 (M EUR)	in 2021 (M EUR)
Scenario 1	No extra policies	598.7	6.5 (->Sell designs for 49.9M)	-6.2
Scenario 2	Market risk = 0%	669.9	33.7 (->Sell designs for 49.9M)	-6.2
Scenario 3	Market risk = 0% + Tax cut	723.5	54.14	-4.4
Scenario 4	Average EIF grant	598.7	63.6	-0.4
Scenario 5	Tax cut + average EIF grant	692.9	99.6	7.85
Scenario 6.1	Market risk = 0% + average EIF grant	669.9	90.8	11.1
Scenario 6.2	Market risk = 0% + average EIF grant + wait period at node 3	669.9 (in 2033)	114.9	21.3

Table 4.10: Results of Option Tree Scenarios

From the results of these scenarios and the comparative statics of Figure 2 can be concluded that awarding a grant to reduce CAPEX costs in Phase 2 of the project is the most effective individual policy instrument to increase the project NPV. However, none of the instruments result in a positive NPV by themselves. Solely lowering the market risk at the operational stage is not sufficient, nor is only awarding an average EIF grant. The EIF grant was applied in by itself in Scenario 4, which resulted in a slight negative NPV. However, as shown in Figure 2a, when the grant size is slightly increased to 58.1M EUR, the NPV will reach the turning point. When the CAPEX in Phase 2 lowers to around 300 M EUR, the NPV at t=0 shifts to a positive value.

Reason why a grant affects the NPV as much is because of the high CAPEX costs early in the project. Obtaining feedstock externally instead of investing an electrolyzer unit and a direct air capture system already reduces the early CAPEX costs significantly, yet, the remainder still has a great impact on the project NPV. In addition, the plant creates no revenue in the first two stages of the project. The longer the duration of the two, the higher the cost of capital that affects the project value. The impact of the CAPEX would even be higher for plants wanting to develop these in house. This could be reason why the vast majority of full scale plants currently in development in Europe are choosing to source their CO2 externally rather than developing solutions in-house. Even though direct air capture systems provide a more secure supply compared to recycled biogenic carbon with limited availability, the systems low TRL level requires too high investment costs to be profitable in the current situation without additional funds.

When the average sized EIF grant was applied in combination with other instruments, in Scenarios 5, 6.1 and 6.2, the resulted in a positive NPV. Scenarios 5 and 6.1 portray the tree model with the average EIF grant and either optimal market conditions through additional policies or a complete tax cut on e-fuel revenues. As seen in the results of the two, the NPV of Scenario 6.1 is higher than that of Scenario 5. Therefore, the combination with market certainty seems most effective in optimizing the project NPV.

Scenario 6.2 replicated the situation of Scenario 6.1 with introducing a waiting period before starting Phase 2. Implementing a waiting period was found to be favorable, as the NPV at t= 0 increases when implementing a waiting period of 0-3 years because of the risk reduction in Phase 2. In addition, the resulting NPV is would be higher in the with a waiting period of 0-4 years compared to that of Scenario 6.1. However, increasing the cost of capital and asset depreciation will outweigh the benefits of waiting for the years beyond that. Ultimately, waiting for more than 6 years will result in a negative NPV.

5 Discussion

5.1. Contribution and Implication

Like in most emerging markets, government intervention is required for a new technology to become successful in the current regime. The results of this analysis show that PtL plants producing high volumes of e-kerosene can potentially be successful in the Netherlands. Following the work of previous techno-economical analysis of these plant types, risk and options are incorporated within the calculation to enrich the valuation model. Therefore, the methodology used in this analysis provides a more fitting representation of PtL plant project development within the Dutch landscape specifically. The application of real option decision tree in combination with the policy scenarios gives policy makers a framework to find which mechanisms would give most optimal results. The scenario's defined in this study show some of the possibilities, but additional ones could be created to provide more insight. Other scenario's including incentives with different intensities, for example, a higher grant size, less market incentives and a waiting period in Phase 2 can be evaluated. The buttons of the framework allow for adjustment to see under which conditions the PtL project would yield a positive NPV.

As mentioned earlier in this paper, there have currently 25 large scale e-kerosene projects been announced in Europe. As the decision tree modeled in this paper is based on the PtL plant landscape in the Netherlands specifically, the results of this analysis specifically are not directly generalizable. Moreover, the base case scenario in the Netherlands is not equal to that of Norway. The difference with other geographical context mostly lies in the feedstock and grid congestion risk, which determine the success probability of Phase 2. In addition, the market demand also varies in different European countries, as there is a different competitor landscape and demand for aviation fuel. However, the framework of this model can be applied to evaluate other PtL plants in the world. If the parameters within the tree model stages are adjusted correctly, this methodology provides a useful tool to evaluate PtL projects feasibility in each respective geographical context.

5.1.1. Strategies

For European and Dutch policy makers wanting to stimulate the development of PtL plants in the Netherlands, the results of the different scenarios show which combination of policy incentives has the greatest impact on the NPV of a PtL plant in this context. Although creating demand through blend mandates is essential for creating market demand for e-jet fuel, the model shows that optimizing the market conditions in the aviation fuel market by itself is not sufficient for these plants to start operations. Instead, the high CAPEX and risk of feedstock availability showed to be the two most influential factors to the project NPV. Therefore, despite recommendations of other papers, the main focus should not only be on creating additional market demand for e-fuels in the aviation sector. Although helpful in increasing the project NPV, other measures showed to have a higher impact. Instead, the focus should be on allocating additional funds through grants at the start of the project. In addition, measures increasing hydrogen and green electricity availability, therefore lowering the risk in Phase 2, will significantly improve the NPV of these plants.

From an investing standpoint, more aspects need to be considered for allocating an EIF grant. For example, whether the amount of emission savings e-kerosene plants account for justifies the size of grant. Perhaps projects from other industries result in similar emission savings with a smaller grant size. On the other hand, lowering emissions in the aviation industry is proven to be difficult in the shorter term, while the demand for flying is only increasing. Since grant money is scarce, and multiple emerging sustainability projects from other industries also require investment, the grant commission need to decide which projects have priority over the other, and consider alternative routes. In the event where funds need to be spread over more projects, a combination of scenario 5 and 6 would also be an option. The tax cut would partially make up for the smaller grant size, however, this option will cost more over time as the state misses out on a significant sum of tax income.

Another option would to be to increase the probability of green hydrogen availability and grid connection for the PtL plant. The risk in Phase 2 can be lowered by either government intervention or by waiting for further market development. Delaying the construction phase until 2030 would be beneficial, as the anticipated hydrogen certainty and grid congestion risk will diminish as their capacity increases. However, the market risk in this case increases, as the chance the competitor reaches market first increases with a longer waiting period. This could be resolved by increased demand in the early years of operation and creating optimal market conditions for the PtL plant. Additional policies could be created by the Dutch national government prioritizing hydrogen and green electricity supply to PtL plants in the Netherlands. In collaboration with policy makers, project developers and operators can adjust their business strategies depending on how the hydrogen and green electricity markets develop.

Another strategy for the plant operators is to (partially) rely on fossil feedstock for the earlier years of operation to generate revenue. Since the plant does not require green feedstock for fuel production, the operational phase can commence in 2030 with an adjusted business strategy. Since all SAF are only approved as a blend-in fuel up to 50% with fossil kerosene, fuel providers can offer a modified deal providing part e-kerosene and part fossil kerosene. This way, contracts supplying airlines and other industries with part e- and part fossil fuels can be made, entirely shifting to e-fuels at a later stage. This will generate an earlier revenue stream and lower the hydrogen certainty risk in Phase 2. The overall Phase 2 risk would not be as low as in Scenario 6.2, as there would still be high grid congestion risk.

The results of the paper also indicate the trade-off between sustainability and economic values. In all cases for policy incentive types, the financial burden will lie on one of the stakeholder groups. Awarding high EIF grants to PtL plants might come to the expense of other emerging projects types, and put the financial burden on the European Union and in turn, on polluting industries, who will increase prices for the consumer. Incentives to increasing the market demand for e-SAF might seem to not have a direct monetary consequence for national governments, it brings indirect consequences. Increasing taxes for fossil kerosene and reducing them for SAF might aid the market demand for SAF fuel, however, it will in turn increase the overall flight ticket prices for passengers. Since the SAF blend mandates only hold for intra-EU flights and only up to 50% blend-in limit, consumers might turn to alternative transportation modes when airfares increase too much. Less turnover within Dutch the aviation industry leads to less tax revenue for the Dutch government. This can be problematic when the market transition period is too short, as the Dutch economy and other stakeholders are depended on the aviation industry. On the other hand, change is required, since a growing market mainly reliable on fossil fuels will continue to cause harm to its environment. Policy makers will need to find which incentives would lead to the most plausible trade-off in this situation. Change will need to happen slow, so the consumer will not carry the entire burden. Stakeholders need to well informed and on board, so they can adapt to the changing market.

5.2. Limitations and Recommendations for Future Work

Overall, the application of a real option decision tree to this case shows the effect of project and market risk on the NPV, as well as the option flexibility to wait or abandon. It shows that for the same scenario, a real option valuation results in a much lower NPV than the NPV determined by discounted cash flow analysis. Basing an investment decision solely on DCF analysis can be misguiding, as it paints a overly optimistic picture of the project value, as no risk in included in the analysis. Real option valuation is a step forward to a more realistic conclusion. The decision tree model method used in this analysis, however, is a simplified version of reality. The options at nodes 1, 3 and 5 are binary, to proceed or to stop. Only Scenario 6.2 includes an option to wait. The modeled project phases result in either success or failure. In reality, there are infinite routes to take, which are very difficult to summarize in a decision tree model. Likewise, the revenue forecast, like all forecasts, remains an estimation. We cannot predict the future, especially when it includes high risk emerging technologies. In addition, the model uses the assumption of the project being entirely financed by its overarching corporations, with no external debt. In reality, additional capital may be required externally, therefore lowering the expected enterprise value. Hence, the model and the numbers involved remain a simplified estimation of reality. Future studies could work on improving the model and adding more complexity to it. For example, options to expand in the operational stage, or investing in direct air capture development for the carbon source.

In addition, the CAPEX and OPEX values have been taken from earlier literature on this subject. This was a techno-economic analysis on a PtL plant, which in turn, also relied on theoretical assumptions of costs. Because retrieving financial information from PtL plant projects in practice was not doable with the means and time frame of this thesis, the findings from literature were used within the decision tree analysis. Moreover, one of the main limitations of this study was the absence of expert and market data to base the project and market risk on. With the absence of e-kerosene specific performance and forecast data, the method for the probability estimation was based on subjective estimation. An inherent assumption of real option valuation is that the market and technical risk values are known. Since this case is rather novel, no such information is publicly available.

In addition, the success of the PtL plant is largely dependent on the development of green hydrogen and other external factors, which are very uncertain in itself. Therefore, the present and future status of the factors that influence the project development were investigated. Each risk was then valued within the Likert scale and assigned a probability range. As this remains a very rough estimation of reality, the results of this study do not paint a precise picture of reality. Rather, it provides a method for project developers to do so with the right information. It also shows how different values interact with each other. Future studies can focus on gathering empirical data and expert opinions on technical and market risk. This can be done by conducting interviews or performing a field study so see the current status and hurdles of developing a PtL plant in real time. Based on these, a more precise risk estimation for the probability distribution can be made to improve the model.

6 Conclusion

This thesis aimed to answer the following research question:

Which potential policy incentive scenario will yield a positive net present value for a Power-to-Liquid (PtL) fuel plant with 50,000 tonnes annual jet-fuel capacity in the Netherlands?

From the evaluation of the policy scenarios was found that the base scenario representing the current situation resulted in a negative NPV. The comparative statics showed that CAPEX reduction and Phase 2 risk reduction in this scenario would impact the NPV the most. Therefore, incentives such as the EIF grant awarding or green hydrogen and electricity supply prioritization are most effective to increase the NPV. However, each by itself is not sufficient for a positive NPV. When the grant size was increased with 1M EUR and beyond, the NPV surpassed the turning point and became positive. The scenarios combining the average sized EIF grant with market optimization, a complete tax cut or a waiting period to reduce green hydrogen and electricity supply risk resulted in a positive net present value. The project value of an emerging technology project like a PtL e-kerosene plant is highly depended on various external factors. Estimating the project value without including these does not paint an adequate picture of the actual project value. Of these factors, the project risk and high investment cost in the early stages have the most impact on whether the project would be worth pursuing or not. The application of real options in this field is novel and shown to be insightful, as risk in managerial flexibility in different phases can be modeled within the valuation. The inclusion of multiple policy scenarios show how the NPV can be influenced based on the combination of policy types present. Policy makers can this model as a framework to find for which variation of incentives the project becomes financially viable.

Recommendations for future work in this field include optimizing the decision tree model with data sourced from field studies and expert interviews to refine values for technical, market and feedstock risk. The cash flow forecast can be updated to reflect the actual anticipated market demand and the CAPEX and OPEX costs from industry sources. Next to that, the decision tree model can be expanded to include more option types.

The main take-away of this study is that the current market landscape in the Netherlands does not allow a large scale e-kerosene plant to be financially viable. Only when a combination of policy incentives are applied, mainly those lowering earlier CAPEX costs and green hydrogen and electricity availability risk, the business case for such plant would be feasible. The demand for international transportation will only increase over the next years. If the Dutch government and the European Union want to reduce aviation reductions through the use of PtL e-kerosene, more is required to be done than currently incentivized for these projects to become operational and successful in the long-term. The focus needs to shift towards lowering capital expenditures for PtL plant construction and reducing feedstock supply risk in the following years. Only then can the first two full scale plant in the Netherlands continue to the next phases of their projects and eventually cover the market demand of the first years following 2030. A trade-off needs to be made by all stakeholders in the industry between sustainability and economic values to enable this. Achieving this balance will be necessary to ensure the both environmental and economic objectives are met, enabling a sustainable and prosperous future for the Dutch aviation industry.

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A

Discounted Cash Flow Analysis

A.1. Phase 1 & 2

Selling price (SP) Jet fuel in 2030	5,799	EUR/t	Max capacity jet fuel	50,000	t/year	Annual price decay	-1.516%		
SP Diesel in 2030	1,525	EUR/t	diesel	8,333					
SP Naphtha in 2030	719	EUR/t	naphtha	8,333					
OPEX	4,234	EUR/t							
disc	10%								
tax	0.10								
Inflation after 2025	2.9%								
	Initiate		Evaluate		Design		Construction		
	2021	2022	2023	2024	2025	2026	2027	2028	2029
T cash flow	-	1	2	3	4	5	6	7	8
T operation	-	-	-	-	-	-	-	-	-
Item									
Gross revenues full capacity	-	-	-	-	-	-	-	-	-
Favorable market demand									
Revenue from Jet Fuel									
Revenue from Diesel									
Revenue from Naphtha									
Total Gross Revenues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
OPEX	-	-	-	-	-	-	-	-	-
EBITDA	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Depreciation	-10,804	-10,804	-50,742	-50,742	-175,267	-175,267	-1,744,107	-1,744,107	-1,744,107
EBIT	**-10,804**	**-10,804**	**-50,742**	**-50,742**	**-175,267**	**-175,267**	**-1,744,107**	**-1,744,107**	**-1,744,107**
Taxes									
Net Income after Tax	**-10,804**	**-10,804**	**-50,742**	**-50,742**	**-175,267**	**-175,267**	**-1,744,107**	**-1,744,107**	**-1,744,107**
Initial investment	-3,133,082	-	-10,783,266		-31,131,375		-360,833,062		
Other investmetn	-	-	-	-	-	-	-	-	-
total Investment	**-3,133,082**	**-**	**-10,783,266**	**-**	**-31,131,375**	**-**	**-360,833,062**	**-**	**-**
Cash flow after tax	**-3,133,082**	**-**	**-10,783,266**	**-**	**-31,131,375**	**-**	**-360,833,062**	**-**	**-**
Cash flow Discounted									
Salvage values Success	3,122,278	3,111,475	13,843,999	13,793,257	44,749,365	44,574,098	403,663,054	401,918,947	400,174,840
Salvage values Failure						37,887,983			340,148,614

Figure 1: Annual CAPEX investments, depreciation and salvage values in case of project success and failure.

A.2. Favorable Market demand

	Selling price (SP) Jet fuel in 2030	5,799	EUR/t	Max capacity jet fuel	50,000	t/year	Annual price deca	-1.516%			
	SP Diesel in 2030	1,525	EUR/t	diesel	8,333						
	SP Naphtha in 2030	719	EUR/t	naphtha	8,333						
	OPEX	4,234	EUR/t								
	disc	10%									
	tax	0.10									
	Inflation after 2025	2.9%									
	Operation										
	2030	2031	2032	2033	2034	2035	2036	2037	...	2049	2050
T cash flow	9	10	11	12	13	14	15	16	...	28	
T operation	-	1	2	3	4	5	6	7	...	19	
Item									...		
Gross revenues full capacity	289,967,568	285,571,098	281,241,287	276,977,124	272,777,615	268,641,777	264,568,648	260,557,274	...	216,910,764	
Favorable market demand	**33%**	**33%**	**58%**	**59%**	**100%**	**100%**	**100%**	**100%**	...	**100%**	
Revenue from Jet Fuel	94,850,849	94,969,605	162,965,066	163,082,816	272,777,615	268,641,777	264,568,648	260,557,274	...	216,910,764	
Revenue from Diesel	4,156,028	4,347,829	7,795,301	8,150,742	14,244,533	14,657,624	15,082,695	15,520,093	...	21,871,513	
Revenue from Naphtha	1,959,802	2,050,247	3,675,925	3,843,535	6,717,101	6,911,897	7,112,342	7,318,600	...	10,313,653	
Total Gross Revenues	**100,966,679**	**101,367,681**	**174,436,292**	**175,077,093**	**293,739,248**	**290,211,299**	**286,763,685**	**283,395,968**	...	**249,095,930**	
OPEX	-69,241,120	-69,327,812	-118,964,498	-119,050,456	-199,127,659	-196,108,497	-193,135,113	-190,206,810	...	-158,344,857	
EBITDA	**31,725,560**	**32,039,869**	**55,471,794**	**56,026,637**	**94,611,590**	**94,102,801**	**93,628,572**	**93,189,158**	...	**90,751,072**	
Depreciation	-6,545,029	-6,654,113	-11,594,051	-11,781,052	-20,008,742	-20,008,742	-20,008,742	-20,008,742	...	-20,008,742	
EBIT	**25,180,530**	**25,385,756**	**43,877,742**	**44,245,585**	**74,602,848**	**74,094,059**	**73,619,830**	**73,180,416**	...	**70,742,330**	
Taxes	-2,518,053	-2,538,576	-4,387,774	-4,424,558	-7,460,285	-7,409,406	-7,361,983	-7,318,042	...	-7,074,233	
Net Income after Tax	**22,662,477**	**22,847,181**	**39,489,968**	**39,821,026**	**67,142,563**	**66,684,653**	**66,257,847**	**65,862,374**	...	**63,668,097**	
Initial investment	-	-	-	-	-	-	-	-	...	-	
Other investmetn	-	-	-	-	-	-	-	-	...	-	
total Investment	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	...	**-**	
Cash flow after tax	**29,207,506**	**29,501,294**	**51,084,019**	**51,602,078**	**87,151,305**	**86,693,395**	**86,266,589**	**85,871,116**	...	**83,676,839**	
Cash flow Discounted	**29,207,506**	**26,819,358**	**42,218,198**	**38,769,405**	**59,525,514**	**53,829,778**	**48,695,241**	**44,065,460**	...	**13,681,832**	
Salvage values Success	**Disc cash flow in 2030**	**638,505,167**									

Figure 2: DCF with Favorable Market demand, analysed plant reaches market first

A.3. Unfavorable Market demand

	Selling price (SP) Jet fuel in 2030	5,799	EUR/t	Max capacity jet fuel	50,000	t/year	Annual price deca	-1.516%			
	SP Diesel in 2030	1,525	EUR/t	diesel	8,333						
	SP Naphtha in 2030	719	EUR/t	naphtha	8,333						
	OPEX	4,234	EUR/t								
	disc	10%									
	depreciation period	20	years								
	tax	0.10									
	Inflation after 2025	2.9%									
	Operation										
	2030	2031	2032	2033	2034	2035	2036	2037	...	2049	2050
T cash flow	9	10	11	12	13	14	15	16	...	28	
T operation	-	1	2	3	4	5	6	7	...	19	
Item									...		
Gross revenues full capacity	289,967,568	285,571,098	281,241,287	276,977,124	272,777,615	268,641,777	264,568,648	260,557,274	...	216,910,764	
Unfavorable market demand	**0%**	**0%**	**6%**	**7%**	**48%**	**100%**	**100%**	**100%**	...	**100%**	
Revenue from Jet Fuel	-	-	16,719,597	19,054,711	130,088,194	268,641,777	264,568,648	260,557,274	...	216,910,764	
Revenue from Diesel	-	-	799,768	952,338	6,793,246	14,657,624	15,082,695	15,520,093	...	21,871,513	
Revenue from Naphtha	-	-	377,136	449,081	3,203,399	6,911,897	7,112,342	7,318,600	...	10,313,653	
Total Gross Revenues	**-**	**-**	**17,896,501**	**20,456,131**	**140,084,840**	**290,211,299**	**286,763,685**	**283,395,968**	...	**249,095,930**	
OPEX	-	-	-12,205,306	-13,909,939	-94,964,382	-196,108,497	-193,135,113	-190,206,810	...	-158,344,857	
EBITDA	**-**	**-**	**5,691,195**	**6,546,192**	**45,120,458**	**94,102,801**	**93,628,572**	**93,189,158**	...	**90,751,072**	
Depreciation	-	-	-1,189,506	-1,376,506	-9,542,209	-20,008,742	-20,008,742	-20,008,742	...	-20,008,742	
EBIT	**-**	**-**	**4,501,690**	**5,169,685**	**35,578,249**	**74,094,059**	**73,619,830**	**73,180,416**	...	**70,742,330**	
Taxes	-	-	-450,169	-516,969	-3,557,825	-7,409,406	-7,361,983	-7,318,042	...	-7,074,233	
Net Income after Tax	**-**	**-**	**4,051,521**	**4,652,717**	**32,020,424**	**66,684,653**	**66,257,847**	**65,862,374**	...	**63,668,097**	
Initial investment	-	-	-	-	-	-	-	-	...	-	
Other investmetn	-	-	-	-	-	-	-	-	...	-	
total Investment	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	...	**-**	
Cash flow after tax	**-**	**-**	**5,241,026**	**6,029,223**	**41,562,633**	**86,693,395**	**86,266,589**	**85,871,116**	...	**83,676,839**	
Cash flow Discounted	**-**	**-**	**4,331,427**	**4,529,845**	**28,387,838**	**53,829,778**	**48,695,241**	**44,065,460**	...	**13,681,832**	
	Disc cash flow in 2030	**479,214,294**									

Figure 3: DCF with Unfavorable Market demand. Competitor reaches Dutch market first

A.4. Optimized market through Policy Incentives

	Selling price (SP) Jet fuel in 2030	5,799	EUR/t	Max capacity jet fuel	50,000	t/year	Annual price deca	-1.516%			
	SP Diesel in 2030	1,525	EUR/t	diesel	8,333						
	SP Naphtha in 2030	719	EUR/t	naphtha	8,333						
	OPEX	4,234	EUR/t								
	disc	10%									
	depreciation period	20	years								
	tax	0.10									
	Inflation after 2025	2.9%									
	Operation										
	2030	2031	2032	2033	2034	2035	2036	2037	...	2049	2050
T cash flow	9	10	11	12	13	14	15	16	...	28	
T operation	-	1	2	3	4	5	6	7	...	19	
Item									...		
Gross revenues full capacity	289,967,568	285,571,098	281,241,287	276,977,124	272,777,615	268,641,777	264,568,648	260,557,274	...	216,910,764	
Favorable market demand	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	...	**100%**	
Revenue from Jet Fuel	289,967,568	285,571,098	281,241,287	276,977,124	272,777,615	268,641,777	264,568,648	260,557,274	...	216,910,764	
Revenue from Diesel	12,705,352	13,073,807	13,452,948	13,843,083	14,244,533	14,657,624	15,082,695	15,520,093	...	21,871,513	
Revenue from Naphtha	5,991,291	6,165,038	6,343,824	6,527,795	6,717,101	6,911,897	7,112,342	7,318,600	...	10,313,653	
Total Gross Revenues	**308,664,211**	**304,809,944**	**301,038,059**	**297,348,003**	**293,739,248**	**290,211,299**	**286,763,685**	**283,395,968**	...	**249,095,930**	
OPEX	-225,324,874	-222,511,259	-219,757,783	-217,064,042	-214,429,651	-211,854,248	-209,337,490	-206,879,056	...	-181,840,029	
EBITDA	**83,339,337**	**82,298,685**	**81,280,276**	**80,283,961**	**79,309,597**	**78,357,051**	**77,426,195**	**76,516,911**	...	**67,255,901**	
Depreciation	-20,008,742	-20,008,742	-20,008,742	-20,008,742	-20,008,742	-20,008,742	-20,008,742	-20,008,742	...	-20,008,742	
EBIT	**63,330,595**	**62,289,943**	**61,271,534**	**60,275,219**	**59,300,855**	**58,348,309**	**57,417,453**	**56,508,169**	...	**47,247,159**	
Taxes	-6,333,060	-6,228,994	-6,127,153	-6,027,522	-5,930,086	-5,834,831	-5,741,745	-5,650,817	...	-4,724,716	
Net Income after Tax	**56,997,536**	**56,060,949**	**55,144,381**	**54,247,697**	**53,370,770**	**52,513,478**	**51,675,708**	**50,857,352**	...	**42,522,443**	
Initial investment	-	-	-	-	-	-	-	-	...	-	
Other investmetn	-	-	-	-	-	-	-	-	...	-	
total Investment	-	-	-	-	-	-	-	-	...	-	
Cash flow after tax	**77,006,278**	**76,069,691**	**75,153,123**	**74,256,439**	**73,379,512**	**72,522,220**	**71,684,450**	**70,866,094**	...	**62,531,185**	
Cash flow Discounted	**77,006,278**	**69,154,264**	**62,110,019**	**55,789,962**	**50,119,194**	**45,030,593**	**40,464,003**	**36,365,512**	...	**10,224,348**	
	Disc cash flow in 2030	**669,928,660**									

Figure 4: DCF with policy incentives optimizing market demand

A.5. Optimized market through Policy Incentives & Taxcut

Selling price (SP) Jet fuel	5,799	EUR/t	Max capacity jet fuel	50,000	t/year	Annual price decay	-1.516%
SP Diesel in 2030	1,525	EUR/t	diesel	8,333	t/year		
SP Naphtha in 2030	719	EUR/t	naphtha	8,333	t/year		
OPEX	4,234	EUR/t					
disc	10%						
depreciation period	20	years					
tax	-						
Inflation after 2025	2.9%						

	Operation										
	2030	2031	2032	2033	2034	2035	2036	2037	...	2049	2050
T cash flow	9	10	11	12	13	14	15	16	...	28	
T operation	-	1	2	3	4	5	6	7	...	19	
Item									...		
Gross revenues full capacity	289,967,568	285,571,098	281,241,287	276,977,124	272,777,615	268,641,777	264,568,648	260,557,274	...	216,910,764	
Favorable market demand	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	...	**100%**	
Revenue from Jet Fuel	289,967,568	285,571,098	281,241,287	276,977,124	272,777,615	268,641,777	264,568,648	260,557,274	...	216,910,764	
Revenue from Diesel	12,705,352	13,073,807	13,452,948	13,843,083	14,244,533	14,657,624	15,082,695	15,520,093	...	21,871,513	
Revenue from Naphtha	5,991,291	6,165,038	6,343,824	6,527,795	6,717,101	6,911,897	7,112,342	7,318,600	...	10,313,653	
Total Gross Revenues	**308,664,211**	**304,809,944**	**301,038,059**	**297,348,003**	**293,739,248**	**290,211,299**	**286,763,685**	**283,395,968**	...	**249,095,930**	
OPEX	-225,324,874	-222,511,259	-219,757,783	-217,064,042	-214,429,651	-211,854,248	-209,337,490	-206,879,056	...	-181,840,029	
EBITDA	**83,339,337**	**82,298,685**	**81,280,276**	**80,283,961**	**79,309,597**	**78,357,051**	**77,426,195**	**76,516,911**	...	**67,255,901**	
Depreciation	-20,008,742	-20,008,742	-20,008,742	-20,008,742	-20,008,742	-20,008,742	-20,008,742	-20,008,742	...	-20,008,742	
EBIT	**63,330,595**	**62,289,943**	**61,271,534**	**60,275,219**	**59,300,855**	**58,348,309**	**57,417,453**	**56,508,169**	...	**47,247,159**	
Taxes	-	-	-	-	-	-	-	-	...	-	
Net Income after Tax	**63,330,595**	**62,289,943**	**61,271,534**	**60,275,219**	**59,300,855**	**58,348,309**	**57,417,453**	**56,508,169**	...	**47,247,159**	
Initial investment	-	-	-	-	-	-	-	-	...	-	
Other investmetn	-	-	-	-	-	-	-	-	...	-	
total Investment	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	...	**-**	
Cash flow after tax	**83,339,337**	**82,298,685**	**81,280,276**	**80,283,961**	**79,309,597**	**78,357,051**	**77,426,195**	**76,516,911**	...	**67,255,901**	
Cash flow Discounted	**83,339,337**	**74,816,986**	**67,173,782**	**60,318,528**	**54,169,522**	**48,653,564**	**43,705,069**	**39,265,274**	...	**10,996,877**	
	Disc cash flow in 2030	**723,545,148**									

Figure 5: DCF with policy incentives optimizing market demand & a complete tax cut