International Hydrogen Ramp-up Programme – H2Uppp

Pre-feasibility summary of the green methanol production from Biogas and Green Hydrogen in Paraná, Brazil

Prodution of Green Methanol from Biogas and Green Hydrogen

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

mele UNTERNEHMENSGRUPPE

NIRAS

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Legal information

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Abbreviations

AFAP	Agência de Fomento do Estado do Amapá S/A
AFEAM	Agência de Fomento do Estado do Amazonas S/A
AGE	Agência de Empreendedorismo de Pernambuco
AGERIO	Agência de Fomento do Rio de Janeiro
AGN	Agência de Fomento do Rio Grande do Norte S/A
ASTM	American Society for Testing and Materials
APOC	Adiabatic POst Convertor
BADESC	Agência de Fomento do Estado de Santa Catarina
BANDES	Banco de Desenvolvimento do Espírito Santo
BASA	Banco da Amazônia
BB	Banco do Brasil
BDMG	Banco de Desenvolvimento de Minas Gerais
BECCU	Bioenergy with carbon capture and utilization
BNB	Banco do Nordeste Brasileiro
BRDE	Banco Regional de Desenvolvimento do Extremo Sul
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DANIDA	Danish International Development Agency
DEG	Deutsche Investitions und Entwicklungsgesellschaft
EIB	European International Bank
EPC	Engineering, procurement, and construction
EU	European Union
FEL	Front-end Loading
FT	Fischer-Tropsch
GFP	Green Fuels Paraná
GHG	Green House Gas
GIS	Geographic Information System
GIZ	German Society for International Cooperation
HEFA	Hydrotreated Esters and Fatty Acids
IDB	Inter-American Development Bank
IEA	Internation Energy Agency
IFC	International Finance Corporation
IFI	International financial institutions
IRENA	Internation Renewable Energy Agency
IRR	Internal Return Rate
KFW	Kreditanstalt für Wiederaufbau
LCOM	Levelized Cost of Methanol
MEA	Monoethanolamine
MTD	Metric Ton per day
NIC	NIRAS International Consulting
NPV	Net Present Value
NWB	Nederlandse Waterschapsbank
PEM	Proton Exchange Membrane
PPA	Power Purchase Agreement
PtX	Power-to-X
PV	Photovoltaics
RE	Renewable Energy
RED	Renewable Energy Directive
RFNBO	Renewable fuels of non-biological origin
RWGS	Reverse Water Gas Shift
TRL	Technology Readiness Level
SAF	Sustainable Aviation Fuel
SIDA	Swedish International Development Cooperation Agency
SMR	Steam Methane Reformer
SPV	Special Purpose Vehicle
WACC	Weighted Average Cost of Capital

1 Project scope and objective

1.1 Objective of this document

The present document aims to address potential investors and/or potential partners, presenting the overall project concept and background, e-fuels market potential and attractiveness and the business model results for the current project configuration.

1.2 H2Uppp project executive summary: scope and goals of the project

The German Society for International Cooperation (GIZ) is responsible for the implementation of the H2Uppp program which financed the feasibility study for mele Biogas GmbH in Germany and its partners. GIZ invited and awarded this contract to NIRAS International Consulting (NIC) to manage the team of experts in Brazil, Denmark, Chile and Belgium to conduct FEL 1 Engineering assessments for the production of green fuels from biogas and green hydrogen. The assessment focused on a Power-to-X facility located in the Western Paraná region, and is composed of three main parts: multiple biogas plants connected to cooperative of farmers, a renewable energy park (PV and/or wind), a chemical synthesis factory for green fuels including green hydrogen production. The developed plant concept is outlined in Figure 1.1.
NIRAS International Consulting advised on a spectrum of aspects: hydrogen production, chemical synthesis technology and plant design, e-fuels certification, requirements to guarantee a proper animal welfare for the cooperatives producing biogas, legal, regulatory and environmental licensing for the different parts of the project, economic viability and financial modelling and international financial advisory to prepare the project documentation as requested by international donors and investors.

The purpose of this assessment was to explore the techno-economic feasibility of the production of green fuels in the Western Paraná region, solving the sanitation issues in the region while addressing the significant amount of animal and agricultural waste. The relatively large biogenic carbon, from said wastes, available in the region therefore offers a unique opportunity to synthezise bio and e-fuels, as biogas from animal/agricultural waste digestion is considered one of the most cost-effective form of carbon from which green fuels can be synthetized (1).

The present paragraph outlines the major findings of the feasibility study, at the same time providing perspective on project reason, green fuels future market. Further details are presented in later chapters in this document.

Why green fuels?
According to the roadmap to achieve zero carbon emission by 2050, published by the International Energy Agency, IEA, (2), the market of biofuels and green hydrogen derivative fuels, e-fuels, is set to increase significantly in the future decades in order to comply with the goals of limiting global warming and relative CO_2 emission. Global use of hydrogen (including hydrogen derivatives) is forecasted to expand from less than 90 Mt in 2020 to more than 200 Mt in 2030; the proportion of low-carbon hydrogen rises from 10% in 2020 to 70% in 2030, where roughly half comes from water electrolysis (green hydrogen).

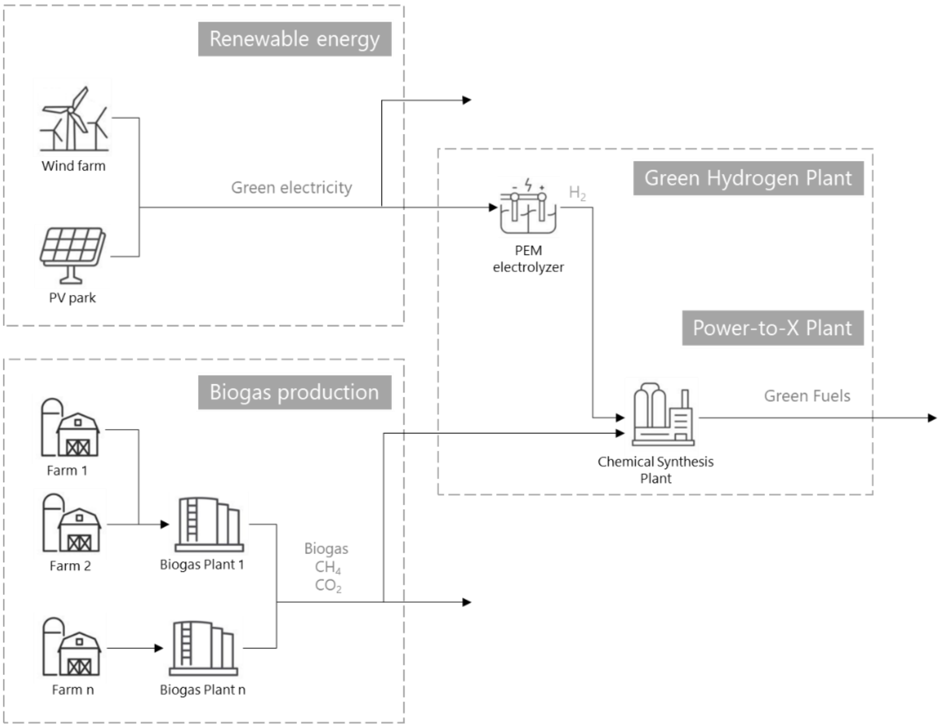


Figure 1.1: General plant concept

Green fuels demand will increase and eventually substitute the majority fossil oil sources both in the industrial and transportation sectors. Green fuels, including biofuels derived from biogenic carbon sources and green hydrogen derivatives (e-fuels), are going to play a major role in the decarbonization of both light and heavy mobility, chemical industry, acting as low-carbon chemical compounds, as well as in industrial high temperature heat generation and electrical grid stabilization, as it is highlighted in following Figure 1.2. Additionally, there are specific targets in the EU regulation for both biofuels and e-fuels utilization as highlighted in Fit for 55, RED III, RefuelEU Aviation and Maritime, among others.

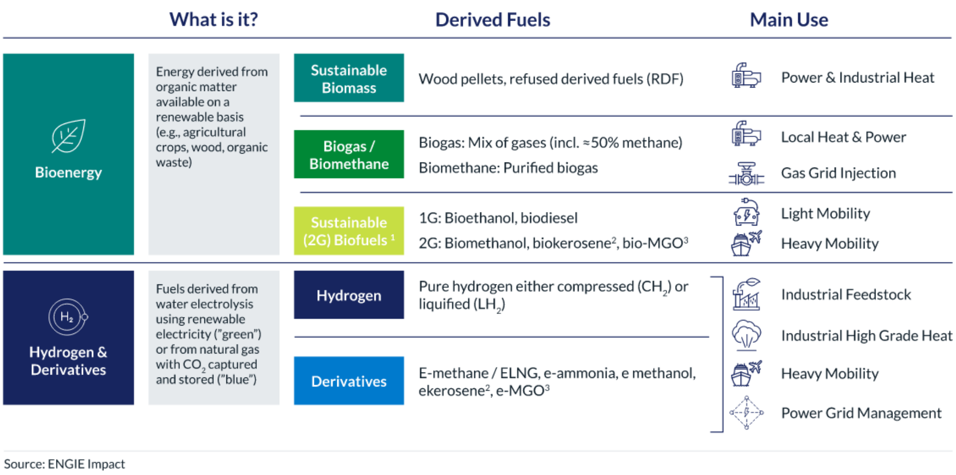


Figure 1.2: Sustainable fuels and their main usages.

Green fuels comparative study

Within the H2Uppp feasibility assessment, two types of green fuels are considered and compared, namely methanol and syncrude/SAF (substitute for kerosene), from technical and economic pont of view. A comparative study is conducted to reduce project risk. For both green fuel products, plant layouts have been designed, carrying out production technology review and selection, as well as exploring the adaptability to variable load conditions. The results of this comparative analysis indicate that it is economically possible to produce both SAF or methanol. With dedicated plant designs, the levelized costs are comparable with expected price ranges. However, it is highlighted that methanol route provides a larger variety in applications range, see Figure 1.3, and therefore larger offtakers base, as well as a significantly higher degree of flexibility in process design and process operation. For these reasons, a more detailed process design and economic assessment has been carried out for a green methanol plant, which includes green hydrogen, produced from water electrolysis plant. Comparative study and cases analysed are described in higher detail in later as chapter of this document.

As can be seen in Figure 1.3, global methanol demand is significant and increasing, and renewable methanol occupies only a small fraction of the demand. Furthermore, methanol applications are pertinent to different fields and markets, not only the mobility sector. These applications will also need to be decarbonized in the future.

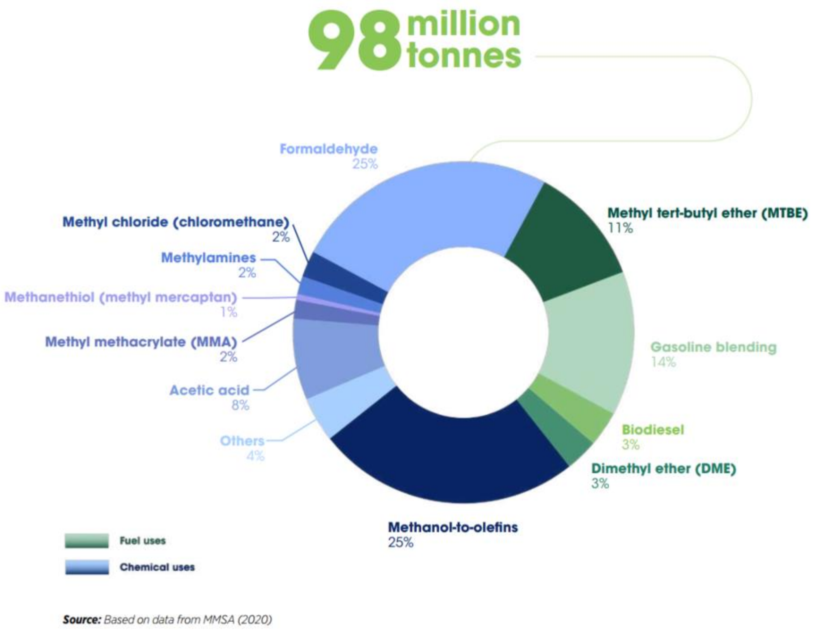


Figure 1.3: Global methanol demand and use distribution.

Green fuels expected price ranges

Green fuels prices, including both bio-fuels and e-fuels, currently and for the next decades are encumbered by a significantly large uncertainty. The green fuel market, especially for the e-fuels case, is currently in a start-up phase therefore a relative large deviation in forecast is to be expected. Considering the methanol case first, according to many international reports and references the projected price of e-methanol in the near future is attending between 820 USD/ton and 1620 USD/ton, (1), (3) depending on regionality, cost of electricity and cost of CO_2 supply. In the next decades the cost of e-methanol is expected to drop as the technology, value chain and market mature to a level between 250 USD/ton and 650 USD/ton. Uncertainty on bio-methanol price is relatively smaller, as it is currently produced from biogenic carbon sources, although not at a significant scale compared to global demand; its price stands between 327 USD/ton and 1013 USD/ton (1). Also in this case, price differences are mainly attributed to regionality and cost of carbon source. It is extremely relevant to mention that green fuel prices, despite the already relatively large window of values provided by international agency, are highly dependent on the market conditions, for example bio-methanol has been bought at around 2500 USD/ton by Mearsk in 2023 (4).

Secondly, considering SAF, current fossil-originated aviation fuel price sets around 400 USD/ton and 800 USD/ton globally. SAF production, through HEFA and Alcohol-to-Jet pathways, is still nowadays limited compared to global kerosene demand, despite interest peak after ReFuelEU Aviation initiative of 5% SAF blending by 2030 for all flights departing from European airports. Given high fluctuations in biomass supply SAF price is oscillating between 800 USD/ton and 2400 USD/ton (5), (6), (7). E-SAF is estimated to be on a similar range, in the latter case uncertainty is the highest.

PtX facility design and performance

The developed final concept for green methanol production has the potential to produce 1030 MTD of methanol, selling a part as certified bio-methanol and a part as certified, e-methanol, following the RFNBO directive regarding the green hydrogen derivatives. It has been estimated, as part of a class 5 cost analysis (± 50%), that for the whole facility, composed of biogas plants, RE farm, PtX plant and infrastructures, that a total investment, CAPEX, of approximately 1.3 billion euros is necessary. The relative levelized cost of methanol for such project stands approximately between 900 and 1200 EUR/ton, placing it well within the expected price window. (Given the design stage of the project there is a not negligible level of uncertainty). Further details are reported in the Financing Chapter.

Risk Mitigation

Given the size of the CAPEX investment for the project and in order to mitigate risks and uncertainties, it is advisable to implement a systematic approach to the project development, with the goal of gradually reducing risk at minimal cost, to reach financinal closure. In the feasibility study performed, four essential points were examined and the exposed conceptual recommendations have been followed and verified. It is to be noted that a more thorough investigation of these points is required in the successive, more detailed, design phases of the project.

- Technical feasibility: the processes, technology, and equipment to be employed must exhibit a high maturity level and be capable of generating production output and revenues in line with the projected capacity. Additionally, ensure a high maturity level i.e. high technology readiness level. This has been verified engaging with technology suppliers.
- Economic viability: The project has to demonstrate the ability to generate cash flow associated with its operation, showing that the generated revenues are sufficient to cover debt costs while also providing an attractive return rate to investors and financiers. A business model analysis has been conducted to verify the project bankability.
- Guarantee of supply: it is has been studied and verified that there are sufficient natural resources (water, electricity, carbon sources) to ensure the project's operation throughout the projected cash flow period. An agreement has already been signed with a consortium of farmers for the biogas supply and its purchase value.
- Guarantee of offtake: it must be demonstrated that there are available buyers for the products and that the market pricing considered in the project analysis reflects real market conditions. A preliminary market analysis has been conducted and several potential offtakers, both local and international, have been contacted and expressed interest.

In this phase, partners and investors are being sought to secure the necessary guarantees such as process performance and intake and offtake actors, to ensure the successful production of green fuels. In particular, given an already existing agreement for biomass supply, it is sought an offtake agreement, potentially an offtake partner to be involve directly in the project. This would establish a secure partner for the entire project value chain, from biomass to green methanol use and would help reduce the market's demand for higher returns.

1.3 Stakeholders

In this chapter, an introduction to the main partners and participants envolved in the project will be conducted. It is important to highlight that specific partners for the renewable energy and PtX plant have yet to be identified. These partners may consist of a single entity or a combination of multiple parties.

1.3.1 Mele Biogas

Mele Biogas GmbH, a constituent of the mele® Group headquartered in Torgelow, Mecklenburg-Western Pomerania, is a full-service biogas provider. Operating both domestically and internationally, it specializes in tailoring bespoke solutions for biomass utilization to produce sustainable energy. Mele Biogas GmbH manages all aspects of biogas project execution, including development, planning, construction, and operational oversight, ensuring successful implementation.

1.3.2 GIZ

The German Society for International Cooperation (GIZ) is a service provider specializing in international cooperation for sustainable development and international education work. With over 50 years of experience, GIZ operates across diverse areas, encompassing economic development, employment promotion, energy, environment, and peace and security. Renowned for their expertise, GIZ is globally sought after by various entities, including the German Government, European Union institutions, the United Nations, private sector entities, and foreign governments. In 2021, GIZ recorded a business volume of approximately EUR 3.7 billion., with nearly 70% of their 24,977 employees being national staff working in around 120 countries.

1.3.3 NIRAS

NIRAS and NIRAS International Consulting is an advisory, development and engineering consulting company with over 3000 employees worldwide, present globally in over 65 offices across all continents. NIRAS clients portfolio includes Development Donors such as KFW, GIZ, DANIDA, SIDA, The European Comission, the World Bank, and numerous private companies. NIRAS conducts over 400 projects per year with a turnover of 508,8 millions of Euros in 2023. NIRAS field of expertise include international development cooperation, green fuels and green energy transitions (greensition programme), renewable energy, GIS and special analysis, automation, energy efficiency in particular for the food and beverage industries worldwide.

2 Background for the Green Fuels Paraná (GFP) project

2.1 The environmental problem

The Western Paraná region of Brazil is a hotspot for animal production, particularly pig and poultry production. The resulting manure causes significant environmental problems because disposal is not guaranteed. Manure seeps into the soil or flows into rivers; large amounts of nitrous oxide and methane are emitted when the manure is stored in open lagoons. The Green Fuels Paraná project includes the utilization of pig manure, chicken manure and other residues from agricultural production in the Western Paraná region to produce biogas, whose composition comprises approximately 60% biomethane and 40% carbon dioxide. This biogas is subsequently utilized as carbon source for the production of green fuels, in combination with green hydrogen.

Table 2.1. Production Key Figures. Source: own elaboration.

Fattening pigs, sows, piglets	4,012,000 pigs
Poultry production	63,130,000 pieces of poultry
Dairy Production	26,455 dairy cows
Manure per year	More than 13,000,000 m^3
Biogas determined potential	50,000 Nm^3/h
CO_2e avoided from biogas	1 million tCO_2e per year
CO_2 avoided through separated CO_2 (BECCU)	0.28 million tCO_2e per year

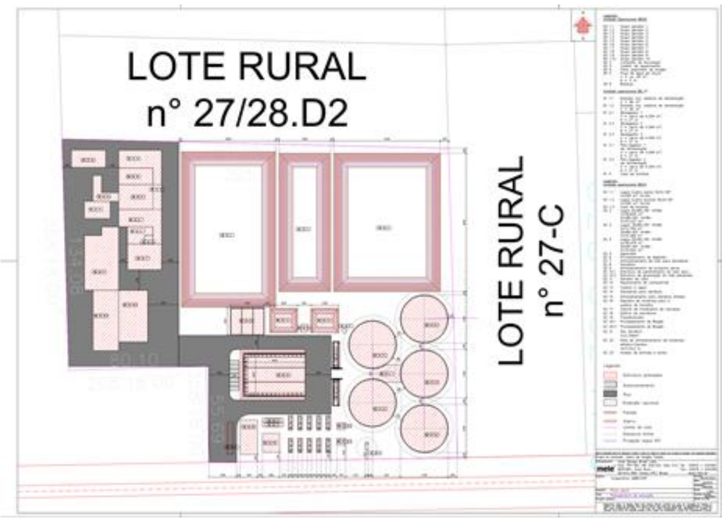
2.2 Location

The project is a central part of the Government of Paraná's State Sustainability Program for Western Paraná (Paraná Oeste Sustentavel). The location is shown in Figure 2.1.

2.3 Biogas production potential in Paraná

The region's potential for biogas production is driven by a wide range of available carbon sources. Over 2,500 local producers, in particular animal fattening farms, slaughterhouses, cassava processors supply animal manure and agricultural residues. In total, around 13.5 million cubic meters of substrates are available per year, of which around 1.5 million cubic meters of higher-quality substrates (poultry manure, residues of slaughtering and cassava-production liquified by pig slurry) are fed into the digestors and the rest, around 12 million cubic meters of pig manure, is fermented in lagoon systems.

A first biogas plant with the concept of pipe connection to the manure suppliers with a planned production of around 1,300 Nm^3/h of biogas has already been developed and approved. Construction is scheduled to begin in May 2024. The facility is being built in Toledo, Rocio district and its site plan is shown in Figure 2.2.



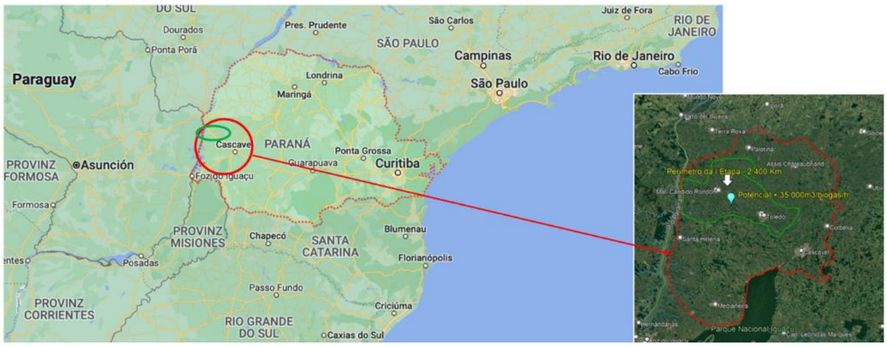


Figure 2.1. Project location

Figure 2.2. Site plan for the first planned biogas production facility

Pig manure is fermented in lagoons, producing biogas that feeds into pipelines. The digestate becomes natural fertilizer in a nearby composting plant. The remaining substrates are fermented in reinforced concrete containers, and the resulting biogas is stored temporarily before being fed into the central production facility.

2.4 Renewable Energy potential in South Brasil

The South Region of Brazil, of which Paraná is part of, has a large capacity to generate electrical energy from the most diverse sources, according to data from the Brazilian National Electric System Operator (8). The southern subsystem of the country contributed, in the year 2022, to the generation of more than 95,000 GWh, distributed among hydro-generation (82.1%), thermal-generation (11.4%), and wind-generation (6.4%). For thermal energy, it is considered the generation coming from renewable sources (biomass and agro-industrial waste) and non-renewable sources (coal, gas, fuel oil, diesel oil, and petroleum). Based on this, it is observed for the year in question a generation of 92% coming from renewable sources, with the category primarily represented by hydroelectric projects. To highlight the large renewable share, Figure 2.3 demonstrates the evolution of the share of renewable and non-renewable energy in the electrical matrix of the Southern subsystem. Therefore, following the RED II / III directives (9) on bidding zone where the synthetic fuel plant is located, the South submarket of the Brazilian electrical system, data suggest that the 90% renewable share target was met from 2016 to 2019, and again in 2022. This scenario is very positive for the States in the southern region of Brazil, making it attractive for projects whose main purpose is the production of RFNBO.

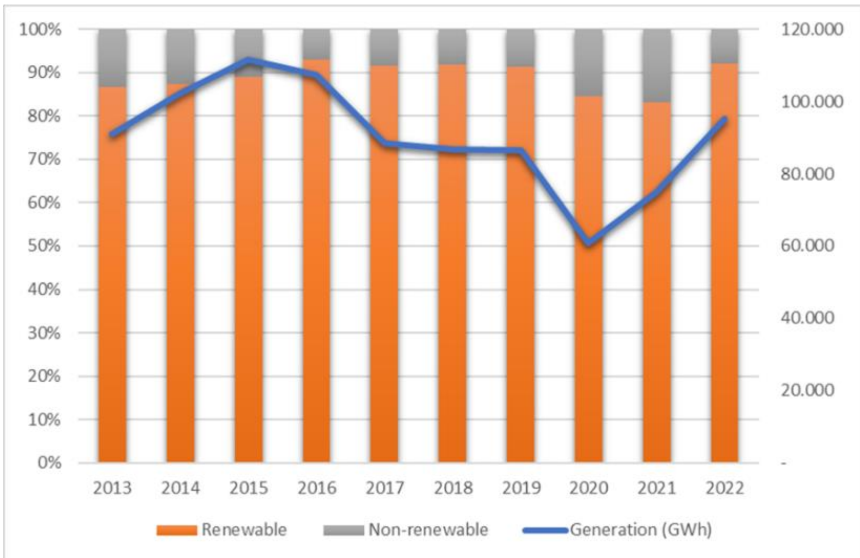


Figure 2.3: Share of renewable and non-renewable energy in the Southern submarket Electricity Generation (8).

3 Feasibility assessment – technical analysis

A feasibility assessment was performed considering different synthetic fuels and many technologies for biogas utilization and green fuels production.

3.1 Process design

The process design phase aimed to compare the feasibility of producing different green fuels, syncrude/SAF or methanol.

This phase was aided by process modelling software and established kinetic models to achieve higher prediction accuracy. The decision to focus exclusively on proven technologies (higher TRL levels) reduced technological risks. Therefore, despite being theoretically more efficient, technologies such as biogas direct reforming were excluded due to current proven maturity level. Furthermore, the design concept prioritized maximizing CO_2 utilization from the biogas stream to produce green fuels, which is proven to be challenging from both technical perspectives, where certain reaction products are favoured instead of others, reducing overall yield, and economic perspective, as it is typically required to design larger synthesis loop and reactors due to the unreacted species. Having a syngas with a relative higher concentration of CO_2 generally requires composition correction, in this study such intervention is carried out adding green H_2 to the mixture. Therefore, the use of green hydrogen in the scenarios analysed is directly dependent to the CO_2 utilization degree and may be relatively significant in size.

3.1.1 Proposed scenarios

Three different scenarios were proposed and investigated for converting biogas and green hydrogen into syncrude or methanol, explained as follows and shown in Figure 3.1.

The fundamental block of the process design proposed, common to all three scenarios, is the conversion of biogas into syngas, a mixture of H_2, CO and CO_2; this is realized with a combination of steam reforming unit, SMR reactor, and an adiabatic post convertor (APOC). This methodology has the advantage of creating a syngas composition more suitable for downstream synthesis processes, Fischer-Tropsch (FT) or methanol synthesis, maximizing the CO_2 carbon source; furthermore, it improves the SMR operating conditions, reducing its size as well.

Scenario A and B present two possible version of SAF plant with different complexity degree, hydrogen utilization and overall productivity.

Scenario A

Scenario A is the simplest pathway to produce SAF, and follows the existing conventional plants configuration. Syncrude is produced through Fischer-Tropsch (FT) synthesis, distilled and hydrocracked to SAF. The tailgas and unreacted gas species from the FT loop are recovered and partially converted in a Pre-Reformer reactor before the SMR step. In this case, green hydrogen is utilized mainly in the hydrocraking step. From the technological perspective this scenario represents the highest TRL level for SAF production. Since not the entirety of available CO_2 is utilized, the SAF productivity stands at approximately 365 MTD.

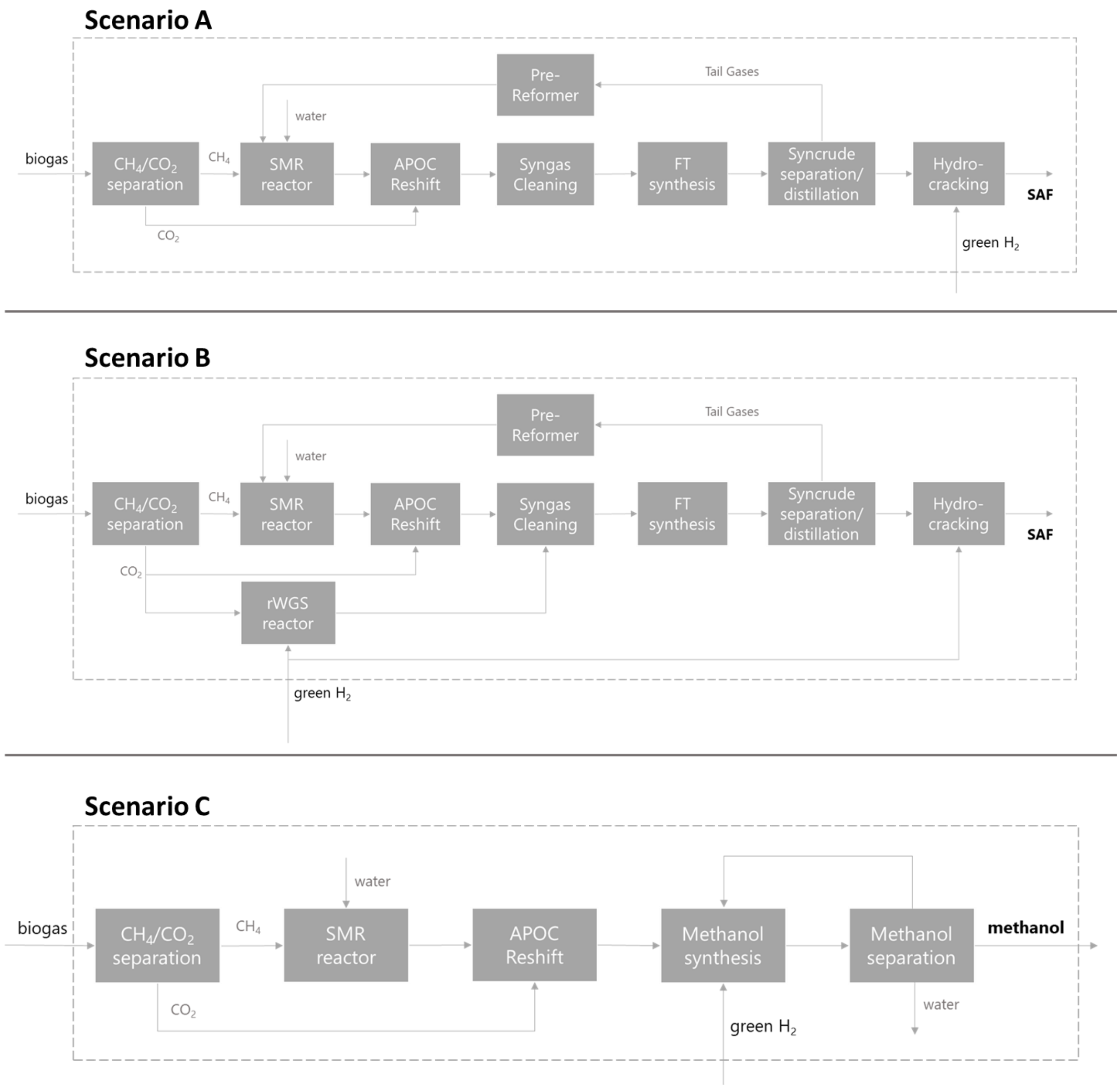


Figure 3.1: different scenarios designed for syncrude/SAF or methanol production

Scenario B

Scenario B stems from Scenario A layout and intends to maximize the CO_2 carbon source to improve syncrude productivity. Some of the CO_2 is indeed fed to a rWGS unit together with a relevant stream of green hydrogen, to promote generation of CO rich syngas, which is then mixed with H_2 rich syngas from the SMR side. Size of SMR and rWGS is optimized to achieve the correct syngas composition at the FT reactor entry. Tail gases and unreacted gases recovery layout, out of FT reactor, is kept the same as in Scenario A. SAF productivity compared to scenario A is largely improved and sets at approximately 528 MTD, configuration complexity and component size is also significantly increase.

Scenario C

Methanol synthesis configuration, Scenario C, is composed of the same SMR-APOC syngas producing block. In this case, the plant configuration presents less units and dimished complexity; the latter is to be attributed to the less strict requirements for syngas composition at the entry of the methanol synthesis loop. A certain, not negligible, fraction of CO_2 can be sustained by traditional methanol reactors and effectively converted to methanol. Significant amount of green hydrogen is also utilized in the methanol synthesis loop to fully employ the CO_2 from biogas, adjust the syngas composition and therefore maximizing the methanol productivity. Scenario C layout is also characterized by a large recycle of unreacted components, however this affects only the methanol syntesis loop and not the other reactors/steps, avoiding larger size for those components. keeping the reducing these gases similar to the syncrude production process. Methanol productivity is approximately 1060 MTD.

3.1.2 Techno-Economic comparison: methanol VS syncrude/SAF

The technical feasibility of each process scenario layout was evaluated and it was found that with an optimized process design both green fuel production routes (specifically syncrude/SAF, scenario A, and methanol, scenario C) can be economically feasible. Each process configuration has its own advantages and disadvantages in terms of cost, yield, hydrogen requirements, and water utilization, making them suitable for specific local conditions and requirements. From the technical complexity point of view, it is observed that a methanol plant offers advantages and a higher degree of flexibility for future investments and changes. Therefore, it is the preferred route.

Table 3.1 summarizes the main requirements and outputs.

Table 3.1. Summary scenario C

Maximum methanol output	44500 kg/h
Green hydrogen requirements	3400 kg/h
Power requirements	250 MW
Electrolyzer capacity	205 MW
Compressors	45 MW
Water requirements	237 m^3/h

A simplified economic comparison was performed estimating Capex and Opex to compare the different scenarios. Considering the final levelized cost of the products and comparing that to estimated methanol and SAF price, respectively in the range of 820-1620 \$/ton, (1), for methanol, and 1200-2400 \$/ton for SAF, it was found that both methanol plant scenario C and syncrude/SAF scenario A could potentially result in positive business cases. (Details of this comparison is not reported in this document, it can be retrieved from other reports.) Green methanol production is therefore chosen as the most attractive, mainly due to its higher degree of flexibility in process layout and process operation. A more detailed process and plant design for methanol production has therefore been conducted to aid a more precise financial assessment of the project. Chapter 4 outlines the main financial results.

It is worth to mention optimization studies of the methanol plant design are recommended to be carried out in successive design phases, FEL 2 and FEL 3, to further enhance plant productivity-cost ratio.

3.1.3 Renewable energy

Renewable energy park, wind and PV, has been assessed for the PtX facility. Renewable energy is necessary to produce green hydrogen, certified as RFNBO. For such reason a PV farm of 200 MWp in size and a wind park also of 200 MW as capacity have been considered to power electrolyzer and main synthesis plant utilities. In paragraph 2.4 the advantageous fraction of renewable electricity, >90%, in the Brazilian grid has been presented. Among several renewable energy configurations considered, it has been identified that a hybrid solution, RE park in combination with PPA for green electricity, provides the highest potential to optimize facility operation and methanol productivity.

Wind and solar potential in the western Parana have been studied, as can been seen in Figure 3.2 a) and b). Furthermore, a dynamic hourly-based model has been developed, using solar and wind load profiles from internal databases to evaluate feasibility of the suggested hybrid solution, RE farms plus green PPA thr命rgh grid connection, and optimize the yearly productivity of green fuels. Energy consumption profiles resulted from modelling are presented in Figure 3.2 c).

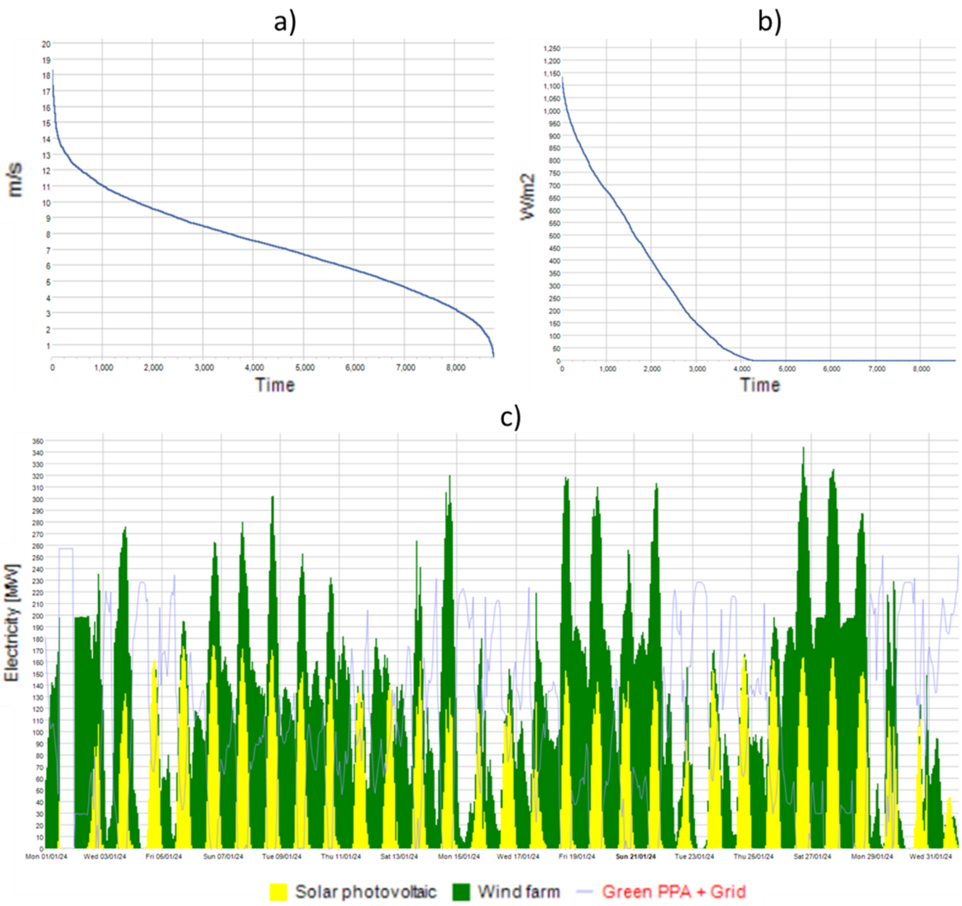


Figure 3.2: a) Western Parana wind potential, cumulative wind speed per hour representation. b) Western Parana solar potential, cumulative power density per hour representation. c) Dynamic model result for plant operation, showing wind and solar production and electricity imported through green PPA grid connection.

It is noted that a more detailed dynamic model needs to be developed in the next design phases, to refine and optimize electricity consumptions and chemical compound storage sizes.

Electricity price defined in the PPA will have a large influence on economic feasibility of the entire project, therefore deeper analysis is required as well as direct communication with potential provider/partner to achieve the most favourable economic conditions. Paragraph 4.5 offers more detailed insights on the electricity cost impact on the business model.

3.1.4 Production of green hydrogen

The electricity generated in the renewable energy farm is used to produce green hydrogen through a direct connection to the central production site. A technology comparison has been carried out between alkaline and proton exchange membrane (PEM) electrolyzers. It was concluded that alkaline and PEM are relatively similar in economic terms, however PEM offers certain useful technical advantages, such as a higher delivery pressure (30 bar) without additional equipment, and a better dynamic response to electrical input load changes; also PEM technology does not have to dispose of used alkaline solution (potassium hydroxide solution at 30%) and connected harmufulness and costs. Therefore, for the current project PEM electrolyzer is the preferred technology.

The electrolysis plant has a maximum capacity of 205 MW_{el} accordingly to process design calculations for methanol synthesis plant.

Feasibility studies on water sources availability have been conducted, assessing both the surface water and ground water sources. It has been established that in the selected region around Toledo the water supply availability largely cover the electrolizer and PtX facility requirements.

3.2 Required biogas production expansion

The design of the green fuels synthesis plant assumes a total biogas capacity of 50,000 Nm^3/h, with a biomethane fraction of 60%. Thus, an expansion of the current biogas production facility is necessary. For this purpose, additional cooperatives of biomass suppliers from the region have been identified, successive ingration within the project will happen in stages.
A total of up to 45 biogas plants are to be built by 2028/2029 in four municipalties: Toledo, Marechal, Quatro Pontes and Nova Santa Rosa. The planned locations are shown in Figure 3.3. The conceptual design of biogas plant is identical for every site, technologically and capacitively. It corresponds to the technical concept of the mele group, which is also implemented in Germany.

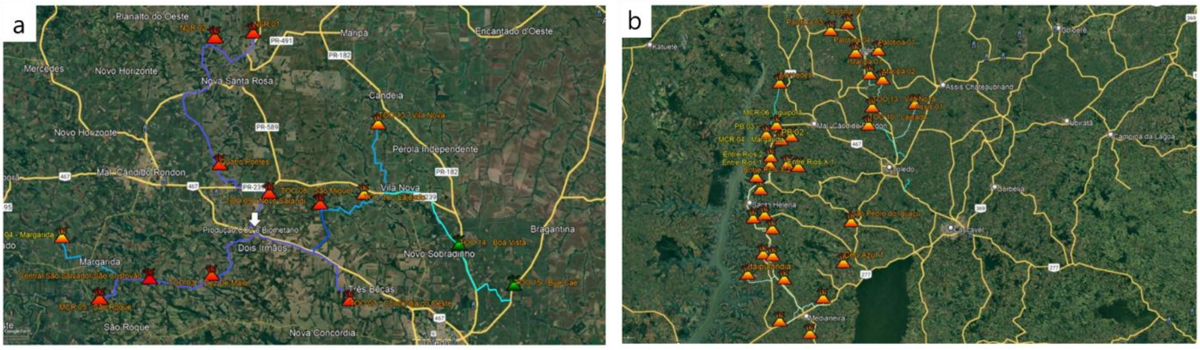


Figure 3.3. a) Location of the first 19 biogas plants. b) Possible location of the remaining biogas plants.

3.3 Certification & regulation

The compliance with relevant regulations was reviewed, including the EU's RED II / III for green fuels, REFuel aviation EU regulation, international standards like CORSIA and ASTM D7566, and potential entry into the RFNBO market, was analyzed, along with the impact of a Brazilian regulation under development.
On the other hand, the socio-environmental compliance and viability of the GFP project was assessed, considering formal licensing requirements from a federal, state and municipal perspective. Although specific variables (such as the final product, e.g., Syncrude/SAF or Methanol) and precise project locations have not yet been determined, the project aims for full three-phase environmental licenses: Prior licensing (LP), Installation Licence (LI), Operating Licence (LO). Additionally, regardless of the chosen approach, obtaining water resource permits will be essential and environmental conditions may vary depending on production volumes. Overall, the project demonstrates positive environmental suitability, considering both socio-environmental aspects and formal licensing requirements. However, a specific and detailed GHG emissions assessment shall be performed in the next phase.

3.4 Animal welfare

In 2023, visits to rural properties and farms in the municipalty of Toledo were conducted within the H2Uppp project with the aim of recognizing the current animal welfare practices adopted.
Customized questionnaires were designed for individuals involved in the pig production chain, broiler poultry chain, and dairy cattle farming. According to legal classifications, the majority of properties are small-scale family farms. Regarding experience, 68% of families have been engaged in their respective agricultural activities for 10 to 30 years. This experience plays a crucial role in animal welfare, as it enables producers to understand the animals' needs, prevent diseases, and manage livestock more effectively. Regarding the poultry and pig farming, the majority of producers are integrated into cooperatives and integrators, while dairy cattle farming mainly work independently.
Based on the answers of the questionnaires, a workshop on welfare was conducted with the purpose of improving animal welfare and sustainable livestock practices.

Moreover, comparing legal regulations between Germany and Brazil reveals substantial differences, but initial assessments highlight both commonalities and divergences. Closing these gaps necessitates collaboration among Brazilian and German experts, including farmer organizations.

The project aims to enhance understanding, provide farmer training, and consider sustainability and environmental aspects, ultimately elevating Brazil and Germany's international position in animal welfare.

3.5 Logistics & transport

Preliminary logistics and transport considerations were carried out within the feasibility assessment. The liquid pig manure is fed to the biogas plant via a pipeline network connected to the respective fattening plants. An expansion of the pipeline network is required due to the construction of additional biogas plants. The manure can be permanently fed into the gas-tight interim storage facility at the biogas plant using pumps without the need for vehicle transport. Other organic residues are planned to be transported by trucks due to short distances within the microcenter area, around 100 square kilometers.

Biogas transport to the chemical (methanol) synthesis plant should happen through adequate pipeline network, detailed design of piping route is left for the next design phases.

In Brazil, truck transport dominates, with only a few rail connections specializing exclusively in freight. There is a continuous rail connection in the region from the town of Cascavel, approx. 60 km south of the production site, to the Atlantic port of Paranagua (Ferrooeste). Plans exist to extend this line northward in the coming years, passing near the identified methanol production site area. Although the exact route remains undetermined, the possibility of constructing a siding exists.

Since the methanol is liquid, it must first be transported to the freight station in tankers and then pumped into tank cars. The methanol is then pumped into a ship in the port. If marketing takes place in Brazil, the transport costs must be determined alternatively, depending on the destination.

The costs requested from freight forwarders are 40 euros/ton for truck transport exclusively with tankers to the port of Paranagua. Using partial transport by train results in a total saving of 25%.

4 Business Model and Financial Strucuture

A business model has been produced to assess the business case hypothesis and financial structure. The capital and operative costs estimation follows the indications of a FEL 1 analysis, therefore class 4 cost estimates (10), +50%, -30%.

To estimate CAPEX and OPEX different methodologies were implemented, depending on the level of details of available information and topics knowledge.

4.1 CAPEX & OPEX analysis for green methanol and green H2 production

As previously mentioned, a more detailed plant design effort has been conducted for the methanol synthesis plant, employing specific process engineering simulation tools (Aspen Plus, Honeywell Unisim), to reach a more detailed description of process components and their sizes[1]. In connection to this more detailed methodology, it was possible to calculate chemical plant components costs individually, following the Guthrie Individual Factor method (11), obtaining an estimate of the bare module cost. Cost estimates of key components, (reformer and APOC reactors) is carried out following either existing quotations (12), (13), (14) or with direct communication with technology providers. Estimates regarding development engineering, site cost, balance of plant, buildings and construction costs and various contingencies are added to the bare modules cost.

Electrolyzer CAPEX has been obtained from Niras internal knowledge and interaction with electrolyzer providers and additional public references (15).

Operative costs for chemical plant and electrolyzer system are calculated based on designed utilities consumption, it includes electricity consumption, water consumption, catalyst consumption, site and administrative personel cost and maintenance. Additional electricity consumption, provided from the grid, has been calculated employing a dynamic model for system operations, with solar radiation and wind load profiles derived from international databases, as described more extensively in paragraph 3.1.3.

[1] Desing specifications are reported in a different document.

Table 4.1 provides CAPEX and OPEX for the different parts of the PtX facility.

Table 4.1: CAPEX and OPEX of chemical syntheis plant including electrolyzer

CAPEX Methanol Synthesis and Electrolyzer System Plant	
Methanol Plant	293.2 milEUR
Electrolyzer System	149.0 milEUR
OPEX Methanol Synthesis and Electrolyzer System Plant (yearly based)	
Electricity consumption (from grid)	782044 MWh/y; 25.98 milEUR ÷ 85.40 milEUR
Water and Catalyst consumption	1.063 milEUR/y
Personel	3.810 milEUR/y
Maintenance	27.96 milEUR/y

4.2 CAPEX & OPEX analysis for renewable energy

CAPEX and OPEX calculated for the two renewable energy farms, PV and wind, 200 MW in capacity each, has been carried out with a reference base approach, specifically for similar PV and wind parks projects in Brasil. Table 4.2 presents the relevant data.

Table 4.2: CAPEX and OPEX of renewable energy farms, PV and wind

CAPEX RE farms	
PV farm	180 milEUR (16), (17), (18), (19), (20)
Wind farm	205 milEUR (21)
Grid substation	0.60 milEUR
OPEX RE farms	
PV farm	3.4 milEUR (22)
Wind farm	4.67 milEUR (21), (23)

4.3 CAPEX & OPEX analysis for biogas production

Biogas project partner, mele Biogas GmbH, provided estimates on CAPEX and OPEX for the biogas plants expansion, based on previous projects experience.

Table 4.3: CAPEX and OPEX of biogas plants

Biogas plants (45 plants)	
CAPEX	548.1 milEUR (24)
OPEX	107.2 milEUR (24)

4.4 Business Case Analysis

Total CAPEX,OPEX and yearly revenues, and its composition, are shown in Table 4.4.

Table 4.4: CAPEX, OPEX and renevues for the entire business case.

Total CAPEX	1410 milEUR
Total OPEX	225.3 milEUR/y
Revenues	738.0 milEUR/y
Methanol Sale	*526.7 milEUR; (**average methanol price of 1484 EUR/ton**)*
Fertilizer Sale	*44.1 milEUR* (24)

Carbon Credits	*14.4 milEUR* (24)
Biogas Surplus Sale	*13.1 mil EUR; (Average price of 0.2988 EUR/Nm3)*
Electricity Surplus Sale	*1.99 milEUR*

In the OPEX an average electricity price from grid, following Brasilian tariffs (25), (26), has been used. Grid connection together with green electricity PPA should offer a reduced electricity consumption costs compared to just a grid connection tariffs. OPEX in Table 4.4 can be further reduced, improving business performance. A dedicated sensitivity analysis on electricity costs is hown in the next paragraph.
Accumulated discounted cashflow has been calculated and is shown in Figure 4.1. Business case performance are summarized in Table 4.5, NPV, IRR (on unlevered free cash flow, UFCF, basis and on equity basis) together with the assumed cost of capital is calculated as the weighted average cost of capital, WACC.

Table 4.5: Business case performance figures

Business Case Performance	
NPV	**371.0**
IRR	**14.65%**
IRR_equity	**8%**
Levelized cost of Methanol (LCOMeOH)	**934**
Payback Year	**12.3**
Debt Service Coverage Ration (DSCR)	**3.2 ÷ 4.2**
Capital Sources and Cost of Capital, WACC	
Equity (E)	30%
Third Party Capital (D)	70%
Income Tax rate	34%
Cost of internally sourced capital (Ke)	28%
Cost of capital from external sources (Kd)	12%
WACC	**11%**

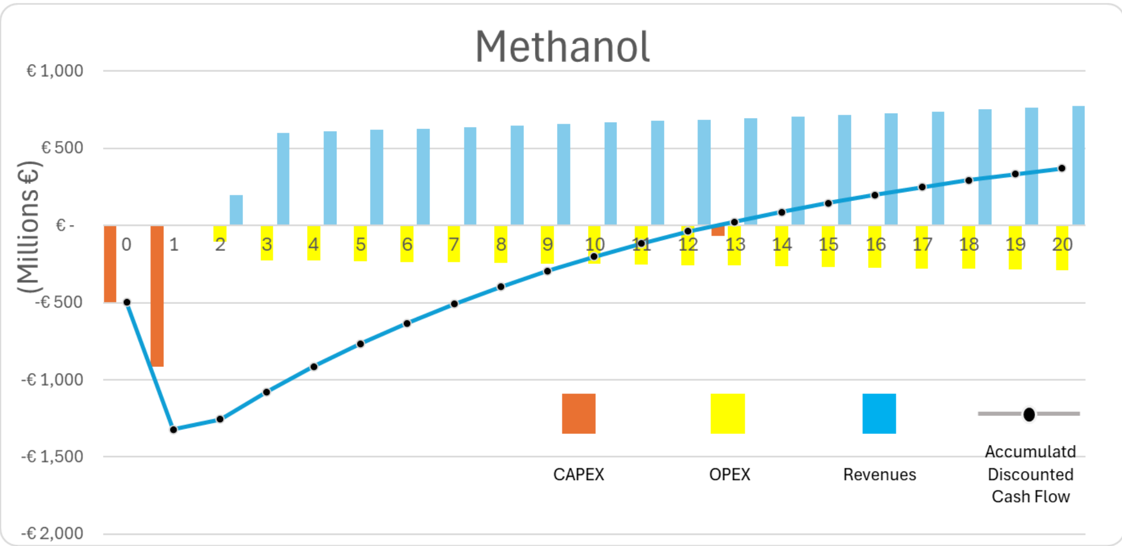


Figure 4.1: Business case Cash flow

4.5 Sensitivity Studies

A preliminary sensitivity study using the business cash flow model has been conducted, considering the following variables: CAPEX, methanol price and productivity, electricity price, and cost of capital. For these variables, 3 scenarios were considered, a reference scenario, a more favourable scenario and a less favourable one, to give potential partners and investors a preliminary indication on the business case potential and risk. The impact is visualized using the main business case performance indicators, NPV, IRR and Levelized Cost of Methanol (LCOM), as can be seen in Figure 4.2.

It can be seen that methanol price and the cost of capital has the most influence on the business case, followed by methanol productivity and CAPEX. The results highlight the importance of green fuels market and its uncertainty represents the main risk.

A ±15% variation to the reference value, whose results are presented in Table 4.5, is applied to the six aforementioned variables. This analysis identifies the variables with highest impact on business case.

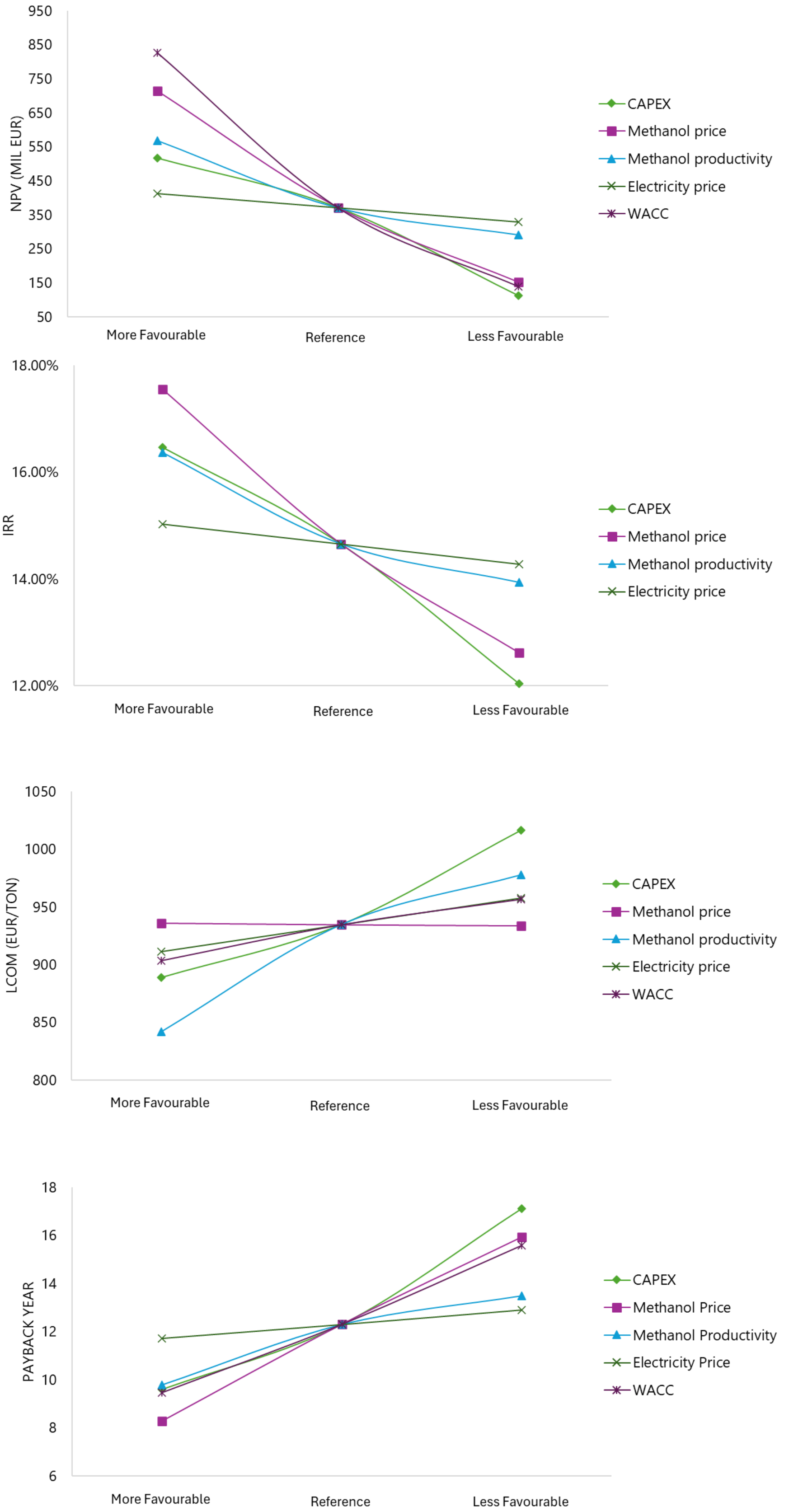


Figure 4.2: Sensitivity analysis of business model: independent parameters evaluated against main business performance criteria

From this comparative analysis results that CAPEX, cost of capital (WACC) as well as the methanol price have the most signifcant impact on how positive the business model can be. A matrix is therefore proposed to better evaluate how different combinations of methanol price and CAPEX influence the internal return rate.

Table 4.6: CAPEX, methanol price comparison and impact on business performance. WACC value kept at 11% as in reference scenario

IRR			Methanol Price					
		E-methanol (EUR/ton)	1700	1900	2000	2500	3000	3500
		Bio-methanol (EUR/ton)	1100	1250	1600	2000	2400	3000
		average	*1287*	*1453*	*1725*	*2156*	*2587*	*3156*
CAPEX (EUR)	1,244,732,872 EUR		15%	17%	20%	25%	29%	34%
	1,464,391,614 EUR		12%	14%	17%	22%	26%	30%
	1,684,050,356 EUR		10%	12%	15%	19%	23%	27%
	1,852,455,392 EUR		9%	11%	14%	18%	21%	25%
	2,037,700,931 EUR		8%	10%	12%	16%	20%	24%

It has been recorded that prices for e-methanol and bio-methanol can reach values in the 3000-3500 EUR/ton range, especially in the maritime transport application (27), (28). Methanol market prices are therefore currently vastly exceeding IEA and IRENA predictions, mainly driven by supply-demand conditions and green fuels directives. From Table 4.6 it can be clearly evaluated that, almost independently of the CAPEX, with methanol prices above 2000 EUR/ton the business case is extremely favourable.

A similar matrix, Table 4.7, is also proposed to evaluate the impact of OPEX costs on business case performance, IRR, driven by different levels of electricity prices. It can be noted the business model is less sensitivite to operative costs; therefore, also with relatively high electricity prices business appears to be favourable across the majority of methanol price values.

Table 4.7: OPEX, methanol price comparison and impact on business performance. WACC value kept at 11% as in reference scenario.

IRR				Methanol Price					
			E-methanol (EUR/ton)	1700	1900	2000	2500	3000	3500
			Bio-methanol (EUR/ton)	1100	1250	1600	2000	2400	3000
			Average	*1287*	*1453*	*1725*	*2156*	*2587*	*3156*
OPEX, EUR (El prices)	186,160,273 EUR	0.151 R/kWh (lowest PPA prices (29))		13%	15%	18%	22%	27%	30%
	208,482,585 EUR	0.275 R/kWh (low range grid prices)		13%	15%	18%	22%	26%	30%
	225,318,625 EUR	0.4 R/kWh (average grid prices)		12%	14%	17%	21%	26%	29%
	247,277,067 EUR	0.562 R/kWh (high range grid prices)		11%	13%	16%	21%	25%	29%
	272,321,645 EUR	0.75 R/kWh		10%	12%	16%	20%	24%	28%
	305,625,605 EUR	1 R/kWh (never registered el. prices)		9%	11%	14%	19%	24%	28%

Figure 4.3: Sensitivity analysis of business model: independent parameters evaluated against main business performance criteria

4.6 Risk Mitigation and Financial Structure

Given the relatively high risk profile of the project Niras consulted on financial strategies and risk mitigations strategies. Major highlights are described in the current paragraph.

As shown from the sensitivity analysis, paragraph 4.5, the cost of capital and the methanol price represent a significant impact factor on the project finance and bankability.

The main mitigation strategy is to establish partnerships across the entire value chain, involving key offtakers and key technology developers to enhance credibility toward additional financial partners, thus mitigating demands for unrealistically high returns.

The first step in the mitigation strategy is to establish one or multiple Special Purpose Vehicles, SPVs, (a new, legally distinct, and ring-fenced entity specifically for the purpose of owning, constructing, and operating the project). The partnership contract within the SPVs will cover the complete value chain from biomass purchase to methanol (or green fuels) offtake. A preliminary contract regarding biomass supply from farmers cooperatives in the western Parana region is already in place. Examples of such SPVs structure is given in Figure 4.3.

It is also recommended to establish a relatively high equity share by the project partners, around 30%, upfront available in

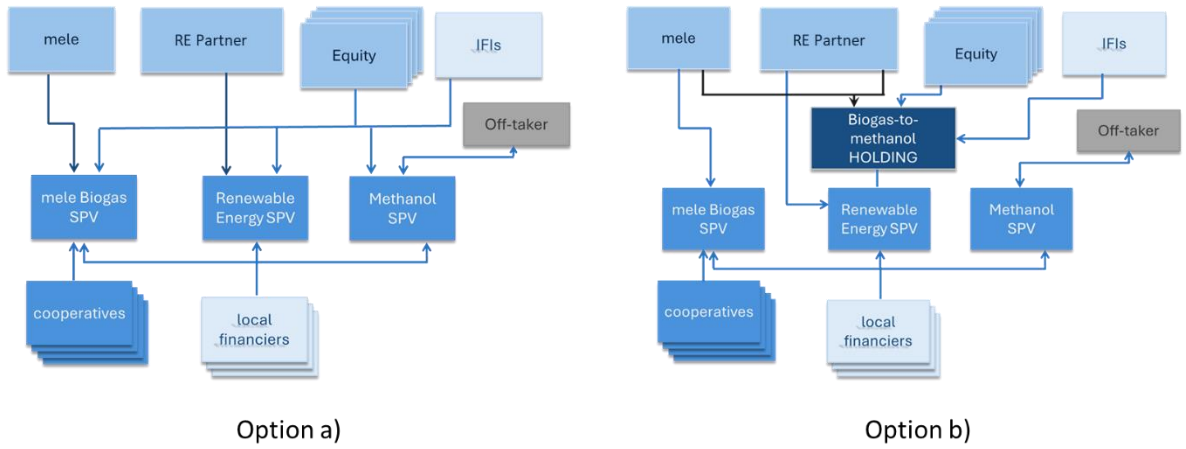


Figure 4.4: SPVs structure option for the project. Option a): three SPVs to group invesotrs interests for each production stage. Option b): three SPVs structure and a holding company hoding the shares of different SPVs, potentially useful for channeling loan funds. (IFIs stands for Internation Financing Investors).

the SPV. This will help in securing additional loan guarantees financing and investment funds. (Effective final percentage will defined in greater detail in successive project stages, accordingly to lender's requirements and financial models and covenants.)

For the same latter reason, potential partners to be involved in this project needs to be stable investors, capable of guaranting investments banks or funds that potential losses in the project can be addressed. It is necessary to establish supply and offtake agreements for the entirety of the project/facility lifetime, especially negotiating on methanol offtake prices and its evolution across multiple years.

Contractual structure for each SPV, graphically shown in Figure 4.4, will need to encompass the following main sets of agreements:

- Shareholders and Sponsors Support Agreement
- Offtake Agreements
- Equipment Supply Agreements
- EPC Contracts (and sub-contracts)
- Operation and Maintenance Contracts

- Infrastructure related agreements (e.g. grid connection agreement, water supply agreement, transport agreements)
- Permissions by local authorities
- Insurance Agreements.

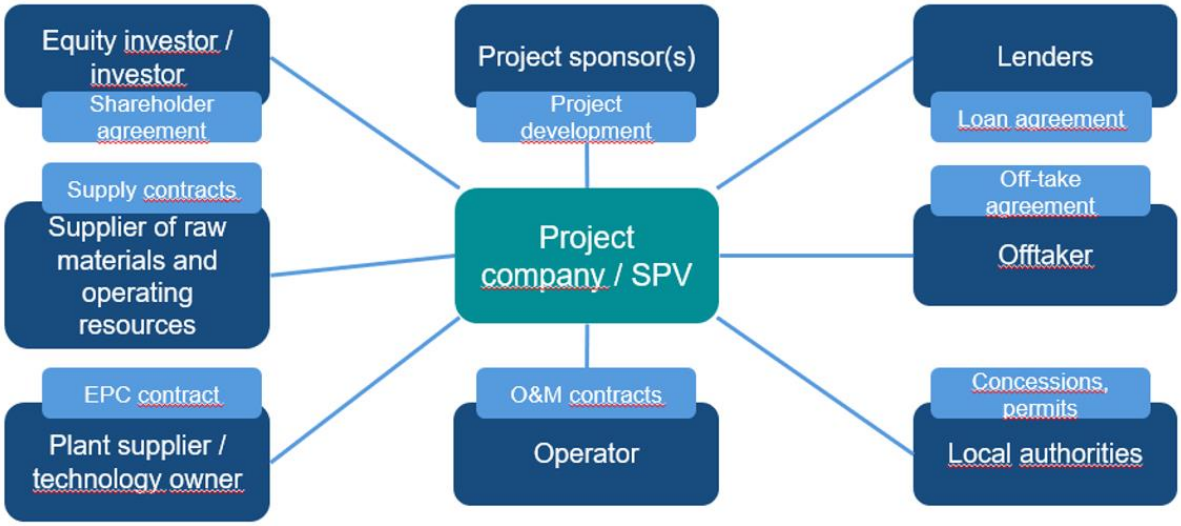


Figure 4.5: Contractual structure within a SPV

4.6.1 Financial & Technical Partners

The consultant identified both local and international potential lenders and funds to finance the next project design phases and/or as financial partners for the entire project.

International Lenders:

- Multilateral Financiers (IFIs), e.g. International Finance Corporation (IFC), Inter-American Development Bank (IDB), European Investment Bank (EIB).
  - IFS has already engaged in green hydrogen projects such as:
    - South Africa: In 2022, the IFC invested US$ 40 million in HyGreen Africa, a South African green hydrogen company developing a 100 MW electrolyser plant for clean fuel production.
    - Egypt: The IFC partnered with the Egyptian Green Hydrogen Alliance to support the development of a green hydrogen ecosystem in the country. This includes a feasibility study for a 100 MW green hydrogen production facility.
    - Portugal: The IFC invested € 40 million in H2Sines, a green hydrogen project in Portugal focused on renewable energy production and hydrogen production for transportation and industrial use
    - Netherlands: The IFC joined forces with Nederlandse Waterschapsbank (NWB) to launch a € 200 million green hydrogen financing facility supporting Dutch SMEs involved in the sector.
  - The EIB provides capital in the form of loans and project financing of up to around € 250 million as well as through equity investments. In Brazil EIB is involved in the Global Gateway hydrogen project "Green Energy Park" in the state of Piauí which shall export hydrogen to Croatia. Furthermore, EIB is managing the € 459 million Green Hydrogen Trust Fund. This fund shall co-finance projects by capital subsidies and project development.
  - IDB offers senior and subordinated loans of up to US$ 200 million (in exceptional cases up to US$ 400 million) for larger project and corporate financing of ecologically, socially, economically, or financially sustainable projects. IDB is aiming to finance green hydrogen in Latin America. A first major loan has been extended to Chile's economic development agency Corfo together with other IFIs.

    Brazil and IDB have initiated the creation of a unique financial solutions and hedging platform aimed at reducing foreign exchange risk for investments aligned with socio-environmental principles and climate change adaptation and mitigation. These innovative tools seek to attract green investments within Brazil's Green Transformation Plan. Initially, the platform has the potential to mobilize coverage of up to US$ 3.4 billion.

- Bilateral Development Finance Institutions (KFW, DEG)
  - KFW manages the BMZ's PtX Development Fund for developing countries and emerging economies.The PtX Development Fund of € 270 million aims to promote public organizations and private companies in developing countries and emerging economies where the conditions for green hydrogen are particularly good.
  - DEG is the private sector finance subsidiary of the KFW banking group. DEG has ample experience with the financing of renewable energy IPPS and syndicates loans.

Local Lenders active in renewable energy projects:

- AFAP – Agência de Fomento do Estado do Amapá S/A
- AFEAM – Agência de Fomento do Estado do Amazonas S/A
- AGE – Agência de Empreendedorismo de Pernambuco
- Agência de Fomento de Goiás S/A
- AGERIO – Agência de Fomento do Rio de Janeiro
- AGN – Agência de Fomento do Rio Grande do Norte S/A
- BADESC – Agência de Fomento do Estado de Santa Catarina
- BADESUL
- Banco BV
- BANDES – Banco de Desenvolvimento do Espírito Santo
- BASA – Banco da Amazônia
- BB – Banco do Brasil
- BDMG – Banco de Desenvolvimento de Minas Gerais
- BNB – Banco do Nordeste Brasileiro
- BRDE – Banco Regional de Desenvolvimento do Extremo Sul
- Desenbahia – Agência de Fomento da Bahia S/A
- Desenvolve Alagoas – Agência de Fomento de Alagoas
- Desenvolve MT – Agência de Fomento de Mato Grosso
- Desenvolve Roraima – Agência de Fomento do Estado de Roraima
- Desenvolve SP – Agência de Fomento de São Paulo
- FG/A Gestora de Recursos Ltda - Fundo Garantidor de Biogás
- Fomento Paraná – Agência de Fomento do Paraná
- Fomento Tocantins – Agência de Fomento do Estado de Tocantins
- Piauí Fomento – Agência de Fomento e Desenvolvimento do Piauí S/A
- Commercial banks with experience in project finance

Detailed information are reported in the main feasibility study report.

From the technical and offtake perspectives, multiple interactions were conducted with technology developers, including Topsoe A/S, Casale SA and ThyssenKrupp AG, as well as energy companies, Uniper. Contacts have also been initiated with relevant offtakers and/or potential project partners, both local ones such as Petrobras S.A. and Eletrobras S.A., and international ones such as Evonik and Maersk.

5 Timeline & roadmap

A preliminary project implementation timeline is provided in Table 5.1.

Table 5.1: Project implementation timeline

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Biogas Expansion Plant													
	Design	■											
	Design FEL2/FEL3		■	■									
	Licenses and permits	■	■	■	■								
	Construction			■	■	■							
	Licenses and permits 2nd phase				■	■							
	Construction 2nd phase					■	■	■					
	Licenses and permits 3rd phase						■	■					
	Construction 3rd phase							■	■	■			
	Licenses and permits 4th phase							■	■				
	Construction 4th phase								■	■	■	■	
	Commissioning												■
Renewable Energy farms													
	Design FEL2				■								
	Design FEL3					■							
	Licenses and permits					■	■	■					
	Construction							■	■	■	■		
	Commissioning										■		
Chemical Synthesis & H2 Plant													
	Design FEL2				■								
	Design FEL3					■	■						
	Licenses and permits						■	■	■				
	Construction								■	■			
	Commissioning										■		■

The process of acquiring environmental licensing and necessary permits for the biogas plants expansion has already started with the first biogas plant in Rocio.
The 45 biogas plants expansions plan is composed of 4 phases, where roughly 11 plants are built per phase. Financing of the 4 different construction phases is expected to be carried out also following the prescribed phases. Obtaining the different licenses and permits for the multiple biogas plants is estimated to last roughly 2 years per phase given the relatively large amount of plants and sites to be evaluated.
Regarding the Renewable Energy farm and the chemical synthesis plant since a specific site analysis has yet to be conducted, the timeline for such facility have been estimated following Niras experiences in similar projects.

The first step necessary for the following project is to proceed with the next design phases FEL 2 and FEL 3, essential for both renewable energy farm and chemical synthesis and electrolizer facilities. For that purpose a roadmap document (REFERENCE) describing the methodology, the necessary items and documentation to be produced to achieve FEL 2 stage has been drawn up. Financing of such a design phase is currently sought after, together with relevant partners and offtakers to join the project.

6 References

1. *Innovation Outlook Renewable Methanol.* s.l. : Internation Renewable Energy Agency, IRENA, 2021.
2. *Net Zero by 2050 - A Roadmap for the Global Energy Sector.* s.l. : Internation Energy Agency, 2021.
3. S&P Global. [Online] https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/chemicals/021523-renewable-methanol-drives-maritime-industry-decarbonization-institute-ceo.
4. *Tradewindsnews.* [Online] https://www.tradewindsnews.com/containerships/maersk-s-morten-bo-christiansen-on-green-methanol-supply-we-have-mountains-to-climb-/2-1-1470250.
5. European Union Aviation Safety Agency, EASA. [Online] https://www.easa.europa.eu/eco/eaer/topics/sustainable-aviation-fuels/current-landscape-future-saf-industry.
6. Reuters. [Online] https://www.reuters.com/sustainability/us-sustainable-aviation-fuel-production-target-faces-cost-margin-challenges-2023-11-01/.
7. IATA Sustainability and Economics. [Online] https://www.iata.org/en/iata-repository/publications/economic-reports/sustainable-aviation-fuel-output-increases-but-volumes-still-low/.
8. ONS – OPERADOR NACIONAL DO SISTEMA ELÉTRICO. [Online] https://www.ons.org.br/Paginas/resultados-daoperacao/historico-da-operacao/geracao_energia.aspx .
9. *Directive (EU) 2018/2001 of the European Parliament and of the Council.* s.l. : European Parliament and the Council of the European Union, 2018.
10. *Cost Estimate Classification System.* s.l. : AACE International Recommended Practice . No. 17R-97.
11. Seider, W. D., Lewin, et al. *PRODUCT AND PROCESS DESIGN PRINCIPLES Synthesis, Analysis, and Evaluation.* 2017.
12. *Techno-economic assessment of membrane assisted fluidized bed reactors for pure H2 production with CO2 capture.* V. Spallina, D. Pandolfo, A. Battistella, M.C. Romano, M. Van Sint Annaland, F. Gallucci. 120, 257-273, s.l. : Energy Conversion and Management, 2016.
13. *Analysis of hydrogen production costs in steam-methane reforming considering integration with electrolysis and CO2 capture.* M. Katebah, M. Al-rawashdeh, P. Linke. 10, 100552, s.l. : Cleaner Engineering and Technology , 2022.
14. *Assessment of hydrogen production with CO2 capture Volume 1: baseline state-of-the-art plants.* . s.l. : NETL – National Energy Technology Laboratory. U.S. Departament of Energy, 2011.
15. *Cost forecast for low tempeerature electrolysis - technology driven bottom-up prognosis for PEM and alkaline water electrolysis systems.* Freiburg : FRAUNHOFER - FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE, 2022.
16. Dias, A. R. und Nieto, R. C. *Geração Fotovoltaica centralizada: estudo de viabilidade financeira.* 2021.
17. *Power Technology.* [Online] https://www.power-technology.com/news/eneva-692mw-solar-complex-brazil/.
18. *New Energy Events.* [Online] https://newenergyevents.com/the-766-mw-sol-do-cerrado-solar-park-located-in-brazil-has-started-generating-power/.
19. *PRnewswire.* [Online] https://www.prnewswire.com/news-releases/essentia-energia-a-patria-investments-company-announces-the-beginning-of-sol-do-sertao-solar-power-plant-operations-301406282.html.
20. *AA Energy.* [Online] https://www.aa.com.tr/en/energy/news-from-companies/enel-starts-build-of-s-americas-largest-pv-plant/22033.
21. *Renewable power generation costs in 2022.* s.l. : International Renewable Energy Agency, 2023.
22. [Online] BloomberNEF. https://assets.bbhub.io/professional/sites/24/BloombergNEF-How-PV-Plus-Storage-Will-Compete-With-Gas-Generation-in-the-U.S.-Nov-2020.pdf.
23. [Online] https://guidetoanoffshorewindfarm.com/wind-farm-costs.
24. *H2UPPP - Biogas Plant Expansion Report.* s.l. : mele Biogas GmbH, 2023.
25. [Online] http://www.dme-pc.com.br/atendimento/tarifas.
26. [Online] https://www.celesc.com.br/tarifas-de-energia.
27. [Online] https://aiche.confex.com/aiche/2023/meetingapp.cgi/Paper/660535.
28. [Online] https://www.argusmedia.com/en/news-and-insights/latest-market-news/2569030-low-carbon-methanol-costly-eu-bunker-option.
29. [Online] https://denergia.com.br/dashboard.

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The International Hydrogen Ramp-up Programme (H2Uppp) of the German Federal Ministry for EconomicAffairs and Climate Action (BMWK) promotes projects and market development for green hydrogen in selected developing and emerging countries as part of the National Hydrogen Strategy.