TECHNO-ECONOMIC SIMULATION MODEL FOR OPTIMIZATION OF POWER-TO-X GREEN HYDROGEN SYSTEMS INVOLVING SEVERAL ENERGY SOURCES: A CASE STUDY OF AMMONIA PRODUCTION IN SOUTH AFRICA

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ABSTRACT

The design of an industrial facility to produce green hydrogen and derivates requires many technical and economic considerations, such as the way of obtaining renewable energy or the water intake. This entails that the overall system could include not only the electrolysers but also a renewable energy solar or wind park, a battery energy storage system, or a desalination plant to obtain water. Furthermore, the complexity escalates if the hydrogen serves as a feedstock for processes like ammonia or methanol production. These reactors operate steadily and require a continuous hydrogen supply, necessitating careful synchronization within the overall system design. Balancing these factors is crucial for ensuring the reliability and efficiency of the entire production process without oversizing the equipment.

The paper presents a techno-economic model proposing an approach to achieve optimal design by minimizing the Net Present Cost (NPC) and Levelized Cost of Ammonia (LCOA) in a complex Power-to-Ammonia system in South Africa. This system involves various main components such as electrolysers, a photovoltaic plant, a wind plant, a battery energy storage system, a potential grid connection, a desalination plant, compressors, hydrogen storage, an ammonia loop, and air separation units. Three configurations were analyzed, each with different energy sources, and optimized to find the most favorable size of each component. Results indicate that the LCOA ranges from 0,925 to 1,163 €/kg NH_3, with grid-connected systems falling within the lower range and off-grid systems in the higher range.

1 INTRODUCTION

In 2030, global ammonia demand is expected to reach 223 million metric tons, with approximately 85% dedicated to fertilizer production (IRENA, 2022). Traditionally, ammonia has been produced via the thermochemical conversion of nitrogen and hydrogen through the Haber-Bosch process, where nitrogen is sourced from air and hydrogen mainly from natural gas. However, due to the significant contribution of this sector (1,8%) to global greenhouse gas emissions (The Royal Society, 2020), there is a shift towards decarbonization by changing the way of obtaining the hydrogen: from coal or natural gas reforming to water electrolysis using renewable energy.

The demand for ammonia is surging worldwide, driven by agricultural, chemical, and maritime industries, where green ammonia is emerging as a preferred fuel for the future. In this context, South Africa stands out as one of the few regions with highly favorable conditions for green hydrogen and ammonia production and export. The country boasts world-class renewable resources (Figure 1), strategic harbors, access to the sea, and extensive land.

Numerous models and studies about green hydrogen production have been developed (Blanco, 2022), but only a few combines green hydrogen production with ammonia synthesis. Some of these studies focus on wind-based ammonia production (Morgan, 2014), solar-based (Osman, 2020) or combinations of wind and solar energy sources (Nayak-Luke, 2018), while others explore the flexibility of Haber-Bosch reactors in the design process (Gallardo, 2021).

To perform this kind of studies there are two possibilities: one consists of simulating one reference year and extrapolate the values to the rest of the year. This methodology works for quick calculations but overlooks crucial factors that can determine project feasibility, such as system degradation over time, efficiency losses, and the potential for system augmentation. The other approach, used in this paper, involves simulating the overall system during the project's whole life with an hourly step resolution to

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achieve the feasible optimal solution. This way, the novel comprehensive model proposed for this study differs from the previously mentioned ones as it accounts for non-linearities as system degradation over time, replacements, performance curves dependent on load points, restrictions on load changes, start-up and shutdown times, availabilities, and the interconnection of all subsystems during all the project lifespan. To accomplish this, an algorithm called LHySA, with hourly resolution, has been developed to accurately simulate the system's performance. It considers all the mentioned parameters and integrates them with an energy management algorithm that regulates energy flows between subsystems. Additionally, a hydrogen management algorithm was devised to optimize the hourly production profile, minimizing storage requirements while enabling alignment of fast renewable energy variations with the slow reaction time of ammonia reactors.

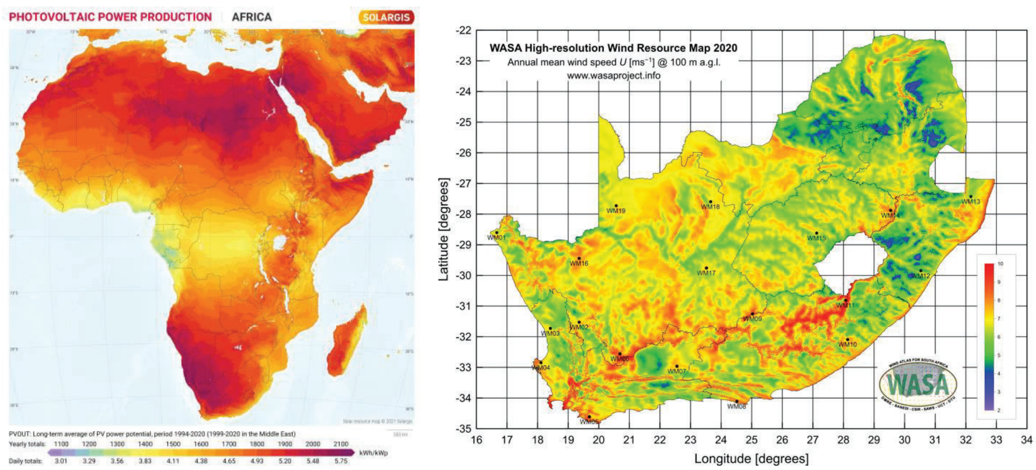

Figure 1: Photovoltaic potential in Africa at the left side (Solargis, 2021) and annual mean wind speed in South Africa at the right side (WASA, 2020)

The model calculates the CapEx and OpEx costs, cashflows, and revenues of each system, and, to come up with the optimal solution, an iterative non-derivative optimization process is used. This process tests different configurations and sizes to optimize the system, minimizing the NPC and LCOA of the project while fulfilling the production targets over the whole lifetime. The accuracy of the model has been validated according to a Class 4 study as per AACE International Recommended Practice.
Merging all these concepts, this Power-to-X green molecules model approach allows for finding an optimal techno-economic configuration of a highly complex system as the one shown in Figure 2.
This paper is structured as follows: In Section 2 the different case studies are presented and described. Section 3 explain the technology used and the main parameters considered. The methodology is explained in Section 4. Finally, Sections 5 and 6 respectively outline the results and conclusions.

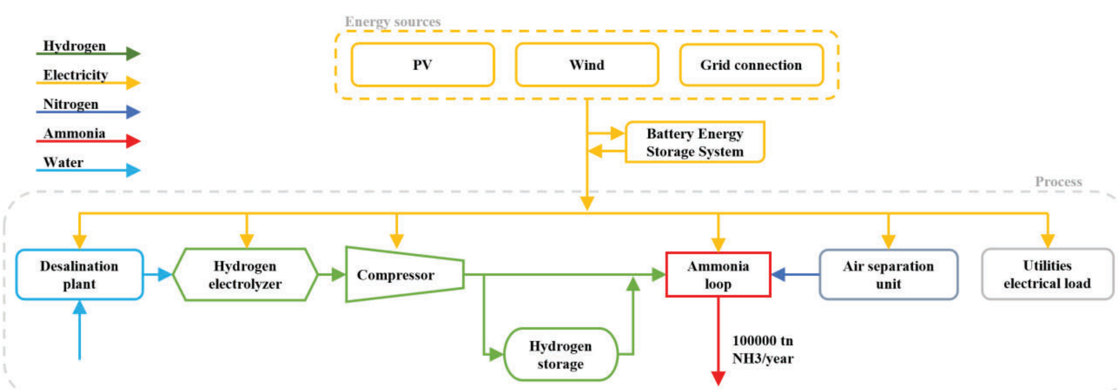

Figure 2: Schematic diagram of the Power to Ammonia system

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2 CASE STUDIES

The study conducted considers an ammonia facility in South Africa with an annual target of 100 ktn NH_3. Three cases were examined, each utilizing different energy sources while keeping the ammonia loop capacity constant at 13,86 tn NH_3/h. The electrolyser, desalination plant, battery energy storage system, and hydrogen storage sizes were varied to determine the optimal configuration for each case, following the methodology outlined in Section 4 to minimize the NPC and the LCOA.
The different cases studied are the following:

- **Case 1** considers a photovoltaic plant with a battery energy storage system and no grid connection with the electrolysers only working coupled with the photovoltaic plant.

- **Case 2** mixes both photovoltaic plant and a wind farm with a battery energy storage system without grid connection with the electrolysers only working coupled with the photovoltaic plant and the wind farm.

- **Case 3** considers a photovoltaic plant, a wind farm and a grid connection enough to maintain the electrolysers working at 100% always.

In all Cases the assumptions listed in Table 1 are considered: The target is to produce a yearly amount of 100 kt NH_3 during the whole life of the project stopping the ammonia loop only once a year for maintenance purposes. The objective of the BESS system is not to feed the electrolyser but to maintain running all the systems needed to produce the ammonia when there are no energy sources available. The working hours during a year are 8250 in every case.

Table 1: Case studies main parameters

Ammonia target	Lifespan	Working hours	Discount rate
100 ktn/year	30 years	8250 h/year	8%

A scheme of the cases considered is shown in Figure 3.

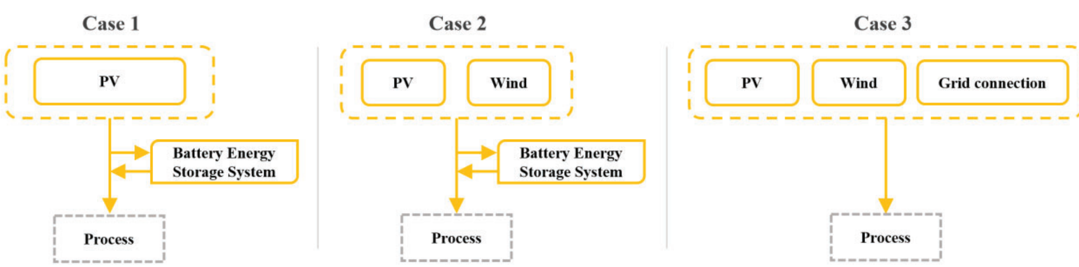

Figure 3: Scheme of the energy sources available in each case

3 TECHNOLOGY DESCRIPTION

The description of the technology and ratios employed in the simulation is described below.

3.1 Ammonia loop

Ammonia (NH_3) is produced through the Haber-Bosch process from a mixture of hydrogen (H_2) and Nitrogen (N_2) that react at high temperature (300~500ºC) and high pressure (140~250 bar) according to the reaction defined in Equation (1).

$$3H_2 + N_2 = 2NH_3 + Heat \quad (1)$$

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The process is driven in an ammonia loop that comprises a synthesis reactor, compressors, heat exchangers, mixing units, a waste heat boiler and a bottom cycle to recover part of the energy released in form of heat to reduce the overall electrical consumption.

Only part of the hydrogen and nitrogen is converted into ammonia by passing through the catalyst beds, so the process is designed to recirculate the streams to achieve a high reaction rate. After the syngas passes through the ammonia converter, the outlet gas is cooled to condensate the ammonia and the heat released together with the heat produced in (1) is used to produce high pressure steam in the waste heat boiler to feed the bottom cycle to produce electricity.

Traditional ammonia loops have a limited turndown ratio, need and almost continuous feed of hydrogen, nitrogen and electricity and are designed for steady-state operation. Although some licensors are starting to offer flexible ammonia loops with impressive turndowns and dynamics, the industrial scale plants use the before-mentioned technology. For that reason, in this paper it has been considered and ammonia loop with a load range of 40-100% with ramp up and ramp down rate of 20% per hour.

The electricity consumption is 0,154 kWh/kg when the load point is above 80% and 0,308 kWh/kg if below. Other parameters are listed in Table 2.

Table 2: Ammonia loop parameter considered in the model

Parameter	**Unit**	**Value**
Technology	-	Haber-Bosch
Specific consumption	kWh/kg	0,154-0,308
Hydrogen consumption	kg H_2/kg NH_3	0,186
Nitrogen consumption	kg N_2/kg NH_3	0,824
Ramp up rate	%/h	20
Ramp down rate	%/h	20
Turndown	%	40
Availability	%	94,17
CapEx	€/(kg/h)	7632
OpEx	€/(kg/h)/year	210
Lifespan	year	30

3.2 Electrolyser

Electrolysers are electrochemical devices that split water molecules into hydrogen and oxygen using electricity.

The core of the electrolysers are the cells where the electrochemical process happens. Each cell is composed of two electrodes (anode and cathode), an electrolyte, two porous transport layers and bipolar plates to provide mechanical support and to distribute the flow. Many of these cells are stacked in series forming a stack, and many stacks are connected in series or parallel to reach the desired hydrogen production. Apart from the stacks, an electrolyser is composed of several subsystems including rectifiers, transformers, cooling system, purification system and a demineralized water supply system among others.

Electrolyser technology can be divided in PEM (Proton Exchange Membrane), ALK (Alkaline), SOEC (Solide Oxide) and AEM (Anionic Exchange Membrane). While SOEC and AEM are still in development, ALK and PEM are commercially available now.

In this paper, PEM technology has been chosen due to the high flexibility and short start-up time that, against AEC technology, makes it more suitable to be coupled to the renewable energy variability. It has been modelled considering the features in Table 3. The range of specific consumptions shown in the Table depends on electrolyser load point, being 57 kWh/kg corresponds to 100% load, and 53 kWh/kg to 40% load. The degradation considered affects this ratio by increasing it causing a decrease in the hydrogen production for the same electricity consumption. To counter-back this issue during the life of the project, a power overcapacity of 5% with respect to electrolyser nominal design is considered to avoid producing less hydrogen.

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Table 3: Electrolyser parameter considered in the model

Parameter	Unit	Value
Technology	-	PEM
Specific consumption	kWh/kg	53-57
Water consumption	L/kg	15
Pressure	bar	40
Degradation	%/year	1
Ramp rate	%/s	Instantaneous
Turndown	%	30
Availability	%	99
CapEx	€/kW	1145
OpEx	€/kW/year	31250
Stack replacement	€/kW	200
Lifespan	EOH	80000

3.3 Air Separation Unit

The other main feedstock for the ammonia synthesis process is nitrogen. It can be obtained from air using an Air Separation Unit (ASU) and there are three different technologies available: Cryogenic distillation, Pressure Swing Adsorption and Membrane Permeation. Cryogenic distillation is the most used technology in large-scale industry and consists of distillation columns operating at very low temperatures to separate air components (O_2, N_2, Ar, etc) according to their different boiling temperatures. On the other hand, Pressure Swing Adsorption is a discontinuous separation process which consists of separating nitrogen from air by adsorbing the oxygen on carbon particles. This technology allows for flexible operation (30-100%) and it is usually employed in medium applications (25-3000 Nm3/h). Finally, Membrane Permeation technology separate the nitrogen from the air via selective gas permeation through a membrane. It is usually used for small applications and the main disadvantage is the low purity compared to the other methods.
In the model presented in this paper, PSA technology has been selected due to the nitrogen production capacity required and the high load range feasible. Specifically, a constant electricity consumption ratio of 0,33 kWh/kg N_2 and a load range from 30 to 100% is considered with no degradation expected over time. The CapEx is estimate as 1758,00 €/(kg/h) N_2 and the OpEx as 16,27 €/(kg/h)/year (Rueda *et al.*, 2024).

3.4 Desalination plant

The water required for the process of hydrogen production is obtained directly from the sea. There are two main desalination methods: thermal and membrane water separation from salts. During the last century, the majority of the desalinated water was produced by thermal evaporation, however, in recent years, reverse osmosis is taking the lead thanks to its lower energy consumption and the advances in the technology.
In this paper, the selected technology is Reverse Osmosis with an energy consumption ratio of 3,3 kWh/m3. Reverse Osmosis is a process where the seawater is pumped under high pressure through a semi-permeable membrane creating a stream of treated water called permeate and a stream of reject water named brine. The plant is composed of a sea water intake, a brine outfall, a pre-treatment system, the Reverse Osmosis system, and a post-treatment system.
In the model, the CapEx is estimated as 57130 €/m3/h and the OpEx as 2400 €/m3/h/year. No degradation is expected during the life of the project (World Bank, 2019. Coxabengoa, 2024).

3.5 Hydrogen storage

Hydrogen can be stored in different ways. Liquified, hydrogen has been widely used as rocket fuel but it is complex and costly because the gas has to be cooled to -253ºC and stored in insulated tanks. Other option is the material-based storage, where the hydrogen is absorbed into a solid and then released. Also, to store big amounts of hydrogen it is also being developed the geological storage in salt cavern

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or depleted oil fields and aquifers. Anyhow, the most widely technique to store hydrogen is compressed in tanks made of steel or composite that allow reaching pressures up to 900 bars.
In this project, due to the size and the maturity of the technology, the chosen option is compressed storage in steel tanks type I at a maximum pressure of 100 bars. The CapEx considered is 870 €/kg, the OpEx is 8,7 €/kg/year, and no replacements are expected during the lifetime of the project (Hydrogen Europe, 2022. Coxabengoa, 2024).

3.6 Hydrogen compressors

Reciprocating oil-free compressors have been considered to increase the hydrogen pressure from 40 bars at the outlet of the electrolyser to the storage pressure of 100 bars. The electrical consumption is assumed as an average of 0,52 kWh/(kg/h) and a CapEx of 429 €/(kg/h). The yearly OpEx is 42,9 €/(kg/h) and no replacements nor degradation are expected during the lifetime. The compressors are modelled to work coupled with the electrolysers.

3.7 Photovoltaic plant

The photovoltaic power production is calculated using PVSyst software and Meteonorm data. For this paper, single axis tracking and bifacial modules with a DC:AC ratio of 1,08 are employed. The CapEx is 572 €/kWp and the OpEx 3,36 €/kWp/year. The expected degradation has been modelled as 0,4% per year. No replacements nor augmentations have been considered during the 30 years.

3.8 Wind

The wind power production has been modelled using turbines of 6 MW of unitary nominal power with a cut-off speed of 25 m/s. The lifespan considered is 30 years and the annual degradation is 0,4%. Wind data were obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program. CapEx is estimated as 1230,4 €/kW and OpEx as 28,33 €/kW/year. No replacements are expected during the lifetime of the project. (NREL, 2023)

3.9 Battery Energy Storage System

For the Battery Energy Storage System (BESS) there are several technologies available: lithium ion, lead acid, nickel cadmium or flow batteries. In this paper it has been considered lithium-ion batteries thanks to the high efficiency, energy capacity and depth of discharge and due to the long lifespan. As its name implies, the lithium-ion battery uses lithium salts for the electrolyte, a lithium compound for the cathode electrode and usually graphite for the anode. The model considers 5 MWh modules with the characteristics shown in Table 4. During the lifetime of the project, it will be performed a yearly augmentation strategy to recover initial performance every year.

Table 4: BESS parameter considered in the model (Coxabengoa, 2024)

Parameter	Unit	Value
Technology	-	Lithium-ion
Operating consumption	kWh/MWh	5,34
Iddle consumption	kWh/MWh	0,42
Degradation	%/year	3,1
RTE	%	82,8
DOD	%	2-100
Augmentation strategy	-	Yearly
CapEx	€/kWh	152
OpEx	€/kWh/year	2,85
Lifespan	year	20

3.10 Grid connection

In the cases where exists a grid connection, it has been modelled as a 100% available energy source. As average, the electricity cost considered is 59,9 €/MWh (NERSA, 2022). The excess energy produced by the renewables does not generate any revenue.

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3.11 Auxiliary consumption

The facility's auxiliary total power consumption, including HVAC, lighting, fire protection, and other systems, has been estimated as approximately 0,8% of the total installed power of the electrolyser.

3.12 Interconnections of the systems

To incorporate the cost of utilities, interconnection pipes for hydrogen and ammonia, and electrical transmission lines into the model, an additional 5% has been assumed on top of the calculated CapEx. This adjustment assumes the facility's proximity to the coast. Land rental costs are not considered in this analysis.

4 METHODOLOGY OF THE SIMULATION MODEL

The simulation model follows an algorithm aimed at identifying the solution with the lowest Net Present Cost (NPC) calculated as in Equation (3) and Levelized Cost of Ammonia (LCOA), Equation (2). This algorithm calculates mass and energy balances as well as cash flows for each hour of the project. A schematic of the algorithm is depicted in Figure 5. The process begins by generating N scenarios with different equipment sizes, followed by simulating the plant for each hour during the project lifetime. In Figure 4 it can be seen some of the mass and energy balances calculated each hour, and, in Figure 6, an example of the the yearly balances for Case 1.

The operational philosophy recognizes that the ammonia loop requires a nearly constant supply of hydrogen and that changes in the load point of the ammonia loop occur slowly compared to those of the electrolyser. Therefore, it is essential to store hydrogen and energy to ensure the continuous operation of the ammonia loop. However, designing the hydrogen storage to meet the demands of the most critical days in terms of renewable energy scarcity could result in oversizing, with the storage being fully utilized only on certain days each year. To mitigate this issue, the methodology presented includes anticipative control, which adjusts the load point of the ammonia loop if the forecast for the upcoming days indicates insufficient hydrogen availability. By reducing the load point, less hydrogen is consumed, allowing the ammonia loop to operate for longer periods until a more favorable forecast is anticipated. This concept is elaborated upon in Section 4.1.

Additionally, to ensure optimal energy utilization and proper sizing of every system, the energy strategy outlined in Section 4.2 has been implemented.

$$LCOA = \frac{\sum_{n=0}^{30} \frac{cost(n)}{(1+r)^n}}{\sum_{n=0}^{30} \frac{Ammonia\ produced(n)}{(1+r)^n}} \tag{2}$$

$$NPC = \sum_{n=0}^{30} \frac{cost(n)}{(1+r)^n} \tag{3}$$

4.1 Hydrogen Management Algorithm

The objective of the Hydrogen Management Algorithm (HMA) is to optimize the operation strategy of the ammonia loop by adjusting its load point to prevent hydrogen depletion and consequent plant shutdown. The algorithm assesses the state of the hydrogen storage every hour and forecasts hydrogen production for the subsequent hours based on the input renewable energy power profile. If the algorithm anticipates insufficient stored or generated hydrogen in the upcoming hours, it decreases the load point of the ammonia loop, thereby reducing hydrogen consumption and allowing for continued operation without interruption. Conversely, if the ammonia loop is not operating at full capacity and sufficient hydrogen production is expected to support higher loads in the next hours, the load point is increased; otherwise, it remains unchanged.

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4.2 Energy Management Strategy

Operating a Power to X plant needs accurately management of diverse energy demands. When energy availability falls short, strategic decisions must be made regarding the utilization of battery storage or grid access to compensate. On the other hand, during surplus energy conditions, allocation decisions arise concerning whether to prioritize hydrogen production, battery recharging, or grid exportation.
To address these complexities, an Energy Management Algorithm has been implemented. Its operational framework is as follows:

i. Hourly evaluations are conducted to assess the availability of renewable energy and to determine the energy requirements of both the electrolysers and the ammonia loop necessary to meet production targets.
ii. Projections of energy consumption across different plant components are derived based on these targets.
iii. If there are enough renewable energy to feed all those consumptions, they are fed. If not, BESS or grid are used to compensate.
iv. The remaining energy is allocated to hydrogen production. If there is sufficient energy to produce the target amount of hydrogen, it is generated, and any surplus energy is utilized to produce additional hydrogen (if feasible), charge the Battery Energy Storage System (BESS), or inject energy into the grid. In cases of energy deficiency, the BESS or grid connection are utilized. If the electrolyser lacks sufficient capacity, stored hydrogen is deployed to meet demand.
v. Once the real amount of hydrogen, ammonia and the other products are calculated, the consumption of each system is re-calculated according to the new productions and the process is repeated from step (ii) until it converges. Thus, system consumption dependent on load point can be accurately modeled.

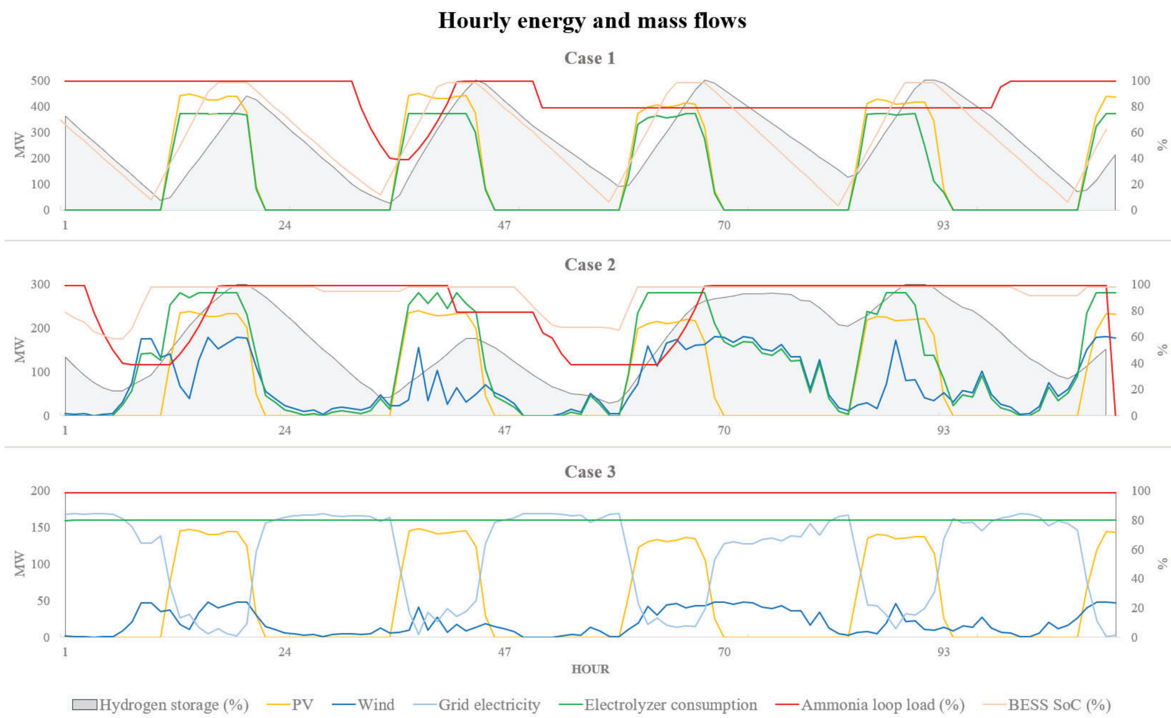

Figure 4: Hourly energy and mass main flows

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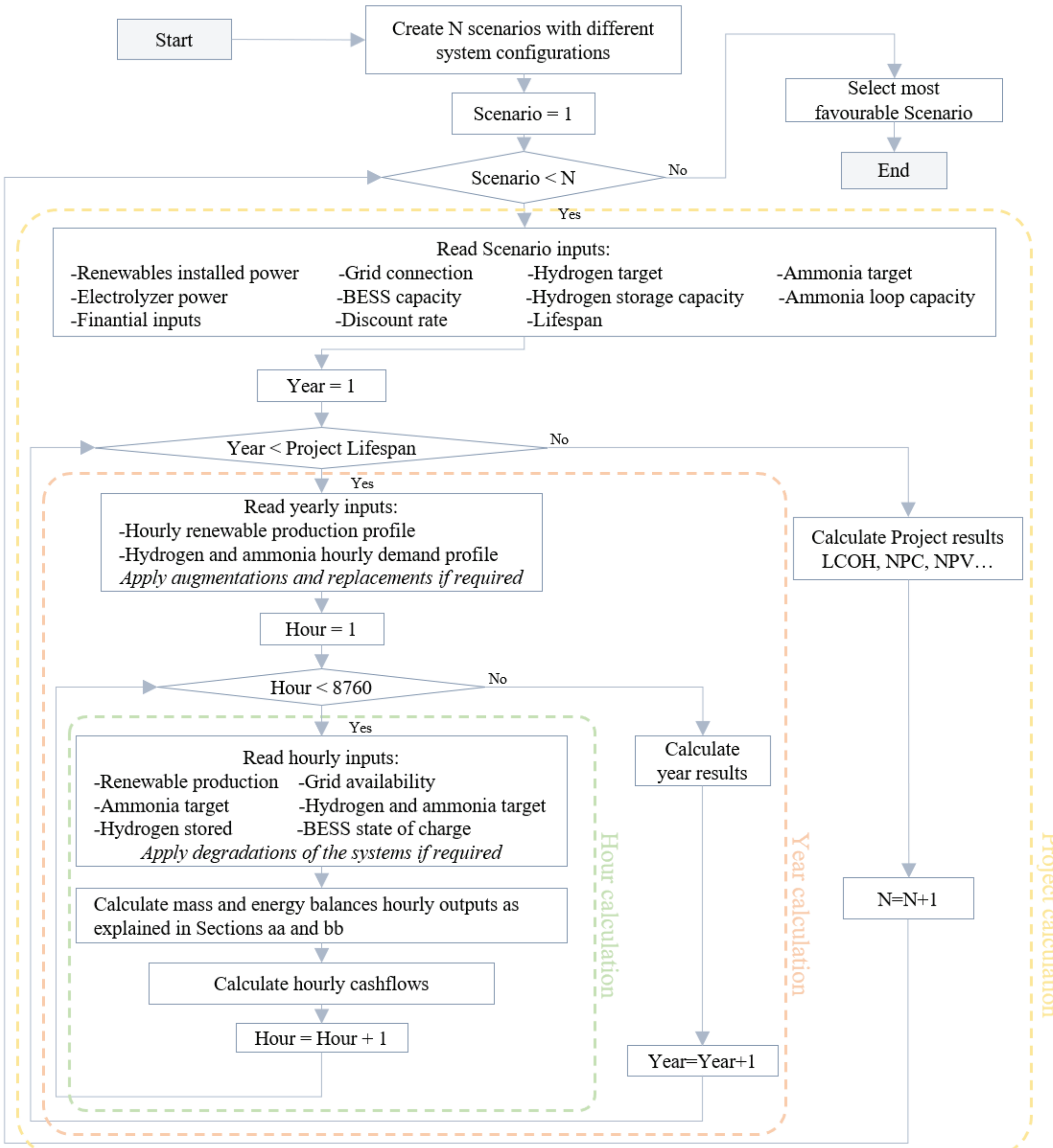

Figure 5: Scheme of the methodology

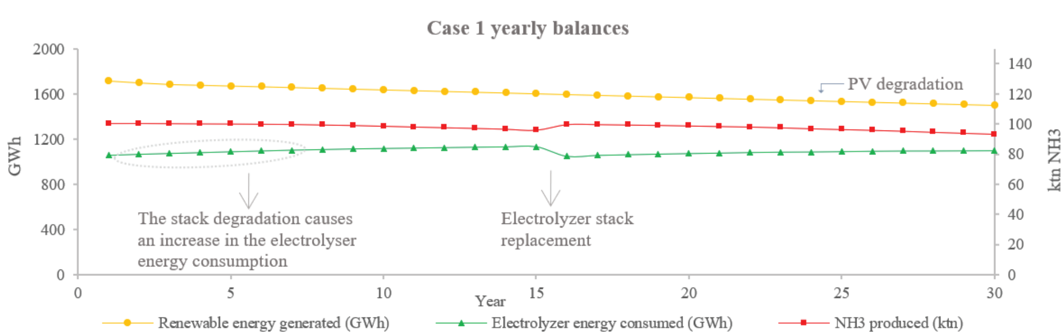

Figure 6: Example of Case 1 yearly balances

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5 RESULTS

For each case, the optimal sizes required to produce 100 ktn of NH_3 annually using an ammonia loop with a nominal capacity of 13,86 tn/h are detailed in Table 5, with key results summarized in Table 6.

Table 5: Optimal size of each system

Case	PV	WIND	GRID	BESS	ELY	DES	STO	ASU	AMM
	MWp	MW	MW	MWh	MW	m^3/h	kg	tn/h	tn/h
1	685	-	-	180	370	35	40000	11,42	13,86
2	365	180	0	150	280	35	38000	11,42	13,86
3	226,5	48	170	-	160	37	5000	11,42	13,86

In Case 1, where only a PV plant is available to provide energy, the electrolyser is oversized because all hydrogen must be produced during solar hours (capacity factor, CP, of 34,96%). The addition of a wind farm enables significant reductions in both the PV plant and electrolyser sizes, achieving a CP of 46,07% in Case 2. A Battery Energy Storage System (BESS) is required in both cases to sustain the ammonia loop and other equipment during periods without sunlight or wind. In Case 3, incorporating a grid connection results in an electrolyser CP close to 100%, allowing for a reduction in size and achieving a minimum LCOA of 0,925 €/kg NH_3. In comparison, Case 1 yields values of 1,163 €/kg NH_3 and 1,147 €/kg NH_3, respectively.
Given that the simulated ammonia loop has a turn-down ratio of 40% and slow load change times (20%/h), the adopted methodology facilitates the design of an optimal hydrogen storage system to attain a capacity factor of the ammonia loop between 87 and 100%. This factor is crucial for meeting project targets and ensuring profitability.

Table 6: Main results

Case	ELY CF	AMM CF	CAPEX	OPEX	NPC	LCOA
	%	%	M€	M€/year	M€	€/kg
1	34,96	87,78	1057,15	21,97	-1297,27	1,163
2	46,07	87,55	982,06	22,22	-1226,89	1,147
3	99,88	99,88	530,43	59,67	-1189,80	0,925

Figure 7 presents a breakdown of the LCOA for each case. Notably, electrolyser CapEx and PV and wind CapEx collectively account for approximately 60% in Cases 1 and 2. However, in Case 3, the primary cost arises from grid electricity. Additional expenses, including desalination plant CapEx, Air Separation Unit (ASU), compressors, interconnections, stack replacements, and associated OpEx, contribute toghether to around 15% of the total. Hydrogen storage and energy storage account for less than 5%.

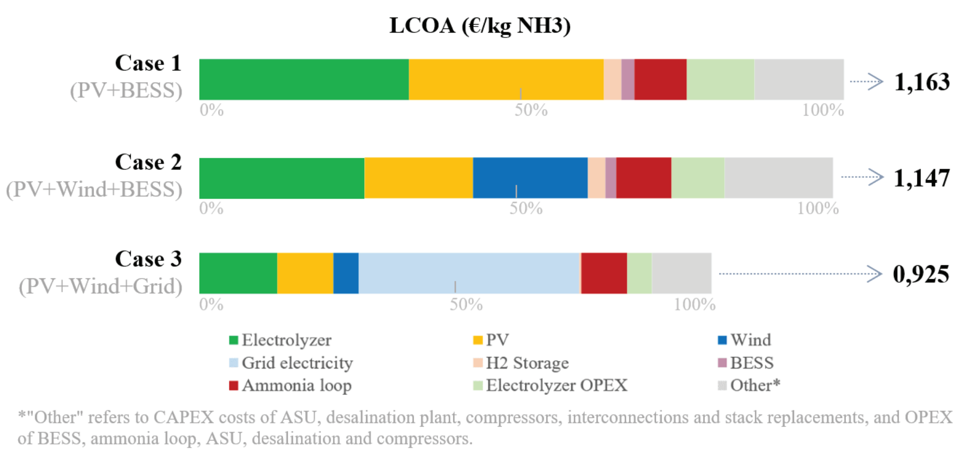

Figure 7: LCOA of each case

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Figure 8 illustrates yearly cash flows for each case from year 1 to year 30. Notable spikes are observed due to stack replacements, with an additional spike in year 20 attributed to BESS overhaul. In Case 3, there is an evident cost increase over time, primarily due to electrolyser degradation and the need for increased energy consumption to maintain constant production.

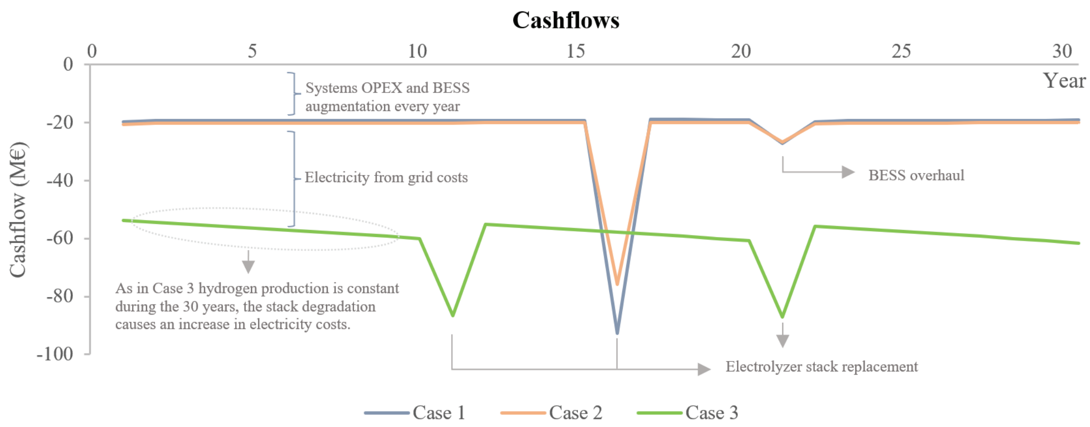

Figure 8: Cashflow of each case

6 CONCLUSIONS

This study explores the cost of ammonia production in South Africa through three scenarios with different energy sources available: Case 1 has PV, Case 2 has PV and wind, and Case 3 has PV, wind and grid connection. The results of the optimal design for each scenario indicate a Levelized Cost of Ammonia (LCOA) ranging between 0,925 and 1,163€/kg NH_3. The upper limit corresponds to the case where only PV is used, while the lower limit is observed when grid access is available.
Further analysis reveals that the primary costs stem from the capital expenditures (CapEx) of PV, wind, and electrolysers in off-grid systems, while grid electricity costs dominate in grid-connected systems. Hydrogen and energy storage expenses constitute less than 5% of the total, with negligible costs associated with the water obtention.

Based on these findings, several key conclusions emerge:

- Ammonia production in South Africa using green hydrogen and renewable sources yields an LCOA ranging from 0,925 to 1,163 €/kg NH_3.
- Investment in hydrogen storage design, operational strategies, and appropriately sized Battery Energy Storage System (BESS) can maximize ammonia production without oversizing primary equipment.
- The flexibility of the ammonia loop is crucial for green ammonia projects, as greater flexibility minimizes restrictions on hydrogen supply, thereby decreasing the costs.
- Although the amount of water needed for green hydrogen production may be a handicap depending on its availability, the cost associated with it are neglibible in the total amount, even if desalination of seawater is required.
- Electrolyser efficiency and degradation significantly influence results and must be carefully considered in analyses.
- Efforts to mitigate electricity-related expenses and reduce electrolyser costs are crucial for enhancing project profitability. Although renewable energy costs are on a downward trajectory, the reduction of electrolyser costs remains imperative for profitability.

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NOMENCLATURE

PV	Photovoltaic park
WIND	Wind farm
ELY	Electrolyser
GRID	Grid connection
BESS	Battery Energy Storage System
AMM	Ammonia loop
ASU	Air Separation Unit
DES	Desalination plant
STO	Hydrogen storage
CapEx	Capital expenditure
OpEx	Operational expenditure
NPC	Net Present Cost
LCOA	Levelized Cost of Ammonia
EOH	Equivalent Operation Hours

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