Inclusive carbon neutral pathways – Assessing the role of two renewable energy supply chains between Africa and the EU in greening their respective energy mix

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Abstract

The European Union has set itself the target of becoming climate neutral by 2050 through a series of policies affecting industries such as the energy sector. This sector will be subject to considerable change with renewable energies set to replace fossil fuels. However, the EU will not be able to solely rely on its domestic production of renewable energies. An option would be to import from Africa as it is close to Europe, while it has considerable potential in terms of renewable energies. Therefore, this research addresses the following question: *How can Africa-EU hydrogen and biomass supply chains contribute to the greening of the EU's energy mix by 2050 while contributing to Africa's renewable energy development?* This question is answered by assessing two renewable energy supply chains: biomass and hydrogen. This study uses the Strength, Weaknesses, Opportunities and Threats (SWOT) analysis framework to investigate these intercontinental supply chains. The research identifies the top-three African countries based on parameters relevant to both supply chains, such as their existing energy infrastructure, transport infrastructure and natural resources. The three best performing countries for each supply chain are assessed based on their potential biomass and hydrogen production and exports to the EU by 2050 considering distinct scenarios (*realistic* and *ambitious*) for each energy product. The scenarios account for the size of the EU's demand for biomass and hydrogen respectively in 2050, with hydrogen also containing an *average* scenario taking into account the average of the forecasted EU energy demanded in existing research. The results show that the best suited African countries for the export of biomass to the EU are Morocco, Egypt and South Africa, while for hydrogen these include Morocco, Egypt and Algeria. It is also found that in a *realistic* scenario, 5,7% of the EU's import demand for biomass and 100% of its import demand for green hydrogen could be fulfilled by the top three supplier countries in each case. In the *average* hydrogen scenario, 33,7% of the EU's import demand would be fulfilled. For the *ambitious* scenario, 4% of the biomass import demand and 4,2% of the EU's hydrogen import demand would be met. The lower percentages of coverage in the *ambitious* scenario are due to the significantly larger demand of biomass and hydrogen with respect to the *realistic* scenario. The research finds that across all scenarios, African countries will be able to meet their own demand for biomass and hydrogen through domestic production, except for South Africa which will not be able to fulfil its demand entirely by itself. Additionally, the research highlights important policy areas which need to be considered, which include setting clearer goals for biomass and hydrogen, and encouraging the development of renewable energy demand in Africa and the EU.

Table of Contents

Table of Figures

Table of tables

List of Abbreviations

DRC	= Democratic Republic of Congo
DSO	= Distribution System Operators
EC	= European Commission
EU	= European Union
FCH	= Fuel Cells and Hydrogen
FiTs	= Feed-in-Tariffs
HVC	= High Value Chemicals
HVDC	= High-Voltage Direct Current
IE	= Industrial Ecology
MCA	= Multi-Criteria Analysis
ME	= Material Economics
NGO	= Non-Governmental Organisation
OFAT	= One-Factor-At-A-Time
RE	= Renewable Energy
RED II	= EU Renewable Energy Directive 2 (revised)
SMART	= Specific, Measurable, Achievable, Relevant and Realistic, Time-related
SWOT	= Strengths, Weaknesses, Opportunities and Threats
TSO	= Transmission System Operators
UN	= United Nations

1. Introduction

The European Union (EU) has set a series of goals aiming at climate neutrality by 2050 (European Commission, 2021). The aim is that 40% of the EU's energy mix will be based on renewable energies by 2030, while advances in energy efficiencies will lead to a decrease of 36-39% of final energy demand by the same year (European Commission, 2021). Crucially, to reach these EU goals, considerable efforts from member states will be required to change their current energy systems. Additionally, the EU needs to find solutions to its dependency on Russian oil and gas which has led to considerable energy supply issues during the Russia-Ukraine war (Fisher, 2022). One of the solutions is to invest in renewable energy sources. However, there is no guarantee that all member states will be able to sustain their energy demands solely with domestic renewable energy production. Therefore, other possibilities will need to be considered, namely importing renewable energies from areas outside the EU, such as Africa (Trieb et al., 2012). This leads to the following research problem: *The EU will struggle to meet its renewable energy needs by 2050, which is why this thesis offers a solution by investigating the potential of exporting biomass and hydrogen from Africa to the EU in order to meet future demand while also identifying policies and stakeholders that can support the development of such supply chains.*

Africa is a continent within close proximity to Europe, which has considerable potential in terms of solar and wind production, as well as hydrogen and biomass-based energy production (Hackenesch et al., 2021). According to the African Development Bank, Africa has an untapped renewable energy potential estimated at 350 GW for hydroelectric energy, 110 GW for wind energy, 15 GW for geothermal energy and 1,000 GW for solar, while the continent's current electricity demand is of 700 TWh (Hafner et al., 2018; IEA, 2019). This current demand would be equivalent to approximately 6%[1] of the African renewable energy potential.

Overall, the surplus of renewable energies produced in Africa could also be used as a fuel for a water electrolysis, converting water into hydrogen. The sustainable nature of an electrolysis is very dependent on the energy used as a source, which is why if countries want to produce green hydrogen it will have to be based on renewable energies (Dawood et al., 2020). Moreover, numerous African countries have demonstrated potential in terms of biomass from agricultural residues and forestry residues, as well as from municipal solid waste (Dasappa, 2011). The main primary biomass types which can be used for export are agricultural residues and forestry residues. As it is often the case, a large amount of agricultural residues remain unused and simply stay in the fields (Batidzirai et al., 2016), which is why the export of biomass to EU countries would pose a valuable opportunity for African countries with

[1] Calculated from the total African renewable energy potential (350+110+15+1,000 = 1.475TW), and assuming, for ease, an annual operation of 8000h/year for all power systems (1.475 TW * 8,000 h = 11,800 TWh). Hence, the current demand (700TWh) would represent a 5,9% of the African renewable energy potential.

excess renewable energy (Mai-Moulin, 2019). Thus, an international trade arrangement on energy carriers, such as biomass and hydrogen, could be seen as a win-win situation for both African and EU countries. As a result, the African potential to produce and export hydrogen and biomass to the EU could help to green the EU energy mix and reach its climate neutrality goals. Therefore, this research seeks to assess the potential of selected African countries for the export of biomass and hydrogen to the EU, while looking at the necessary stakeholders and risks to consider, as well as the policies needed to develop these supply chains.

1.1. Knowledge gap

Currently, existing literature addresses the potential of renewable energy in African countries (Elliott & Cook, 2018; Olaofe, 2018; Omoju, 2020; Parawira, 2009). In terms of hydrogen, existing research mainly focuses on North African countries, which can partly be attributed to their favourable weather conditions and the proximity to the EU (Timmerberg & Kaltschmitt, 2019; van Wijk & Wouters, 2019; van Der Zwaan et al., 2021). The biomass availability in Africa has also been explored for certain countries, such as South Africa and Kenya, by mainly looking at the potential of unused agricultural residues, forest residues and waste (Akinbami et al., 2021; Mai-Moulin et al., 2018). Additionally, forecasts have been conducted on the EU's biomass and hydrogen demand by 2050 (Wang et al., 2021; ME, 2021). With regard to hydrogen, it is interesting to note that most of these predictions are within a similar quantity range (European Commission, 2020d; Tsiropoulos et al., 2020; FCH, 2019; Wang et al., 2021). For biomass, ME (2021) establish two scenarios regarding the future biomass demanded by the EU. Finally, in various researches, scholars have also come with policy recommendations for the EU and African countries on ways to develop renewable energies in Africa (for more details see Literature Review section).

Overall, existing literature has demonstrated the considerable potential of renewable energy and renewable electricity in African countries (Omoju, 2020). However, in the current state of the art only few researchers have attempted to forecast the potential export of biomass and hydrogen energy from Africa to the EU by 2050. Moreover, there is no assessment of the contribution of such renewable energy supply chains between Africa and the EU to the EU's 2050 goals. Therefore, this thesis addresses a gap in the literature by investigating the feasibility of renewable energy supply chains between Africa and Europe, while relating it to the EU 2050 goals.

1.2. Research Question

Subsequently, based on this gap, this thesis seeks to answer the following question:

- *How can Africa-EU hydrogen and biomass supply chains contribute to the greening of the EU's energy mix by 2050 while contributing to Africa's renewable energy development?*

1.3. Sub-questions

In line with the previously stated research question, the following sub-questions are answered for the two renewable energy supply chains analysed in this research:

- *What are the advantages and disadvantages of hydrogen and biomass supply chains between Africa and the EU?*
- *What are the potential quantities of hydrogen and biomass which can be exported from selected African countries to the EU?*
- *How resilient are the hydrogen and biomass supply chains between Africa and the EU?*
- *How does an exchange of hydrogen and biomass between Africa and the EU align with the EU's 2050 goals?*
- *Which policies are needed to develop a hydrogen and biomass energy supply chain?*

1.4. Relevance of the Research

1.4.1. Social Relevance

From a social relevance perspective, this research addresses a fundamental issue which impacts every human being, namely global warming. Consequently, it attempts to offer a pathway to solve the current dependency of consumers on unsustainable energies, such as fossil fuels. Moreover, despite current efforts from countries to reduce their carbon emissions by transitioning to more sustainable energy mixes, it remains a slow and lengthy process which is why this thesis could offer a valuable solution to achieve climate neutrality. From a European perspective, seeking solutions to decrease dependency on fossil fuels also entails decreasing the current dependency on Russian oil and gas which has led to considerable supply issues during the Russia-Ukraine war (Fisher, 2022). This situation has demonstrated that it is important for the EU to diversify its import partners in order to limit dependency on single suppliers which can severely jeopardise energy supplies in the case of wars or conflicts (Christopher & Peck, 2004). On the other hand, researching the possibilities for renewable energies in Africa is also relevant to local African communities which could benefit economically and socially from the development, implementation and deployment of such projects on renewable energy systems. For the past years, the percentage of the African population with access to electricity has been in decline, which is also why there is a huge potential in developing energy production on the continent (IEA, 2020). Finally, this thesis also offers policy recommendations in order to develop renewable energies in Africa which could also contribute to an increase in the energy access of local populations.

1.4.2. Relevance to Industrial Ecology

This research is relevant to the field of Industrial Ecology (IE), and sustainability as a whole since it investigates sustainable energy solutions in order to replace existing fossil fuel-based energies. These are key solutions which can considerably help reaching climate goals, while generally contributing to the global climate mitigation. This is in line with El Haggar's (2010) view on the field of Industrial Ecology: "the ultimate goal of IE is to achieve sustainable development that will eventually lead to achieving compliance with the environmental regulations aimed at protecting the environment" (p.139). The concept of sustainability encompasses three main pillars: the economic, environmental and social (Purvis et al., 2019). The environmental pillars encompasses the green energy transition while the renewable energy access can be seen as one of the main social pillars. Ultimately, the socio-economic benefits and disadvantages of the renewable energy supply chains can be considered as being an integral part of the economic pillar (Purvis et al., 2019). This research is also part of a larger research project on analysing the potential of exporting renewable energy from Africa to the EU which incorporates multidisciplinary approaches to the issue. The project includes four students, of which two focus primarily on exporting hydrogen from Africa, while the third student focalises on exporting biomass. Ultimately, this research serves as an overview for both energy carriers, by bringing a social and environmental aspect to the broader project.

1.5. Thesis Outline

This research will be structured as follows: First, a background section details the existing energy mix and the renewable energy goals for biomass and hydrogen in the EU and in Africa. Second, a literature review details existing research on the topic, followed by the methodological choices made in this thesis. Third, the Multi-criteria analysis highlights the advantages and disadvantages of African countries based on parameters relevant to both supply chains. Fourth, the potential biomass and hydrogen export section presents the results based on different scenarios relating to the local production and consumption in African countries and the EU by 2050. Fifth, the key stakeholders and threats section discusses the resilience of the supply chains. Sixth, the SMART framework is applied to assess the alignment of the supply chains with the EU 2050 goals, while a policy recommendation section discusses the important policies needed and the opportunities for the supply chains. Finally, the discussion section gives an overview of the results from the SWOT analysis and reflects on the implications of the research.

2. Background

2.1. The European Union's energy sector

2.1.1. Current energy mix and dependencies

In 2019, the EU's energy mix was composed as follows: solid fossil fuels represented 12,7%, total petroleum products (including crude oil) 36,3%, natural gas 22,3%, nuclear energy 13,1%, renewable energy 15,5% and other alternative energies represented 0,1% (Eurostat, 2019a). Regarding renewable energies, biofuels and biogas only accounted for 3,5% of the EU's gas and fuels consumption in 2019 and are mostly based on food and feed crops, while hydrogen contributed to less than 2% of Europe's energy consumption (European Commission, COM/2020/299).

Out of its total energy needs, the EU was able to cover 39% of it through locally produced energy, while 61% was imported from countries outside the EU (Eurostat, 2019a). In 2019, the main imported energy type was petroleum products which represented 66% of imports, followed by natural gas (27%) and solid fossil fuels (6%) (Eurostat, 2019b). For these three energy types, the main import partner was Russia, which was responsible for 27% of the EU's import of crude oil, 41% of the import of natural gas and 47% of solid fossil fuel imports (Eurostat, 2019b). Other important EU trading partners for energy imports included Norway, Iraq, the United States, Nigeria, Algeria, Saudi Arabia, Australia, Kazakhstan and Qatar (Eurostat, 2019b). This demonstrates the considerable energy dependency rate (61% of energy imported) which the EU is currently attempting to reduce by investing in domestic renewable energy production (Eurostat, 2019b).

However, even though these figures give an overview of the union as a whole, these do not reflect the considerable difference in the energy mixes and specific dependencies of EU countries. For example, countries such as Malta (97,2%), Luxembourg (95%) and Cyprus (92,7%) have a very high dependency rate, while others such as Estonia (4,8%) or Sweden (30%) have comparatively low energy dependency rates (Eurostat, 2019c). Therefore, the focus of the EU will also have to be on helping highly dependent countries to become significantly less energy dependent on other non-EU countries. Nevertheless, this is a difficult balance to achieve since the EU will also want to green its energy mix, which will force EU countries to focus on the domestic production of renewable energy but also on the import of renewable energies to meet the EU's goals on time.

2.1.2. EU 2030 and 2050 Goals

The EU and its member states have set themselves the target of becoming climate neutral by the year 2050, in accordance with the UN Paris Agreement (European Commission, 2021a). This entails that the EU will have most of its energy needs met by renewable energies by 2050. Moreover, by 2030, the EU aims at reducing net emissions by 55% compared with the emission levels recorded in 1990 (European Commission, 2021a). The EU's larger environmental policy package for 2030 and 2050, also known as the Green Deal, encompasses a set of proposals on climate, energy, transport and taxation policies which should help reduce greenhouse gas emissions (European Commission, 2021a). This package will result in changing the current business model of many different European industries in order to decrease the EU's greenhouse gas emissions considerably. One of these industries is the energy industry which the EU aims at decarbonising. This sector is especially important to the EU since it represents 75% of total greenhouse gas emissions (European Commission, 2021b). To reach this target the EU aims at increasing the share of renewable energies to at least 40% of the European energy consumption by 2030 (European Commission, COM/2021/557). Additionally, the EU plans on increasing the energy efficiency of the current energy grid while also pushing for stronger energy system integration (European Commission, 2021b)

The last target, namely the energy system integration, encompasses three main concepts: "a more circular energy system", "a greater direct electrification of end-user sectors" and "the use of renewable and low-carbon fuels including hydrogen, for end-use applications where direct heating or electrification are not feasible" (European Commission, COM/2020/299). The "use of renewable and low-carbon fuels" is especially relevant for this report since this concept focuses on biomass and low-carbon hydrogen as solutions for industrial processes, but also for the transport sector (European Commission, COM/2020/299). In fact, the EU also published a parallel strategy which solely focuses on the development of hydrogen in the union (European Commission, COM/2020/301).

Hydrogen strategy

The European Commission's roadmap for hydrogen is divided into 3 phases, with the main objective of especially developing renewable/green hydrogen, which is based on different types of renewable carriers. First, the aim between 2020 and 2024 is to develop 6GW of renewable hydrogen electrolysers in the EU and the production of 1 million tonnes of renewable hydrogen (European Commission, COM/2020/301). During this period, the EU plans on boosting demand and supply by creating a better understanding for potential investors and stakeholders on the needed hydrogen technologies in Europe and the favoured types of hydrogen, namely green hydrogen (European Commission, COM/2020/301).

Second, between 2025 and 2030, the objective is to install a minimum of 40GW of renewable hydrogen electrolysers and the production of 10 million tonnes of renewable hydrogen (European Commission Communication, COM/2020/301). During this period it is also thought that existing fossil-based hydrogen will be replaced by carbon capture technologies in order to reduce pollutant gases even more. Moreover, it is expected that electrolyser costs, which have already decreased by 60% within the past decade, will further be halved by 2030 and will contribute to a decrease in the price of hydrogen in the future (European Commission, COM/2020/301). Additionally, until 2030, the “need for an EU-wide logistical infrastructure will emerge” which will lead to a need for adequate infrastructure to transport hydrogen over longer distances, from production areas to demand centres in other regions and Member States (European Commission, COM/2020/301, p.7). At this stage the European Commission predicts that hydrogen will mostly be used in the steel industry and in the transport sector (European Commission, COM/2020/301).

Third, from 2030 towards 2050, the EU aims to have a sufficiently developed renewable hydrogen infrastructure to reach “all hard-to-decarbonise sectors where other alternatives might not be feasible or have higher costs” (European Commission, COM/2020/301, p.7). In parallel this will require the renewable electricity production to considerably increase, since it is thought that a quarter of renewable energy will be used for the production of hydrogen (European Commission, COM/2020/301). At this stage, it is predicted that a larger part of the European economy will be dependent on hydrogen, and that some of the locally produced biogas will be used to produce hydrogen instead of natural gas.

To make these goals reachable, large investments will be required, but also new partnerships with the EU’s neighbourhood. The EU sees clean hydrogen as an opportunity to diversify and design new energy supply chains with other partnering countries (European Commission, COM/2020/301). The hydrogen roadmap also highlights that, according to estimates, “40 GW of electrolysers could be potentially installed in the Eastern and Southern Neighbourhood by 2030, ensuring a sustained cross-border trade with the EU” (European Commission, COM/2020/301, p.19). Related to this, the EU is currently in talks with African countries in order to raise awareness on the opportunities for clean hydrogen, and to boost renewable energy research and innovation projects in Africa (European Commission, COM/2020/301).

Bioenergy strategy

Despite not having a dedicated roadmap for bioenergy in the EU, this energy type is still planned to have a bigger role in the EU’s future energy mix. Currently, the majority of biofuel targets are related to the transport sector.

A first step was made in the second Renewable Energy directive (RED-II) which introduced a 2030 target of having 14% of the transport sector powered by renewable energies while 3,5% of the energy needed for the sector will be from advanced biofuels (European Commission, COM/2021/557). However, the directive also has a cap of maximum 7% of conventional biofuels from the final consumption of energy in the transport sector of each Member State (European Commission, COM/2021/557). Regarding EU goals for 2050, the share of natural gas in gaseous fuels is supposed to decrease down to 20%, while most of the leftover 80% of gaseous fuels should be of renewable origin.

However, as mentioned by the EU, “the future mix of these gaseous energy carriers – biogas, biomethane, hydrogen or synthetic gases – is hard to project” (European Commission, COM/2020/299, p.16).

It is important to mention that some of the EU’s biodiversity targets could have a negative impact on the development of biofuels and biomass in the EU. One of these targets is to place 30% of the EU’s land area under protection which will limit the area available for the production of biomass, thus impacting the European bioeconomy (European Commission, COM/2021/557). This measure is in line with the prohibition to “source biomass for energy production from primary forest, peatlands and wetlands” (European Commission, 2021b, p.2). Additionally, there will also be no support given to forest biomass in “electricity-only installations” from 2026 onwards (European Commission, 2021b, p.2). Therefore, these stricter EU regulations could lead to larger biofuel imports in the future.

2.2. The African Energy Sector

The energy development of Africa varies considerably between countries and regions. While the majority of populations in North African countries have access to energy, and specifically electricity, others, such as sub-Saharan countries, often only have half or less of their populations’ basic energy needs fulfilled (IEA, 2020). In 2018, North Africa (24%), Nigeria (19%), and South Africa (16%) together accounted for almost 60% of energy demanded despite only representing 35% of the total population of the continent (IEA, 2019). In 2018, the average energy consumption per person in most African countries was considerably lower than the world average of around 2 tonnes of oil equivalent (toe) per capita and can be broadly comparable to India’s average of 0.7 toe/capita (IEA, 2019). However, the demand for energy per inhabitant, which is especially low in Sub-Saharan Africa, is predicted to increase considerably within the next years (IEA, 2019). The total primary energy demand for 2018 was 838 mtoe but is supposed to increase to 1204 mtoe, or even 1318 mtoe, by 2040 depending on different scenarios (IEA, 2019). Therefore, the fossil fuel infrastructure of African countries, such as natural gas, is still very much being developed to meet this increasing demand for energy domestically but also for the fossil fuel demands of trading partners such as the EU (IEA, 2019).

However, many countries across the continent also have considerable potential to develop renewable energy sources, thanks to favourable conditions for solar and wind energy development as well as for hydropower and biomass (Boie et al., 2016). Moreover, this considerable potential has made multiple African countries very interesting in order to develop the production of green hydrogen (van Wijk & Wouters, 2019). The climate goals set by many African countries have led to an increase in the amount of renewable energy projects and the amount of renewable energy in current energy mixes (Boie et al., 2016). The EU and certain of its member states have also co-financed programmes for the research and development of renewable energy supply chains in African countries (European Commission, JOIN/2020/4). In some of these projects, the EU also envisions importing renewable energy from Africa in order to help EU member states reach their climate goals, while also decreasing their fossil fuel dependency (European Commission, JOIN/2020/4).

2.3. Definition of Key Concepts

Renewable Energy Supply Chains

In the context of this research, renewable energy supply chains refers to the entire process of producing renewable energy, from the moment it is acquired until it reaches the final energy consumer. When considering renewable energies, the supply chain can be divided into three parts: the upstream process, the production process and the downstream process (Luthra et al., 2015). The upstream process is the first step which mainly focuses on the procurement of the energy source, while the production process investigates the transformation of clean energy sources into different forms of energy (Luthra et al., 2015). Finally, the distribution system concerns the process of transporting energy to the energy consumers (Luthra et al., 2015). In the case of this research, the energy supply chain would regard all these steps from acquiring the raw energy in Africa until its distribution to the European consumer. However, when forecasting hydrogen exports, the renewable energies required to produce hydrogen are not directly considered as the data retrieved already consider this process.

Supply chain resilience

In this study, supply chain resilience is mainly used in terms of the risk management of the supply chains in relation to potential political instabilities, such as wars, terrorism and domestic conflicts, and changes in demand and supply. The ”social ecological resilience perspective”, which this research will focus on, “requires managers to strive for adaptability and transformability, thereby foreseeing and influencing developments that occur outside the supply chain” (Wieland & Durach, 2021, p.320). This contrasts with the engineering view of supply chain resilience, which “strives for optimality and a fail-safe design” (Wieland & Durach, 2021, p.320). Christopher & Peck (2004) highlight three risks to the resilience of a supply chain, namely the risks that are (1) Internal to a company, including process and control; (2) external to a company, but internal to the supply chain, such as changes in demand or supply; (3) external risks related to the environment, such as terrorism and political instabilities. Out of these risks, this research focuses on risks (2) and (3).

Climate neutrality

The term of climate neutrality mainly refers to achieving a net-zero amount of greenhouse gas emissions, so that the emissions caused by human activity reach a level at which our planet is capable of absorbing those emissions (European Parliament, 2021). Many countries across the world have set aims to reach climate neutrality. The EU has set a goal of reaching climate neutrality by 2050, which involves many different sectors such as the industry, mobility, agriculture and the energy sector (European Parliament, 2021).

Africa-EU partnership

The Africa-EU partnership is based on a comprehensive strategy and roadmap to develop the relationship between both continents regarding five key global trends (European Commission, JOIN/2020/4). These five types of partnerships include: "the Green Transition and Energy Access", "Digital Transformation", "Sustainable Growth and Jobs", "Peace, Security and Governance", "Migration and Mobility" (European Commission, JOIN/2020/4). Overall, the main focus of this research will be on the green transition and energy access aspects of the partnership and how a renewable energy supply chain between Africa and the EU could solidify it.

Feasibility

In the context of this project, "feasibility" refers to the overall aim of this research which is to understand the potential for renewable energy production which can be exported from African countries to the EU, while also examining the advantages and disadvantages of each renewable supply chain (biomass and hydrogen) for possible implementation. Other aspects such as the security of the supply chain, the policies required to promote the production of renewables in Africa and their export to the EU will also be considered when assessing the "feasibility" of these projects.

3. Literature Review

Currently, literature addresses the potential for renewable energies in Africa (Elliott & Cook, 2018; Olaofe, 2018; Omoju, 2020; Parawira, 2009), and the barriers to the investment in renewable energies in North Africa (Komendantova, 2012; Loudiyi et al., 2019). The barriers identified include regulatory, economic and technical barriers, such as the lack of harmonised regulations, geopolitical risks and fossil fuel subsidies (Komendantova, 2012; Loudiyi et al., 2019). However, the academic debate concurs with the fact that the African continent has a huge potential for renewable energies (Hafner et al., 2018), such as the coastal zones of North Africa which currently "possess excellent offshore wind energy resource potential" (Olaofe, 2018).

At the same time, it is often argued that the EU will need to develop closer ties and partnerships with African countries (Scarlat et al., 2018; van der Zwaan et al., 2021). There are different manners of developing renewable energies in Africa, whether that is financially or through the sharing of knowledge (Omoju, 2020). Scarlat et al. (2018) discuss this aspect by referring to the Dutch development programme which aims at increasing the production of biogas in African countries such as Ethiopia, Kenya and Tanzania. The study found that Biogas can encourage the development of rural areas and help creating new supply chains for biomass feedstock, especially when based on waste and residues from agriculture (Scarlat et al., 2018). Overall, to develop the production of renewable energy in Africa, the EU and its member states will need to support the key areas of the continent which detain the highest potential.

The current biomass potential of certain African countries has been researched, focusing mainly on the potential of unused agricultural residues, forest residues and waste (Dasappa, 2011; Duku & Hagan, 2011; Gabisa & Gheewala, 2018; Okello et al., 2013). For instance, Batidzirai et al. (2016) investigate the potential of maize and wheat residues in South Africa to produce biomass energy. Moreover, it has been mentioned that South Africa already exports wood pellets to the EU, showing possibilities for future intensification of biomass cooperation (Akinbami et al., 2021). Other studies, such as Mai-Moulin et al. (2018) have also attempted to identify the possibilities for sourcing overseas biomass to meet the EU's needs by focusing on Brazil, Colombia, Indonesia, Kenya, Ukraine, and the United States. The study concludes that, out of these countries, the United States, Ukraine, Indonesia, and Brazil detain a higher biomass export potential (Mai-Moulin et al., 2018).

However, as a first step, it is important to investigate the infrastructural and political feasibility of a renewable energy supply chain between Africa and Europe (Beneking et al., 2016). Purvins et al. (2011) look at this on a small scale, with the case of supplying the island of Sardinia with renewable electricity from North Africa in order to meet the island's 2030 goals. The research concludes that to make the system of the island capable of accommodating high renewable energy penetration, the electricity highways will need to be reinforced, while the interface of the regional power system needs to be carefully thought through (Purvins et al., 2011). Similarly, on an EU level, Benasla et al. (2019) suggest that Italy or Spain would be the most suitable entry points for the import of African renewable electricity to Europe. Their research also stresses that the import of electricity should be done via High-Voltage Direct Current (HVDC) links. Eventually, this would help the EU reach its goals in a cost effective way without needing large investments in storage systems and transmission structures, as originally intended for the EU's energy transition (Benasla et al., 2019).

In this research, one of the main renewable energies which is investigated is the EU's import of green hydrogen from Africa. Existing research has been conducted on the possibilities of using renewable energy from wind and solar to produce green hydrogen in various African countries (Ayodele & Munda, 2019; Amoo & Fagbenle, 2014; Elshabli et al., 2021). In some cases, innovations are required to adapt to geographical constraints. Delpisheh et al. (2021) explored the possibilities of using seawater via a desalination unit in order to produce hydrogen in arid areas, which would potentially be necessary for certain African countries. As depicted in Figure 1, research has also been made on the potential of supplying hydrogen from North Africa to Europe in existing gas pipelines (Timmerberg & Kaltschmitt, 2019; van Wijk & Wouters, 2019; van Der Zwaan et al., 2021). So far, it has been concluded that developing the export of hydrogen from North Africa to Europe through existing gas pipelines is the cheapest option (Timmerberg & Kaltschmitt, 2019). Moreover, van der Zwaan et al. (2021) found, through an integrated assessment model, that from a monetary cost perspective, it is cheaper to produce solar electricity and renewable hydrogen in North Africa than in Europe. In turn, this would have positive effects on employment, income, and stability in North Africa (van der Zwaan et al., 2021). However, a certain environment is needed to develop hydrogen in Africa, such as long lasting mutual cooperation between North Africa and the EU, as well as a regulatory environment and market design to attract the necessary investments (van Wijk & Wouters, 2019).

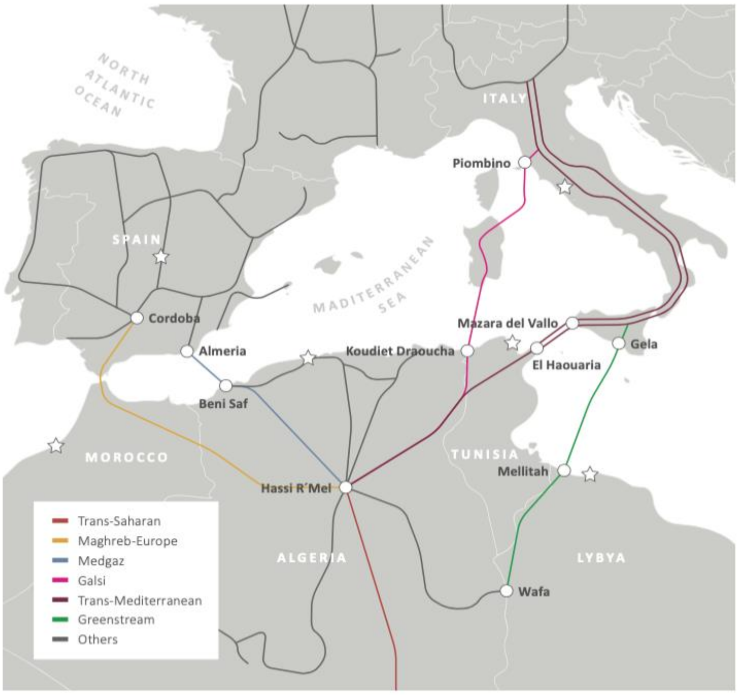

Figure 1*: Map of existing gas pipelines from North Africa to Europe (taken from: van Wijk et al., 2019).*

Importantly, the majority of academic papers currently look at North Africa due to its considerable renewable energy potential and its geographical proximity to Europe (Benasla et al., 2019; Beneking et al., 2016; Boie et al., 2016; Komendantova, 2012; Loudiyi et al., 2019; Purvins et al., 2011; Timmerberg & Kaltschmitt, 2019; Trieb et al., 2012; van Wijk & Wouters, 2019; van der Zwaan et al., 2021). Boie et al. (2016) estimate that the renewable energy needs for North African countries, such as Morocco and Algeria, will be entirely fulfilled by locally produced renewable energies by 2050. Therefore, it is not unthinkable that a renewable energy network could be made between Africa and Europe (Timmerberg & Kaltschmitt, 2019). Nevertheless, this is not always the case, as some countries will also need to first meet their own renewable energy demands before exporting, thus highlighting the importance of importing ethically (Rahmouni et al., 2016).

Additionally, there are also certain security threats which need to be considered (Urciuoli et al., 2014). Measures to counter security threats to supply chains, such as wars or terrorism, will need to be implemented in a similar way to how it has been done for oil and gas supplies from the Middle-East and North Africa (Urciuoli et al., 2014). Another concern, from a more practical side, is that it will be important to harmonise grid codes between Northern Africa and Europe (Loudiyi et al., 2019). This is especially relevant for the renewable energy integration, since there are certain technical grid connection requirements which need to be the same in order for a African-European grid to be functionable (Loudiyi et al., 2019).

Policy recommendations are also made by researchers regarding the development of renewable energies locally in Africa. For Biomass, Mana et al. (2021) make recommendations for the biomass industry in Morocco which includes focusing more on the agricultural sector, and, more specifically on using olive residues. Others, such as Abdulrahman et al. (2018), recommend Egypt to encourage local biomass collection companies to collect unused agricultural residues. For hydrogen, Boulakhbar et al. (2020) make a series of recommendations to Morocco, which should make sustainability requirements an integrated part of its hydrogen roadmap. Also, Rahmouni et al. (2017) recommend Algeria to consider the role of the gas industry in the development of hydrogen, as it is currently an important stakeholder for the country's electricity production. These country-specific recommendations can also be applied to a variety of other African countries.

When looking more closely at the EU, certain researchers have attempted to forecast the supply and demand of hydrogen in the upcoming years (European Commission, 2020d; Tsiropoulos et al., 2020; FCH, 2019; Wang et al., 2021). The average demand forecasted for hydrogen by 2050 in the EU varies across these sources, with the European Commission (2020d) estimating it to reach 2178 TWh, while Tsiropoulos et al. (2020) rather believe it to be 3102 TWh. As the predicted amounts are based on assumptions, it is interesting to note that these are rather similar in their range, which is also reflected in studies made by FCH (2019) and Wang et al. (2021), whom respectively predict that the EU's hydrogen demand will amount to 2607 TWh and 2300 TWh by 2050 (see Figure 6**Table 24**). However, interestingly van Wijk et al. (2019) have a very different view as they assume that 50% of the EU's energy needs will be fulfilled by hydrogen, making the forecasted energy demand total 12 000 TWh in 2050 (see Table 25).

Despite there being limited research on the topic, researchers have also attempted to forecast the EU's supply and demand for biomass in the upcoming years (ME, 2021). For example, Material Economics (ME) (2021) have developed multiple scenarios with regard to future biomass demanded by the EU. The first scenario predicts that 8-19 EJ of primary biomass will be demanded in the EU by 2050, while the other scenario considers a higher use of biomass resulting in 22 EJ of primary biomass being demanded (ME, 2021).

Overall, existing literature addresses the considerable potential of renewable energies in Africa, and in particular in North Africa. Most of the existing research focuses on the topic within the current timeframe or towards 2030. Others, have also attempted to investigate the future energy demand of the EU. However, in the current state of the art, only few researchers have explored the potential export of biomass and hydrogen from Africa to the EU. As a result, the current academic debate comes short in exploring the potential of biomass and hydrogen supply chains between Africa and the EU by 2050.

4. Methodology

This research is mainly qualitative in its nature, while also including some quantitative data. The qualitative data is comprised of existing data on policies, climate goals, and potential stakeholders. However, the Multi-criteria analysis in this research can be regarded as semi-quantitative as the data retrieved serves to give a numerical score to African countries based on their attributes. Also, this research does include data retrieved from literature on energy export forecasting, which is of quantitative nature, to assess the potential of a renewable energy supply chain between both continents.

This research will rather be inductive due to the limited amount of existing literature and theories on the topic, while ultimately this will allow for theoretical patterns to be inferred from collected data (Bhattacherjee, 2012). The conclusions made on the feasibility of energy supply chains between Africa and the EU, will allow for certain patterns to be observed from the final results. Finally, this study follows the principles of an exploratory research by exploring a new area of enquiry, while also testing the feasibility of a project (Bhattacherjee, 2012). Due to its exploratory nature, it will serve as a basis and an overview for future in-depth research on the topic.

4.1. Case Research Approach

This study will be following a case research approach, which is a "formal research technique that involves a scientific method to derive explanations of organizational phenomena" (Bhattacherjee, 2012, p.93). More broadly, the unit of analysis in case research approach can vary from an individual to a corporation (Zucker, 2016). This type of research approach can both be used in a positivist manner, for theory testing, as well as for interpretive research, in the case of theory building (Zucker, 2016). Furthermore, it is useful when studying complex organizational processes involving "multiple participants and interacting sequences of events, such as organizational change and large-scale technology implementation projects" (Bhattacherjee, 2012, p.94). When using this approach, there are four aspects to consider, such as the main units of analysis of a research, which sites and locations should be chosen, and whether a single or a multiple-case design would be most suitable (Bhattacherjee, 2012).

The first step to consider is whether the case research approach is right for the research question of the study. Bhattacherjee (2012) explains that the case research method is "particularly appropriate for exploratory studies for discovering relevant constructs in areas where theory building at the formative stages" and for understanding temporal processes which mostly include why and how questions (p.94). This is the case of this research, which is both exploratory, while also containing a temporal research question addressing renewable energy supply chains between the EU and Africa by 2050. Moreover, the case research approach is well suited for large scale technological and infrastructural projects, which is very much the case of this thesis topic (Zucker, 2016).

The second step is to assess which units of analysis will be used for the case research study and at what level (Bhattacherjee, 2012). For this research, the renewable energy supply chains will be looked at from different levels, whether that is on a national or institutional level and from an energy consumers' perspective. On the one hand, the relevant units of analysis for the national and institutional level will be the quantity of energy made available by a technology, and the policies needed to develop it. Additionally, for the section on the advantages and disadvantages of these countries, data on the existing infrastructure and resource availabilities are taken into account. On the other hand, the relevant units of analysis for consumers and individuals, is the access to renewable energy for local African populations and also for EU consumers.

The third step considers whether a single or a multiple case design is the most suitable for this research (Bhattacherjee, 2012). This study will have a multiple case design, since different energy types will be investigated in parallel, namely hydrogen and biomass.

The fourth step, considers the geographical location of the different energy types (Bhattacherjee, 2012). In this research the countries will be selected based on the outcome of the Multi-criteria analysis comparing different African countries for both energy types. The pre-selected countries considered for the analysis are listed in the country selection section of this methodology. Based on their assets, three African countries will be chosen among the pre-selected countries as case studies for biomass, while three countries will also be selected for hydrogen supply chains with the EU.

Finally, the fifth step is the type of data collection which needs to be used (Bhattacherjee, 2012). This research is a desk research which is based on data from secondary sources, such as qualitative data from existing literature and previous studies on the development of renewable energy supply chains between Africa and Europe. Moreover, the quantitative data found in previous studies on renewable energy supply chains will also be used, whether that is from existing data bases, models or calculations. The retrieved data will also be combined with forecasting calculations and assumptions made in this research to assess future energy exports to the EU. These calculations are based on data from existing studies and published national energy goals and pathways. At times, when forecasting future African energy exports, assumptions are made to overcome the lack of data availability on energy production and consumption in 2050. These are further detailed in the export potential and scenarios section of this methodology.

4.2. SWOT analysis

The Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is a framework which was originally used to conduct business and marketing analysis, but has evolved and is currently used in many other research fields (Chen & Yamaguchi, 2014). SWOT has more recently been used to assess policies, energy projects and energy management research (Chen & Yamaguchi, 2014). Essentially, SWOT assesses both internal and external aspects. The internal assessment mainly looks at the strengths and weaknesses of a company or a project, while the external assessment mainly investigates the potential opportunities and threats experienced by a project (Chen & Yamaguchi, 2014). In other words, strengths mainly encompasses the local environment and the available resources which can help develop a renewable energy project, while the weaknesses are the flaws which could hinder its development (Paliwal, 2006). Opportunities are changes which could have an impact on the development of the project while threats are external factors which would hinder this development (Paliwal, 2006).

In this research, a SWOT analysis will be used for both renewable energy projects, namely hydrogen and biomass. Other scholars have already used the SWOT analysis as a tool to look at renewable energy projects, such as Beneking et al. (2016) and Chen et al. (2014). Similarly to Beneking et al. (2016), the strengths and weaknesses will mainly encompass the advantages and disadvantages of biomass and hydrogen supply chains with African countries and the potential amounts of biomass and hydrogen exported to Europe. The external threats will especially relate to security aspects such as wars, terrorism and local instabilities, as well as variations in demand and supply. The opportunities which arise from these threats will mostly include solutions to cope with the threats as well as policy recommendations to develop the energy supply chains and counter the identified threats.

4.3. Country selection

Considered countries for biomass

In order to narrow down the research, a restricted amount of African countries need to be preselected when assessing the advantages and disadvantages of renewable energy supply chains between Africa and Europe. Existing literature and governmental reports have highlighted a number of relevant African countries for the development of bioenergy. Therefore, it was agreed among the students of this project that nine countries would be included and preselected for the assessment of potential countries for biomass supply chains with the EU. In North Africa, Egypt and Morocco have been seen as countries with potential in terms crop residue biomass, while also being geographically close to the EU (Said et al., 2013; Mana et al., 2021). In Sub-Saharan Africa, the preselected countries are Nigeria, Ethiopia, South Africa, Democratic Republic of Congo (DRC), the Republic of Congo, Ghana and Uganda. On the one hand, South Africa, the Republic of Congo and Uganda have especially a potential in crop and forest residue based biomass (Liu et al., 2018; Dasappa, 2011; Okello et al., 2013). On the other hand, Ghana and the DRC have a biomass potential which is especially based on cultivating energy crops (Duku et al., 2011; Dasappa, 2011). Finally, countries such as Nigeria and Ethiopia have a potential in both biomass from residues and energy crops (Oyedepo et al., 2019; Gabisa & Gheewala, 2018; Radenahmad et al., 2021).

Considered countries for hydrogen

Academic literature has also highlighted a series of African countries which could be interesting for the development of hydrogen. As for biomass, the considerable amount of African countries meant that it was agreed among the students of this project that eight countries would be included in the assessment of potential hydrogen supply chains with the EU. In North Africa, Egypt, Morocco, Algeria, Libya and Tunisia were identified due to their location, but also due to their climate which could favour the production of considerable amounts of renewable energy to produce green hydrogen (Shedid & Elshokary, 2015; Touili et al., 2018; Rahmouni et al., 2017; Elshabli et al. 2020; Okonkwo et al., 2021). In Sub-Saharan Africa, the chosen countries are Angola, South Africa and Nigeria. Firstly, Angola has recently seen the investment of German companies in the intent of establishing a hydrogen plant (Gauff, 2022). Secondly, South Africa has clear hydrogen goals and has considerable assets in terms of its climate, in order to develop numerous types of renewable energies (Ayodele & Munda, 2019; Hoffman, 2019). Thirdly, as for Nigeria, Amoo & Fagbenle (2014) see considerable potential in the development of hydrogen as a way of ensuring a low-carbon future for the country. However, this also includes grey hydrogen produced through natural gas (Amoo & Fagbenle, 2014).

An overview of all preselected countries for biomass and hydrogen can be found in Figure 2.

Figure 2*: Preselected African countries for each renewable energy type.*

4.4. Assessment Method: Multi Criteria Analysis

4.4.1. Relevant parameters

The selection of African countries based on their advantages and disadvantages will be assessed through the Multi-Criteria Analysis (MCA) approach. This approach requires multiple criteria/parameters to be identified which are important when selecting a specific pathway (Perimenis et al., 2011). In this case, the pathways are the African countries which need to be selected on the basis of energy-related parameters. These parameters were selected based on the requirements of the selected supply chains, considering existing literature relevant to this research and the research of the fellow students of the broader research project.

Biomass parameters

Table 1*: Assessment parameters for the biomass supply chain*

Parameters	*Description*
Proximity to EU	The purpose of this parameter is to see what the distance is between the selected African country's main harbour and the closest European harbour in order to assess the distance which is needed to transport biomass to the EU (Portworld, 2022). For

	countries which do not have a coastline, the distance is taken from the country's capital to the closest harbour in the neighbouring country, followed by the distance to the closest European harbour. This is done by using the tool offered by Portworld (2022), which calculates sea route distances.
Existing Transport infrastructure	This parameter assesses existing transport infrastructure, namely roads and railway networks, to understand which possibilities are available to transport biomass. The parameter uses the quality of roads ranking and the quality of railroad infrastructure index established by the World Bank in 2017 (World Bank, 2017; World Bank, 2017b). The existing railway infrastructure is ranked from 1 (bad) to 7 (good). For the roads, countries are ranked against each other, leading to a ranking of 137 considered countries.
Infrastructure -Sea/Harbour access	This parameter first looks at whether the selected African country has a coastline and especially determines the level of development and efficiency of the domestic ports and harbours. This is especially relevant to assess the possibilities to export biomass to Europe. The World Bank's quality of port infrastructure index is used since it assesses the quality of a country's harbours by giving a value index between 1 (extremely underdeveloped) and 7 (extensive and efficient), while also taking the accessibility of seaport facilities into account for landlocked countries (World Bank, 2017c). The most recent results of the quality of port infrastructure index is from 2017 (World Bank, 2017c).
Water Stress	Examining the water stress levels of African countries is also a relevant parameter since it can indicate the ease with which crops can be grown for the production of biomass. Moreover, if a country suffers from water stress, the amount of water used to grow crops for biomass could also create certain ethical problems. The water stress level is assessed by the Water Resource Institute which attributes scores to countries based on five levels of water stress, namely "extremely high", "high", "medium-high", "low-medium" and "low" (Hofste et al., 2019). The most recent ranking is from 2019 (Hofste et al., 2019).
Existing EU-financed RE projects in Africa	This parameter determines whether there are existing renewable energy (RE) projects financed by the EU to support African

	countries. If an African country's renewable energy sector is already being supported by the EU it can show that there already is a demonstrated potential and that the African country's government already has established ties to the EU. For this parameter there are three options: the African country does not benefit from EU financing for RE projects, the country does benefit from external financing but only from specific member states or the country benefits from EU-financing.
Existing fossil-Energy trade	This parameter shows whether there is existing trade in fossil energies between African countries and the EU. Existing energy trade can prove to be important, since it displays an existing infrastructure for energy exports while also showing that there are economic ties between countries. The EU energy import data is from 2019 (Eurostat, 2019b).
Energy poverty	For the energy poverty parameter, the access of the population to electricity is the main indicator (World Bank, 2019d). This parameter is relevant since it portrays the size and supply of the current electricity grid. If a vast proportion of a country does not have access to electricity, this can also pose certain ethical concerns regarding the export of energy directly to Europe. The data retrieved from the World Bank is from 2019 (World Bank, 2019d).
Clear RE Goals	This parameter examines whether African countries have set clear renewable energy goals and whether there are existing goals which specifically mention biomass or biofuels as a solution. It can help indicate how far the African country has gotten, but also what can be predicted for the development of the energy in the upcoming years. This parameter is based on national governmental pathway documents detailing future energy goals.
Electricity stability	Electricity stability describes how stable the electricity supplied to consumers is on a national level. This can be relevant for the production of biofuels, where electricity is needed to power the production process (World Bank, 2017d). Therefore, if the supply of electricity is not reliable, this could have considerable impacts on production levels. This parameter uses the World Bank's

	(2017d) quality of energy supply index, which ranks the quality of the supply from 1 to 7.
Political stability	This parameter is of interest when considering the security of the supply chain, since it encompasses the risk of political instability and of violence or terrorism in a country. Instability in an exporting African country could have import ramifications leading to impacts in the stability of supplies to Europe. Countries are ranked by their political stability index, ranging from the most unstable (-2.5) to the most stable (2.5) (World Bank, 2020b). The most recent data is from 2020.
Biomass Potential	The biomass potential is a standard measurement of biomass productivity that takes into account the NPP (Net Primary Production) which is the quantity of carbon fixed and accumulated by plants as biomass per year and is given in tC/ha/yr (IRENA, 2021). This parameter can be a useful indicator to understand how much biomass could potentially be produced per country per year. It is also relevant to note that the global average is between 3-4 tC/ha/yr (IRENA, 2021). The most recent data provided is from 2020 (IRENA, 2021).
Tertiary Education	This parameter takes into account the gross enrollment ratio in tertiary education per country as a percentage of the total population of the five-year age group leaving secondary school (Roser & Ortiz-Ospina, 2016). The data for each country can be useful to assess whether there will be enough qualified professionals locally in order to develop the supply chain. Having an educated population could help to transfer, implement, and develop the needed technologies and skills and could also save money and time when hiring experts in the field. The most recent data is from 2016.
Foreign investment	Foreign investments can be an useful indicator to demonstrate the potential seen by foreign stakeholders in the African country's economy. The Foreign Direct Investment (FDI), which is used for this parameter, looks at cross-border investments "associated with a resident in one economy having control or a significant degree of influence on the management of an enterprise that is resident in

	another economy" (World Bank, 2020). The gathered FDI data is from 2020 (World Bank, 2020).
Arable land	This parameter specifically designates "land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow" (World bank, 2018). The amount of arable land per country is given as a percentage of the total land area for the year 2018 (World Bank, 2018). This especially relevant for crop and residue based biomass, since it can give an indication of the amount of available land for temporary crop cultivation.

Hydrogen parameters

***Table 2**: Assessment parameters for the biomass supply chain*

Parameters	*Description*
Proximity to EU	Same parameter as for biomass.
Gas connection to EU	There are multiple options to export hydrogen from Africa to the EU. One of them, is to export hydrogen as a gas in existing gas pipelines (Timmerberg & Kaltschmitt, 2019). Therefore, it is relevant to examine which African countries already have natural gas pipelines leading to EU countries, by looking at existing research which has mapped the natural gas pipelines from Africa (van Wijk et al., 2019).
Transport infrastructure	This parameter has three distinct sub-categories: *-Railway Quality* As it was the case for the biomass parameter, the railway quality sub-parameter helps to understand which possibilities are available to transport biomass. Transporting hydrogen by train is currently an option which is being investigated in Europe, which is why this could be an option in Africa in the future (World Bank, 2017b). *-Roads' Quality* Same parameter as for biomass. *-Harbour quality and access* Same parameter as for biomass. Hydrogen can be transported in different ways, one of which would be by ship (World Bank, 2017c).
Climate	This parameter has three distinct sub-categories: *-Sun*

	For this parameter the average photovoltaic power output per day is taken for each country (Solargis et al., 2022). This can indicate the solar power potential of a country, which is relevant for the production of green hydrogen. -*Wind* For this parameter the mean wind speed measured in the 100% windiest areas of a country at a height of 100m is taken into account (Solargis et al., 2022b). This can indicate the wind power potential of a country, which is also relevant for the production of green hydrogen. -*Sea* This parameter solely indicates whether a country has a coast or whether it is landlocked. It is relevant for transport reasons but also since hydrogen can be produced from seawater.
Existing RE infrastructure	This parameter has three separate sub-categories: -*Solar* This parameter investigates whether there already are solar farms installed in designated African countries. -*Wind* This parameter investigates whether there already are wind farms installed in the African countries. -*Hydrogen* This parameter investigates whether there are facilities installed which are producing hydrogen in the African country. -*Hydro* This parameter investigates whether there already are hydropower plants in the African country.
Infrastructure -*Chemical plant*	This parameter is relevant to the hydrogen supply chain since chemical plants can indicate that it would be possible to implement a hydrogen carrier synthesis process locally.
Water Stress	To operate electrolysers properly, considerable amounts of water need to be used (Hofste et al., 2019). Therefore, it is relevant to examine whether countries already have water shortage problems, which could make it difficult to produce large amounts of hydrogen in the future (Hofste et al., 2019).

Existing EU-financed RE projects in Africa	Same parameter as for biomass.
Existing fossil-Energy trade	Same parameter as for biomass.
Energy poverty	Same parameter as for biomass. Energy poverty is very relevant since other energy sources are needed to produce hydrogen and could therefore decrease energy supply if the entirety of local populations do not already have access to electricity (World Bank, 2019).
Clear RE Goals	Same parameter as for biomass. This parameter examines whether African countries have set clear renewable energy goals and whether there are existing goals related to hydrogen.
Political stability	Same parameter as for biomass.
Tertiary Education	Same parameter as for biomass.
Electricity stability	This parameter is similar to the parameter for biomass. However, it is relevant for the production of hydrogen since it is important to have a stable electricity supply in order to perform the electrolysis (World Bank, 2017d).
Foreign Direct Investment	Same parameter as for biomass.
Electricity export	This parameter can help indicate whether some of the infrastructure necessary to export energy is already present in an African country (CIA, 2017). This parameter is assessed in term of the quantities of kWh of electricity exported annually by a country (CIA, 2017).

4.4.2. Multi Criteria Analysis

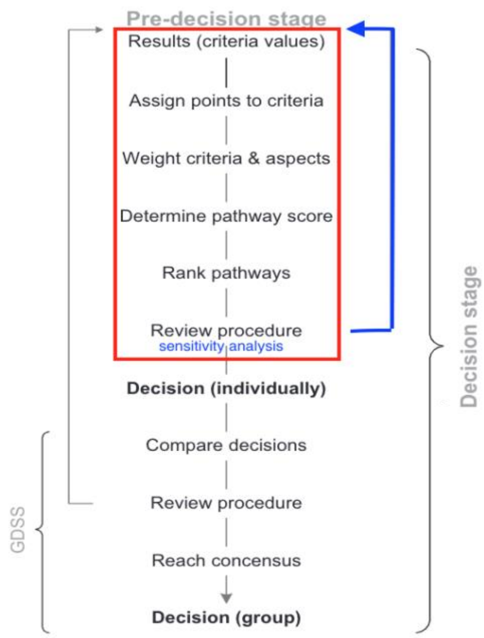

***Figure 3**: MCA steps (taken from: Perimenis et al., 2011, p.1787).*

The multi-criteria analysis (MCA) method is suited for the "comparative assessment of alternative actions with respect to multiple and possibly conflicting evaluation aspects" (Perimenis et al., 2011, p.1787). MCA is especially useful since it allows the researcher to combine the analytical part of a research with personal preferences, since priorities can be given to specific parameters which are deemed to be of higher importance than others, by attributing weights to each criteria (Perimenis et al., 2011). This method is important for the advantages and disadvantages section of this research since it helps structuring the evaluation of the key parameters to consider when choosing the appropriate countries as case studies (Diakoulaki et al, 1992).

The MCA follows multiple steps listed in Figure 3 of which the first six are applied to this research. The first step consists in establishing which parameters are important for the specific field of research (Perimenis et al., 2011). For this research the relevant parameters and their ratings for biomass and hydrogen can be found in section 4.4.1. The second step consists in assigning points to each of the selected parameters, as to have a numerical score attributed reflecting their importance in the country selection process. Since the chosen parameters are both quantitative and qualitative, these need to be converted to then be assessed on a similar grade scale (Perimenis et al., 2011). For biomass and for hydrogen, the score starts from the lowest (1) to the highest (5), indicating the worst to the best respectively; see Table 3 & Table 4 (Perimenis et al., 2011). More details on the specific star rating per parameter can be found in Table 1 and Table 2.

***Table 3**: Biomass grade scale and parameters*

Parameters	*Star rating*					*Sources*
	1*	2*	3*	4*	5*	
Proximity to EU	6000 km and above	4000-6000 km	2000-4000 km	500-2000 km	500km and below	Portworld (2022)
Existing Transport infrastructure *-Railway Quality*	1.2 - 2	2 - 3.2	3.2-4.4	4.4-5.5	5.5-6.6	(World Bank, 2017)
-Roads	137th-100th	100th-75th	75th-50th	50th-20th	20th-1st	(World Bank, 2017b).
Infrastructure *-Sea/Harbour*	1.4 - 2.2	2.2 - 3.2	3.2-4.4	4.4-5.5	5.5-6.8	(World Bank, 2017c)
Water Stress	Extremely high	High	Medium-high	Low-Medium	Low	(Hofste et al., 2019).
Existing EU RE projects	None	-	Not EU, but EU MS	-	Yes	EU or Governmental documents
Existing Energy trade	None	-	-	-	Yes	(Eurostat, 2019b).
Energy poverty	0-35%	35-60%	60-70%	70-85%	85-100%	(World Bank, 2019d).
Clear RE Goals	Not clear	-	Clear RE goals	-	Clear RE Goals (also for biomass)	Governmental documents per country
Electricity stability	1.2 - 2	2 - 3.2	3.2-4.4	4.4-5.5	5.5-6.9	(World Bank, 2017d).
Political stability	-2.5 ← -1.5	-1.5 ← -0.6	-0.6 ← 0.0	0.0 ← 0.6	0.6 ← 1.7	(World Bank, 2020b).
Biomass Potential	0-1 tc/ha/yr	1-3 tc/ha/yr	3-5 tc/ha/yr	5-8 tc/ha/yr	8-11 tc/ha/yr	(IRENA, 2021).
Tertiary Education	15% and below	15-30%	30-45%	45-60%	60% and above	(Roser & Ortiz-Ospina, 2016).
Foreign Direct investment	-2 billion $ ← 0 $	0 $ and 1 billion $	1 -2 billion $	2-3 billion $	3 billion $ and above	(World Bank, 2020).
Arable land	< 5.66%	5.66 - 13.12%	13.12 - 20.86%	20.86 - 30.32 %	> 30.32 %	(World Bank, 2018).

***Table 4**: Hydrogen grade scale and parameters*

Parameters	Star-rating					Sources
	1*	2*	3*	4*	5*	
Proximity to EU	6000 km and above	4000-6000 km	2000-4000 km	500-2000 km	500 km and less	(Portworld, 2022)
Gas connection to EU	No	-	In progress	-	Yes	(van Wijk et al., 2019).
Transport infrastructure *-Railway Quality*	1.2 - 2	2 - 3.2	3.2-4.4	4.4-5.5	5.5-6.6	(World Bank, 2017)
-Roads' Quality	142nd-100th	100th-75th	75th-50th	50th-20th	20th-1st	(World Bank, 2017b).
-Harbour quality and access	1.4 - 2.2	2.2 - 3.2	3.2-4.4	4.4-5.5	5.5-6.8	(World Bank, 2017c)
Climate *-Sun*	Pvout= 2.3-3.0 kwh/kwp	Pvout= 3.0-3.5 kwh/kwp	Pvout= 3.5-4.4 kwh/kwp	Pvout= 4.5-4.9 kwh/kwp	Pvout= 4.9-5.8 kwh/kwp	(Solargis et al., 2022).
-Wind	0-2.5 m/s	2.5-4.5 m/s	4.5-6 m/s	6-7.5 m/s	7.5-11 m/s	(Solargis et al., 2022b).
-Sea	None	-	-	-	Yes	-
Water Stress	Extremely high	High	Medium-high	Low-Medium	Low	(Hofste et al., 2019).
Existing RE infrastructure -Solar	None	-	In progress	-	Yes	Sources are country specific
-Wind	None	-	In progress	-	Yes	Sources are country specific
-Hydrogen	None	-	In progress	-	Yes	Sources are country specific
-Hydro	None	-	In progress	-	Yes	Sources are country specific
Infrastructure *-Chemical plant*	None	-	-	-	Yes	Sources are country specific
Existing EU RE projects	None	-	Not EU, but EU MS	-	Yes	EU or Governmental documents
Existing Energy trade with EU	None	-	-	-	Yes	(Eurostat, 2019b).
Energy poverty	0-35%	35-60%	60-70%	70-85%	85-100%	(World Bank, 2019d).
Clear RE Goals	Not clear	-	Clear RE goals	-	Clear RE Goals (also for hydrogen)	Governmental documents per country
Political stability	-2.5 ← -1.0	-1.0 ← -0.4	-0.4 ← 0.1	0.1 ← 0.6	0.6 ← 2.5	(World Bank, 2020b).
Tertiary Education	0-15%	15-30%	30-45%	45-60%	60% and above	(Roser & Ortiz-Ospina, 2016).
Electricity stability	1.2 - 2	2 - 3.0	3.0-4.4	4.4-5.5	5.5-6.9	(World Bank, 2017d).
Foreign Direct Investment	-2 billion $ ← 0 $	0 $ and 1 billion $	1 -2 billion $	2-3 billion $	3 billion $ and above	(World Bank, 2020).
Electricity export	0 Kwh	0 - 1 billion kWh	1-2 billion kWh	2-3 billion kWh	3 billion kWh and above	(CIA, 2017).

The third step, determines the weight and the importance of the parameter. In this research, the weighting procedure is slightly different from the MCA framework since it does not attribute points based on the pair-wise preferential ranking of two parameters but rather on the degree of correlation of two parameters (Perimenis et al., 2011). In other words, if two parameters are strongly linked then these are "highly correlated" and will score 3 points, if the parameters are "somewhat correlated" these will score 2 points, and if the parameters are "not correlated" these will score 1 point. Since this research is part of a larger research project, the parameters identified here will be correlated with important parameters identified by other students in their own research. It is important to mention that the weighting factors where decided and agreed on together with the students/supervisors involved in the project. This allows for the parameters of other students to be considered when identifying the most promising African countries for the development of hydrogen and biomass supply chains. Once the correlation points have been summed up for each parameter, this total is then translated into weights by dividing it with the total amount of points of all parameters (Perimenis et al., 2011). In this way, the weights will reflect the importance of each parameter in comparison with other parameters (Perimenis et al., 2011). The weighting table for the relevant biomass and hydrogen parameters can be found in Table 5 and Table 6.

Table 5: Multi-criteria analysis: Biomass correlation table

	Energy efficiency	Feedstock conversion ratio	Development status*	Capital-related costs	Consumption related costs	Operation related and other costs	Compatability	Complexity	GHG emissions	**Total Points**	**Parameter Weight**
Proximity to EU	1	1	1	1	3	1	1	1	3	13,00	**0,07**
Existing Transport infrastructure	1	1	3	2	1	2	3	1	2	16,00	**0,08**
Climate/Infrastructure *-Sea/Harbour access*	1	1	2	2	1	2	2	1	2	14,00	**0,07**
Water Stress	1	2	1	1	1	1	1	1	1	10,00	**0,05**
Existing EU RE projects	1	1	3	2	1	1	2	1	1	13,00	**0,07**
Exisiting Energy trade	1	1	3	3	2	2	3	1	2	18,00	**0,09**
Energy poverty	2	1	2	2	2	1	1	1	1	13,00	**0,07**
Clear RE Goals	1	2	3	2	1	1	1	1	3	15,00	**0,08**
Electricity stability	3	1	2	1	1	2	1	2	1	14,00	**0,07**
Political stability	1	1	2	2	1	1	1	1	1	11,00	**0,06**
Biomass Potential	1	3	2	1	3	1	1	1	3	16,00	**0,08**
Tertiary Education	1	1	3	1	1	3	1	2	1	14,00	**0,07**
Foreign investment	1	1	3	3	1	1	2	2	1	15,00	**0,08**
Arable land	1	2	2	1	2	1	1	1	2	13,00	**0,07**
TOTAL										195,00	**1,00**

*Technical readiness

1	**No correlation**
2	**Somewhat correlated**
3	**Highly correlated**

Table 6: Multi-criteria analysis: Hydrogen correlation table

		H_2 storage capacity	Feedstock price	Toxicity	Energy demand	Product storage	Material handling	Process design	Stability	Technical readiness	Pressure	Extra compound	Total points	Parameter Weight
Proximity to EU		1	1	1	1	1	1	1	1	1	1	1	11	0,04
Tertiary education		1	1	3	1	3	3	3	3	1	3	1	23	0,07
Existing energy trade with EU		1	1	1	1	2	1	1	1	1	1	2	13	0,04
Infrastructure (renewable energy sources) - *Solar*		1	1	1	3	1	1	1	1	1	1	1	13	0,04
-Wind		1	1	1	3	1	1	1	1	1	1	1	13	0,04
-Hydrogen		1	1	1	3	1	1	1	1	3	1	1	15	0,05
-Hydro		1	1	1	3	1	1	1	1	1	1	1	13	0,04
Infrastructure (chemical plant)		1	1	3	2	3	3	3	2	3	3	1	25	0,08
Existing EU RE projects		1	1	1	1	1	1	1	1	3	1	2	14	0,05
Political stability		1	2	1	2	1	1	1	1	1	1	2	14	0,05
Electricity stability		1	1	1	3	2	1	1	1	1	2	1	15	0,05
Electricity export		1	1	1	3	1	1	1	1	1	1	1	13	0,04
Gas connection to EU		1	1	1	1	2	1	1	1	1	1	1	12	0,04
Climate	Sun	1	1	1	3	1	1	1	1	1	1	1	13	0,04
	Wind	1	1	1	3	1	1	1	1	1	1	1	13	0,04
	Sea	1	1	1	3	1	1	1	1	1	1	1	13	0,04
Water stress		1	1	1	3	1	1	1	1	1	1	1	13	0,04
Foreign investment		1	2	1	1	1	1	1	1	3	1	2	15	0,05
Energy poverty		1	1	1	3	2	1	1	1	1	2	1	19	0,06
Clear RE goals		1	1	1	1	1	1	1	1	3	1	2	14	0,05
Transport inrastructure		1	2	1	1	2	1	1	1	3	1	3	17	0,05
TOTAL													311	1,00

1	No correlation
2	Somewhat correlated
3	Highly correlated

The fourth step, is to determine the pathway score, or in this case the country score, which consists in attributing a score for each parameter based on the grade scale (Perimenis et al., 2011). Afterwards, the points for each parameter are multiplied with their respective weights and are summed up in order to determine a final score per pathway/country (Perimenis et al., 2011). This score is a country-specific score and allows for a comparison between countries (Perimenis et al., 2011). In the fifth step, the countries can then also be ranked by score to give a better overview of the highest scoring countries and their similarities and differences (Perimenis et al., 2011). Then, in the sixth step, the process needs to be reviewed by making a sensitivity analysis before a decision can be made on which countries perform the best, and especially, which African countries will be selected as case studies (Perimenis et al., 2011). The sensitivity analysis consists in changing the values in the weighting table to verify whether this changes the outcome in terms of the best performing countries.

4.5. Export potential and scenarios

4.5.1. Biomass potential methodology

Mai-Moulin et al. (2019) use a methodology to calculate biomass potentials. There are multiple steps which consider aspects such as potential exports, GHG emissions and costs (Mai-Moulin et al., 2019). For this research the surplus potential (PSS) and the export potential (PE) are considered, as these potentials will play a central role in understanding how much renewable energy is available for export from African countries to the EU . Thus, the surplus potential is calculated by equation (1):

$$\text{Eq. (1): } PSS = PS - LDi.$$

Where the Sustainable potential (PS) is defined as “the share of the technical potential that meets environmental, economic, and social sustainability criteria”, and the LDi “represents the local demand of crop i in the case-study region” (Mai-Moulin et al., 2019, p.297). In this research, the sustainable potential will simply be the available biomass for energy-use in African countries, which does not consider the biomass which is used for material purposes. The LDi will mainly consider the local biomass demand in energy terms. The following step is to calculate the export potential (Mai-Moulin et al., 2019). This is defined as “the potential that could be exported, taking into account requirements such as the availability of transport infrastructure and pre-treatment plants” (Mai-Moulin et al., 2019, p.297). In this research, this entails subtracting the national demand in each African country from the quantity of locally produced biomass. When calculating the amount of exportable biomass, a capacity factor is used in order to take into account the losses made while pre-treating biomass for export. Based on Mai-Moulin et al. (2019), an optimistic capacity factor of 80% is applied to the primary biomass energy available in order to consider the losses made during the pelletising process. As a result, 20% is taken off the total value of biomass available for export in African countries.

4.5.2. Hydrogen potential methodology

A similar approach is used to identify the available hydrogen for export of selected African countries. The surplus potential is calculated in the same manner. However, in this case, the sustainable potential will be the expected hydrogen production in African countries by 2050. On the other hand, the LDi considers the forecasted local hydrogen demand per country.

The hydrogen export potential will be tackled differently to that of biomass. Instead of considering the capacity factor, the loss caused by storage and transportation are taken into account. Based on the conditions set by van Wijk et al. (2019), the losses amount to a total of 30% of primary production. Therefore, the total amount of primary production will need to be 30% higher than the forecasted demand in order for demand to be met. This is already considered in the hydrogen scenario 3 as the value for the primary production needed is already included in van Wijk et al.'s (2019) research, while in scenario 1 and 2 this is calculated separately.

4.5.3. Scenario development

One of the main aims of the analysis of this research is to identify the potential of African countries to export biomass and hydrogen to the EU, based on the amounts of exportable energies. To do so, data is retrieved and estimates are made regarding the availability of hydrogen and biomass by 2050 in selected African countries. By identifying the forecasted energy demand and supply of African countries and the EU in existing literature, it is possible to determine the surplus available for export to the EU. However, these amounts can be very different depending on future developments, which is why multiple export scenarios are presented. Mai-Moulin et al. (2019) have also used scenarios for energy forecasting as it allows to anticipate the possible changes in trade, and future market developments.

In this research, two scenarios are considered, i.e. "realistic" and "ambitious" scenarios for each energy type. Additionally, for hydrogen another scenario is considered, namely the "average" scenario. These scenarios are based on the development of the energy demand in the EU when considering the development of each sector/industry. Furthermore, the scenarios also consider Africa's energy production, which is either *realistic* or *ambitious* depending on the development of technologies and internal and external supply chains. On the one hand, the *realistic* scenarios assume a lower EU energy demand which is caused by developments in other competing renewable energies in important sectors of the economy. The realistic *scenario* also considers a lower African energy production rate when considering future forecasted ranges. This can be attributed to a slower development of renewable energies in these countries and lower feedstock availabilities. On the other hand, the *ambitious* scenarios consider a higher energy demand in the EU, caused by a higher development of local demand for biomass and hydrogen. Moreover, it is assumed that higher production rates are ensured by African countries due to a higher level of development in terms of energy production and feedstock availability.

Finally, the *average* scenario is used as a safer mathematical/statistical scenario as it considers the EU's hydrogen import needed by 2050 based on the average results of multiple sources (European Commission, 2020d; Tsiropoulos et al., 2020; FCH, 2019; Wang et al., 2021). This allows for similar researches to be taken into account in order to have a more precise quantity demanded. The *average* scenario also considers the rather realistic forecasted amount of hydrogen produced in African countries by 2050, as it is the case for the *realistic* scenario.

4.5.4. Assumptions for export scenarios

General assumptions

The following general assumptions were made when forecasting the energy export potential of African countries:

- It is considered that the local demand for energy in African countries has a priority over exports, meaning that the domestic energy demand for biomass and hydrogen need to be fulfilled first before exporting to the EU. This allows for a more protective approach towards local African resources, while it also prevents the distortion of local markets and guarantees an ethical import of energies from an EU perspective (Mai-Moulin et al., 2019).
- This research considers that there is an exclusive energy trade partnership between African countries and the EU. This means that all the available excess hydrogen and biomass in African countries are solely exported to the EU. Although, in reality at times more energy is exported than the surplus, this is not considered as an option as this could be seen as being unethical (in line with the previous point).
- The EU's domestic biomass and hydrogen primary production will remain the same value across the different domestic demand scenarios. Keeping this value constant across scenarios will allow for a more representative comparability between them.
- The EU needs Africa to support its growing hydrogen and biomass demand (van Wijk et al., 2019; Mai-Moulin et al., 2019).
- The data retrieved is based on published studies which already consider the renewable energy sources required to produce the needed hydrogen quantities.

Biomass assumptions

The following assumptions are applicable when calculating the available biomass exports to the EU:

- Energy crops are not considered for biomass, only agricultural residues and forest residues are considered for exports. This is mainly because this research already accounts for residues from crops, while the data availability on energy crops is limited and difficult to predict in the future.

- The agricultural residues are exported as pellets as this is the most common pre-treatment technology for solid biomass (Mai-Moulin, 2019). Lignocellulosic biomass generally has to be pre-treated and densified before being transported over longer distances as it limits safety hazards and also because it limits costs and the energy needs for transport (Mai-Moulin et al., 2019). Based on Mai-Moulin et al. (2019), an optimistic capacity factor of 80% was used to consider the pellet producing capacity (as explained in section 4.5.1. Biomass potential methodology)
- For each country, only the biomass available for energy is considered and not the biomass used for material purposes (*e.g.*, food, cosmetics or biobased plastics).

The individual assumptions made for each scenario when calculating the forecasted biomass exports in 2050 can be found in Appendix B 1.

Hydrogen assumptions

The following assumptions are applicable when calculating the available hydrogen exports to the EU:

- Based on van Wijk et al. (2019), the amount of primary hydrogen required to meet the final EU demand is 30% higher. This is mainly because of the losses that are made during its storage and transport. This is already considered by van Wijk et al. (2019) in the hydrogen scenario 3, while this is assumed in the calculations of scenario 1 and 2.
- The research considers transporting hydrogen through existing gas pipelines as a technically viable possibility (van Wijk et al., 2019).
- The storage of hydrogen will be done in conventional hydrogen storage spaces but also in salt caverns which have considerable potential in terms of storage (van Wijk et al., 2019). This would especially be relevant when storing hydrogen in Europe, as this is where the salt cavern storage potential is the highest (van Wijk et al., 2019). This is already considered in the data and assumptions retrieved from van Wijk et al.'s (2019) research.

The individual assumptions made for each scenario when calculating the forecasted hydrogen exports in 2050 can also be found in Appendix B 1.

4.6. SMART policy framework

The SMART framework was initially designed by Doran (1981) as a tool to write down and assess management goals and objectives. This framework has since been used for other purposes, such as the development of policy goals. Therefore, there are some variations in the definition of the different components. In this research, the alignment of the scenarios with the EU's goals will be assessed based on the following criteria (Doran, 1981; Atkinson & Chois, 2012):

- ***S**pecific*: What are the specific goals of the policy/scenario.
- ***M**easurable*: What are the exact data targets which are set in the scenario.

- ***A**chievable*: Is it feasible to accomplish the specific scenario or goal.
- ***R**elevant and **R**ealistic*: Is the goal worthwhile, and will it meet the needs of the project.
- ***T**ime-related*: Can the specific scenario or goal be accomplished within the given timeframe.

These five criteria will be used in order to understand how realistic each scenario is in terms of its achievability within the set timeframe, and how it aligns with the EU's existing renewable energy goals for hydrogen and biomass. Moreover, the criteria especially serve as a structure to facilitate the comparison between scenarios.

5. Analysis

5.1. Advantages and disadvantages of energy supply chains with African countries

This section identifies the advantages and disadvantages of African countries for the import of biomass and hydrogen based on the previously identified parameters. This can be considered as the main component of the "Strengths and Weaknesses" part of the SWOT framework. Additionally, this section also partly includes the "Opportunities" and "Threats" aspects of the framework.

5.1.1. Biomass in Africa: MCA results

The MCA conducted on the nine selected African countries gives an overview of their main advantages and disadvantages, while also identifying the best performing countries for a potential large scale production of biomass with the intention of exporting to the EU. The countries are listed in the order given in the overview table in Appendix A 1.

Nigeria

Advantages

Nigeria has multiple advantages for developing biomass supply chains with the EU. Firstly, the water stress is categorized as being medium-low, meaning that the conditions for growing energy crops are good, while the amount of arable land in the country is also high (Hofste et al., 2019). Secondly, there are also existing ties with the EU, since there is an existing energy trade in crude oil between the two actors (Eurostat, 2019c). The EU is also active in Nigeria through the financing and participation in renewable energy projects in the country (European Commission, 2020). Additionally, Nigeria is experiencing high rates of foreign investments (2.385 billion dollars), ultimately showing that foreign investors see considerable potential in the country (World Bank, 2020). Finally, despite Nigeria's lower biomass potential (2.5 tC/ha/yr), this would suffice to supply considerable amount of biomass to the EU (IRENA, 2021).

Disadvantages

Nigeria does not score well in terms of logistics and transport infrastructure. The country is not very close to Europe, and receives the lowest scores for roads and railway infrastructure while it also does not score so well for sea/harbour infrastructure and access (World Bank, 2017; World Bank, 2017b;

World Bank, 2017c). This could be problematic when transporting biomass to the EU. In terms of energy, only 55,4% of Nigeria's population has access to electricity, while the quality of the electricity supply is poor which could make the production of biofuels very unreliable (World Bank, 2017c, World Bank, 2019). Moreover, the country's level of tertiary education enrolment is low (10,07%), meaning that, if qualified experts are needed to develop the supply chains, the qualified labour force would most probably need to be sourced outside the country (Roser & Ortiz-Ospina, 2016). Ultimately, Nigeria also scores the worst among selected countries in terms of political stability (World Bank, 2020b). This can mainly be explained by the numerous conflicts in multiple regions of the country such as the insecurity caused by banditry in the north-west, jihadist groups in the north-east, violent conflicts between farmers and pastoralists in the centre of the country, and the secessionists in the south-east (Beaumont, 2021). Overall, these conflicts could heavily affect the biomass supply chain.

Final score: 2,88/5,00

Table 7*: Nigeria's score per parameter for biomass*

Nigeria	*Score*	*score x weight*
Proximity to EU	2	0,13
Transport infrastructure *-Roads*	1	0,04
-Railways	1	0,04
Climate/Infrastructure *-Sea/Harbour*	2	0,14
Water stress	4	0,21
Existing EU RE projects	5	0,33
Existing Energy trade	5	0,46
Energy poverty	2	0,13
Clear RE Goals	5	0,38
Electricity stability	1	0,07
Political stability	1	0,06
Biomass Potential	2	0,16
Tertiary Education	1	0,07
Foreign investment	4	0,31
Arable land	5	0,33
Total		**2,88**

Ethiopia

Advantages

Similarly to Nigeria, Ethiopia has no issues with water stress which is at a medium-low level (Hofste et al., 2019). The country has a mid-level biomass potential with a Net Primary Production (NPP) of 4,5 tC/ha/yr and the country also benefits from a fair share of arable land, totalling 14,33% of its land area (IRENA, 2021). Regarding the country's ties with the EU, existing EU funded renewable energy projects are already present in the country which demonstrates the potential seen by the EU in the country (European Commission, 2020b). Finally, Ethiopia has clear goals for the development of renewable energies and biomass in the next decades, showing the willingness of the country to transition.

Disadvantages

Ethiopia does not score well in terms of logistics and transports. Despite being closer to Europe than many other African countries, Ethiopia is a landlocked country and does therefore not have an ideal location for the shipping of biomass abroad (World Bank, 2017c). Moreover, its roads and railway infrastructure do not score well, which could lead to certain logistical issues for the export of biomass (World Bank, 2017; World Bank, 2017b). It is also worth mentioning that Ethiopia does currently not have any energy trade with the EU. Regarding Ethiopia's electricity network, it can be deducted that the electricity supply is slightly more reliable than Nigeria's, even though it remains poor (World Bank, 2017d). The energy poverty is also high, with only 48,27% of the population with access to electricity which could lead to certain ethical issues if newly developed energies should be exported to the EU in the near future (World Bank, 2019). Finally, Ethiopia is not politically stable, which could pose a risk in terms of supply chain security (World Bank, 2020b). The instability in the country is mainly caused by the presence of armed rebel groups in the southern and western areas of the country, while internal religious and ethnic conflicts also cause political rifts (HRW, 2021).

Final score: 2,68/5,00

***Table 8**: Ethiopia's score per parameter for biomass*

Ethiopia	*Score*	*score x weight*
Proximity to EU	3	0,20
Transport infrastructure *-Roads*	2	0,08
-Railways	2	0,08
Climate/Infrastructure *-Sea/Harbour*	2	0,14
Water stress	4	0,21
Existing EU RE projects	5	0,33
Existing Energy trade	1	0,09
Energy poverty	2	0,13
Clear RE Goals	5	0,38
Electricity stability	2	0,14
Political stability	1	0,06
Biomass Potential	3	0,25
Tertiary Education	1	0,07
Foreign investment	4	0,31
Arable land	3	0,20
Total		**2,68**

Egypt

Advantages

Egypt was found to have several advantages. In terms of transport and infrastructure, the country is located very close to the EU, while it has a good harbour infrastructure, as well as decent roads and railway infrastructure (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). The country also has close ties with the EU, since there are ongoing renewable energy projects which are co-financed by the EU in Egypt. There is also an existing energy trade in which Egypt exports crude oil and natural gas to the EU (EU, 2020; Eurostat, 2020b; Eurostat, 2020c). In general, Egypt attracts considerable amounts of foreign direct investments, with a total of 5,85 billion dollars in 2020 (World Bank, 2020). Moreover, Egypt's electricity supply is considered to be stable, while energy poverty is non-existent since the entirety of the population has access to electricity (World Bank 2017d; World Bank 2019). Finally, it is also important to mention that Egypt has the highest level of tertiary education enrolment compared to other selected African countries (Roser & Ortiz-Ospina, 2016).

Disadvantages

Egypt also has certain disadvantages for large scale biomass and biofuels production. A large part of the country's area is arid and can be subject to water stress (Hofste et al., 2019). This can have an important impact on the crops and forests which can be used for biomass, since the amount of arable land in the country is already limited, totalling 2,92% of its territory (World Bank, 2018). This is also reflected in the country's biomass potential score, which is low (IRENA, 2021). The water stress could also be aggravated by a conflict with Ethiopia which is planning on building a hydroelectric dam on the river Nile to supply its domestic energy demand, which, in turn, could have an impact on the water supply of downstream countries such as Egypt (Lawson, 2017). This conflict is one of multiple reasons for Egypt's lower ranking in terms of political stability (World Bank, 2020b). Overall, Egypt's sustainable development goals do not include a specific section on biomass which can make it difficult to assess how determined the country is to develop this energy in the years to come.

Final score: 3,48/5,00

***Table 9**: Egypt's score per parameter for biomass*

Egypt	*Score*	*score x weight*
Proximity to EU	5	0,33
Transport infrastructure *-Roads*	3	0,12
-Railways	3	0,12
Climate/Infrastructure *-Sea/Harbour*	4	0,29
Water stress	2	0,10
Existing EU RE projects	5	0,33
Existing Energy trade	5	0,46
Energy poverty	5	0,33
Clear RE Goals	3	0,23
Electricity stability	4	0,29
Political stability	2	0,11
Biomass Potential	1	0,08
Tertiary Education	3	0,22
Foreign investment	5	0,38
Arable land	1	0,07
Total		**3,48**

South Africa

Advantages

Similarly to Egypt, South Africa scores well in terms of road and railway infrastructure as well as for its harbour infrastructure (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). Moreover, South Africa also has close ties with the EU, since there are already existing renewable energy projects supported by the EU in the country while there is also an existing energy trade in solid fuels (European Commission, 2021c; Eurostat, 2020). Regarding the country's energy grid, the energy poverty is currently low, with 85% of the population having access to electricity, while the energy stability is average (World Bank, 2019; World Bank, 2017d). In terms of biomass potential, South Africa benefits from a decent biomass potential with a NPP of 4,5 (IRENA, 2021). Additionally, South Africa also benefits from high levels of direct foreign investments, with a total of 3,2 billion dollars, showing the interest of foreign investors in the country (World Bank, 2020). Finally, the country is among the most politically stable African countries considered (World Bank, 2020b).

Disadvantages

One of the main disadvantages of South Africa is the distance to the EU, which will have a negative impact on the time spent on transporting biomass (Portworld, 2022). Another issue is that, despite having clear renewable energy goals, South Africa does not have specific biomass goals which could show a lack of incentive of the country to bet on biomass as a future energy solution. Additionally, South Africa has a low tertiary education enrolment rate, which could show that if biomass supply chains were to be developed, skilled labour would need to be recruited from outside the country (Roser & Ortiz-Ospina, 2016). Finally, despite a decent biomass potential, South Africa does not score highly in terms of its total arable land, representing 9,89% of the country's total area (World Bank, 2018).

Final score: 3,41/5,00

***Table 10**: South Africa's score per parameter for biomass*

South Africa	*Score*	*score x weight*
Proximity to EU	1	0,07
Transport infrastructure *-Roads*	3	0,12
-Railways	3	0,12
Climate/Infrastructure *-Sea/Harbour*	4	0,29
Water stress	3	0,15
Existing EU RE projects	5	0,33
Existing Energy trade	5	0,46
Energy poverty	5	0,33
Clear RE Goals	3	0,23
Electricity stability	3	0,22
Political stability	3	0,17
Biomass Potential	3	0,25
Tertiary Education	2	0,14
Foreign investment	5	0,38
Arable land	2	0,13
Total		**3,41**

D. R. Congo (DRC)

Advantages

DRC's advantages are that it has very little water stress, and that it has one of the highest biomass potential scores, with an NPP of 9,5 (Hofste et al., 2019; IRENA, 2021). The country also benefits from good relations with the EU, since there are existing renewable energy projects funded by the EU in the country. There is also an existing energy trade in crude oil from the DRC to the EU (Eurostat, 2020c).

Disadvantages

However, the DRC has many disadvantages. Firstly, its transport and logistics infrastructure is underdeveloped, which is why its roads and railway infrastructure collects the lowest score, while its harbour infrastructure collects the second lowest score (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). Reliable logistics infrastructure would be crucial as the country is located far from the EU (Portworld, 2022). Secondly, the energy sector and especially the electricity supply are a source of great concern. The energy poverty in the country is the worst of the analysed countries, with only 19,1% of the population having access to electricity, which could lead to ethical issues when exporting energy away from the DRC to the EU (World Bank, 2019). Moreover, the quality of the electricity supply does also not score well. Thirdly, the tertiary education enrolment level is very low, which, with only 6,64%, is the second lowest among the analysed African countries (Roser & Ortiz-Ospina, 2016). Finally, the country scores poorly in terms of political stability which can be attributed to an undemocratic electoral system which has caused mass demonstrations and internal conflicts (Gavin, 2021).

Final score: 2,47/5,00

***Table 11**: D. R. Congo's score per parameter for biomass*

D.R.Congo	*Score*	*score x weight*
Proximity to EU	1	0,07
Transport infrastructure *-Roads*	1	0,04
-Railways	1	0,04
Climate/Infrastructure *-Sea/Harbour*	2	0,14
Water stress	5	0,26
Existing EU RE projects	5	0,33
Existing Energy trade	5	0,46
Energy poverty	1	0,07
Clear RE Goals	1	0,08
Electricity stability	2	0,14
Political stability	1	0,06
Biomass Potential	5	0,41
Tertiary Education	1	0,07
Foreign investment	3	0,23
Arable land	1	0,07
Total		**2,47**

Ghana

Advantages

Ghana has multiple advantages, one of which is it's low water stress levels, which is helpful when growing crops (Hofste et al., 2019). This is also partly reflected in the country's decent biomass potential which totals an NPP of 4.5 (IRENA, 2021). Moreover, Ghana has good relations with the EU since there are existing renewable projects financed by the EU in the country while oil, petroleum and natural gas are exported to EU member states (European Commission, 2020c; Eurostat, 2020b; Eurostat, 2020c). It can also be noted that the country does not experience high levels of energy poverty, as 83,5% of the population have access to electricity (World Bank, 2019). Finally, one of Ghana's major attributes is its political stability which scores the highest among analysed African countries. This can be extremely important when considering the resilience of the supply chain (World Bank, 2020b).

Disadvantages

Ghana also has certain disadvantages, which primarily involve its transport infrastructure. Despite having a decent harbour infrastructure, Ghana ranks badly in terms of road infrastructure and especially railway infrastructure which could lead to problems for the export of biomass (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). Additionally, despite having low energy poverty levels, the electricity supply network in Ghana is unstable (World Bank, 2017d). Finally, the tertiary education enrolment rate is also quite low, with only 16,23% of the population following on from secondary school (Roser & Ortiz-Ospina, 2016). However, this is not the lowest among the considered African countries.

Final score: 3,36/5,00

***Table 12**: Ghana's score per parameter for biomass*

Ghana	*Score*	*score x weight*
Proximity to EU	2	0,13
Transport infrastructure *-Roads*	2	0,08
-Railways	1	0,04
Climate/Infrastructure *-Sea/Harbour*	3	0,22
Water stress	5	0,26
Existing EU RE projects	5	0,33
Existing Energy trade	5	0,46
Energy poverty	4	0,27
Clear RE Goals	5	0,38
Electricity stability	2	0,14
Political stability	4	0,23
Biomass Potential	3	0,25
Tertiary Education	2	0,14
Foreign investment	3	0,23
Arable land	3	0,20
Total		**3,36**

Uganda

Advantages

Developing a biomass supply chain with Uganda could have a few advantages. The water stress levels in the country are very low, due to considerable rainfall throughout the year, making it a good area to grow crops (Hofste et al., 2019). The biomass potential score of the country is also very high with a total NPP of 8,5, while the amount of arable land represents 34,41% of the total land area (IRENA, 2021; World Bank, 2018). Finally, Uganda also has clear renewable energy goals, with a specific section on the development of biomass, showing the government's will to invest in biomass and biofuels (MEMD, 2013).

Disadvantages

Uganda also has multiple disadvantages. Firstly, the country has a poor transport infrastructure, since their road network, harbour infrastructure and especially the railway system are not developed enough (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). The country is also landlocked and located far away from the EU making the shipping of biomass more complicated (World Bank, 2017b). Secondly, Uganda does not have strong ties with the EU as such, but rather with specific member states such as the Netherlands who are currently developing renewable energy infrastructure in the country (RVO, 2018). Regarding the electricity grid, the energy poverty is quite high with only 41,3% of the population having access to electricity, while the quality of the electricity supply is average (World Bank, 2019). Finally, the political stability of Uganda also scores badly, which should be considered when looking at the security of the supply chain (World Bank, 2020b). This is mainly caused by its human rights and democracy deficits, as well as it's rising population due to the arrival of refugees from neighbouring countries (DOS, 2022).

Final score: 2,76/5,00

Table 13*: Uganda's score per parameter for biomass*

Uganda	*Score*	*score x weight*
Proximity to EU	2	0,13
Transport infrastructure *-Roads*	2	0,08
-Railways	1	0,04
Climate/Infrastructure *-Sea/Harbour*	2	0,14
Water stress	5	0,26
Existing EU RE projects	3	0,20
Existing Energy trade	1	0,09
Energy poverty	2	0,13
Clear RE Goals	5	0,38
Electricity stability	3	0,22
Political stability	2	0,11
Biomass Potential	5	0,41
Tertiary Education	1	0,07
Foreign investment	2	0,15
Arable land	5	0,33
Total		**2,76**

Morocco

Advantages

Morocco's transport infrastructure and its' ideal geographical location are among its main assets. In terms of the different transport infrastructure parameters, the country scores the highest overall among the selected African countries (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). Additionally, Morocco has good relations with the EU since there is an existing crude oil trade between the two partners and also because the EU finances and develops renewable energy projects in the country (Eurostat, 2020c; European Commission, 2021d). Also, Morocco's energy grid does not suffer from energy poverty, since 99,6% of the population has access to electricity, and its' electricity supply can be characterised as being stable (World Bank, 2019; World Bank, 2017d). The country has clear renewable energy goals with some specifically aiming at the development of biomass within the next decades (Kingdom of Morocco, 2021). Finally, Morocco also benefits from considerable amounts of arable land, constituting 16,75% of its territory (World Bank, 2018).

Disadvantages

One of Morocco's liabilities is it's high level of water stress, especially in the southern areas of the country (Hofste et al., 2019). Additionally, the biomass potential score is not very high compared with other African counties, with a total of 1,5 NPP (IRENA, 2021). Finally, as many of the other African countries, the tertiary education enrolment level is quite low (28,14%), despite being the second highest among the selected African countries (Roser & Ortiz-Ospina, 2016).

Final score: 3,79/5,00

***Table 14**: Morocco's score per parameter for biomass*

Morocco	*Score*	*score x weight*
Proximity to EU	5	0,33
Transport infrastructure *-Roads*	4	0,16
-Railways	3	0,12
Climate/Infrastructure *-Sea/Harbour*	4	0,29
Water stress	2	0,10
Existing EU RE projects	5	0,33
Existing Energy trade	5	0,46
Energy poverty	5	0,33
Clear RE Goals	5	0,38
Electricity stability	5	0,36
Political stability	3	0,17
Biomass Potential	2	0,16
Tertiary Education	2	0,14
Foreign investment	3	0,23
Arable land	3	0,20
Total		**3,79**

Republic of Congo

Advantages

The republic of Congo's main attributes are its very low water stress levels and its high biomass potential (Hofste et al., 2019). Its total biomass potential is equal to that of the DRC, totalling 9,5 NPP (IRENA, 2021). Furthermore, the country already trades crude oil with the EU, which could facilitate future biomass trade (Eurostat, 2020c). Finally, the country also experiences high levels of foreign direct investment (4,016 billion dollars) demonstrating the potential which investors see in the country (World Bank, 2020).

Disadvantages

One of the issues with the republic of Congo is the lack of data available for the different parameters, which ultimately has a negative impact on its final score. However, the country scores badly in other categories as well which is partly due to it not having any existing EU supported renewable energy projects, and its lack of clear renewable energy goals for the next decades. Also, only 48,33% of the country's population have access to electricity, meaning that efforts will first need to be made to electrify the country (World Bank, 2019). Additionally, the republic of Congo has, proportionately to its size, only 1,61% of its land as arable land (World Bank, 2018). Finally, the country is rather unstable politically, which is mainly caused by its' corrupt political system (World Bank, 2020b).

Final score: 2,11/5,00

***Table 15**: Republic of Congo's score per parameter for biomass*

R. of Congo	*Score*	*score x weight*
Proximity to EU	1	0,07
Transport infrastructure *-Roads*	-	0,00
-Railways	-	0,00
Climate/Infrastructure *-Sea/Harbour*	-	0,00
Water stress	5	0,26
Existing EU RE projects	1	0,07
Existing Energy trade	5	0,46
Energy poverty	2	0,13
Clear RE Goals	1	0,08
Electricity stability	-	0,00
Political stability	2	0,11
Biomass Potential	5	0,41
Tertiary Education	1	0,07
Foreign investment	5	0,38
Arable land	1	0,07
Total		**2,11**
		**Low data availability*

5.1.2. Biomass and biofuels in Africa: Country selection discussion

The MCA has demonstrated that, based on the assessed parameters, the three best performing countries for the development of biomass and biofuel supply chains are Morocco (3,79 points), Egypt (3,48 points) and South Africa (3,41 points) (entire country overview: Appendix A 1). On the one hand, despite not having a high score for their biomass potential, Morocco and Egypt do score the highest overall which can be partly attributed to their good performances in terms of their transport infrastructure and the existing energy access of their populations. On the other hand, South Africa, which is located the furthest from Europe, scores considerably better in terms of its biomass potential, helping it to reach a high overall score. However, despite not being among the three best performing countries, Ghana also achieves a high overall score of 3,36 points which can be assigned to its good biomass potential. As a result, a brief sensitivity analysis is made in order to assess the reliability of this ranking to see if a change in weighting could have an impact on the top-three ranking.

5.1.3. Biomass in Africa : Sensitivity analysis

In order to test the reliability of the results, a simplified "one-factor-at-a-time" (OFAT) method is applied to this MCA (Razavi & Gupta, 2015). The characteristic of this method is to increase the weight of a single variable in order to observe a change in the final results, allowing for a higher traceability for the cause of a change in input (Razavi & Gupta, 2015). For this supply chain, an important factor is the biomass potential of the countries. However, despite this parameter being already highly weighted (*i.e.* 0,08) it does not weigh enough in the final results, as can be seen for Morocco and Egypt. Therefore, the weight of the biomass potential parameter is increased from 0,08 to 0,11. It is important to mention that, due to the nature of the MCA, by increasing the weight of one parameter the weight of all the other parameters will decrease proportionately. This means that the relative weight change of the variable assessed is even larger than the value change in itself.

The results show that, despite a change in the final score, an increase in the weight of the biomass potential parameter leads to an identical outcome in terms of the top-three best performing countries. As a result, despite a change in final scores, the best performing countries for the development of hydrogen supply chains with the EU remain the same, namely: Morocco (3,74 points), Egypt (3,40 points) and South Africa (3,39 points). Once more, Ghana (3,35 points) scores well but does not outperform the previously mentioned countries.

5.1.4. Green hydrogen in Africa: MCA results

The MCA conducted on the following eight African countries gives an overview of their main advantages and disadvantages, while also identifying the countries scoring best for a large scale production of hydrogen. Certain parameters and the countries for hydrogen are the same as for biomass, which is why the results for the individual parameters might also be the same. Therefore, these specific parameters might only be briefly mentioned or omitted in the following section to avoid repetition. The countries are listed in the order given in the general MCA overview table in Appendix A 2.

Morocco

Advantages

Morocco has multiple advantages for developing hydrogen supply chains with the EU. Its proximity to the EU and its existing gas connection to the EU makes it an interesting option as it allows for the export of hydrogen in multiple ways, since the other types of transport infrastructure are also well developed (Fox, 2022). Morocco's climate is also an important asset since it receives a high amount of solar radiation (5,02 kWh/kWp) and a fair share of wind (5,91 m/s on average), while also being located at the sea, allowing for the development of renewable energies which can be used to produce hydrogen (Solargis et al., 2022; Solargis et al., 2022b). The country is already developing in this regard, as it already produces solar, wind and hydro energy and is currently developing a plant to produce hydrogen (IRENA, 2021; Menon, 2021). This is in line with the country's renewable energy goals which also specifically address the development of hydrogen (GlobalData, 2022). As mentioned previously, the country does not suffer from energy poverty and has a stable electricity supply, which is an important factor when producing hydrogen (World Bank, 2017d; Work Bank, 2019). Finally, the country has multiple chemical plants which could indicate that it would be possible to implement the hydrogen carrier synthesis process locally (Kingdom of Morocco, 2022).

Disadvantages

Morocco does have certain disadvantages, some of which were previously mentioned such as its water stress and its' low tertiary enrolment rate. Moreover, the electricity export levels are fairly low, at 165 million kWh, which indicates that the country has existing infrastructure to export electricity but that the quantities are currently limited (CIA, 2017).

Final score: 4,10/5,00

***Table 16**: Morocco's score per parameter for hydrogen*

Morocco	Score	score x weight
Proximity to EU	5	0,24
Gas connection to EU	5	0,19
Transport infrastructure -Roads' Quality	4	0,07
-Railway Quality	3	0,05
-Harbour quality and access	4	0,07
Climate *-Sun*	5	0,21
-Wind	3	0,12
-Sea	5	0,21
Water Stress	2	0,08
Existing RE infrastructure -Solar	5	0,21
-Wind	5	0,21
-Hydrogen	3	0,14
-Hydro	5	0,21
Infrastructure -Chemical plant	5	0,40
Existing EU RE projects	5	0,22
Existing Energy trade	5	0,21
Energy poverty	5	0,30
Clear RE Goals	5	0,22
Political stability	3	0,13
Tertiary Education	2	0,15
Electricity stability	5	0,24
Foreign Direct Investment	3	0,14
Electricity export	2	0,08
Total		4,10

Algeria

Advantages

Algeria has many advantages for the development of hydrogen, as it is, similarly to Morocco, close to Europe and has gas pipelines leading to the European continent (Fox, 2022). It also has good railway and harbour infrastructure which would allow for multiple options in terms of export (World Bank, 2017b; World Bank, 2017c). Algeria also has a similar climate to Morocco, in that it receives a high amount of solar radiation and is located by the sea, while it has a larger wind potential than its neighbour (7,33 m/s) (Solargis et al., 2022; Solargis et al., 2022b). The country has started to harness this potential by investing in renewable energy infrastructure, which has led to it having solar, wind and hydro energy produced locally (IRENA, 2021). It can also be noted that Algeria is the third highest exporter of electricity among the considered African countries, with a total of 641 million kWh (CIA, 2017).

However, the amounts do remain limited. The relationship with the EU is also good as it already exports crude oil and natural gas to EU member states and the EU is active in promoting renewable energy projects in Algeria (Eurostat, 2020b; Eurostat, 2020c; European Commission, 2017). Finally, Algeria also possesses a chemical industry which could potentially enable a hydrogen carrier synthesis (Saleh, 2021).

Disadvantages

Algeria also has certain disadvantages, including a bad road infrastructure which could hinder the smooth transport of hydrogen to the EU (World Bank, 2017). Additionally, much like Morocco, it also has issues in terms of water stress, which could lead to ethical problems when using water to produce hydrogen (Hofste et al., 2019). It is also important to mention that Algeria has not started building hydrogen infrastructure yet, despite ongoing talks (Jewkes, 2021). Finally, another issue is that the country does not score well in terms of political stability which is mainly caused by terrorist activity in the southern region of the country (World Bank, 2020b; FCDO, 2022). Such activity could cause problems for the security of the supply chain.

Final score: 3,92/5,00

Table 17*: Algeria's score per parameter for hydrogen*

Algeria	*Score*	*score x weight*
Proximity to EU	5	0,24
Gas connection to EU	5	0,19
Transport infrastructure -Roads' Quality	2	0,04
-Railway Quality	3	0,05
-Harbour quality and access	3	0,05
Climate *-Sun*	5	0,21
-Wind	4	0,17
-Sea	5	0,21
Water Stress	2	0,08
Existing RE infrastructure -Solar	5	0,21
-Wind	5	0,21
-Hydrogen	1	0,05
-Hydro	5	0,21
Infrastructure -Chemical plant	5	0,40
Existing EU RE projects	5	0,22
Existing Energy trade	5	0,21
Energy poverty	5	0,30
Clear RE Goals	5	0,22
Political stability	2	0,09
Tertiary Education	3	0,22
Electricity stability	3	0,14
Foreign Direct Investment	3	0,14
Electricity export	2	0,08
Total		3,92

Egypt

Advantages

Similarly to Morocco and Algeria, Egypt has the advantage of being located very close to the EU and to have an existing gas pipeline crossing the Mediterranean (Fox, 2022). As mentioned previously, its mid-level roads and railways as well as its good harbour infrastructure would ease the transport of hydrogen (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). Moreover, the climate in the country offers many solutions for renewable energy production as it receives large quantities of sun and wind, while being located by the sea (Solargis et al., 2022; Solargis et al., 2022b). The country is already making use of this potential since it produces energy from solar, wind and hydropower (IRENA, 2021). The country's electricity supply is also stable making the production of hydrogen more reliable (World Bank, 2017d). It is also noteworthy that Egypt is the second largest exporter of electricity among the analysed countries, further showing the presence of existing energy infrastructure (CIA, 2017). Finally, Egypt has chemical plants which could be used for the hydrogen carrier synthesis (Crowe, n.d.).

Disadvantages

Egypt also has disadvantages. Egypt experiences considerable water stress, as it is also the case for Morocco and Algeria (Hofste et al., 2019). Regarding the hydrogen infrastructure in the country, it is still very much in the early stages, which can partly be explained by a lack of clear renewable energy goals on hydrogen. Also, Egypt is among the lower ranking countries in terms of political stability which could lead to supply chain resilience issues (World Bank, 2020b).

Final score: 4,01/5,00

***Table 18**: Egypt's score per parameter for hydrogen*

Egypt	*Score*	*score x weight*
Proximity to EU	5	0,24
Gas connection to EU	5	0,19
Transport infrastructure -Roads' Quality	3	0,05
-Railway Quality	3	0,05
-Harbour quality and access	4	0,07
Climate *-Sun*	5	0,21
-Wind	4	0,17
-Sea	5	0,21
Water Stress	2	0,08
Existing RE infrastructure -Solar	5	0,21
-Wind	5	0,21
-Hydrogen	1	0,05
-Hydro	5	0,21
Infrastructure -Chemical plant	5	0,40
Existing EU RE projects	5	0,22
Existing Energy trade	5	0,21
Energy poverty	5	0,30
Clear RE Goals	3	0,13
Political stability	1	0,04
Tertiary Education	3	0,22
Electricity stability	4	0,19
Foreign Direct Investment	5	0,24
Electricity export	3	0,12
Total		4,01

Libya

Advantages

Being in North Africa, Libya's main advantage for this project is its proximity and its existing gas pipeline to the EU (Fox, 2022). The country is also currently exporting energy to the EU, showing existing ties between both sides (Eurostat, 2020c). Another of Libya's important assets is its climate which offers large amounts of sun and wind, as well as a coastline (Solargis et al., 2022; Solargis et al., 2022b). So far, Libya has only capitalised on its solar potential, while it does not produce energy from other renewable energy sources (IRENA, 2021).

Disadvantages

One of Libya's disadvantages is its lack of data available for the different parameters, which is reflected in its final score. However, the available data does show that the country has important issues in terms of water stress, making it the lowest ranked among the considered African countries (Hofste et al., 2019). Additionally, despite its energy trade with the EU, there are currently no EU funded renewable energy projects in the country, which could be caused by the country's unstable political situation. It is important to mention that Libya also ranks the lowest in terms of political stability which can mainly be explained by the Libyan crisis which has lasted since 2011 and has caused a humanitarian crisis as well as a political and military instability (World Bank, 2020b; Knipp, 2021). This instability is also one of the reasons for its' weak electricity stability and supply which now only provides for 68,5% of the population's needs (World Bank, 2017d; Work Bank, 2019). Finally, Libya's bad transport infrastructure is another reason why a hydrogen supply chain with the country could be complicated (World Bank, 2017; World Bank, 2017c).

Final score: 2,10/5,00

Table 19: *Libya's score per parameter for hydrogen*

Libya	*Score*	*score x weight*
Proximity to EU	5	0,24
Gas connection to EU	5	0,19
Transport infrastructure -Roads' Quality	1	0,02
-Railway Quality	-	0,00
-Harbour quality and access	2	0,04
Climate *-Sun*	5	0,21
-Wind	4	0,17
-Sea	5	0,21
Water Stress	1	0,04
Existing RE infrastructure -Solar	3	0,12
-Wind	1	0,04
-Hydrogen	1	0,05
-Hydro	1	0,04
Infrastructure -Chemical plant	-	0,00
Existing EU RE projects	1	0,04
Existing Energy trade	5	0,21
Energy poverty	3	0,18
Clear RE Goals	3	0,13
Political stability	1	0,04
Tertiary Education	-	0,00
Electricity stability	2	0,10
Foreign Direct Investment	-	0,00
Electricity export	1	0,04
Total		2,10
		*Low data availability

Nigeria

Advantages

One of Nigeria's advantages is that it has low water stress levels (Hofste et al., 2019). What could also become an advantage for Nigeria is that it is in the process of being connected to the gas pipelines in Algeria, which would bring gas, but also potentially hydrogen, from Nigeria to the EU (Fox, 2022). Moreover, Nigeria has decent sun and wind conditions for the development of renewable energy (Solargis et al., 2022; Solargis et al., 2022b). The country has already invested in some of these resources and produces solar energy and hydropower (IRENA, 2021). Some of the renewable energy projects are supported by the EU. Nigeria also benefits from a considerable FDI (2,385 billion dollars), showing the potential foreign investors see in the country (World Bank, 2020).

Disadvantages

One of Nigeria's disadvantages is that its overall transport infrastructure is poor, with the road infrastructure score being the worst among considered African countries (World Bank, 2017). Another issue is the energy stability and the energy poverty of the country where only 55,4% of the population has access to electricity (World Bank, 2017d; Work Bank, 2019). With regard to other energies, Nigeria does not currently have any hydrogen or wind infrastructure. The main reason for the lack of hydrogen infrastructure is the lack of precise hydrogen goals for the years to come. The country also has issues in terms of its tertiary education enrolment rate, which is at 10,07%, meaning that qualified labour would have to be sourced from abroad (Roser & Ortiz-Ospina, 2016). Finally, as mentioned previously, the political stability of the country is the second worst among selected countries, and could also be a source of concern (World Bank, 2020b).

Final score: 2,97/5,00

***Table 20**: Nigeria's score per parameter for hydrogen*

Nigeria	Score	score x weight
Proximity to EU	2	0,10
Gas connection to EU	3	0,11
Transport infrastructure -Roads' Quality	1	0,02
-Railway Quality	1	0,02
-Harbour quality and access	2	0,04
Climate *-Sun*	3	0,12
-Wind	3	0,12
-Sea	5	0,21
Water Stress	4	0,17
Existing RE infrastructure -Solar	5	0,21
-Wind	1	0,04
-Hydrogen	1	0,05
-Hydro	5	0,21
Infrastructure -Chemical plant	5	0,40
Existing EU RE projects	5	0,22
Existing Energy trade	5	0,21
Energy poverty	2	0,12
Clear RE Goals	5	0,22
Political stability	1	0,04
Tertiary Education	1	0,07
Electricity stability	1	0,05
Foreign Direct Investment	4	0,19
Electricity export	1	0,04
Total		2,97

Angola

Advantages

Angola has a few advantages which include its climate and its coast which allow for low water stress levels and considerable sun exposure (Hofste et al., 2019; Solargis et al., 2022). Therefore, Angola does detain considerable solar energy potential (Solargis et al., 2022). Moreover, despite not having any EU financed renewable energy projects in the country, Angola does trade fossil fuels with the EU which could facilitate future cooperation (Eurostat, 2020). Finally, Angola also has chemical plants which could be used for the hydrogen carrier synthesis (Reuters, 2019).

Disadvantages

Angola has multiple disadvantages, including its capacity to export hydrogen, as it is located far from the European continent and does not share a gas pipeline with the EU (Portworld, 2022). Moreover, its transport infrastructure is lacking which is mainly caused by the bad state of its roads, railways and its harbours (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). Regarding its existing renewable energy infrastructure, the country mainly relies on one type of renewable energy, namely hydropower (IRENA, 2021). The lack of hydrogen infrastructure can be attributed to its climate goals which do not include a specific section on the development of hydrogen (IEA, 2022). Additionally, Angola's current situation, in terms of electrification, is that the supply of electricity is unstable for the only 45,67% of the population who have access to it (World Bank, 2017d; Work Bank, 2019). To develop the renewable energy system in Angola, the expertise will probably need to come from outside the country as only 9,31% are enrolled in tertiary education, making it the lowest among analysed countries (Roser & Ortiz-Ospina, 2016). Finally, Angola does not score very well in terms of political stability but is among the more stable African countries considered for hydrogen (World Bank, 2020b).

Final score: 2,31/5,00

***Table 21**: Angola's score per parameter for hydrogen*

Angola	Score	score x weight
Proximity to EU	1	0,05
Gas connection to EU	1	0,04
Transport infrastructure -Roads' Quality	1	0,02
-Railway Quality	1	0,02
-Harbour quality and access	2	0,04
Climate *-Sun*	4	0,17
-Wind	2	0,08
-Sea	5	0,21
Water Stress	4	0,17
Existing RE infrastructure -Solar	1	0,04
-Wind	1	0,04
-Hydrogen	1	0,05
-Hydro	5	0,21
Infrastructure -Chemical plant	5	0,40
Existing EU RE projects	1	0,04
Existing Energy trade	5	0,21
Energy poverty	2	0,12
Clear RE Goals	3	0,13
Political stability	2	0,09
Tertiary Education	1	0,07
Electricity stability	1	0,05
Foreign Direct Investment	1	0,05
Electricity export	1	0,04
Total		2,31

South Africa

Advantages

As mentioned previously, South Africa is located far from the EU but it does have a satisfactory transport infrastructure overall (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). The climate of the country also allows for investments in solar energy, while the coastal areas could also offer wind energy (Solargis et al., 2022; Solargis et al., 2022b). South Africa has already capitalised on this potential and is already producing sun and wind energy, as well as hydropower (IRENA, 2021). However, the country has not started building any hydrogen infrastructure yet, despite having dedicated hydrogen goals for the future (DST, 2021). Overall, South Africa has good potential for renewable energies, which has also lead to the EU granting its support for the development of its energy system (European Commission, 2021c). Also, the fact that the country is currently the highest electricity exporter (16.55 billion kWh) among the selected countries, demonstrates that some of the infrastructure necessary to export energy is already present (CIA, 2017). Finally, South Africa also has a chemical industry which could be used for the hydrogen carrier synthesis (Kew, 2021).

Disadvantages

South Africa has certain disadvantages. Its distance from the EU and the fact that it does not have a gas connection to the EU could make the transport of Hydrogen more lengthy (Portworld, 2022).

Additionally, as previously mentioned, the country's tertiary education enrolment levels are low (Roser & Ortiz-Ospina, 2016).

Final score: 3,81/5,00

***Table 22**: South Africa's score per parameter for hydrogen*

South Africa	*Score*	*score x weight*
Proximity to EU	1	0,05
Gas connection to EU	1	0,04
Transport infrastructure -Roads' Quality	3	0,05
-Railway Quality	3	0,05
-Harbour quality and access	4	0,07
Climate *-Sun*	5	0,21
-Wind	3	0,12
-Sea	5	0,21
Water Stress	3	0,12
Existing RE infrastructure -Solar	5	0,21
-Wind	5	0,21
-Hydrogen	1	0,05
-Hydro	5	0,21
Infrastructure -Chemical plant	5	0,40
Existing EU RE projects	5	0,22
Existing Energy trade	5	0,21
Energy poverty	5	0,30
Clear RE Goals	5	0,22
Political stability	3	0,13
Tertiary Education	2	0,15
Electricity stability	3	0,14
Foreign Direct Investment	5	0,24
Electricity export	5	0,21
Total		3,81

Tunisia

Advantages

As for other north African countries, Tunisia is located close to the EU and has a gas connection to the European continent, offering an alternative for the transport of hydrogen (Portworld, 2022; Fox, 2022). Moreover, the climate in the country allows for considerable investments in renewable energy infrastructure, since Tunisia experiences high amounts of sun and wind, while also being located by the sea (Solargis et al., 2022; Solargis et al., 2022b). Currently, wind and solar energy, as well as hydropower are a part of the country's energy mix (IRENA, 2021). However, this is not the case of hydrogen which has not been developed yet, as there are no clear hydrogen goals for the country (UNDP, 2018). Regarding the electricity grid, the country is able to supply the entire population, while the quality of the supply is also stable (World Bank, 2017d; Work Bank, 2019).

Disadvantages

Tunisia also has certain drawbacks. It can be noted that the gas pipeline could be needed as an alternative transport method, as the transport infrastructure in the country is average. While the harbour infrastructure is decent, the roads and railways in the country do not score very well (World Bank, 2017; World Bank, 2017b; World Bank, 2017c). Another issue, is that the country has a arid regions, leading to higher water stress levels (Hofste et al., 2019). It also seems that the country has not been noticed as much for its potential as other North African countries, since there are currently no renewable energy projects being directly supported by the EU, nor is the FDI very high (World Bank, 2020). This could be caused by Tunisia's relatively bad score in terms of political stability which can partly be explained by the political crisis in the country (World Bank, 2020b; Ibrahim, 2021). The current crisis between president Kais Saied and the Assembly of the Representatives of the People has caused mass demonstrations in the country (Ibrahim, 2021). This could make the development of renewable energy supply chains in Tunisia very complicated.

Final score: 3,69/5,00

Table 23*: Tunisia's score per parameter for hydrogen*

Tunisia	*Score*	*score x weight*
Proximity to EU	5	0,24
Gas connection to EU	5	0,19
Transport infrastructure -Roads' Quality	2	0,04
-Railway Quality	2	0,04
-Harbour quality and access	3	0,05
Climate *-Sun*	4	0,17
-Wind	4	0,17
-Sea	5	0,21
Water Stress	2	0,08
Existing RE infrastructure -Solar	5	0,21
-Wind	5	0,21
-Hydrogen	1	0,05
-Hydro	5	0,21
Infrastructure -Chemical plant	5	0,40
Existing EU RE projects	3	0,13
Existing Energy trade	5	0,21
Energy poverty	5	0,30
Clear RE Goals	3	0,13
Political stability	2	0,09
Tertiary Education	3	0,22
Electricity stability	4	0,19
Foreign Direct Investment	2	0,10
Electricity export	2	0,08
Total		3,69

5.1.5. Green hydrogen in Africa: Results discussion

The MCA has demonstrated that the three best performing countries for the development of biomass and biofuel supply chains are Morocco (4,10 points), Egypt (4,01 points) and Algeria (3,92 points) (entire country overview: Appendix A 2). Among other aspects, these three countries are similar in the sense that they are all located in the North-African region, making their geographical location ideal for a quicker shipping time to the EU. Moreover, all countries have an optimal climate to develop renewable energies and hydrogen while also benefitting from a good overall transport and energy infrastructure. However, it is also worth mentioning that South Africa, despite not being among the three best performing countries, obtained a final score of 3,81 points. The country's main disadvantage is its distance from the European continent. Therefore, a brief sensitivity analysis is performed to assess the reliability of this ranking based on the relevant parameters.

5.1.6. Green Hydrogen in Africa : Sensitivity analysis

Once again, a sensitivity analysis is performed with the OFAT method in order to ensure the reliability of the country ranking for green hydrogen supply chains in Africa (Razavi & Gupta, 2015). For this case, the variable which is changed in weight is the proximity to the EU variable. The weight of the variable is decreased as it is not key to the selection of the African countries, and also because it is one of the main reasons for the lowering of South Africa’s final score. As a result, the weight of the proximity to the EU variable is decreased from 0,05 to 0,04, which is the lowest weighting possible (see Appendix A 3). However, despite an increase in South Africa’s final score (3,84 points), the results reveal that the three best performing countries for the development of hydrogen supply chains remain the same. The best performing countries include: Morocco (4,09 points), Egypt (4,0 points) and Algeria (3,91 points).

5.1.7. Key Findings: Chapter 5.1

The outcome from the MCA is that, based on the considered parameters, the worst performing countries for hydrogen are Libya, Angola and Nigeria, while for biomass these include the republic of Congo, the DRC and Ethiopia. This is mostly due to identified weaknesses, such as underdeveloped renewable energy infrastructures and transport infrastructures, but also threats such as political instabilities and unstable electricity supplies. On the other hand, the best performing countries for the development of biomass supply chains with the EU are Morocco (3,74 points), Egypt (3,40 points) and South Africa (3,39 points). Moreover, the best countries to develop green hydrogen supply chains with are Morocco (4,09 points), Egypt (4,0 points) and Algeria (3,91 points). Overall, these countries scored the best because of their main strengths, namely their existing energy infrastructure and low energy poverty levels which favour the development of supply chains with the EU. Also, opportunities are highlighted by the amount of foreign investments in the African countries but also the existing favourable climates and resources to develop renewable energies (see Figure 4).

Figure 4: *Main MCA findings contributing to the SWOT analysis.*

5.2. Potential biomass and hydrogen exports to the EU

This section assesses the potential biomass and hydrogen exports of the best performing African countries from the MCA analysis. This part of the research can also be considered as a part of the Strengths and Weaknesses of the SWOT framework as this section highlights the more promising and the less promising scenarios for biomass and hydrogen exports to the EU.

5.2.1. Scenario outline

To assess the quantities of biomass and hydrogen that could be exported from Africa to meet the EU's 2050 energy needs, multiple scenarios were developed regarding the EU's future energy demand based on various assumptions from academic literature and reports. These scenarios allow for an overview of what could happen to the quantities of energy exported from Africa to the EU when there are "technological and economic developments and changes in climate, energy, agricultural, and business policies" (Mai-Moulin et al., 2019, p.298).

Biomass – Scenario 1 ("Realistic")

This scenario builds on the existing climate scenarios developed by Material Economics (ME) which estimate that 18-19 EJ of primary biomass will be demanded in the EU by 2050 (ME, 2021). This scenario assumes the following for the EU:

- While in a net-zero transition the use of biomaterials will increase in competitiveness and use, its current traditional use in industries will shift considerably (ME, 2021). This is mainly because other renewable energies will become cheaper as battery costs and prospects of cheaper hydrogen will replace the use of biomass. As a result, biofuels will be used less extensively in the shipping sector and for power generation (ME, 2021).

- Instead, biomass will be used as a hybrid solution as a backup for electricity or hydrogen for industrial heat applications (ME, 2021). Additionally, biofuels will become more commonly used in power systems and the aviation sector (ME, 2021).
- The biomass import needed for this scenario totals 1805,55 TWh/year (or 6,5 EJ/year, the average between 5-8 EJ/year in import needs; see Table 24).

This scenario assumes that for African countries:

- The production of biomass is rather realistic, as this represents the lower range of the forecasted amounts available in existing research (Kingdom of Morocco, 2021c). The scenario assumes that African countries will have the adequate infrastructure to export biomass from agricultural residues and the forestry.

Biomass – Scenario 2 ("Ambitious")

This scenario is more ambitious and builds on the biomass demand of specific sectors of the economy, leading to a total of 22 EJ of primary biomass being demanded as energy in the EU by 2050 (ME, 2021). This scenario assumes that:

- Biomass will be used across multiple sectors and will play a considerable role in helping the European economy to reach the net-zero pledges.
- Sustained biomass demand growth will lead to 4–5 EJ being required for road transportation, "5–6 EJ for biogas, 7 EJ for power generation, and more than 4 EJ for chemicals. Adding other sectors, these claims would bring bioenergy use to more than 20 EJ" (ME, 2021, p.8).
- The biomass import needed for this scenario totals 2777,77 TWh/year (or 10 EJ/year, the average between 9-11 EJ/year in import needs; see Table 24).

This scenario assumes that for African countries:

- The production of biomass is rather ambitious, when considering the range of data retrieved as this represents the higher end of the forecasted amounts available in literature (see Appendix B 1) (Kingdom of Morocco, 2021c; Batidzirai et al., 2016). This assumes that the technologies and the supply chains are well developed in order to capitalize on the increasingly available biomass.

***Table 24**: Overview of the EU's forecasted demand Scenario 1 and 2 for biomass.*

	EU (2050)	Biomass		Comment	*Source*
	Primary production in EU	between 11-13	EJ/yr		ME (2021)
Scenario 1	Primary Biomass demanded	between 18-19	EJ/yr		ME (2021)
	Scenario 1: import needs	between 5-8	EJ/yr		
	Import needs range average	6,5	EJ/yr	*=1 805.5 TWh/yr*	
Scenario 2	Primary Biomass demanded	22	EJ/yr		ME (2021)
	Import needs	between 9-11	EJ/yr		
	Import needs range average	10	EJ/yr	*=2 777.7 TWh/yr*	

Hydrogen – Scenario 1 ("Realistic")

This hydrogen scenario is realistic, especially compared with scenario 3, because it is based on the lowest amount of the range of retrieved data on the forecasted hydrogen demanded by the EU in 2050. Moreover, these are the predictions made by the European Commission (EC) itself who believe that 2178 TWh of hydrogen will be demanded by 2050 (see Figure 5).

The level of hydrogen demand implies that by 2050:

- Hydrogen is seen to have an important part to play in the transport sector (1155 TWh), while hydrogen will play a reasonable role in decarbonising the industry (528 TWh) and residential buildings (429 TWh) (Wang et al., 2021). However, this scenario predicts that hydrogen will not be used much in the European power system (Wang et al., 2021).
- This scenario implies a considerable improvement in terms of infrastructure, such as hydrogen fuel stations, and the efficient supply of decarbonised electricity from renewables (European Commission, 2020d). This scenario also implies that the EU's dependency on hydrogen imports will be low compared with other scenarios.

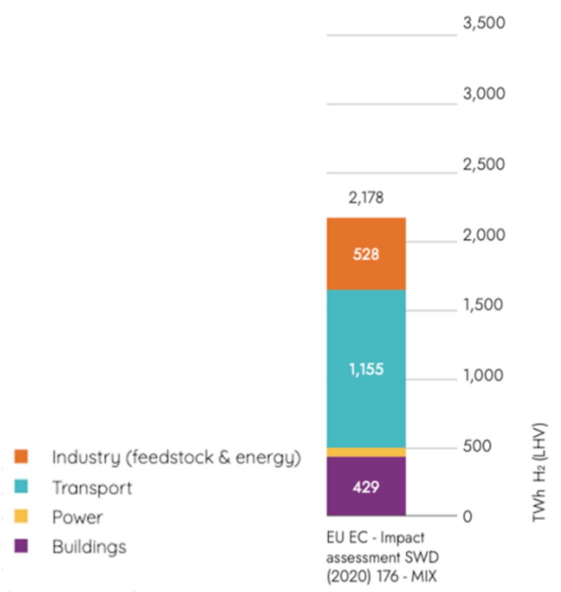

***Figure 5**: EU 2050 hydrogen demand forecasted by European Commission (2020d).*

This scenario assumes that for African countries:

- The amount of hydrogen produced is realistic when considering the range of data retrieved, as this represents the lower forecasted amounts available from previous studies (see Appendix B 1) (Kingdom of Morocco, 2021b). The scenario assumes that the renewable energies needed to produce green hydrogen are available by 2050, but not to the same extent as in scenario 3. However, the necessary infrastructure is present to export surplus hydrogen to the EU.

<u>Hydrogen – Scenario 2 ("Average")</u>

In this scenario, an average demand is made based on multiple similar forecasts from existing literature as can be seen in Figure 6 (European Commission, 2020d; Tsiropoulos et al., 2020; FCH, 2019; Wang et al., 2021). The average demand of these forecasts amounts to a total EU hydrogen demand of 2457,8 TWh/year by 2050. Scenario 2 will mainly consider the assumptions made by Wang et al.'s (2021) study, as its estimates are the closest to the average of the different studies (2300 TWh/year) and it contains certain similar assumptions to what has been forecasted by the EU.

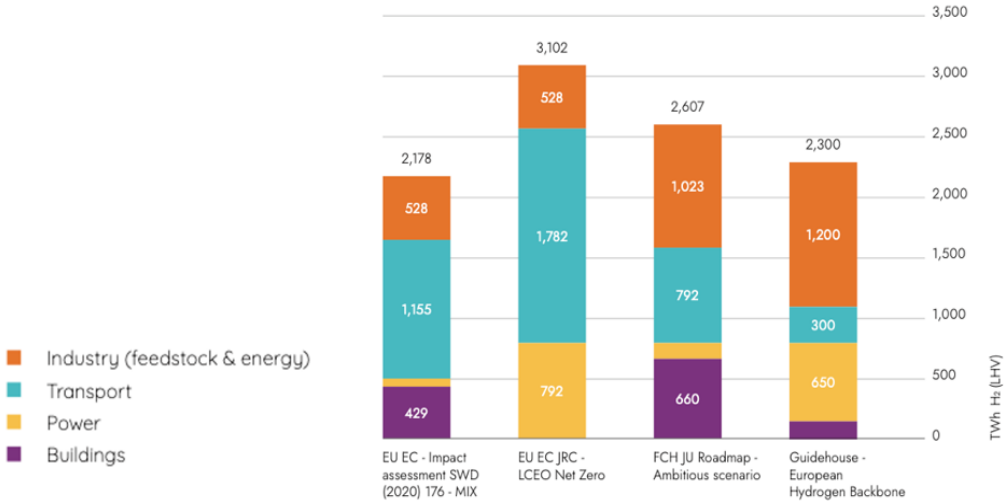

***Figure 6**: EU 2050 hydrogen demand forecast by different sources (Wang et al., 2021).*

Despite being an average of the results given by multiple sources, this hydrogen scenario can be considered as being more realistic than hydrogen scenario 3 (i.e. ambitious scenario). The level of hydrogen demand implies that by 2050:

- Hydrogen is set to become an important feedstock in multiple sectors. It is especially relevant for "ammonia, high value chemicals (HVC), iron and steel, and bio and synthetic kerosene production, where electrification is not an option" (Wang et al., 2021, p.12). In industrial heat, hydrogen will mostly be used for high temperature processes (Wang et al., 2021).
- The road and rail transport sectors will mainly be subject to electrification. However, this scenario expects that hydrogen will still have a role as a fuel in trucking and aviation (Wang et al., 2021).

- For the heating of buildings, this scenario assumes that hydrogen will be used since Europe will have made large scale renovations of buildings which could lead to hybrid heating systems for homes with gas connections (Wang et al., 2021).

This scenario assumes that for African countries:

- As for scenario 1, the amount of hydrogen produced in this scenario is realistic when considering the range of data retrieved, as this represents the lower forecasted amounts available (see Appendix B 1) (Kingdom of Morocco, 2021b). The scenario assumes that the renewable energies to produce hydrogen are available by 2050, but not to the same extent as in scenario 3. However, the necessary infrastructure is present to export hydrogen to the EU.

Hydrogen – Scenario 3 ("Ambitious")

This hydrogen scenario is based on van Wijk et al. (2019), who assume that the total EU energy demand will represent 12 000 TWh/year of which 50% will be fulfilled by electricity and 50% by hydrogen (van Wijk et al., 2019). It is believed that the share of the energy demanded for each industry will remain the same as it currently is, as can be seen below.

***Table 25**: Share of the EU's final energy use per sector (taken from van Wijk et al., 2019).*

Sector	TWh/a (2050)	Share (2017)
Industry Energy	2,500	21 %
Industry Feedstock	1,300	11 %
Transport in EU	3,100	26 %
Transport international	700	6 %
Commercial and Services	1,500	12 %
Households	2,700	22 %
Other	200	2 %
Overall	**12,000**	**100 %**

As a result, the total final hydrogen demand of the different sectors will amount to 6000 TWh/year, the largest consumers being the EU's transport sector, households and industry (van Wijk et al., 2019). This scenario can be regarded as very ambitious as it implies that the consumption of hydrogen will increase considerably across the EU's main sectors by 2050.

Table 26: *Overview of the forecasted hydrogen demand in scenario 1, 2 and 3.*

	EU (2050)	Hydrogen		Comments	Source
Scenario 1: 'Realistic'	Forecasted hydrogen demanded	2178	TWh/yr		EU EC - MIX
	Hydrogen primary production needed	2831,4	TWh/yr	*Based on 30% loss assumption*	
	Primary hydrogen production in EU*	2720	TWh/yr		van Wijk et al. (2019)
	EU Primary production import needed	**111,4**	TWh/yr		
Scenario 2: 'Average'	Forecasted hydrogen demanded	2178	TWh/yr		EU EC - MIX
	Forecasted hydrogen demanded	3102	TWh/yr		EU EC JRC
	Forecasted hydrogen demanded	2251	TWh/yr		FCH -H2 roadmap
	Forecasted hydrogen demanded	2300	TWh/yr		Guidehouse
	Forecasted demand average	**2457,8**	TWh/yr		
	Hydrogen primary production needed	3195,1	TWh/yr	*Based on 30% loss assumption*	
	Primary hydrogen production in EU	2720	TWh/yr		van Wijk et al. (2019)
	EU Primary production import needed	**475,1**	TWh/yr		
Scenario 3: 'Ambitious'	Forecasted hydrogen demanded	6000	TWh/yr		van Wijk et al. (2019)
	Hydrogen primary production needed	8530	TWh/yr		
	Primary hydrogen production in EU	2720	TWh/yr	*1/3 of what is needed*	
	EU Primary production import needed	**5810**	TWh/yr	*2/3 of what is needed*	

*forecasted hydrogen produced in the EU in 2050

This scenario assumes that for African countries:

- The amount of hydrogen produced is rather ambitious, when considering the range of data retrieved as this represents the higher end of the forecasted amounts available (see Appendix B 1). This assumes that the renewable energies to produce hydrogen are well developed and that the necessary technologies and the supply chains are adapted to export their surplus hydrogen (Rystad Energy, 2022).

5.2.2. Results and findings

African production and consumption

In order to retrieve data regarding the future energy production and consumption in African countries in 2050, certain calculations and assumptions were required which can be found in Appendix B 1. The assumptions were mainly needed due to a lack of data availability on national energy forecasts for 2050.

The results highlight certain notable findings which are depicted in Table 27. Firstly, it has been found that, across the different scenarios, all African countries can suffice their own future local demand for biomass and hydrogen, apart from South Africa. It is estimated that while South Africa will produce large amounts of biomass, the country's local demand will also increase considerably in both production scenarios. As a result, the country will not have a surplus of energy which it will be able to export to the EU. Secondly, it can be deducted that Egypt will be exporting the largest amount of biomass as it is the country with the highest surplus among the three selected countries when considering its forecasted production and demand in both scenario 1 and 2. This can mainly be attributed to the fact that Egypt produces larger amounts of agricultural residues than Morocco, which ultimately impacts its biomass potential and hence the amount of pellets exported.

Thirdly, Morocco will become the highest hydrogen exporter among the selected African countries across scenarios, with a total of 122.1 TWh/year in scenario 1 (and 2) and 162.8 TWh/year in scenario 3. This is higher than Algeria's export potential, as both countries have different policies for their future use of hydrogen. Algeria plans on using a great deal of its produced hydrogen for its domestic industry while Morocco is rather betting on producing green hydrogen for export purposes (Drenkard & Mirakyan, 2021). Finally, it is estimated that the total amount of hydrogen available for export will be the equivalent of 160.2 TWh/year in the realistic scenario 1 (and 2) and 243.7 TWh/year in the ambitious scenario 3. For biomass, the total energetic value of the exportable biomass from all African countries after pelletising is estimated at 103.4 TWh/year in scenario 1 and 111.9 TWh/year in scenario 2.

__Table 27__: Hydrogen and Biomass availabilities for export in African countries per scenario.

Countries	Energy consumed locally (2050)		Potential primary Energy produced (2050)				Primary energy left over for export (2050)				Units
	Hydrogen	Biomass	Hydrogen (S1&S2)	Hydrogen (S3)	Biomass (S1)	Biomass (S2)	Hydrogen (S1&S2)	Hydrogen (S3)	Biomass (S1)	Biomass (S2)	
Morocco	1,4	7,8	122,1*	162,8*	41,5	45,1	122,1	162,8	33,7	37,3	TWh/year
Egypt	60,2	13,5	31,1*	103,6	109,1	116,1	31,1	43,4	95,6	102,6	TWh/year
South Africa	-	174,7	-	-	159	161,8	-	-	No biomass available	No biomass available	TWh/year
Algeria	118	-	125	37,5*	-	-	7	37,5	-	-	TWh/year
*Value already represents what is available for export						**Total**	160,2	243,7	129,2	139,8	TWh/year
(S1) Scenario 1						**After pelletising**	-	-	103,4	111,9	TWh/year
(S2) Scenario 2											
(S3) Scenario 3											

EU exports

Biomass scenario results

<u>Scenario 1</u>

In this scenario, the EU's biomass import demanded is considerably lower than that of scenario 2. This is because it considers that the current traditional use of biomass in industries will shift considerably towards other renewable energies, leading to biomass not being predicted to have a large role in the shipping sector nor for power generation (ME, 2021). In turn, this has an important impact on the amount of biomass demanded by the EU and hence the amount covered by African imports. Based on the data retrieved, South Africa is not in the capacity of exporting, which is why exportable biomass quantities are relatively low (103.4 TWh/year), as these are only the amounts available to Egypt and Morocco. Therefore, it can be concluded that 5,7% of the EU's biomass demand can be met by both countries in 2050.

<u>Scenario 2</u>

This scenario is regarded as being more ambitious. The EU's overall biomass demand will be higher by 2050 as it is forecasted that biomass will be used across many sectors, in order to reach the net-zero goals. Biomass will be used for multiple purposes such as biogas, power generation and chemicals (ME, 2021). Therefore, the EU will be required to import more biomass to fulfil its demand, leading to an import demand of 2777,77 TWh/year compared with scenario 1's 1805,6 TWh/year. However, this scenario also assumes that African countries will be able to produce more biomass for exports, due to a higher amount of forecasted residues for biomass. Nevertheless, Egypt and Morocco's biomass-based pellet exports will only cover 4,0% of the EU's biomass import demand.

***Table 28**: Biomass export results for scenario 1 and 2.*

Biomass	Scenario 1	Scenario 2	Unit
EU import demand	1805,6	2777,8	TWh/yr
Total exportable biomass from African countries	103,4	111,9	TWh/yr
Left-over EU import demand	1702	2666	TWh/yr
Total EU import demand covered by African countries	5,7	4,0	%

Hydrogen scenario results

<u>Scenario 1</u>

This scenario can be considered as the realistic scenario, especially compared with scenario 3, because this scenario is based on the lowest amount of forecasted hydrogen demanded by the EU in 2050. In scenario 1, hydrogen is seen to have an important part to play in the transport sector, while hydrogen will play a reasonable role in decarbonising the European industry and residential buildings. This scenario is less ambitious in terms of the development of hydrogen in Europe which is also reflected in the forecasted hydrogen demand, which is the lowest among the three scenarios. In terms of the hydrogen produced in Africa, this is lower than that of scenario 3 which is more ambitious on behalf of the development of renewable energies on the continent. As a result, the EU will be demanding less hydrogen from imports, leading to 111,4 TWh/year being needed by 2050. This means that the EU's total hydrogen import demand will be entirely met (100%) by African exports. Additionally, this would also leave selected African countries with a total surplus of 48,8 TWh/year which could be exported to other countries and regions.

Scenario 2

This scenario can be considered as rather realistic compared with scenario 3. This is mainly because, despite predicting a considerable role for hydrogen in the European economy, it does not consider it to be used equally as much as renewable electricity. For purposes such as the heating of buildings, it is expected that hydrogen will only be used for hybrid buildings with existing gas connections. However, the scenario does consider hydrogen to become an important feedstock in multiple sectors, such as the iron and steel industry or for synthetic kerosene production for example. As a result, the European economy will demand less hydrogen than in scenario 3 leading to an EU import demand of 475,1 TWh/year. In this scenario, the African surplus hydrogen for export is the same as in scenario 1. This means that the total exportable hydrogen from North African countries could cover up to 33,7% of the EU's needs. This would still be a significant amount, especially when considering that this represents the hydrogen which is sourced from only three countries.

Scenario 3

This scenario can be considered as rather optimistic in terms of the role which hydrogen will play in the EU's economy. This is mainly because it assumes that hydrogen will have an equally important role to electricity, as 50% of the EU's energy demand will be fulfilled by electricity and 50% by hydrogen (van Wijk et al., 2019). Moreover, the difference here is that in the transport sector and in a considerable amount of households, hydrogen will be used as a fuel or for heating which is less the case in scenario 1 (van Wijk et al., 2019). As a result, in this scenario, it is forecasted that the EU's hydrogen import demand will reach 5810 TWh/year by 2050. Therefore, it is not surprising that hydrogen imports from selected African countries will cover a lot less of the EU's demand compared with scenario 1, despite a higher amount of exportable hydrogen from African countries. It is estimated that the exports from Africa will only cover 4,2% of the EU's import needs.

Table 29*: Hydrogen export results for scenario 1, 2 and 3.*

Hydrogen	Scenario 1	Scenario 2	Scenario 3	Unit
EU import demand	111,4	475,1	5810	TWh/yr
Total exportable hydrogen from African countries	160,2	160,2	243,7	TWh/yr
Left-over EU import demand	0	314,9	5566,3	TWh/yr
Total EU import demand covered by African countries	100	33,7	4,2	%

5.2.3. Key Findings: Chapter 5.2

The first biomass scenario is rather realistic and would ensure that 5,7% of the EU's biomass import demand would be met, while in the second scenario 4,0% of the demand would be covered. An important finding across both scenarios is that South Africa will not be able to export to the EU because it does not have enough local biomass to fulfil its own forecasted demand. As a result, it is interesting to note that depending on the scenario, already 5,7% or 4,0% of the EU's import demand for biomass would be met by two African countries which do not detain the highest biomass potential on the continent. This shows the significant potential of Africa to meet its own needs and the EU's needs. Regarding the hydrogen scenarios, scenario 1 is realistic and would ensure that 100% of the EU's hydrogen import demand would be met, while in scenario 2, 33,7% would be covered compared with only 4,2% in scenario 3. The realistic scenario has the lowest EU import demand, explaining the higher amount covered by African countries compared with scenario 3 which requires a larger hydrogen transition. On the other hand, the ambitious scenario expects too much from the development of the hydrogen market in the EU, resulting in a very high hydrogen demand which will be difficult to meet even with larger hydrogen surpluses in Africa.

5.3. Key stakeholders and supply chain resilience

This is an overview of key stakeholders and the resilience of the biomass and hydrogen supply chain based on relevant findings in existing academic literature. It is important to identify stakeholders' roles to understand their influence on the overall supply chain, which in turn also helps identifying sustainability objectives and policies required to develop the supply chain (Zavala-Alcívar et al., 2020). Due to the limited scope of this research, this section will not look at the stakeholders of each African country individually, but rather highlight the general stakeholders to consider in biomass and hydrogen supply chains with Africa. As mentioned previously, Christopher & Peck (2004) highlight three risks to the resilience of the supply chain. However, for this research only two of these risks are considered relevant, namely the external risks to the firm but internal to the supply chain network, such as demand and supply variations, and the external risks to the supply chain, such as political instabilities (Christopher & Peck, 2004). These risks will also be assessed based on existing research and reports. The identified risks in this section can be regarded as the "threats" component of the SWOT analysis framework, while this section also highlights important "opportunities".

5.3.1. Stakeholder mapping: Power-Interest matrix

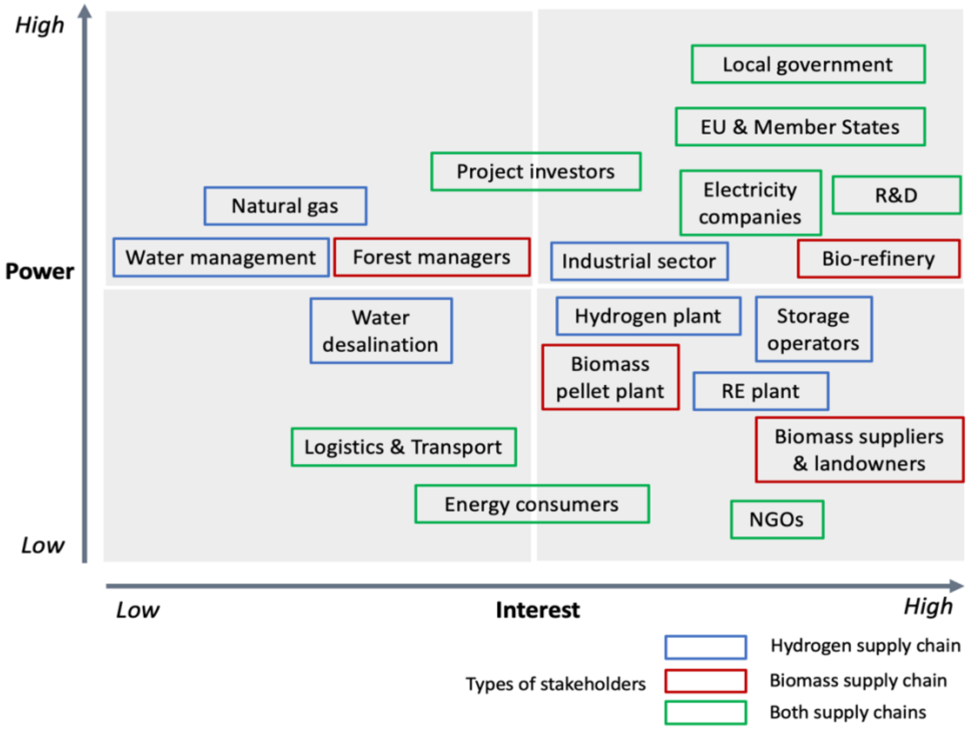

Figure 7: *Power-Interest matrix of stakeholders for both supply chains*

The Power-Interest matrix is a simple tool which assists project governance to visualise the relevant stakeholders for a project, and to assess their power and interest in the project (Scholes, 2001). In this case, a distinction is made between stakeholders which are unique to the hydrogen and biomass supply chain, and those who are relevant for both supply chains. Overall, the stakeholders with high power but with limited interest in the specific supply chain are located in the top-left corner (context setters), while those with a high interest and a considerable amount of power are located in the top-right corner (Players) (Scholes, 2001). Furthermore, stakeholders with a low interest and limited power are located in the bottom right corner (Crowd), while those with a high interest in the project but with limited power are located in the bottom right corner (Subjects) (Scholes, 2001). The positioning of these stakeholders in the matrix above, is based on existing literature on renewable energy stakeholder mapping (Guðlaugsson et al., 2020; Maqbool et al., 2022).

5.3.2. Key stakeholders in the biomass supply chains

Table 30: *Key stakeholders in the biomass supply chain.*

Key Stakeholders	*Description*
Local government	This stakeholder is the local African government and the relevant governmental bodies responsible for the biomass project.

Consumers in Africa and Europe	These are the biomass energy consumers in Africa and in Europe, such as citizens and households (Lokesh et al., 2018).
EU and Member States	The political and governmental entity of the EU encourages the development of renewable energies in Africa with the hope of receiving a biomass supply from African countries in order to guarantee local energy needs (Urciuoli et al., 2014).
Electricity companies	These include the existing distribution system operators (DSOs) and the regulated transmission system operators (TSOs) (Gold, 2011). This stakeholder is responsible for the distribution and transmission of energy to the biomass pellet plant or the bio-refinery.
Project Investors	The biomass project investor group mainly contains the local government and potentially the EU, and also pension funds, insurance companies and other private funds (Lokesh et al., 2018).
Biomass suppliers/farmers and Landowners/forest owners	The biomass farmers and landowners are key to this supply chain as they ensure the cultivation of feedstock, such as energy crops or crop residue for example (Hazelton et al., 2013).
Forest managers	The role of forest managers is to oversee the cultivation of wood for it to be transformed into timber for the production of biomass (Gold, 2011). Managing the forest includes taking into account the biomass business but also the environment.
Biomass pellet plant	This stakeholder primarily transforms wood, energy crops and residues into biomass pellets which can either be exported as such or used in the bio-refinery to be converted to energy (Gold, 2011).
Bio-refinery	The biorefinery for biomass is important for the overall supply chain as it converts biomass into energy (Gold, 2011).
Non-Governmental Organisations (NGOs)	The role of local and international NGOs in the biomass supply chain is to lobby for environmental

	and social causes in order to ensure the protection of locals, consumers and the environment (Hazelton et al., 2013).
Research & Development	Universities and research institutes can be key stakeholders in the development of biomass supply chains as these can be a source of expertise in the early stages of the research and development of the project (Gold, 2011).
Logistics and Transport infrastructure	It is important that logistics and transport infrastructure is developed as these guarantee the export of biomass domestically, in African countries, and abroad, to the EU (Lewandowski, 2015). The stakeholders from the transport sector include both public and private groups, which include the harbour, the roads and the railways. On the other hand, the logistics stakeholders include port authorities, shipping companies and carriers.

5.3.3. Resilience of the biomass supply chain

Risk 1: Supply and demand fluctuation

Biomass supply variations

As some of the selected countries, especially Morocco and Egypt, do suffer from water scarcity, this could lead to lower harvests of biomass related crops (Hofste et al., 2019). A change in water availability could be caused by weather conditions or geopolitical conflicts which could cause biomass supply issues for the EU, as the harvests will be less fruitful (Mana et al., 2021). Therefore, from an EU perspective, it will be important to prevent the dependency on one single supplier, by importing from suppliers in different countries in order to guarantee a constant availability of biomass (Siva Kumar & Anbanandam, 2020). As explained by Siva Kumar & Anbanandam (2020), "sourcing from a single supplier is considered as the root cause of some supply end problems" (p.119). From an African perspective, diversifying suppliers nationally is also relevant in order to guarantee a biomass supply to meet local demand despite threats such as water scarcity. Additionally, the lack of water could also have an impact on stakeholders such as local biomass farmers, forest owners and forest managers in Africa, ultimately affecting the general resilience of the supply chain.

Biomass demand variations

There are multiple aspects which can impact energy demand, such as energy price variations and consumer income variations in a country (Aziz et al., 2013). The previously mentioned changes in the quantities of biomass supplied, caused by water shortages or political situations, can also have an impact on its price, as can be explained by the basic laws of demand and supply (Aziz et al., 2013). Moreover, the consumers' income can also have an impact on demand and especially on the choice of the energy type, which could affect the supplies to third parties, such as the EU (Aziz et al., 2013).

The energy poverty of a country can also have an impact on the amount of energy which can be ethically imported by the EU without it hindering the access of energy to African citizens (Sovacool, 2013). However, the three selected countries for biomass do not suffer from energy poverty, allowing for a more ethical import of biomass (World Bank, 2019d). Finally, what also needs to be considered is the forecasted increase in global energy demand over the next years, which will also affect African countries (Ibrahim, & Ibrahim, 2017). This could also affect the amount of energy available as an export to the EU, which needs to be considered since this could impact the EU and its consumers.

Risk 2: Political instability

Morocco

As mentioned previously, Morocco is among the better scoring African countries in terms of political stability (World Bank, 2020b). The country has a constitutional monarchy which has been led by king Mohamed VI who has been in power since 1999 (FCDO, 2017). The Arab Spring in 2011, did not lead to protests of the same scale as in other neighbouring countries, and led to a more progressive constitution (FCDO, 2017). However, the country does have bad relations with Algeria over the status of Western Sahara, causing the border between both countries to be closed since 1994 (Lamboley, 2020). Nevertheless, the overall political stability is one of the reasons why the country has become more interesting for foreign investors within the past years. Therefore, it seems that the risk of political instability for the supply chain and the relevant stakeholders seems limited. The main stakeholder which can ensure this continuous trend is the local Moroccan government and monarchy.

Egypt

Compared with Morocco, the political situation of Egypt is less stable (World Bank, 2020b). The country was hit a lot harder by the Arab spring which led to large protests and general political unrest (FCDO, 2021). Since this period, certain economic reforms have been made, while the current president was elected in 2018 (FCDO, 2021). Moreover, a state of emergency was in place for four years, but was lifted in October of 2021 (Abdallah, 2021). As mentioned previously, one of Egypt's main conflicts is with Ethiopia, which is planning on building a hydroelectric dam on the river Nile to supply its domestic energy demand. This dam is set to be finished in July 2022 and could have an impact on the water supply of downstream countries such as Egypt (Lawson, 2017). If this were to be the case, this could have considerable consequences on the local population, the agricultural sector and the industry (Pemunta et al., 2021). As a result, multiple stakeholders could be affected by such a scenario, including farmers and forest owners, but also forest managers which will need to seek for smarter ways of irrigating their energy crops (Aziz et al., 2019). In turn, this could also have an impact on energy consumers both in Egypt but also in Europe. Ultimately, the political situation in the country could take its toll on the resilience of the supply chain and will need to remain stable to ensure its functioning.

South Africa

Much like Morocco, South Africa is among the better scoring countries in terms of political stability, as it has a relatively stable democracy (World Bank, 2020b). This stability is also reflected in the trust put by investors into the South African economy (Müller, 2021). The most recent unrests were caused by the accusations on the basis of corruption made against Jacob Zuma, the former president of South Africa, which sparked protests among Zuma supporters in July of 2021 (Müller, 2021). These protests did have an impact on multiple supply chains in the country, as key infrastructure locations were destroyed by protesters (Müller, 2021). This does highlight that there are potential risks for supply chain disruptions, even though these disruptions have proven to be rare. However, the protests also highlight that the country does suffer from a certain level of corruption. This corruption could have an impact on the biomass supply chain, since the electricity sector is considered unstable, which is mainly caused by the mismanagement and corruption of Zuma's government (Müller, 2021). The unreliable electricity supplies caused by corruption, is problematic for multiple stakeholders such as DSOs but also for the bio-refineries which need electricity to be able to function properly.

5.3.4. Key stakeholders in the hydrogen supply chains

Table 31*: Key stakeholders in the hydrogen supply chain.*

Key Stakeholders	*Description*
Local government	This stakeholder contains the local African government and the relevant governmental bodies responsible for the biomass project (Andreasen & Sovacool, 2014).
Consumers in Africa and Europe	These are the hydrogen consumers in Africa and in Europe, such as citizens and households (Schlund et al., 2022).
EU and Member States	This stakeholder represents the political and governmental entity of the EU which pushes for the development of renewable energies in Africa with the hope of receiving a hydrogen supply from African countries in order to guarantee local energy needs (Urciuoli et al., 2014).

Electricity companies	These include the existing distribution system operators (DSOs) and the regulated transmission system operators (TSOs) (Schlund et al., 2022). This stakeholder is responsible for the distribution and transmission energy from the renewable plants to the hydrogen plant.
Project investors	The investors in the hydrogen supply chain project includes the local government and potentially the EU, pension funds, insurance companies and other private funds (Schlund et al., 2022).
Hydrogen plant	This is the location where the renewable energy is converted to hydrogen through a process called electrolysis (Andreasen & Sovacool, 2014).
Renewable energy plant operators	These are the operators of renewable energy plants which include wind farms, solar farms, and hydroelectric dams (Schlund et al., 2022).
Natural gas industry	These include the existing gas TSOs and DSOs (Schlund et al., 2022). As mentioned previously, the existing natural gas pipelines can become one of the key transport methods for hydrogen to the EU, as hydrogen can be transported in these pipes.
Non-Governmental Organisations (NGOs)	The role of local and international NGOs in the biomass supply chain is to lobby for environmental and social causes in order to ensure the protection of locals, consumers and the environment (Schlund et al., 2022).
Industrial sector	This sector includes multiple stakeholders such as the chemical and steel industry (Schlund et al., 2022). The chemical industry is relevant to the hydrogen supply chain as its infrastructure can be used for the hydrogen carrier synthesis process and because it often also consumes hydrogen. The steel industry is also relevant as it is a considerable consumer of hydrogen.
Research & Development	The research and development conducted by both public and private entities such as universities and institutes are key to advance hydrogen projects and supply chains (Andreasen & Sovacool, 2014).
Logistics and Transport infrastructure	Logistics and transport infrastructure is also important for the transport of hydrogen abroad. Stakeholders from the transport

	sector include both public and private groups, such as railway operators, seaports and shipping. Additionally, refilling station operators can be a relevant stakeholder as the development and commercialisation of hydrogen cars and trucks increases (Schlund et al., 2022).
Storage operators	These include new hydrogen storage facilities, as well as existing underground natural gas storage which can be converted to hydrogen storage (Schlund et al., 2022).
Water resource management board	This stakeholder overlooks the overall management of water in a country such as the waterworks for the production of drinking water and the treatment of wastewater for example (Schlund et al., 2022). This is relevant to the hydrogen supply chain because considerable amounts of water are needed to produce hydrogen.
Water desalination plant	The desalination of water is the process which removes mineral components from salt water (Delpisheh et al., 2021). This can be necessary for the production of hydrogen, especially when fresh water scarcity is present in a region or country.

5.3.5. Resilience of the hydrogen supply chain

Risk 1: Supply and demand fluctuation

Hydrogen supply variations

There can be multiple reasons for a variation in the supply of green hydrogen. One of the main reasons being that the production of renewable energy can be very dependent on weather conditions, which can be variable despite good geographical preconditions (van Wijk & Wouters, 2019). Therefore, it is not unthinkable that, at times, the supply of green hydrogen could be reduced due to a lack of renewable energy to power the hydrolysis (van Wijk & Wouters, 2019). As a result, it is important that the storage operators have the capacity of storing considerable amounts of renewable electricity or hydrogen in order to continue supplying consumers in this type of scenario. According to van Wijk et al. (2019), it could be possible to use salt caverns or empty gas fields as storage options for hydrogen. Additionally, the water availability and the desalination of water in African countries are aspects which must be considered in order to guarantee a reliable supply of hydrogen locally and to the EU (van Wijk & Wouters, 2019). Once again, to avoid a situation of this type, the EU will need to diversify its supply of hydrogen in order to reduce its dependency on a single supplier (Siva Kumar & Anbanandam, 2020).

Hydrogen demand variations

The demand for hydrogen is predicted to increase considerably within the next years, in Europe but also in many other regions. If demand will experience a sudden increase in African countries, this could also cause certain complications in terms of the quantities supplied to EU member states. This could be possible as multiple parts of the industry are increasingly demanding hydrogen, while the commercialisation of hydrogen cars is also on the rise (Dawood et al., 2020). It is also key for the demand of hydrogen, that its price stays constant or decreases as this will limit fluctuations (Aziz et al., 2019).

Risk 2: Political instability

Morocco

As for the biomass supply chain, Morocco guarantees a relatively stable political environment for the development of renewable energy supply chains. However, there have been reports regarding the country's bad water management (Ferrando, 2022). This highlights a lack of resilience of the water resource management board, which could have an impact on other related stakeholders, such as the industrial sector. The industrial sector, which is one of the main consumers of hydrogen, will also suffer from water shortages as the manufacturing sector often requires water for cleaning reasons (Doorn, 2019). As a result, it is important that Morocco focuses on improving its water management, as it is key for important stakeholders in the hydrogen supply chain.

Egypt

As mentioned for the biomass supply chain, Ethiopia's hydroelectric dam on the river Nile, could have an impact on the water supply of Egypt (Lawson, 2017). This could also impact the hydrogen supply chain, as water is an important component in hydrogen. Similarly to Morocco, this shows a lack of resilience of the water resource management board, but also of the industrial sector as it consumes both hydrogen and water (Ferrando, 2022). Nevertheless, it should be mentioned that the sea water from Egypt's coastal area could also be used for the production of hydrogen, after its desalination (Delpisheh et al., 2021). Another cause for political instability in Egypt are the terrorist groups which are currently present in certain parts of the North-Sinai region of the country (McManus, 2020). The main risk for the supply chain would be in terms of the transport of hydrogen as this could be intercepted by rebel groups. Therefore, in order to ensure the resilience of the supply chain, it would be recommended to avoid operating in these specific areas of the region as long as these instabilities persist.

Algeria

Similarly to Egypt, Algeria does not score very well in terms of its political stability (World Bank, 2020b). This can be attributed to terrorist activities in the southern region of the country and the instability caused by protests in February 2019 against former President Abdelaziz Bouteflika (Lamboley, 2020). The president has since been replaced, but the unstable nature of the current political system could point towards more protests in the years to come (Lamboley, 2020). Additionally, the Algerian governments has over the years been responsible for the bad water management in the country which could ultimately lead to other societal issues (Ferrando, 2022). Finally, Algeria's diplomatic relations with Morocco have been tense due to differing views on the status of Western Sahara (Rachidi, 2022). This has also caused the relationship with Spain to worsen, as Spain has supported Morocco's claims of sovereignty over the Western Sahara region, much to the dislike of the Algerian government (Rachidi, 2022). This has contributed to Algeria's refusal to renew the Maghreb-Europe gas pipeline, which supplies Spain with gas via Morocco (Rachidi, 2022). Ultimately, these different issues can lead to a lack of resilience of multiple stakeholders in the hydrogen supply chain in Algeria, which include the local government, the water resource management board, the natural gas industry, as well as project investors and the EU. The latter could be reluctant to invest in Algeria, as the current political situation is not optimal, while the relations between Algeria and Spain are strained.

5.3.5. Key Findings: Chapter 5.3

Overall, this section highlighted the threats to the supply chain such as changes in supply and demand caused by dependencies on suppliers, increases in energy demand and changes in energy prices. Additionally, certain threats caused by political instabilities could test the resilience of the biomass and hydrogen supply chains. This is not so much of a risk in Morocco or South Africa, but could be slightly more present in certain regions of Egypt or Algeria. These threats, which can have serious repercussions on the predictability of the supply of energy, also highlight an important opportunity namely that the EU should limit its dependency on a single supplier by diversifying the countries it imports from. Other opportunities arising from supply and demand risks, lie in the capacity to store large quantities of energies as this adds to the flexibility in supplying consumers, whether that is for African or EU consumers. This is especially relevant for the storage of hydrogen, as storage technologies still need to be developed.

5.4. Existing policies and policy recommendations

This section of the research highlights how the biomass and hydrogen export scenarios align with the EU's renewable energy ambitions. Additionally, policy recommendations are given to African countries and the EU regarding the important areas which need to be addressed in order to develop these supply chains. From these areas, certain opportunities are also revealed. The policy recommendations will be based on previous findings, regarding risks and important stakeholders, and academic literature.

5.4.1. Alignment of scenarios with EU 2050 goals

As mentioned in the methodology of this thesis, the SMART framework is used for assessing policies and, in this case, for the alignment of scenarios with the EU 2050 goals (Doran, 1981). This allows for a structured overview of how realistic each scenario is in terms of its achievability within the set timeframe and of its impact on the EU's renewable energy transition.

Biomass

Scenario 1

When looking at the **S**pecific aspect of the SMART framework, it can be deducted that the overarching goal of the EU is to reach the 2050 net-zero goal by increasing the renewable share in its current energy mix. Regarding biomass, this is harder to predict as there are no clear goals for bioenergy-use in the EU as it stands. As mentioned previously, the only biomass goals are related to the transport sector, one of which sets a cap of maximum 7% of conventional biofuels from the final consumption of energy in the transport sector in each Member State (European Commission, COM/2021/557). In this scenario, the **M**easurable goal for the EU is to have a total of 1805,6 TWh/year of biomass import to meet its demand. It is difficult to assess whether this is **A**chievable as the amount of import demand covered by the analysed countries only amounts to 5,7%. However, what can be deducted is that many other trade partners are needed to fulfil this demand.

This is the more **R**ealistic scenario compared with Scenario 2 as it considers biomass to have a slightly lower importance in the EU economy. For instance, it assumes that biomass and biofuels will have a limited importance in the transport sector which also seems to be what is forecasted by EU policies (European Commission, COM/2021/557). The goal of increasing the use of biomass as an energy is **R**elevant as biomass will help the greening of the economy. When considering the **T**imely aspect, it can be stated that the EU will need to invest heavily in reforming the energy system in order to be able to use biomass as a hybrid source of energy for industrial heat applications and for power systems by 2050 (ME, 2021). The scenario also implies that the EU and African countries are capable of developing solid trade partnerships.

Scenario 2

The **S**pecific plan for this scenario is the same as for scenario 1, which is to aim at reaching the 2050 net-zero goal by increasing the renewable share of energy. However, the aim of this scenario is more ambitious as biomass will be used for road transportation, biogas, power generation, and the chemical industry. In this scenario, the **M**easurable goal for the EU is to import a total of 2777,77 TWh/year of biomass to meet its demand. This scenario will be a lot more difficult to **A**chieve, as only 4% of the import demand would be covered by Egypt and Morocco. Also, it needs to be remembered that this is despite a larger biomass surplus in both countries than in scenario 1. Additionally, the amount of biomass produced by the EU is bound to decrease, as it plans on placing 30% of its land area under protection and to support forest biomass in "electricity-only installations" (European Commission, COM/2021/557). As a result, this could potentially lead to an increase in its dependency on exports.

However, if the EU is capable of diversifying its biomass supplies from a larger variety of countries this goal could possibly be achieved, even though this seems to be less **R**ealistic. This scenario is also ambitious as it implies that a large demand for biomass will have been developed in the EU by 2050, which will require a consequential change across industries (FCH, 2019). This scenario is also dependent on a high biomass production level in Egypt and Morocco, assuming that supply chains with Europe are well developed by then (Salman & Hosny, 2021). Therefore, when looking at the **T**imely aspect, it seems that it could take time before these changes are implemented.

Hydrogen

Scenario 1

The **S**pecific aim in scenario 1 is to achieve the goals set for 2050, but especially to use hydrogen in the transport sector, where it will have an important role in decarbonizing the European economy (European Commission, 2020d). Moreover, hydrogen will partly be used in the European industry but also in residential buildings. The **M**easurable goal in this scenario is to meet the local demand of 111,4 TWh/year of hydrogen by 2050. This scenario is possibly the most **A**chievable out of the different hydrogen scenarios as it requires the lowest amount of hydrogen production locally and in terms of imports, as it has been shown that 100% of the EU's import demand would be met by the selected African countries. This scenario would also allow for African countries to export their hydrogen surplus to other trading partners. This scenario can be said to be **R**ealistic as the quantities of hydrogen which will be demanded and the development needed are considerably smaller than in scenario 2 and 3. The hydrogen scenarios are also **R**elevant in order to decarbonise various EU industries. Overall, this scenario can be achieved within the 2050 timeframe (**T**imely), even though this will require investments in relevant infrastructure, such as hydrogen refuelling stations for example (European Commission, 2020d).

Scenario 2

The **S**pecific goal for hydrogen is to reach the 2050 net-zero goals, but more specifically to use hydrogen in all hard-to-decarbonise sectors where other alternatives would not be feasible (European Commission, COM/2020/301, p.7). This scenario implies that hydrogen will become an important feedstock in multiple sectors, but that the transport sector will mainly be running on electricity (Wang et al., 2021). The **M**easurable goal is to import a total of 475,1 TWh/year of hydrogen in order to meet local demand. This scenario is a lot more **A**chievable compared with scenario 3 as it has been shown that 33,7% of import demand will be covered by the three analysed African countries. However, this also implies that African countries solely export hydrogen to the EU. Additionally, this scenario will still require that the EU finds other partners to import hydrogen from to fulfil its demand entirely. It can be said that this scenario is rather **R**ealistic as it forecasts that the EU will import considerably less than in scenario 3. The hydrogen scenarios are also **R**elevant in order to decarbonise various EU industries. Similarly to the biomass scenario, the EU will need build a demand for hydrogen in order to have a market for it by 2050, including infrastructure for transport but also for storing hydrogen (**T**imely) (FCH, 2019). These measures are also relevant for African countries which will need to first develop their renewable energies sources in order to produce green hydrogen.

Scenario 3

The **S**pecific plan in this scenario is to reach the 2050 net-zero goal by increasing the renewable share of energy so 50% of the energy mix is based on renewable electricity and the other 50% from hydrogen (van Wijk et al., 2019). To meet this energy mix goal, the **M**easurable aim will be to import 5810 TWh/year of hydrogen from outside the EU. However, this is difficultly **A**chievable as only 4,2% of export demand is covered by selected African countries. This scenario is not very **R**ealistic because the target of having half of the EU's economy based on hydrogen would require extremely high investments and would also make the EU very dependent on imports (van Wijk et al., 2019). African countries would also need to ramp up their hydrogen infrastructure enormously, which would also require large investments (van Wijk et al., 2019). Moreover, the aim of this scenario is less **R**elevant as it is well above what the EU is currently planning on, as the goal is that a quarter of renewable energy will be used for the production of hydrogen by 2050 (European Commission, COM/2020/301). As a result, in terms of **T**ime, it seems that a scenario of this type will take longer to implement than within the horizon 2050 and would probably not be viable economically due to the required investments in infrastructure.

5.4.2. Country policy recommendations

Biomass

Morocco

Morocco already has a policy framework with a pathway towards 2030 aiming at developing biomass in the country (Kingdom of Morocco, 2021). However, these could be more specific as the pathway does not set precise short, middle and long term goals for biomass.

A good way of kickstarting the biomass industry would be to focus on the agricultural sector, and, more specifically on olive residues (Mana et al., 2021). Morocco has a large capacity in olive growing, where the city of Meknes alone produces more than 4000 tons of olives/day (Mana et al., 2021). The stones from these olives can be used for biomass. To give an idea, "2 kg of olive stones represents the equivalent of one litre of gas oil, almost 10 kW" (Mana et al., 2021, p.4). Additionally, Morocco also has potential in terms of woody biomass as its forested areas are estimated to represent a total of 9 million hectares (Kousksou et al., 2015). As a result, partnerships with the olive industry and the forestry should be encouraged by the Moroccan government in order to build the supply chain (Kousksou et al., 2015). Also, investments will be needed in sorting centres which also treat and store biomass, as these are limited in the country (Mana et al., 2021). These changes will also help attract private investors to support the new supply chain (Mana et al., 2021).

Another aspect which needs to be attended are the existing incentives and subsidies given to fossil fuels across sectors (Kousksou et al., 2015). Instead, incentives and tax reductions should be given to renewable energy power generation such as biomass (Kousksou et al., 2015). Mana et al. (2021) also recommend that in order to encourage producers to engage in energy-efficient practices, strategies can be adopted such as "accepting minimum efficiency standards for technologies and devices" (Mana et al., 2021, p.11).

Regarding the previously mentioned resilience aspects, Morocco will have to implement strict water management policies in order to limit the impact of the agricultural sector on the already scarce water levels (Ferrando, 2022). This will imply that stakeholders such as the local government and water management board are engaged in the development of biomass supply chains. In terms of political stability, Morocco's need for policies is limited as the country is currently stable (World Bank, 2020b).

Egypt

Currently, Egypt does not have clear biomass goals. Therefore, a first step would be to develop a strong regulatory framework accompanied by targets detailing the absolute generation capacity of the country in terms of biomass (Abdulrahman et al., 2018). This would give a clear sign that Egypt has concrete goals for the upcoming years.

The main crop residues which could be used for biomass in Egypt are from wheat, maize, rice and sugar cane (Aliyu et al., 2018). Despite having considerable potential in terms of the agricultural residues generated, it is a common practice to combust residues in an open fire stove in rural Egypt (Aliyu et al., 2018). It is estimated that 52% of agricultural residues are burnt (Said et al., 2013). This shows a lack of awareness of the population on the potential of biomass, which could be changed through educative campaigns organised by the government (Said et al., 2013). Additionally, another way of encouraging the development of a biomass market is to encourage local biomass collection companies to collect the unused residues (Abdulrahman et al., 2018).

One of the easiest options to quick start the supply of biomass is to encourage the sugar cane industry to use the bagasse (sugar cane pulp) from the sugarcane mills for biomass (IRENA, 2018). This is already done on a smaller scale where bagasse is used to produce electricity in co-generation systems

(IRENA, 2018). However, a lot of these residues are still unused. Therefore, this could be an opportunity for the government to help the sugarcane industry invest in "high-pressure boilers in steam co-generation systems" which could potentially generate between 30 kWh and 140 kWh per tonne of sugarcane depending on the efficiency of the systems (IRENA, 2018, p.63). Another opportunity, is the least used residue in Egypt namely rice straw (Said et al., 2013). Egypt is the biggest rice producer in Africa, which leads to 3 Mt of rice straw being disposed of every year, which could otherwise be used for energy purposes (IRENA, 2018). Finally, another measure could be to extend the feed-in-tariffs mechanism to renewable energy generation from biomass in order to encourage the private sector to invest in electricity generation from biomass in Egypt (Abdulrahman et al., 2018).

Regarding the previously mentioned resilience issues, Egypt will have to resolve its political and water conflict with Ethiopia as this could have important impacts on the biomass supply chain. One option, would be to sign a legally binding agreement with Ethiopia on the exact amounts of water retained by the dam and the precise periods and dates when the reservoir will be filled (BBC, 2021). This would allow for Egypt to have a legal basis on which to rely if there was to be a deviation from the initially planned water management of the dam, thus reducing water dependency fears. In turn, this would have a positive impact on the local biomass output.

South Africa

South Africa has the advantage that it already has experience in supplying wood pellets to Europe as it was supplying Europe with pellets through its wood pellet plant in KwaZulu-Natal (Akinbami et al., 2021). The country also has a Biofuel Industrial Strategy (BIS) focusing on the development of biofuels in the country (Akinbami et al., 2021). However, there has been a delay in its implementation, and it does not directly contain policies on biomass (Batidzirai et al., 2016). Therefore, certain measures need to be taken in order to develop biomass on a larger scale in South Africa. This will also be necessary if the EU should have any hope of importing biomass from the area one day.

Certain aspects need to be considered including water management, food security and biodiversity (Aliyu et al., 2018). Firstly, even though the water shortages are not on the same scale as Morocco, this aspect is still important to consider as biomass can have an effect on water levels (Aliyu et al., 2018). Therefore, policies aiming at the water management of energy crop producers will be key to develop these supply chains. Secondly, the South African government should also support farmers which produce food crops and not only energy crops, as this will avoid issues with food scarcity (Aliyu et al., 2018). The main crop residues in South Africa are from maize, sugar cane, wheat and the forestry (Aliyu et al., 2018).

To optimise the amount of crop residues retrieved, it would be necessary to incentivise farmers to invest in crop residue collection equipment (Batidzirai et al., 2016). Moreover, in order to obtain higher amounts of crop residues, farmers should move away from conventional tillage farming to no-till farming, as this can considerably increase the amount of residues available for removal (Batidzirai et al., 2016). To encourage such practices, the South African government should finance educational campaigns to encourage farmers to change their practices. Ultimately, moving large quantities of biomass requires adequate transport infrastructure to accommodate the volumes of additional commodities on the system. Batidzirai et al. (2018) argue that in South Africa this will require sufficient investments in the transport system, as "for long term competitiveness of crop residue supply, the rail network would have to absorb most of the traffic" (p.126). Ultimately, South Africa will also need to attend to one of the previously highlighted risks, namely the stability of it electricity supply. This is relevant for the development of its biomass supply chain, but also for other renewable energies as this is the key to a functioning and stable supply of energy locally and abroad.

European Union

Apart from having goals regarding bioenergy in the transport sector, the EU is yet to have a dedicated roadmap for biomass. Therefore, a first step would be to draft a pathway for the development of bioenergy in the EU, including specific goals for the upcoming years (Borzęcka et al., 2019). The pathway should also include a chapter on the cooperation with countries outside of the EU for the import of biomass, as this will also encourage investors to fund specific biomass projects. South Africa would be a good country to start cooperating more intensively with, as there has already been biomass exported from the country to the EU (Akinbami et al., 2021). However, South Africa first needs to be encouraged to meet its own demands otherwise it will be difficult to import ethically from the country.

There are also other ways of developing biomass supply chains with African countries. The EU can make use of its expertise within biomass development in order to facilitate the development of the supply chain (Mai-Moulin et al., 2019). Also, the EU has the capability of co-financing projects in producing countries, which could help accelerate the development process (Omoju, 2020). Within the EU, the biomass supply chain will also need to be further developed as demand is projected to increase over the next decades (Mai-Moulin et al., 2019). This includes developing and building biomass converters which have the capacity of producing energy from biomass on a much larger scale (Mai-Moulin et al., 2019). Ultimately, the EU will need to develop partnerships with many different African countries in order to limit its dependency on a single country for its biomass imports.

When looking more closely at African countries, it will be key for the EU to encourage countries to meet sustainability requirements for biomass, as these have been toughened and will also apply to imported biomass (Mai-Moulin et al., 2019). To do so, making an alliance on renewable energy trade, as it is already the case for the cocoa trade, could help set common standards in African countries and the EU on the sustainable practices required in order to produce biomass and other renewable energies (European Commission, 2022).

Hydrogen

Morocco

The country does have a pathway for hydrogen, including specific goals and forecasts for the future production of green hydrogen, accompanied by specific policies aiming at future export (Kingdom of Morocco, 2021b). Additionally, the country is developing renewable energy sources which will partly be used to power hydrogen. However, despite the considerable advances, there are still certain domains which could be altered. As mentioned previously, in Morocco, fossil fuels are heavily subsidised which does not contribute to the adoption of renewable energies (Kousksou et al., 2015). Therefore, incentives should rather be made to encourage the production of renewable energies, such as hydrogen (Kousksou et al., 2015). It will also be important to develop the existing renewable energy sources, such as wind and solar power in order to produce green hydrogen. Consequently, to facilitate the investment in this area, carbon taxes and market segmentation for the transport sector and the phosphate-based industry will help exploiting the resources of the country (Touili et al., 2018).

Morocco should also focus on financing research on the transport of hydrogen through existing gas pipelines, since this could be a cost efficient way of exporting to the EU (van Wijk & Wouters, 2019). This research could for example be done in partnership with oil and gas companies. However, the Moroccan government should make sustainability requirements an integrated part of the hydrogen roadmap, as exporting industries will have to abide to the carbon tax on products imported by European countries (Boulakhbar et al., 2020). As this is not the case of many relevant stakeholders, the government should encourage the Moroccan industry to comply to the constraints set by the itself and the European market (Boulakhbar et al., 2020).

Egypt

In order to develop the production of hydrogen in the country, the Egyptian government will need to develop a new set of laws and regulations in order facilitate the implementation of the 2022 and 2035 renewable energy targets (IRENA, 2018). It will also be important that the global economy and energy markets will be taken into account when policies are gradually implemented (Esily et al., 2022). Overall, Egypt will need to establish targets and regulations for multiple components of the hydrogen supply chain such as renewable energy generation, electrolyser capacity, and carbon dioxide emissions (Esily et al., 2022).

Currently, Egypt still needs to develop its renewable energy sources considerably in order to produce green hydrogen. This will require industrial and infrastructural investments as well as capacity development (Esily et al., 2022). It is broadly believed that Egypt's investments in renewable energy capacity will average a total of USD2.5billion per year towards 2030 (IRENA, 2018). To develop the supply chain properly research and local manufacturing will also need to be encouraged (IRENA, 2018). Manufacturing is an important factor as Egypt is considered as one of the main industrial leaders in the region, allowing it to leverage its existing steel, glass and cable industries to produce solar, wind and hydrogen infrastructure locally (IRENA, 2018). Moreover, regarding onshore wind, one advantage of locally manufactured bulky parts, such as blades and towers, is avoiding high costs of transport.

These industries can be stimulated further for the production of renewable infrastructure by pushing for policies that facilitate foreign investments and joint ventures with multinational companies (Esily et al., 2022). An existing example of this is SWEG (Elsewedy for Wind Energy Generation), a joint venture focusing on wind turbine manufacturing and the production of cables and transformers (Esily et al., 2022). Ultimately, due to Egypt's current lack of renewable energy to make green hydrogen, a focus should be made on producing blue hydrogen in the upcoming years to develop the local hydrogen market (Esily et al., 2022).

Algeria

Currently, Algeria does have a plan for hydrogen in the country. However, the focus has mainly been on developing renewable energies such as solar and wind, which has been partially financed by the Algerian government through the National Fund for renewable energies and cogeneration (NFREC) (Zahraoui et al., 2021). The fund has helped financing feed-in-tariffs (FiTs) and also helped develop new renewable energy projects (Zahraoui et al., 2021). However, Algeria still needs to develop clear policies and a transparent implementation strategy for hydrogen. This could be done through a long-term energy roadmap detailing annual capacity goals (IRENA, 2020). In turn, the clear goals will make the Algerian market more accessible for investors.

To further attract foreign investors, the current limit on the ownership of foreign investors should be increased compared with the current 49% foreign ownership rule which only allows for a limited share to be owned by foreigners (IRENA, 2020). This would boost foreign investment but also increase competition in the short term, encouraging the local industry to expand (IRENA, 2020). However, Algeria will also need to tackle its instabilities, such as its feud with Spain or the terrorist activities in the southern region.

Policies for an inclusive transition which aim at job creation will need to focus on capacity building, technology transfer and training programmes (IRENA, 2020). This will be important to improve relationships between international developers and the local labour market, ultimately limiting the amount of imported labour and helping local stakeholders (IRENA, 2020). Another aspect which needs to be considered is the role of the gas industry, as it is currently very important for the country's electricity production (Rahmouni et al., 2017). Therefore, encouraging the gas sector to research the possibilities for the use of existing pipelines for the transport of hydrogen would be beneficial. Algeria's current pipelines and transmission grid are well developed in the North of the country, while the grid in the South is isolated and more prone to technical difficulties (IRENA, 2020). As a result, the Algerian government should also look into the possibilities of developing the Southern region while considering the terrorism risks in the area (IRENA, 2020).

European Union

Despite having a regulatory framework aiming at cooperating with countries from the EU's neighbourhood, the EU still has many possibilities to develop partnerships with hydrogen producing countries. The EU can make use of its expertise within the field of hydrogen in order to accelerate the building of the supply chain and assess the needs for the development of a cross border exchange of renewable energy (van der Zwaan et al., 2021). Also, the EU has the capability of co-financing projects in the designated African countries, which could help the development process as well (Omoju, 2020). However, the EU will need to develop partnerships with many different African countries in order to limit its dependency on a single country for its hydrogen imports.

Domestically, the EU will have to focus more intensively on the possibilities offered by existing gas pipelines for the transport of hydrogen, whether that is between Africa and the EU or within the EU's borders. According to van Wijk & Wouters (2019), the emphasis should be put on expanding the grid capacity from the North and South of Europe to load centres, as well as the interconnections between countries. Besides converting the existing pipeline infrastructure, the EU will also need to develop new hydrogen gas pipelines, in order to have a well interconnected European-African grid (van Wijk & Wouters, 2019). As can be seen in Figure 8, an option could be to develop a new 2,500 km pipeline between Egypt and Greece, which would allow for a better connection to the main European gas grid in Italy (van Wijk & Wouters, 2019). A project of this size would require a considerable investment of 16.5 billion euros and would mainly be financed by the EU and possibly Egypt (van Wijk & Wouters, 2019). Additionally, the EU should also finance research in order to develop the large scale storage of hydrogen, as this will be key in order to have a stable and constant supply of hydrogen (van Wijk & Wouters, 2019).

The EU should not only focus on the supply aspects but also on the hydrogen demand in Europe. In order to green the current energy system, the EU will have to encourage the use of hydrogen in multiple sectors (van der Zwaan et al., 2021). Developing a demand for hydrogen in the EU implies for example that combustion engine vehicles are partly replaced by hydrogen powered vehicles, that the heating of houses can also be done by hydrogen boilers and that the European industry uses hydrogen more frequently instead of fossil fuels (van Wijk & Wouters, 2019). This can be implemented through feed-in-tariffs (FiTs), energy usage quotas, grants, and tax incentives to successfully encourage industries to transition (Qadir et al., 2021).

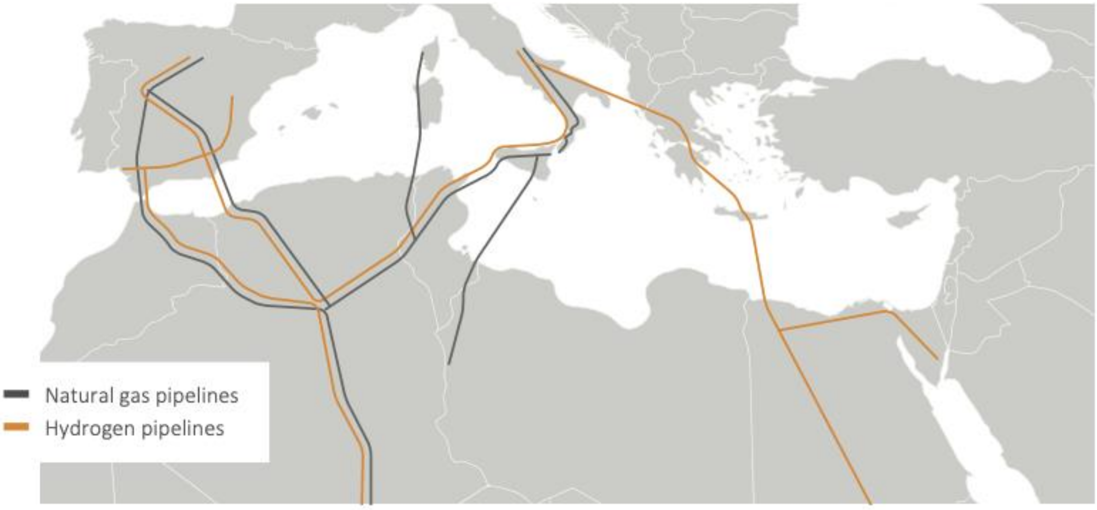

***Figure 8**: Gas pipelines and potential hydrogen pipeline routes to the EU (van Wijk et al., 2019).*

5.4.3. Key Findings: Chapter 5.4

Regarding the alignment of the scenarios with the 2050 goals, it was concluded that biomass scenario 1 is more in line with the EU's existing policies than scenario 2 since it assumes that biomass and biofuels will have a limited importance in the transport sector but will be used across other industries. However, despite being more ambitious, biomass scenario 2, could also be achieved. It will require larger imports of biomass from outside the EU as there will be a higher use of biomass-based energies in European industries. Regarding the hydrogen scenarios, scenario 1 aligns the most with what is forecasted by the EU in terms of future demand. This scenario also seems very achievable based on the potential exports forecasted for African countries. Additionally, when considering scenario 2, it can be deduced that the quantity demanded by the EU could also be fulfilled. However, this would require that the EU also has other trading partners in order to fulfil its hydrogen import demand. On the other hand, scenario 3 is considerably above what the EU plans on consuming, which can also be reflected in the amount of imports required. The achievability of this scenario within the set time frame is highly unlikely as this would entail large investments.

Certain opportunities were highlighted in the policy recommendations section. African countries need to attract foreign investors to develop their renewable energy production. To attract these investors, risks such as political instabilities need to be tackled. Moreover, a common issue among the selected

African countries are the increasing droughts which could also have side effects on biomass and hydrogen supply chains. For hydrogen a solution is to invest in desalination plants. Also, the EU will need to finance and share its expertise with African countries if it wants the project to succeed within the 2050 timeframe. Moreover, many stakeholder will need to be included in the project in order to promote demand for hydrogen and biomass, both in Africa and Europe. Overall, both African countries and the EU need to set clearer goals for hydrogen and biomass to accelerate the transition.

Africa and EU

•Develop/finance desalination plants: increasing droughts in certain regions of Africa could have side effects on biomass and hydrogen supply chains.

•Set clearer goals in terms of quantities of biomass and hydrogen produced by 2050.

•To create a biomass and hydrogen demand: feed-in-tariffs, energy usage quotas, grants, and tax incentives to successfully encourage industries to switch energies.

• Making an alliance on renewable energy trade, as it is already the case for cocoa, could help set common standards in African countries and the EU on the sustainable practices required in order to produce biomass and other renewable energies.

EU

•EU should finance and share its expertise with African countries if it wants the project to succeed by 2050

Africa

•Incentives to attract foreign investors which could help in developing renewable energy production in Africa.

•Example of Algeria: The current limit on the ownership of foreign investors should be increased compared with the current 49% foreign ownership rule.

***Figure 9**: Overview of certain policies needed across supply chains.*

6. Discussion

6.1. Overview of the SWOT-analysis findings

Strengths

This research has highlighted multiple strengths when considering the biomass and hydrogen supply chains. First, the MCA demonstrated that for a biomass supply chain between Africa and EU, the best suited African countries, were Morocco, Egypt and South Africa. The strengths of these countries mainly involved their energy infrastructure, transport infrastructure and their population's access to basic energy needs. Regarding the green hydrogen supply chain, the best performing countries included Morocco, Egypt and Algeria. These countries' advantages involved their potential for renewable energies, their gas connection to the EU and their transport infrastructure. Among these countries it was also found that those with the highest export potential, based on their energy surplus, were Egypt for biomass and Morocco for hydrogen. This shows their forecasted strength compared with other analysed African countries, in terms of their amount of excess resources. Overall, the main advantages of these supply chains include better energy access for African consumers and a significant contribution to the energy transition in both Africa and the EU. Moreover, the economic gains from selling the surplus biomass and hydrogen to the EU could have positive repercussions on the African economy.

Weaknesses

This research also highlighted certain weaknesses, which was especially reflected in the worst performing countries of the MCA. Regarding biomass, the countries which scored the lowest were the Republic of Congo, DRC and Ethiopia. For the hydrogen supply chain the worst scoring countries were Libya, Angola and Nigeria. These low scores can mainly be explained by weaknesses such as political instabilities, bad transport and energy infrastructure, as well as lower energy access rates. A highlighted weakness, among the analysed countries for the export of energy to the EU, was South Africa's lack of biomass surplus. This can mainly be explained by a higher forecasted demand than the forecasted supply of biomass, leading to no biomass being forecasted to be exported from South Africa in 2050. Overall, the bad energy and transport infrastructure are some of the main disadvantages of cross border supply chains between Africa and the EU, as this project would require significant investments.

Opportunities

Based on the identified threats, this research also revealed multiple opportunities for both energy supply chains. Firstly, the opportunities are highlighted by the amount of foreign investments in the African countries but also the existing favourable climates and resources to develop renewable energies. Secondly, diversifying the EU's energy suppliers is an important aspect which can limit the threat posed by energy dependency. Thirdly, the improvement in the capacity of storage systems will also allow for fewer risks associated with changing amounts of energy supplied. This is also relevant as African countries will see a considerable increase in their local energy consumption, which could have a knock-on effect on the amounts of energy available to the EU. Fourthly, an improvement in the security of politically unstable African countries will have important implications for the reliability of the energy supply to the EU. Finally, the development of desalination plants will also help guarantee that arid African countries such as Morocco, Algeria and Egypt will be able to produce hydrogen despite challenging climatic conditions (Delpisheh et al., 2021).

Threats

Multiple threats to the resilience of the energy supply chains were identified. For the EU, there are risks associated with being dependent on a limited amount of suppliers to fulfil demand. For example, an increase in local energy demand in Africa could have an impact on the amount of energy available for export to the EU. Other risks include political instabilities which could have impacts on the supply of energy to the consumer. Considering the best performing countries from the MCA, this is not so much the case of Morocco or South Africa but rather of Egypt or Algeria where governmental instability and terrorism could potentially be sources of concern (Abdallah, 2021). Another threat, is the increasing water scarcity, especially in North African countries. When looking at the energy supply chain, water shortages can have serious impacts on agriculture, hence on biomass supplies, but also on the water needed to produce hydrogen.

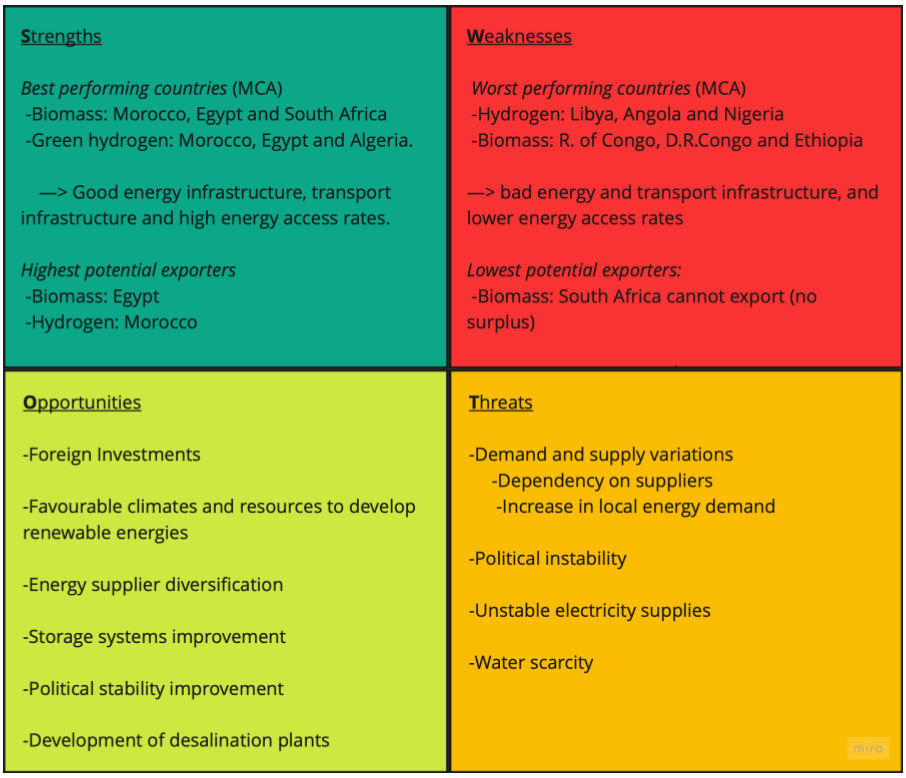

***Figure 10**: Overview of the main SWOT analysis findings.*

6.2. Benefits for African countries

A project of this size would not only benefit the EU but also African countries. Firstly, a supply chain between the EU and Africa would allow for better energy access for African consumers, while it would also quick start the energy transition in Africa (van Wijk et al., 2019). This is mainly because it has been shown that, apart from South Africa's biomass demand, all African countries would be capable of supplying the entire forecasted biomass and hydrogen demand domestically across scenarios. Therefore, these supply chains could be key in greening the energy mix of African countries as well as the EU. Secondly, the economic gains from selling the surplus biomass and hydrogen to the EU could have important repercussions on the African economy. These gains include injections of money into the economy through trade and foreign investors, but also increases in employment and welfare (van Wijk et al., 2019). Thirdly, the investments required to improve the necessary infrastructure to ensure the renewable energy trade would also upgrade African countries' domestic transport infrastructure and the energy grid infrastructure (van der Zwaan et al., 2021). Ultimately, improvements in the energy grid infrastructure could be beneficial for the stability of electricity supplies and also on energy poverty levels (van der Zwaan et al., 2021).

However, it is important to mention that African countries should not only depend on the EU as customers but also other regions and countries (Stein & Uddhammar, 2021). This would ensure that African countries do not become too dependent on the EU, as this could jeopardise their economic independence.

6.3. Implications of the research and reflection on the results

The findings of this research can be used to help policy makers and investors identify which African countries have the biggest potential when considering exporting biomass and hydrogen from Africa to the EU. It is especially relevant when considering the findings relating to the selection of African countries for developing these supply chains and the forecasting of the export potential. The results demonstrate that there are multiple factors to consider including the local political environment, existing infrastructure and energy access. The results from the energy export forecasting section also highlight that, in a realistic scenario, 5,7% of the EU's import demand for biomass and 100% of its import demand for green hydrogen would be fulfilled, while in a more ambitious demand scenario, 4% of the biomass import demand and 4,2% of its hydrogen import demand will be met. In the hydrogen average scenario, it was found that 33,7% of the EU's import demand for green hydrogen would be fulfilled. Additionally, the research highlights important policy areas which need to be considered, which include setting clearer goals for biomass and hydrogen, and encouraging the development of renewable energy demand in Africa and the EU (Borzęcka et al., 2019).

Overall, these results demonstrate the considerable potential which African countries have to green their own economy and the EU’s energy mix. However, certain aspects need to be considered. First, the best scoring countries in the MCA are good countries to trade with on the basis of the selected parameters, but it is important to consider that, especially for biomass, there are other African countries with a higher biomass potential. These countries score less well across other parameters, such as existing energy and transport infrastructure, which is why these do not perform well in this assessment. Nevertheless, countries such as Uganda, DRC or the republic of Congo, could be larger producers of biomass (IRENA, 2021). Second, it is important to mention that despite showing interesting tendencies, the exports forecasted for 2050 should be seen in the light of the uncertainty of future developments. This is because data availability is limited as it is difficult to predict future production and consumption of energies since many external factors could affect these numbers within the next 28 years. Therefore, in order to calculate the potential surpluses and exports, assumptions were needed to overcome the lack of data. Nevertheless, this research gives an overview of the possibilities for exporting energy from Africa to the EU, while it also recommends policy areas which should be considered. As a result, this research can be used as a pathway for developing energy supply chains between Africa and the EU by 2050.

7. Conclusion

This thesis began with explaining that to reach the EU's climate neutrality goals, efforts from member states will be required to change current energy systems. A solution is to invest in renewable energy sources. However, it is doubtful that all member states will be able to sustain energy demands with their domestic renewable energy production by 2050. Therefore, this research answered the following question: *How can Africa-EU hydrogen and biomass supply chains contribute to the greening of the EU's energy mix by 2050 while contributing to Africa's renewable energy development?* As the research demonstrated, African countries could play an important role in greening the EU's energy mix by exporting their excess biomass and hydrogen to the EU. Simultaneously, African countries could also benefit from the development of renewable energies for the greening of their own energy supply.

The previous chapters are discussed while considering the previously stated research question. The first sub-question concerned the *advantages and disadvantages of a hydrogen and biomass supply chain between Africa and the EU*. Based on the considered parameters, the MCA identified the best performing countries for the development of biomass supply chains with the EU. These include Morocco, Egypt, and South Africa. On the other hand, the best countries to develop green hydrogen supply chains with are Morocco, Egypt and Algeria. Overall, these countries scored the best because of their considerable advantages such as their existing transport and energy infrastructure, as well as their renewable resources. On the other hand, countries scoring the lowest most often had insufficient transport infrastructure, low energy access and complicated political situations. Overall, the bad energy and transport infrastructure are some of the main disadvantages of cross border supply chains between Africa and the EU, as this project would require significant investments. The main advantages include better energy access for African consumers and a significant contribution to the energy transition in both Africa and the EU. Also, the economic gains from selling the surplus biomass and hydrogen to the EU could be beneficial to the African economy.

The second sub-question addressed the *potential quantities of hydrogen and biomass exported from African countries to the EU*. In the first biomass scenario, 5,7% of the EU's biomass import demand would be met, while in the second scenario 4% of the demand would be covered. An important finding was that, across both scenarios, all analysed countries will sustain their own demand in hydrogen and biomass apart from South Africa. It was found that South Africa will not be able to export in 2050 as the local biomass produced will not be sufficient to fulfil its own forecasted demand. Consequently, depending on the scenario, 5,7% or 4% of the EU's import demand for biomass would be met by two African countries with a lower biomass potential than other countries on the continent. This shows Africa's significant potential to meet the EU's energy needs. Regarding the hydrogen scenarios, scenario 1 would ensure that 100% of the EU's hydrogen demand would be met, while in scenario 2, 33,7% would be covered compared with only 4,2% in scenario 3. It is noteworthy that scenario 3 expects too much from the development of hydrogen in the EU, leading to a high hydrogen demand which will be difficultly met by imports.

The third sub-question relates to the *resilience of hydrogen and biomass supply chains between Africa and the EU.* It was found that threats to the supply chain included changes in supply and demand caused by dependencies on suppliers, increases in energy demand and changes in energy prices. Moreover, political instabilities could also test the resilience of the supply chains. This is less of a risk in Morocco or South Africa but could be more actual in certain regions of Egypt or Algeria. These threats could have repercussions on the predictability of energy imports. This highlights an important opportunity: the EU should decrease its dependency on a single supplier by diversifying the countries it imports from. Other opportunities emerged from supply and demand risks, such as the development of energy storage as it allows for flexibility in supplying consumers. This is especially relevant for the storage of hydrogen, as storage technologies still need to be developed.

The fourth sub-question focused on *the alignment of the supply chains with the EU 2050 goals.* This thesis concludes that biomass scenario 1 is more in line with the EU's existing policies since it assumes that biomass and biofuels will have a limited importance in the transport sector but will be used across other industries. However, despite being more ambitious, biomass scenario 2, could potentially be achieved, while it would require larger imports of biomass as there would be a higher biomass demand from European industries. Regarding the hydrogen scenarios, in terms of future demand, scenario 1 aligns the most with what is forecasted by the EU. This scenario also seems reachable considering the potential exports forecasted for African countries. Additionally, when considering scenario 2, it can be deduced that the hydrogen import demanded by the EU could also be fulfilled. However, this would require that the EU also has other hydrogen trading partners in order to fulfil the import demand. Finally, scenario 3 is significantly above what the EU is predicted to consume, which is also reflected in the quantity of imports required. Therefore, it is unlikely that this scenario will be achievable within the set time frame.

The fifth sub-question relates to *the EU and African policies needed to develop the supply chains between Africa and the EU.* Policy recommendations were made which included the need to create incentives to attract foreign investors. This could play a significant role in developing renewable energy infrastructure and production in Africa. To attract these investors, risks such as political instabilities need to be tackled. Other policies include investing in desalination plants, as the increasing droughts in certain regions of Africa could have side effects on biomass and hydrogen supply chains. Also, the EU will need to finance and share its expertise on renewable energies with African countries if it wants the project to succeed within the 2050 timeframe. Furthermore, it is recommended that the EU and Africa should set common sustainability standards on renewable energy production practices. Overall, both African countries and the EU need to set clearer goals in terms of quantities of biomass and hydrogen produced by 2050, in order to accelerate the energy transition.

7.1. Contribution

Current literature has demonstrated the considerable potential of renewable energy and renewable electricity in African countries. However, only few researchers have attempted to forecast the potential export of biomass and hydrogen energy from Africa to the EU by 2050. Therefore, this thesis addressed a gap in the literature by investigating the potential of renewable energy supply chains between Africa and the EU, while relating it to the EU 2050 goals. Moreover, the research contributes to the debate by highlighting which African countries have the best preconditions when considering the export of biomass and hydrogen to the EU, while attempting to forecast future export quantities. The research also helps to identify a valuable solution to meet both Africa and the EU's future renewable energy needs. More broadly, renewable supply chains between Africa and the EU could considerably help reaching climate goals, while helping to replace fossil fuel-based energies.

7.2. Limitations and recommendations for further research

Firstly, a limitation of this research is that it is not representative of the whole African continent, but it rather takes a look at the most developed African countries in terms of infrastructure and energy, where a very large part of the population already has access to electricity (IEA, 2020). Secondly, when considering the forecasted exports from Africa in 2050 the uncertainty of future developments should be considered as external factors could influence these numbers. This is also a reason for the limited data availability on the future quantities of energy produced and consumed, thus requiring assumptions to be made. Nevertheless, these assumptions do allow for an overview to be made on potential biomass and hydrogen availabilities.

Further research could be conducted on Sub-Saharan countries with a hydrogen and biomass potential, as conducting research on additional countries would also allow for a better overview of how much can be produced and exported from Africa to the EU when diversifying trading partners. Additionally, based on the findings on South Africa, a more detailed analysis could be conducted on South Africa's future biomass production and its expected capacity to meet its own biomass demand.

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Appendix

Appendix A 1. MCA: Biomass parameters overview for each African country

Countries	Proximity to EU	Transport infrastructure		Climate/Infrastructure	Water stress	Existing EU RE projects	Exisiting Energy trade (With the EU)	Energy poverty	Clear RE Goals	Electricity stability	Political stability	Biomass Potential Net Primary Production (NPP) *(tc/ha/yr)*	Tertiary Education (Tertiary enrollment)	Foreign investment	Arable land	Total points
		Roads	Railway	Sea/Harbour infrastructure and access												
Nigeria	2	1	1	2	4	5	5	2	5	1	1	2	1	4	5	2,88
Ethiopia	3	2	2	2	4	5	1	2	5	2	1	3	1	4	3	2,68
Egypt	5	3	3	4	2	5	5	5	3	4	2	1	3	5	1	3,48
South Africa	1	3	3	4	3	5	5	5	3	3	3	3	2	5	2	3,41
D.R. Congo	1	1	1	2	5	5	5	1	1	2	1	5	1	3	1	2,47
Ghana	2	2	1	3	5	5	5	4	5	2	4	3	2	3	3	3,36
Uganda	2	2	1	2	5	3	1	2	5	3	2	5	1	2	5	2,76
Morocco	5	4	3	4	2	5	5	5	5	5	3	2	2	3	3	3,79
R. of Congo	1	-	-	-	5	1	5	2	1	-	2	5	1	5	1	2,11

Appendix A 2. MCA: Hydrogen parameters overview for each African country

Countries	Proximity to EU	Gas connection to EU	Transport infrastructure			Climate			Water stress	Existing RE infrastructure				Infrastructure	Existing EU RE projects	Existing Energy trade (With the EU)	Energy poverty	Clear RE Goals	Political stability	Tertiary Education (Tertiary enrollment)	Electricity stability	Foreign Direct Investment	Electricity export *2015-2016	Total Points *Max. points = ...*
			Roads	*Railways*	*Harbours*	*Sun*	*Wind*	*Sea*		*solar*	*wind*	*hydrogen*	*hydro*	*Chemical plants*										
Morocco	5	5	4	3	4	5	3	5	2	5	5	3	5	5	5	5	5	5	3	2	5	3	2	4,10
Algeria	5	5	2	3	3	5	4	5	2	5	5	1	5	5	5	5	5	5	2	3	3	3	2	3,92
Egypt	5	5	3	3	4	5	4	5	2	5	5	1	5	5	5	5	5	3	1	3	4	5	3	4,01
Libya	5	5	1	-	2	5	4	5	1	3	1	1	1	-	1	5	3	3	1	-	2	-	1	2,10
Nigeria	2	3	1	1	2	3	3	5	4	5	1	1	5	5	5	5	2	5	1	1	1	4	1	2,97
Angola	1	1	1	1	2	4	2	5	4	1	1	1	5	5	1	5	2	3	2	1	1	1	1	2,31
South Africa	1	1	3	3	4	5	3	5	3	5	5	1	5	5	5	5	5	5	3	2	3	5	5	3,81
Tunisia	5	5	2	2	3	4	4	5	2	5	5	1	5	5	3	5	5	3	2	3	4	2	2	3,69

Appendix A 3. MCA: *Biomass and Hydrogen sensitivity correlation tables*

Biomass

	Energy efficiency	Feedstock conversion ratio	Development status*	Capital-related costs	Consumption related costs	Operation related and other costs	Compatability	Complexity	GHG emissions	Total Points	Parameter Weight
Proximity to EU	1	1	1	1	3	1	1	1	3	13,00	0,06
Existing Transport infrastructure	1	1	3	2	1	2	3	1	2	16,00	0,08
Climate/Infrastructure *-Sea/Harbour access*	1	1	2	2	1	2	2	1	2	14,00	0,07
Water Stress	1	2	1	1	1	1	1	1	1	10,00	0,05
Existing EU RE projects	1	1	3	2	1	1	2	1	1	13,00	0,06
Exisiting Energy trade	1	1	3	3	2	2	3	1	2	18,00	0,09
Energy poverty	2	1	2	2	2	1	1	1	1	13,00	0,06
Clear RE Goals	1	2	3	2	1	1	1	1	3	15,00	0,07
Electricity stability	3	1	2	1	1	2	1	2	1	14,00	0,07
Political stability	1	1	2	2	1	1	1	1	1	11,00	0,05
Biomass Potential	1	3	2	1	3	3	3	3	3	22,00	0,11
Tertiary Education	1	1	3	1	1	3	1	2	1	14,00	0,07
Foreign investment	1	1	3	3	1	1	2	2	1	15,00	0,07
Arable land	1	2	2	1	2	1	1	1	2	13,00	0,06
TOTAL										201,00	1,00

*Technical readiness

1	No correlation
2	Somewhat correlated
3	Highly correlated

Hydrogen

	H_2 storage capacity	Feedstock price	Toxicity	Energy demand	Product storage	Material handling	Process design	Stability	Technical readiness	Pressure	Extra compound	Total points	Parameter Weight
Proximity to EU	1	1	1	1	1	1	1	1	1	1	1	11	0,04
Tertiary education	1	1	3	1	3	3	3	3	1	3	1	23	0,07
Existing energy trade with EU	1	1	1	1	2	1	1	1	1	1	2	13	0,04
Infrastructure (renewable energy sources) *-Solar*	1	1	1	3	1	1	1	1	1	1	1	13	0,04
-Wind	1	1	1	3	1	1	1	1	1	1	1	13	0,04
-Hydrogen	1	1	1	3	1	1	1	1	3	1	1	15	0,05
-Hydro	1	1	1	3	1	1	1	1	1	1	1	13	0,04
Infrastructure (chemical plant)	1	1	3	2	3	3	3	2	3	3	1	25	0,08
Existing EU RE projects	1	1	1	1	1	1	1	1	3	1	2	14	0,05
Political stability	1	2	1	2	1	1	1	1	1	1	2	14	0,05
Electricity stability	1	1	1	3	2	1	1	1	1	2	1	15	0,05
Electricity export	1	1	1	3	1	1	1	1	1	1	1	13	0,04
Gas connection to EU	1	1	1	1	2	1	1	1	1	1	1	12	0,04
Climate – Sun	1	1	1	3	1	1	1	1	1	1	1	13	0,04
Climate – Wind	1	1	1	3	1	1	1	1	1	1	1	13	0,04
Climate – Sea	1	1	1	3	1	1	1	1	1	1	1	13	0,04
Water stress	1	1	1	3	1	1	1	1	1	1	1	13	0,04
Foreign investment	1	2	1	1	1	1	1	1	3	1	2	15	0,05
Energy poverty	1	1	1	3	2	1	1	1	1	2	1	19	0,06
Clear RE goals	1	1	1	1	1	1	1	1	3	1	2	14	0,05
Transport inrastructure	1	2	1	1	2	1	1	1	3	1	3	17	0,05
TOTAL												311	1,00

1	No correlation
2	Somewhat correlated
3	Highly correlated

Appendix B 1. Biomass and hydrogen forecasted exports: *Assumptions and calculations per country*

Forecasted energy production in African countries

Biomass

Morocco

Scenario 1

- 2015*:* "6,6 Millions MWh par an issus du secteur agricole, 3,5 Millions MWh par an issus du secteur forestier" (Kingdom of Morocco, 2021c, p. 21)

- Total all types of biomass 2030: between 21.165.035 and 24.953.873 MWh/year (Kingdom of Morocco, 2021c, p. 21)
- Biomass forestry and agriculture 2030: 16 987 141 MWh/year

	Morocco Biomass 2030			
Region	Agriculture	Forestry	Total	
Tanger	1637824	630814	2268638	Mwh/year
Oriental	667979	471282	1139261	Mwh/year
Fes	2098002	678061	2776063	Mwh/year
Rabat	1940910	605977	2546887	Mwh/year
Beni	1530657	569080	2099737	Mwh/year
Casablanca	1547872	256014	1803886	Mwh/year
Marrakesh	1980594	499761	2480355	Mwh/year
Draa	418244	213335	631579	Mwh/year
Souss	894077	266451	1160528	Mwh/year
Guelmim	41348	21698	63046	Mwh/year
Laayoun	12509	488	12997	Mwh/year
Eddakhla	3071	1093	4164	Mwh/year
			16987141	Mwh/year

- In 2015 (Agri and Forest) : 5 529 662 + 3 479 967 = 9 009 629 MWh/year

  → Increase over 15 years: (16987141-9009629)/9009629*100= 88,544%
- Assume that the same trend continues until 2050:

  2030 → <u>2045</u>: 16 987 141 + 88,54% = 32027555,64 MWh/year

  2045 → <u>2050</u> (88,54%/3=29,51%): 32027555,64 + 29,51% = 41478887,31 MWh/year

Scenario 2

Based on (Kingdom of Morocco, 2021c, p. 21)

- Total Biomass agriculture and forestry 2015 (optimistic): 6,6 million + 3,5 Millions =10,1 million MWh/year
- Total all types of biomass 2015: 13,4 million MWh/year

  Biomass agriculture and forestry: =10,1/13,4 = 0,753731343 = 75,37% of total biomass
- Total all biomass 2030: 24.953.873 MWh/year (optimistic scenario value)

  Total Biomass agriculture and forestry 2030: 24.953.873*0,7537= 18808516,22
- Increase over 15 years: (18808516,22-10100000)/ 10100000*100= 86,2%

Assume that the same trend continues:

2030 → <u>2045</u>: 18808516,22 + 86,2% = 35021457,2 MWh/year

2045 → <u>2050</u> (86,2%/3=28,73%) = 35021457,2 + 28,73%= 45083121,85 MWh/year

<u>Egypt</u>

Scenario 1

Based on IRENA (2018, p.30)

- Agricultural waste totals = 35 million tonnes/year (40% for feeding animals and 60% available for energy purposes), while 5 mtoe/year are available for energy purposes.
  Total (after conversion): 58 150 000 MWh/year (2015)

Based on (Said et al., 2013)

- 185,75 PJ = 51 597 222,22 MWh/year in 2007 (Said et al., 2013)
- Change over 7 years: (58 150 000-51 597 222,22)/ 51 597 222,22*100=12,69%/7 =1,814%/year
  Linear increase in production: 2015-2050 forecast: 58 150 000 + 1,814%^35 = 109 096 852,42 MWh/year

Scenario 2

Based on IRENA (2018, p.30) ;

- Assumption is that 65% of biomass is available for energy purposes and 35% for feeding animals.
- 5 mtoe/year = 60% ; 1,666 = 20%; 5% =0,41666667| 65% energy = 5+0,416= 5,416 mtoe/year
- 5,416 mtoe/year = 62988080 MWh/year (2015)
- Same linear increase as in scenario 1: 1,814%
- 2015-2050 forecast: 62988080 + 1,814%^35 = 116068233 MWh/year

South Africa

Scenario 1

Based on (IRENA, 2021b)

Wood biomass and sugar cane:

6926 GWh/year by 2030 = 6 926 000 MWh/year

7442 GWh/year by 2040 = 7 442 000 MWh/year

- Increase from 2030 to 2040 =7 442 000 - 6 926 000 = 516 000/6 926 000 = 0,07446 = 7,446 %
  Linear increase from 2040 to 2050 = 7 442 000 + 7,446% = 7 996 131,32 MWh/year

Based on (Batidzirai et al., 2016, p.118-126)

- Current conditions: crop residue = 238 PJ = 66111111,11 MWh (per year) → p. 118
  Maize = 88,871% = 58 753 605,55 MWh
  Wheat = 11,129% = 7 357 505,55 MWh

"In the coming decades, other studies also project an average annual increase in maize yields of 2.4% and for wheat an increase in the range of 2.4-3.4% per year for South Africa" (Batidzirai et al., 2016, p.114)

- Assume that it will increase the same way for approx. 34 years as the study is from 2016 (Increase in maize is at 2,4% and wheat at 2.9% - wheat average between range of 2,4-3,4%)
- Maize = 58 753 605,55 * 1,024^34 = 131 593 079,115 MWh/year
  Wheat = 7 357 505,55 * 1,029^34 = 19 447 032,5135 MWh/year
  Total 2050 (maize, wheat, bagasse and wood)=131 593 079,115+19 447 032,5135 + 7996131,32= 159036242.945 MWh/year

Scenario 2

- Wood biomass and sugar cane stays the same = 7 996 131,32 MWh/year
  Maize also remains the same: 131 593 079,115 MWh/year
- For wheat the highest value increase will be considered: 3,4% (Batidzirai et al.)

Wheat: 7 357 505,55 * 1,034^34 = 22 177 284,99

- Total 2050 (maize, wheat, bagasse and wood): 131 593 079,115+22 177 284,99+7 996 131,32= 161766495,4 MWh/year

Hydrogen

Morocco

Scenario 1 (and scenario 2)

Based on (Kingdom of Morocco, 2021b, p.11)

- General green hydrogen exports:
  Reference – 81.4 TWh
  Optimistic – 162.8 TWh

Total is set between the reference and optimistic case: 81,4*1,5=122,1 TWh= 122100000 Mwh

Scenario 3

Based on (Kingdom of Morocco, 2021b, p.11)

Optimistic scenario– 162.8 TWh

Egypt

Scenario 1 (and scenario 2)

"Of this production, nearly 10% is exported in 2030 and almost one-third in 2050, as pure hydrogen or hydrogen-derived fuels such as ammonia and synthetic fuels, drawing on its ample low cost renewable energy resources, especially solar PV." (IEA, 2022b, p.102)

- *30% of the amount forecasted in scenario 2* =103620000*0,3 = 31086000 MWh/year
- Amount which can be exported in scenario 1 = 31086000 MWh/year

Scenario 3

Based on (Rystad, 2022)

- ➔ 1.57 million tonnes of green hydrogen per year by 2035
- 1 kg of hydrogen = 33 MWh
- 1 570 000 *33 = 51 810 000 MWh/year (2035)

Currently no green hydrogen produced, only blue hydrogen…

- Assume that it will increase linearly (so within approximately another 15 years: 51 810 000 MWh)
- Primary production within 30 years (To 2050): 51 810 000*2 = 103 620 000 MWh/year

<u>*Algeria*</u>

Scenario 1 (and scenario 2)

Based on (ITA, 2021) and (Brown, 2021)

Algeria will generate 25 gigawatts of power from green and blue hydrogen by 2050.

- Assume that it is all green hydrogen : 25 GW = 25000 MW
- 8760 = the number of hours in a year

Amount of hours active (max.) = 5000 hours a year → IRENA 'Green Hydrogen Cost reduction'

Production = 25000MW * 5000 = 125 000 000 MWh/year (Assuming this will all be green hydrogen)

Scenario 3

Based on IEA (2022b; p.102)

30% of the amount forecasted in scenario 1 = 125000000*0,3= 37500000 MWh/year

Amount which can be exported in scenario 2 = 37500000 MWh/year

<u>-Forecasted energy demand in African countries</u>

Biomass

<u>*Morocco*</u>

Based on (IEA, 2021)

- Biofuels and waste demand: 2009 → 64 580 TJ

  2014 → 55 940 TJ

  2019 → 53 549 TJ
- In a period of 5 years (2014-2019): -4,27%
- Per year: -4,27%/5 = -0,854%

Assuming similar trend from 2019 towards 2050: 53 549 -0,854%^31 = 41400,6624 TJ

= 11 500 184 MWh (Demand for biomass in 2050 from Biofuels and waste)

Based on (Kingdom of Morocco, 2021c)

- In 2030 =16 987 141 MWh (Agriculture and forestry)
  = 24 953 873 MWh (All types of biomass)

% of agriculture and forestry in biomass energy mix: 16 987 141/24 953 873 MWh = 0,6807 = 68,07%
Assuming that this percentage stays the same in 2050…

- Agricultural and forestry biomass demanded in 2050: 11 500 184*0,6807 = 7828175,249 MWh

<u>*Egypt*</u>

Based on (IEA, 2021b)

- Biofuels and waste demand: 2009 → 62 172 TJ
  2019 → 66 318 TJ (18 421 666,666 MWh)

Increase over 10 years: 66318/62172 = 1,06668 = 6,668 % increase = 6,668/10 = 0,6668 % per year
Assuming similar trend from 2019 towards 2050: 18 421 666,666 + 0,6668 % ^31 = 22507001,5 MWh

Assuming that 60% of agricultural waste is also used for energy in 2050 (Salman & Hosny, 2021)
*No data on wood, but Egypt does not detain many forests…

- Demand for agricultural biomass by 2050 = 22507001,5*0,6 = 13 504 200 MWh

<u>*South Africa*</u>

Based on IEA. (2020b)

- Bioenergy demand: 9 mtoe (2030) = 104 670 000 MWh
  13 mtoe (2040) =151 190 000 MWh

Based on (Batidirai et al., 2016, p.120)
80% of the South African biomass potential is from agricultural residues and forestry
(400-81PJ = 319 PJ/400= 0,7975 = 80%)

- Assuming that this percentage remains the same. Then 80% of the SA biomass demand will be met by agricultural residues and forestry. Therefore, in 2030, the agricultural biomass demand will be: 104 670 000 * 0,8 = 83 736 000 MWh for this type of biomass.
- Then, 151 190 000 MWh * 0,8 = 120 952 000 MWh demanded in 2040.

- Forecasted demand increase between 2030-2040: 120 952 000-83 736 000= 37216000/83736000*100 MWh = +44,44%
  Assumption biomass demand 2040-2050: 120 952 000*1,4444 = 174 703 068.8 MWh

Hydrogen

Egypt

Based on Habib & Ouki (2021) and Goodall (2021)

- In 2019… 1,824,540 tons of hydrogen consumed across industries
  → "a tonne of hydrogen delivers about 33,33 MWh"

- No green hydrogen in 2019: 1 824 540 *33,33 = 60 209 820 MWh/year

As there is no information on the forecasted hydrogen demand for the next years, an assumption is made that the current Egyptian demand for hydrogen will remain but will entirely be met by green hydrogen instead of grey hydrogen in 2050.

Morocco

This is not relevant as the exportable hydrogen for 2050 is already given by Kingdom of Morocco (2021b).

Total= 1.4 Twh = 1 400 000 Mwh

Algeria

Based on (Drenkard & Mirakyan, 2021, p.72-76)

- "le potentiel de demande intérieure en Algérie (118 - 285 TWh)" p.76

In this case the lower demand potential is considered: 118 TWh = 118 000 000 MWh

Based on the assumption that the Algerian society will have shifted from natural gas to hydrogen. This shows that Algeria plans on consuming considerable amounts of its hydrogen.

Forecasted EU energy demand

Biomass

Based on (Material Economics, 2021, p.17)

- Climate scenarios foresee a major increase, from today's 10 EJ to some 17–18 EJ by 2050.
  Available biomass supply: 11-13 EJ/year (2050)
  Forecasted demand: 18-19 EJ/year (2050)
  → 5-8 EJ/year gap (based on existing climate scenario)

Appendix B 2. Biomass and hydrogen forecasted production and exports: *Results in MWh/year*

Countries	Energy consumed locally (2050)		Potential primary Energy produced (2050)				Primary energy left over for export (2050)				Units
	Hydrogen	Biomass	Hydrogen (S1&S2)	Hydrogen (S3)	Biomass (1)	Biomass (2)	Hydrogen (S1&S2)	Hydrogen (S3)	Biomass (1)	Biomass (2)	
Morocco	1400000	7828175	122100000*	162800000*	41478887	45083122	122100000	162800000	33650712	37254947	MWh/year
Egypt	60209820	13504200	31086000*	103620000	109096852	116068233	31086000	43410180	95592652	102564033	MWh/year
South Africa	-	174703069	-	-	159036243	161766495	-	-	No biomass available	No biomass available	MWh/year
Algeria	118000000	-	125000000	37500000*	-	-	7000000	37500000	-	-	MWh/year
*Value already represents what is available for export						**Total**	160186000	243710180	129243364	139818980	MWh/year
(S1) Scenario 1						**After pelletising**	-	-	103394692	111855184	MWh/year
(S2) Scenario 2											
(S3) Scenario 3											

Hydrogen	Scenario 1	Scenario 2	Scenario 3	Unit
EU import demand	111400000	475075000	5810000000	MWh/yr
Total exportable hydrogen from African countries	160200000	160186000	243710180	MWh/yr
Left-over EU import demand	0	314889000	5566289820	MWh/yr
Total EU import demand covered by African countries	100	33,7	4,2	%

Biomass	Scenario 1	Scenario 2	Unit
EU import demand	1805555556	2777777778	MWh/yr
Total exportable biomass from African countries	103394692	111855184	MWh/yr
Left-over EU import demand	1702160864	2665922594	MWh/yr
Total EU import demand covered by African countries	5,7	4,0	%