Report
Decision-Making Methods
Mobility & Logistics, B.Sc

Group 4
Topic: From which country should green hydrogen in the form of LOHC be imported?
Stakeholder: Henkel AG & Co. KGaA

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Table of Contents

Contributions of Students:

Contents	Contributed by
Problem Definition	Safayet Hossain Shimul (32167), Al Jubaiar(26107)
Approach and Methodology	Safayet Hossain Shimul (32167), Al Jubaiar(26107)
Key Decision Points	Safayet Hossain Shimul (32167)
Potential Countries	Md Tuhin Islam (32279)
Requirements and Criteria	Md Tuhin Islam (32279)
Candidate Solution	Md Tuhin Islam (32279)
Risk Profile	Al Jubaiar(26107), Shahnawaz Alam (32445)
Decision Trees	Al Jubaiar(26107)
Analytic Hierarchy Process	Shahnawaz Alam (32445), Md Tuhin Islam (32279), Al Jubaiar(26107)
SWOT Analysis	Shahnawaz Alam (32445), Safayet Hossain Shimul (32167)

Problem Definition

In a world where taking care of the environment is becoming more and more crucial, companies in Germany are establishing targets and strategies to achieve carbon neutrality. German companies are actively engaging in partnerships and research collaborations. Green hydrogen, generated using renewable energy, is vital for achieving Germany's climate goals. In 2020, the German government released the National Hydrogen Strategy (NWS). Besides the NWS, several research studies estimate the demand for green hydrogen in the industry sector. Due to limited domestic production potential, Germany is expanding green hydrogen import agreements both within and outside Europe (Dertinger et al., 2022).

Henkel AG & Co. KGaA is a globally recognized multinational corporation, headquartered in Düsseldorf, sets the target to become a carbon-neutral company by the year 2030. The company generates green energy at sites mainly using wind turbines and solar cells. The required amount of renewable energy produced on-site is insufficient compared to the demand at production sites. Henkel AG & Co. KGaA has three models of conversion to renewable energy: on-site production, direct purchase, and virtual coverage. In 2022, under the direct purchase model, Henkel concluded a long-term renewable energy import contract with Spanish energy company IGNIS (Henkel AG & Co. KGaA, 2023a). This agreement shows Henkel's commitment to the ambitious sustainability goals. Henkel recognizes the importance of green hydrogen in enhancing its renewable energy initiatives. However, there are challenges in importing green hydrogen into its energy portfolio. The complexity arises with identifying suitable import countries because different countries have varying regulations, prices, geopolitical situations, etc. Additionally, designing an efficient supply chain strategy involves considering factors like mode of transportation, distance, and logistics challenges. Therefore, Henkel has a big challenge of finding a way to import green hydrogen. This paper aims to demonstrate the process of identifying from which country green hydrogen in the form of Liquid Organic Hydrogen Carriers (LOHC) be imported.

Before attempting to develop solutions, using 7-Wh-Questions + How to define the problem helps contributing students understand the problem better.

Table 1. 7-Wh-Questions + How to define the problem

WH Questions	Description	Answer
What?	Ask for information	To identify from which country green hydrogen in the form of Liquid Organic Hydrogen Carriers (LOHC) should be imported
Where?	Ask for location	Henkel AG & Co. KGaA,

		Düsseldorf, Germany
Who?	Ask the person doing the action	Main Stakeholder: Henkel AG & Co. KGaA
When?	Ask for the time	By 2030
Why?	Ask for a reason/cause	To achieve carbon neutrality
Which?	Ask for a decision / Specify	Countries like Australia, Norway, Morocco, Spain, Chile are known for their advancements in producing green hydrogen
Whose?	Show possession	Responsibility of regulatory bodies, government agencies, and importing companies to ensure the quality and safety of imported green hydrogen in the form of LOHC
How?	Give an explanation	Available online resources, data analysis, evaluating pros and cons, and utilizing typical decision-making methods. For example- employing decision-making methods such as Analytic Hierarchy Process(AHP) or SWOT analysis may be useful

Approach and Methodology

Several brainstorming sessions were conducted among the contributing students of this paper. Brainstorming was chosen as an idea generation technique, especially when the students lack expertise in the field. As Linus Pauling stated, "The best way to have good ideas is to have lots of ideas." Therefore, brainstorming sessions allowed students to generate a wide range of ideas, perspectives, and insights. All relevant sources were collected predominantly from stakeholder websites, well-known news, journals, and reputable reports. Throughout the decision-making process, the students were engaged in various methods, for example - Decision Tree, Analytic Hierarchy Process, SWOT Analysis, etc. The best-suited methods to the problem were carefully applied. The students made every effort to avoid biases in the analysis and decision-making processes.

Key Decision Points

From Henkel's perspective, the import strategy for green hydrogen in the form of LOHC involves several critical decision points:

1. Source Strategy: Selection of the origin(s) of LOHC import and determining whether to engage with a single supplier or multiple suppliers needed to be defined.

2. Supplier Selection: Identifying potential suppliers based on profile, reputation, and product quality within the LOHC market.

3. Transportation: Selection of mode of transportation and logistics providers that meet the low emissions logistics policies of Henkel. This also involves defining the shipping schedule, volume, and import terminals.

4. Infrastructure: Requirements for storage and handling processes. This includes the required facilities for the dehydrogenation process.

5. Quality Standards: Quality standards and specifications of LOHC need to be aligned with Henkel's Sustainable Development Goals (SDGs).

6. Demand and Price: Demand needs to be assessed to align import quantities with Henkel's needs. Additionally, the purchasing price per unit must be decided upon.

Potential Countries

Several potential countries have emerged as major suppliers in the field of green hydrogen. The distinct characteristics of each country can greatly influence the process of making the decision. This section outlines the potential countries clustered into three categories:

1. The European Union (EU) and the United Kingdom (UK): UK, Spain, Sweden, Norway, Denmark, and Finland.
2. Middle East and North Africa (MENA) Region: Saudi Arabia, Oman, UAE, Morocco, Turkey, and Algeria.
3. Other potential countries: Australia, Brazil, Canada, Chile, New Zealand, USA, and Iceland.

Export-oriented countries from the EU and the UK have advanced infrastructure and commitment to sustainability. Meanwhile, countries from the MENA region have a growing interest in renewable energy and aspire to dominate the global green hydrogen market. Other potential countries have diverse opportunities and strengths in renewable energy resources.

Requirements and Criteria

The identification of requirements and criteria is fundamental to the decision-making process. These requirements ensure alignment with Henkel's strategic objectives. Therefore, contributing students of this paper have assessed Henkel's strategic objectives and goals.

(PwC, n.d.) highlights a projection indicating that by 2030, the average production cost of green hydrogen from the above-mentioned potential countries will remain below 3.00 €. (Weichenhain, 2021) argues that the mode of transportation for LOHC primarily be via ship or pipeline. According to (Dertinger et al., 2022), shipping and pipeline transportation costs are equal up to a distance of 7500 km. The report of (Global Hydrogen Review 2021, 2021) emphasizes bilateral agreements between governments in the green hydrogen sector. The report presents a list of bilateral agreements between Germany and other countries from 2019 to 2021 aimed at cooperation in hydrogen development.

Based on the insights from the aforementioned sources, the following requirements and criteria are derived -

Table 2. Requirements and Criteria

Requirements	Criteria
Strong/Slightly strong export-oriented country	Exporting countries
Maximum production cost < 3,00€ by 2030	Cost
Transportation via ship or pipeline	Mode of transport
Maximum distance < 7500 km	Transport distance
Existing bilateral agreements between governments on hydrogen development	Geopolitics

Candidate Solution

Based on the identified requirements, the top three candidate solutions are Spain, Morocco, and Norway. These countries align well with the specified requirements. For instance, Morocco has a strong orientation toward exporting green hydrogen (Agence France-Presse, 2023). According to (PwC, n.d.), the projected production cost of green hydrogen in Morocco by 2030 is between 2.50 and 2.75 euros. The transport distance by ship from Morocco to Hamburg seaport is approximately 3300 km (*Sea Distance Calculator for Shipping*, n.d.). Moreover, a repurposed

pipeline network by 2030 can facilitate pipeline network between Germany and Morocco. Notably, Moroccan agencies MASEN and IRESEN have already announced two projects in collaboration with Germany aimed at developing clean hydrogen production, research initiatives, and investments across the entire supply chain (Global Hydrogen Review 2021, 2021).

Risk Profile

Importing green hydrogen in the form of LOHC from candidate countries involves uncertainties and risks. From Henkel's perspective, the two main uncertainties associated with importing LOHC are technological maturity and geopolitical stability. As LOHC is still a developing new technology, uncertainties exist in transportation, storage, and dehydrogenation processes. Similarly, uncertainties exist in geopolitical factors that may impact green hydrogen arrangements between countries. For example, sanctions or political instability in supplier countries can disrupt the whole supply chain process. A risk profile table is outlined below to illustrate these key uncertainties, potential outcomes for each candidate country, the likelihood of these outcomes, and their respective consequences.

Table 3. Risk profile

Uncertainties	Outcomes	Consequences of Alternative Spain	Consequences of Alternative Morocco	Consequences of Alternative Norway
Technological maturity	Developed (80%)*	Low-cost Reliable transport	Low-cost Higher generation Reliable transport	Low-cost High generation Reliable transport
	Underdeveloped (20%)*	Not having a comparative low production cost Not Reliable transport	Not having a comparative low production cost Not Reliable transport	Not having a comparative low production cost Not Reliable transport
Geopolitical Stability	Stable conditions (70%)*	Extension of H2Med could deliver a pipeline network (Tracey, 2023)	Repurposed pipeline network by 2030 (International Renewable Energy Agency, 2022)	

		Potential Reliable supply chain/transport	Potential Reliable supply chain/transport	Potential Reliable supply chain/transport
	Geopolitical tensions (30%)*	No pipeline network by 2030 Disruptions in the supply chain	No repurposed pipeline by 2030 Disruptions in the supply chain	 Disruptions in the supply chain

* Assumed likelihood based on reliable sources

Decision Trees

To assess how well each alternative satisfies the requirements, typical decision-making methods can be applied, such as Scoring Methods or Decision Trees. Implementing the scoring method requires assigning weights to each criterion. This demands a deep understanding and reliable sources, often in collaboration with stakeholders. Besides, the contributing students of this paper lack expertise in the green hydrogen field. Moreover, achieving a common understanding of scaling and weighting may be challenging.

On the other hand, Decision Trees work with both qualitative and quantitative data effectively. The graphical representation of the decision tree helps easier interpretation and understandability to stakeholders. From the information provided in the risk profile table, a decision tree is constructed to visually represent the decision-making process.

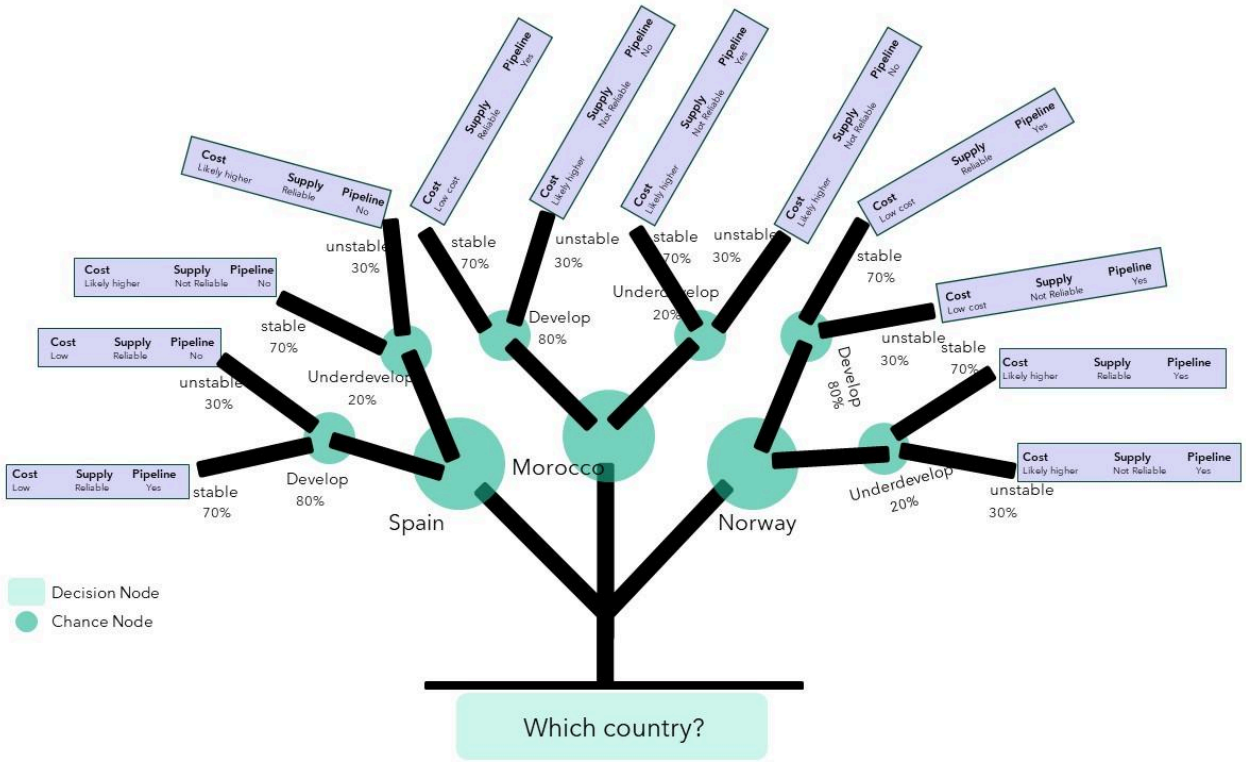

Figure 1. Decision Tree

Analytic Hierarchy Process

In any problem selecting an appropriate decision-making method is crucial. For the given problem, the Analytic Hierarchy Process (AHP) is a preferable method when compared to Cost-Benefit Analysis. Cost-Benefit Analysis mainly focuses on monetary factors, which may not capture the full scope of the given problem. Because some requirements identified above may not be easily quantifiable in monetary value. On the other hand, the Analytic Hierarchy Process (AHP) allows for the consideration of subjective opinions and qualitative factors. AHP also offers a clear decision-making structure and ensures consistency and sensitivity throughout the process. Therefore, AHP is better suited to the problem needs.

The first step of AHP is to conduct pairwise comparisons of each criterion. To achieve this, relevant sources such as Henkel's financial, sustainability, policies, guidelines, and press releases are examined by the students. These sources provide essential information for assuming pairwise comparisons of each criterion. For example, Henkel's goal of becoming a carbon-neutral company and their long-term procurement contract strategies (Henkel AG & Co. KGaA, 2023b) suggest that criteria such as export-oriented country is extremely important compared to transport distance. Similarly, geopolitical conflicts, such as the war in Ukraine-Russia, are significant considerations for Henkel. As a result of such conflicts, Henkel has decided to exit business activities from Russia (Witteck et al., 2023). Therefore, geopolitics

is very strongly important than transport distance in the pairwise comparisons. Here is the full list of pairwise comparisons:

- Export-oriented country has moderate importance than Cost
- Mode of transportation is less important than Cost
- Export-oriented country has very strong importance than the Mode of transportation
- Export-oriented country and the cost are extremely important than Transport distance
- Export-oriented country has moderate importance than Geopolitics
- Geopolitics is equally important to the Cost
- Geopolitics is strongly important than the Mode of transport
- Geopolitics is very strongly important than Transport distance
- Mode of transport is strongly important than Transport distance

The contributing students determine the importance of one criterion compared to another using a table created by Thomas L. Saaty.

Table 4. The fundamental scale for pairwise comparisons

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

Note: Intensities of 2,4,6 and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.

The resulting pairwise comparison of each criterion is as follows:

Table 5. Making pairwise comparison of each criterion / sub-criteria

	Export countries	Cost	Mode of transport	Transport distance	Geopolitics
Export Countries	1	3	7	9	3
Cost	1/3	1	3	9	1
Mode of transport	1/7	1/3	1	5	1/5
Transport distance	1/9	1/9	1/5	1	1/7
Geopolitics	1/3	1	5	7	1
Total	**1.92**	**5.44**	**16.2**	**31**	**5.34**

After performing the basic mathematical calculations, the Relative Priority, Vector of Weights, and Consistency Vector of each criterion are calculated.

Table 6. Relative Priority, Vector of Weights, and Consistency Vector

	Relative Priority	Vector of Weights	Consistency Vector
Export countries	0.47	2.48	5.27
Cost	0.20	1.034	5.17
Mode of transport	0.078	0.383	4.91
Transport distance	0.026	0.145	5.576
Geopolitics	0.21	1.138	5.419
Total	**0.984**	**5.18**	**26.122**

λmax = 26.122/5 = 5.2244
Consistency index, CI = (λmax − n) / (n − 1) = 0.0561

The Consistency Ratio (CR) is calculated using the formula CR = CI / ACI. ACI depends on the number of decision criteria (n = 5), with its value provided accordingly:

Table 7. ACI value depending on the number of decision criteria

N	3	4	5	6	7	8
ACI	0.58	0.90	1.12	1.24	1.32	1.41

Consistency ratio, CR = 0.0500
According to Saaty (1980), a consistency ratio, CR of 0.10 or less is considered acceptable. Therefore, the values of relative priorities are consistent.

Based on different sources, contributing students construct the following comparison criterion according to the alternatives -

Table 8. Comparison criterion according to the alternatives

	Spain	Morocco	Norway
Export countries	Medium◈	Strong◈	Strong◈
Cost (by 2030)	2.5-2.75 euro/kg◇	2.5-2.75 euro/kg◇	2.25-2.50 euro/kg◇
Mode of transport	Ship/Pipeline◆	Ship/Pipeline◆	Ship/Pipeline◆
Transport distance	2439.15 km◍	3676.66 km◍	1466.64 km◍
Geopolitics	Strong▲	Medium▲	Strong▲

Sources:
◈ (Dertinger et al., 2022)
◇ (PwC, n.d.)
◆ (Weichenhain, 2021)
◍ (*Sea Distance Calculator for Shipping*, n.d.)
▲ (*Political Stability and Absence of Violence/Terrorism: Percentile Rank | Data*, n.d.)

Comparison criterion according to the alternatives leads to the calculation of relative priority

Table 9. Relative priority of each criterion

	Relative Priority - Criteria 1	Relative Priority - Criteria 2	Relative Priority - Criteria 3	Relative Priority - Criteria 4	Relative Priority - Criteria 5
Spain	0.0909	0.2	0.428	0.250	0.455
Morocco	0.4545	0.2	0.142	0.096	0.090
Norway	0.4545	0.6	0.428	0.655	0.455

By multiplying the aggregate priorities matrix obtained in the previous step by the vector of relative priorities obtained, composite priorities that rank the alternatives of Spain, Morocco, and Norway are calculated.

Table 10. Relative Priority - Composed

	Relative Priority - Composed
Spain	0.218157
Morocco	0.286087
Norway	0.479579

The Relative Priority - Composed indicates that Norway is the best alternative as the preferred country for LOHC import to Germany. Morocco comes second. Lastly, Spain ranks lower compared to the other alternatives.

(Henkel AG & Co. KGaA, 2023b) mentions that Henkel aims to avoid becoming dependent on individual suppliers to better secure a constant supply of goods and services. Therefore, both Norway and Morocco emerge as the two LOHC supplier countries for Henkel.

SWOT Analysis

The SWOT Analysis is a planning method used to explore four significant aspects of a business venture: Strengths, Weaknesses, Opportunities, and Threats. SWOT Analysis provides a comprehensive evaluation of a problem by focusing on both internal and external factors. For Henkel's given problem, the SWOT Analysis planning method shows strategic planning and scenario exploration.

Other analysis methods, such as Force-Field Analysis, the Delphi Technique, and Scenario Planning, are not perfect fits for the given problem of Henkel. Force-field analysis is mainly focused on driving and restraining forces. For the given problem, analysis of potential countries' profiles from Henkel's strategic point of view is required. SWOT Analysis allows to illustrate this need. The Delphi Technique requires expert opinions and time. Since the contributing students lack expertise in the green hydrogen field, this analysis method is not suitable for Henkel's problem. Additionally, it overlooks internal insights. Scenario planning also requires a long time to plan and may provide uncertain predictions.

The SWOT Analysis of Norway as a LOHC supplier country for Henkel is as follows:

STRENGTHS	WEAKNESS
Strong capabilities in developing advanced energy technologies Stable political environment Environmental regulations promote sustainable energy practices, aligning with Henkel's goal	Limited capacity; production capacity may not meet Henkel's demand
OPPORTUNITIES	THREATS
Collaboration with Norwegian entities can drive innovation and reduce costs Henkel can stand out in the market by targeting environmentally conscious consumers.	Rival companies with similar sustainability goals seeking LOHC from Norway may drive up prices and limit availability Development hurdles may affect LOHC reliability and scalability Policy shifts could disrupt LOHC production and trade

Similarly, the SWOT Analysis of Morocco as a LOHC supplier country for Henkel is as follows:

STRENGTHS	WEAKNESSES
Vast solar and wind potential Lower production and labor costs Morocco government support and commitment to renewable energy development	Significant investment is needed for LOHC production infrastructure Political uncertainties may affect long-term planning for Henkel
OPPORTUNITIES	THREATS
Collaboration with Moroccan entities can drive innovation and reduce costs Henkel can stand out in the market by targeting environmentally conscious consumers.	Rival companies with similar sustainability goals seeking LOHC from Morocco may drive up prices and limit availability Changes in regulations could impact LOHC exports and sustainability standards

	Economic fluctuations in Morocco could affect investment levels, production costs, and market demand

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